Doctoral Dissertation

A Growing Concept of Ergonomics Including Comfort, Pleasure and Cognitive Engineering

An Engineering Design Perspective

Denis Alves Coelho

Department of Electromechanical Engineering
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Dissertation

This dissertation includes a comprehensive analysis based on reflection complemented by literature studies and was triggered by six articles appended in full. Roman Numerals are used to refer to the articles (studies) in the text.

Article I

Coelho, D.A., Dahlman, S. (1999). A pilot evaluation of car seat side support: Leading to a redefinition of the problem. International Journal of Industrial Ergonomics, 24 (1999) - pp. 201-210.

Article II

Coelho, D.A., Dahlman, S. (----). Articulation at shoulder level – an experimental study on car seat comfort. International Journal of Industrial Ergonomics, accepted for publication.

Article III

Coelho, D.A., Dahlman, S. (----). Seat comfort – an evaluation perspective on the feasibility of index formulation. Applied Ergonomics, submitted for publication.

Article IV

Coelho, D.A., Dahlman, S., (2002). Comfort and pleasure. In Pleasure in Product Use, ed. by Patrick Jordan and William Green, Taylor & Francis.

Article V

Coelho, D.A., Dahlman, S. (----). A questionnaire study on basic premises of pleasure with products. Accepted for publication (in abridged form) in Ergonomics in Design.

Article VI

Patterson, E.S., Coelho, D.A., Woods, D.D., Cook, R.I., & Render, M.L. (2000). The Natural History of Technology Change: How Introducing Bar Coding Changes Medication Administration. Paper presented at the Fifth Conference on Naturalistic Decision Making. Tammsvik, Sweden, 26-28 May.

Preface

This dissertation is based on a mixture of theoretical backgrounds (mainly from Scandinavia and the USA) and on empirical experiences collected in Portugal, Sweden and the USA.

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Thank you all!

Covilhã in April 2002

Denis A. Coelho

Abstract

The aim of this dissertation is to study and assess comfort, pleasure and cognitive engineering for relevance in engineering design processes, working towards finding an integrated theoretical structure. From this overall aim, operative aims and research questions were derived and pursued with the support of literature studies and analysis of five empirical studies. The operative aims are: establish the levels of scientific knowledge (in terms of development potential and feasibility); test the levels of development in practice of theoretical structures, data collection methods and representation formats; and, apply activity theory to attempt compatibilizing the three theoretical structures (broken down into subconcepts, operatives and measurable variables). Conclusions and conclusive remarks are delivered, springing from the analyses made.

The results of the assessments of model validity and maturity showed that universal design methods in comfort, pleasure and cognitive engineering, for direct application by engineering design, are presently not available, with an exception found for thermal comfort. Predictability concerning seat comfort, cognitive engineering and pleasure with products has not yet been achieved, but it is deemed feasible for some of their sub-areas: modelling physical discomfort in sitting, modelling pleasurable product properties for cultural sub-groups and predicting patterns of the impact of change on joint cognitive systems. Other sub-areas are not considered worthwhile pursuing for attaining engineering systematization, since their predictability is not deemed attainable. This situation hence precludes the development of a complete integrated comfort, pleasure and cognitive engineering design method for unaided application by engineering design. In these areas, design problems are thus better tackled using a combined process of research and design, which recurs to the existing theoretical structures but also to context based research intended to fill in the gaps of theory.

A moderate level of compatibility between the theoretical structures of comfort, pleasure and cognitive engineering was attained. While pleasure pursues in practice the goal of adding gains, comfort and cognitive engineering struggle in practice with relieving pain and minimizing loss. The psychological human aspect is common to all three areas, although it is not pursued in practice in comfort, nor does cognitive engineering pursue in practice the psychological aspect of emotions. Partial commonalities were found between comfort and pleasure (in what concerns physical aspects) and between cognitive engineering and pleasure (in what concerns psychological aspects) at the level of subconcepts. A common underlying activity structure of activity-goal-user-artefact was demonstrated for the empirical studies dealing with comfort and cognitive engineering. This showed, for both areas, that deriving measurable variables and identifying operatives could be done from the operation level of activity theory, once the elements relevant to the design problem are classified according to the activity-user-goal-artefact categories. Activity theory also enabled structuring and organizing a common research-design process underlying the conduction of specific design studies in comfort and cognitive engineering. This process is also suggested as applicable for designing Human Factors and Ergonomics quality wherever theory gaps are found.

Keywords: product development, human factors quality, theory and methods

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Resumo e sumário em português

Título da tese:

Um conceito de ergonomia em crescimento, incluindo o conforto, o prazer e a engenharia cognitiva.
Uma perspectiva da concepção na engenharia.

A tese que aqui se resume trata de um conjunto de análises baseadas na reflexão, e complementadas por revisão bibliográfica, despertada por seis artigos que se encontram anexados à mesma. Tanto a tese como os artigos anexos foram redigidos na língua inglesa. Os artigos são referenciados através de algarismos romanos. A chave desta numeração encontra-se na página desta obra com o título *Dissertation*. Apresenta-se abaixo um breve resumo da tese, seguido de um sumário mais alargado.

Resumo

O objectivo desta tese é estudar e avaliar os ramos da ergonomia do conforto, do prazer e da engenharia cognitiva com vista à sua relevância para os processos de concepção da engenharia, trabalhando de encontro a uma estrutura teórica integrada. A partir deste objectivo geral, derivaram-se objectivos operacionais e perguntas de investigação buscadas com o apoio de revisão bibliográfica e a análise de cinco estudos empíricos. Os objectivos operacionais são: estabelecer os níveis do conhecimento científico (em termos do potencial de desenvolvimento e daquilo que é exequível); avaliar os níveis do desenvolvimento na prática das estruturas teóricas, dos métodos de colheita dos dados e dos formatos de representação; e, aplicar a teoria da actividade para tentar compatibilizar as três estruturas teóricas (decompostas em sub-conceitos, operacionais e mensuráveis). A partir das análises efectuadas formularam-se conclusões e notas conclusivas.

A avaliação da validade e da maturidade dos modelos das estruturas teóricas mostrou que não existem presentemente métodos universais de concepção nos ramos do conforto, do prazer e da engenharia cognitiva passíveis de aplicação directa à concepção na engenharia, com a excepção do conforto térmico. A possibilidade de se atingir a previsão em relação às áreas do conforto de assentos, da engenharia cognitiva e do prazer com os produtos ainda não foi alcançada, mas considera-se que esta é alcançável para algumas das sub-áreas destes ramos, nomeadamente: para a modelação do desconforto físico da pessoa sentada, para a modelação das propriedades aprazíveis dos produtos para sub-grupos culturais e para a previsão dos padrões do impacto da mudança em sistemas cognitivos adjuntos. Considera-se que a possibilidade de previsão não é passível de ser alcançada para outras das sub-áreas destes ramos, gorando-se presentemente a expectativa de se atingir a sistematização desejada pela engenharia. Esta situação impede o desenvolvimento de um método de concepção completo integrando o conforto, o prazer e a engenharia cognitiva destinado a ser aplicado directamente nos projectos da engenharia. Nestas áreas, os problemas de concepção são portanto abordáveis através de um processo combinado de investigação e concepção, que recorre às estruturas teóricas existentes e à investigação contextualizada de forma a preencher as lacunas da teoria.

Alcançou-se um nível moderado de compatibilidade entre as estruturas teóricas do conforto, do prazer e da engenharia cognitiva. Se na prática o ramo do prazer procura implementar o objectivo da adição de ganhos, os ramos do conforto e da engenharia cognitiva debatem-se na prática com o objectivo do alívio da dor e da minimização de perdas. O aspecto psicológico das emoções do ser humano é comum às três áreas, ainda que na prática este não seja considerado pela área do conforto, nem que esta sua componente ligada às emoções seja desenvolvida na prática pela engenharia cognitiva. Foram encontradas semelhanças parciais entre o conforto e o prazer (no que concerne ao aspecto físico) e entre a engenharia cognitiva e o prazer (no que concerne ao aspecto psicológico) ao nível dos sub-conceitos. Demonstra-se uma estrutura de actividade comum composta por actividade-objectivo-utilizador-artefacto subjacente aos estudos empíricos lidando com o conforto e a engenharia cognitiva. Mostra-se assim para estas duas áreas que se pode derivar variáveis mensuráveis e identificar operacionais a partir do nível das operações da teoria da actividade, uma vez classificados os elementos relevantes para o problema de concepção de acordo com as categorias de actividade, utilizador, objectivo e artefacto. A teoria da actividade também possibilitou a estruturação e a organização do processo comum de investigação-concepção subjacente à condução de estudos de concepção específicos nas áreas do conforto e da engenharia cognitiva. Sugere-se que este processo também é aplicável à concepção com vista às qualidades ergonómicas para as áreas onde haja lacunas na teoria.

Palavras chave: desenvolvimento do produto, qualidades ergonómicas, teoria e métodos

Sumário

Introdução

Nos tempos actuais, a mistura de qualidades do produto é um factor competitivo relevante. O desempenho tecnológico deixa de ser a qualidade mais importante, uma vez que o nível de importância de outras qualidades mais ligadas à utilização (como o conforto, a satisfação ou a facilidade de utilização) aumenta. Ramos da ergonomia ainda em desenvolvimento como o prazer, o conforto ou a engenharia cognitiva, têm sido considerados tentativamente no contexto desta competitividade, como forma de adicionar qualidades relacionadas com a utilização dos produtos. Por outro lado, outros conceitos são também considerados, tais como a macroergonomia, ou a ergonomia participativa, ou ainda o fortalecimento da imagem das empresas.

Esta tese baseia-se no estudo do conforto, do prazer e da engenharia cognitiva, no contexto do contributo ergonómico à concepção na engenharia. A escolha prende-se com o facto de que estas áreas têm uma consequência directa na concepção de produtos, sistemas e serviços. Nesta perspectiva, a Ergonomia é vista como uma ciência que apoia a concepção na engenharia.

Apresenta-se também um conjunto de características comuns a várias definições de ergonomia encontradas na literatura de língua francesa e inglesa, bem como a definição oficial dada pela Associação Internacional de Ergonomia. Esta apresentação tem o intuito de introduzir alguns aspectos gerais da disciplina de ergonomia, como forma de caracterização sucinta da mesma. Esboça-se ainda uma tendência actual do desenvolvimento da ergonomia visando também a maximização dos ganhos e do prazer, por crescimento do paradigma vigente anteriormente, visando apenas a minimização das perdas e da dor.

De seguida, procede-se a uma curta introdução à concepção na engenharia e ao desenvolvimento dos produtos, com o objectivo de situar o papel da ergonomia na concepção em engenharia, sobre o ponto de vista desta última. Apresenta-se ainda uma revisão de uma amostra de bibliografia sobre o tema do desenvolvimento dos produtos e da concepção na engenharia (Anexo A), de forma a demonstrar a relevância da investigação presente para aquelas matérias. Nesta perspectiva, a ergonomia é vista como um dos muitos tipos de informação que deve alimentar o processo de concepção ou de desenvolvimento dos produtos. A ergonomia é também um dos requisitos que compõem a mistura a utilizar na aferição do resultado do processo de concepção.

Com o intuito de abarcar uma perspectiva abrangente, traça-se o paralelo da evolução do conceito de qualidade e da ergonomia em relação ao produto. Numa das intercepções destas duas disciplinas encontra-se o 'valor de utilização' do produto, que concerne aos aspectos da experiência de utilização do produto por parte das pessoas. Este conceito foi estudado e desenvolvido ao longo dos anos pelo Depº de Engenharia dos Factores Humanos da Universidade de Tecnologia de Chalmers, em Gotemburgo, tendo levado, entre outros resultados, à criação de uma ferramenta analítica para o estudo da relação entre o artefacto e o utilizador. A ferramenta adopta uma abordagem sistemática, baseada em parte na teoria da actividade, que relaciona utilizador-tarefa-objectivo-artefacto e ambiente. São tomadas em conta as propriedades do utilizador e do artefacto para que possam ocorrer benefícios a partir da actividade desempenhada. A análise, a partir de definições seleccionadas, do conforto, do prazer e da engenhria cognitiva, permite sugerir intercepções e ligações entre as três áreas segundo as características do utilizador e do produto que são invocadas. Estas semelhanças demonstram a existência de um potencial para a integração das três área numa única abordagem à concepção ergonómica.

Os objectivos e as hipóteses da investigação desenvolvem-se adoptando uma terminologia da investigação baseada em teoria, cujos aspectos essenciais são mencionados. O objectivo primordial da tese é definido como 'dar um contributo para um entendimento aprofundado do nível de desenvolvimento do conforto, do prazer e da engenharia cognitiva, em relação à Ergonomia e com vista à relevância para a concepção na Engenharia'. Pretende-se ainda encontrar as estruturas teóricas dos conceitos de cada uma das três áreas focadas, de forma a explicitar a sua relação integrada. Sugere-se que o nível do desenvolvimento científico ou maturidade das três áreas é presentemente diverso daquele do núcleo da ergonomia (à qual se convenciona tratar como 'ergonomia tradicional'). Chegou-se assim às hipóteses de que tendo a ergonomia tradicional atingido a maturidade, a engenharia cognitiva estará num nível intermédio de desenvolvimento, e o prazer e o conforto estarão num nível de desenvolvimento diminuto.

Tendo sido demonstrado como os requisitos de cariz ergonómico são apenas um dos muitos tipos de requisitos impostos ao processo de desenvolvimento de produtos, e tendo-se sugerido aspectos que potenciam uma possível integração das três áreas focadas, sugere-se uma tentativa de integração, ou pelo menos aproximação, dos seus métodos de concepção. Esta tentativa de integração apoia-se na análise através da teoria da actividade, e considera-se que a integração seria benéfica do ponto de vista da concepção na engenharia, dada a panóplia de ferramentas de concepção para propriedades (‘Design for X’ – DFX) que já são usadas (p. ex. concepção para resistência, durabilidade, montagem, desmontagem, etc...). Em vez de se visar a criação de mais três novos métodos de DFX, ter-se-ia assim apenas mais um. A teoria da actividade poderá ajudar no sentido de se atingir a compatibilidade dos requisitos sobre o produto desenvolvidos a partir da engenharia cognitiva, do conforto e do prazer. Equaciona-se ainda a possibilidade da investigação nestas três áreas extraír benefícios desta compatibilização de conceitos. Contudo, devido às forças antagónicas de cisão e da manutenção da unidade dentro das disciplinas científicas, não é possível adiantar uma previsão determinada da materialização de tais benefícios.

De seguida apresenta-se de forma hierárquica os objectivos, as hipóteses a estes subjacentes e as perguntas de investigação. As questões de investigação são:

R.1 – As teorias e os métodos existentes (no conforto, no prazer e na engenharia cognitiva) produzem resultados viáveis para avaliar a validade dos modelos neles implícitos? E para dirigir o desenvolvimento dos produtos?

R.2 – Os métodos de colheita dos dados e os formatos de representação dos dados são adequados para a comunicação com os utilizadores e os projectistas?

R.3 – Poderá a teoria da actividade ser usada como um veículo para a estruturação de conceitos – conhecimento – dados de uma forma integrada para a articulação e a gestão do prazer, da engenharia cognitiva e do conforto?

Apresenta-se ainda uma visão geral da organização da tese, que é constituída por sete capítulos, apoiados em três anexos e num conjunto de seis artigos.

Método de resposta às perguntas de investigação

Apresenta-se a lógica do processo de resposta às perguntas de investigação. Para cada uma das três áreas focadas, este processo consiste em avaliar as transformações a partir das estruturas teóricas até às directivas de desenvolvimento de produtos. A possibilidade de se atingir o nível de absoluta capacidade de previsão sistemática é avaliada através da transformação dos subconceitos da estrtutura teórica em aspectos operacionais e resultados medidos. Alcançar esta capacidade de previsão sistemática corresponderia na prática à criação de modelos preditivos. Estes permitiriam, a partir das propiedades do dispositivo técnico (produto, sistema, etc...), conceder uma estimativa da avaliação subjectiva que seria feita por seres humanos. A existência ou não, no presente, deste tipo de modelos preditivos auxilia também a caracterização da validade dos modelos implícitos na estrutura teórica correspondente. Para além do processo escolhido, o método de resposta às perguntas de investigação engloba também a aplicação da teoria da actividade com vista à compatibilização das três àreas focadas. Em termos pragmáticos, as acções envolvidas no processo de resposta às perguntas de investigação são as seguintes:

- o desenvolvimento de uma escala de maturidade (baseada na teoria de evolução das ciências de Kuhn),
- a revisão bibliográfica com vista à avaliação das estruturas teóricas e seus conceitos,
- a análise dos estudos empíricos para avaliar a viabilidade das estruturas teóricas,
- a avaliação de métodos para colheita, análise e representação de dados, e
- a aplicação da teoria da actividade para atingir uma estrutura teórica e um conjunto de conceitos comuns.

História dos eventos da investigação

Estabelece-se a história cronológica do trabalho envolvido na elaboração da tese e da investigação que lhe serve de base, que decorreu ao longo de um período de sete anos. O conforto surge como o primeiro domínio investigado e também aquele mais aprofundado. Os estudos I e II, versando o conforto, foram elaborados sequencialmente na Suécia, ainda que o contacto com a engenharia cognitiva tenha sucedido no seu intervalo. O artigo III foi elaborado com base nestes dois estudos, mas numa fase posterior. O artigo IV, ligando o conforto e o prazer, utiliza dados empíricos recolhidos a partir da mesma amostra que participa no estudo II (conforto). O estudo V, versando a área do prazer, é o último a ser elaborado, com base em dados recolhidos em Portugal. O estudo VI, pertencente ao domínio da engenharia cognitiva, foi conduzido nos Estados Unidos e ocorreu entre os estudos de conforto e o estudo de prazer. Ainda que os objectivos dos estudos anexos a esta tese estejam parcialmente demarcados dos objectivos da tese, ao longo do tempo estes últimos começaram a estar já presentes aquando da concepção dos estudos empíricos. Para além dos artigos anexados à tese, a investigação em que esta se baseia foi relatada noutras publicações, tanto em língua portuguesa como inglesa. Apresenta-se ainda algumas reflexões sobre as limitações e restrições subjacentes a esta tese, essencialmente decorrentes do carácter exploratório da mesma, dado que esta se baseia na análise de áreas relativamente novas.

Descrição sucinta dos artigos anexos à tese

A descrição apresentada destina-se a mostrar o valor dos estudos para o parceiro envolvido na sua execução (relevante para os artigos I, II e VI), a evidenciar caso a caso a produção de resultados úteis para a concepção de produtos e sistemas e a mostrar a relevância dos estudos como fontes de resposta às perguntas de investigação. O nível de conteúdo empírico dos artigos varia. Os artigos I, II, V e VI têm uma forte componente empírica. Os artigos III e IV são de índole mais teórica, ainda que o artigo IV inclua os resultados de um pequeno estudo por questionários.

Artigo I – avaliação dos apoios laterais de assentos de automóvel

Este estudo permitiu a produção de conselhos para a concepção, através de uma revisão da formulação do problema, apesar dos resultados experimentais se terem mostrado inconclusivos. O estudo baseou-se na avaliação de quatro assentos protótipo por uma amostra de 4 pessoas. A teoria da concepção de assentos para o conforto não está desenvolvida ao ponto de poder dirigir a concepção dos apoios laterais. Existem também outras lacunas na teoria como a falta de orientação para a selecção de escalas para o escalonamento do (des)conforto e do apoio subjectivos.

Artigo II – aumentando o apoio dado pelo assento às costas

Este estudo envolveu a definição da altura de uma articulação na parte superior do apoio para as costas de um assento de automóvel, com vista a aumentar o apoio e o conforto da região cervical da coluna vertebral. Uma amostra de doze pessoas participou na experimentação dos assentos tanto em condições simuladas como da condução automóvel real. Ficou provada a diminuição do desconforto, permitindo alimentar o processo de desenvolvimento do produto que o estudo apoiou.

Artigo III – explorando a possibilidade de atingir a previsão do conforto de assentos

Este artigo discursa sobre a multidimensionalidade do conforto, demonstrando a maior praticabilidade na criação de índices de desconforto do que de conforto. O artigo baseia-se em estudos da bibliografia e em desenvolvimentos dos estudos I e II. Elucida em parte a resposta à pergunta de investigação R.1 para o conforto.

Artigo IV – ligando conforto e prazer

Os resultados deste estudo, apoiado em conceitos teóricos e nas respostas de 13 pessoas a um questionário sobre a utilização do automóvel e seus assentos, sugerem que o conforto pode ser visto como um aspecto do prazer, ainda que este último contenha dimensões que não estão contidas no primeiro. O estudo também contribui parcialmente para a resposta à pergunta de investigação R.3 ainda que a teoria da actividade não tivesse sido ainda considerada à data da feitura do artigo.

Artigo V – confirmação empírica dos fundamentos do prazer

Este estudo inclui no seu objectivo o desenvolvimento e a prova empírica duma estrutura de conceitos que permita comunicar àcerca do 'prazer com produtos' a utilizadores e a projectistas. Contribui também para a caracterização do nível de desenvolvimento desta área de investigação, para além de sugerir a validação empírica das premissas teóricas testadas através de um questionário ao qual responderam 82 pessoas.

Artigo VI – o impacto da mudança tecnológica na segurança dos pacientes

Este estudo demonstra uma abordagem à engenharia cognitiva vocacionada para sistemas cognitivos distribuídos em que a segurança é crítica. O estudo demonstra também a pertinência do desenvolvimento da capacidade da engenharia cognitiva antecipar proactivamente e avaliar os impactos da mudança tecnológica. Por outro lado, prova-se a necessidade da disciplina desenvolver ainda mais a sua base teórica. O estudo baseou-se na observação não-intrusiva de profissionais clínicos na linha da frente dos cuidados aos pacientes, tal como em entrevistas e métodos de reconstituição dos passos do processo.

Resultados

Os resultados apresentados foram extraídos da revisão bibliográfica e dos estudos empíricos com vista à resposta às perguntas de investigação R.1 e R.2. As particularidades das áreas do conforto, do prazer e da engenharia cognitiva incluem diferenças ao nível da sua conceptualização, das abordagens utilizadas e da dimensão do conhecimento estabelecido.

No que diz respeito ao conforto, discute-se uma área pertencente à ergonomia tradicional (conforto térmico) como forma de contraste com outras áreas ainda num estado pré-paradigmático (conforto na interface humana e conforto de assentos). A estrutura utilizada para a análise destas áreas considera o seu objectivo, os modelos relevantes existentes, o conhecimento relevante para a concepção na engenharia e uma avaliação da qualidade de previsão e da validade dos modelos. Quanto ao ramo do conforto na interface humana, considera-se que este recorre a pessoas para visualizar a distribuição de pressão na interface, e que a relação entre esta última e o conforto ainda não foi compreendida, ainda que estejam desenvolvidos requisitos com o objectivo de assegurar a saúde. A análise do ramo do conforto de assentos, assenta essencialmente no artigo III, considerando-se que a possibilidade de previsão ainda não foi atingida, e que o conforto de assentos continua a ser avaliado recorrendo ao julgamento subjectivo de amostras de pessoas. Considera-se também que a estrutura teórica subjacente a esta área não está desenvolvida e que as directivas de desenvolvimento dos produtos extraídas da mesma não asseguram uma concepção de assentos que leve a um nível garantido e satisfatório de conforto. Há contudo um conjunto de investigações que procuram modelar a ligação entre propriedades de concepção dos assentos e a avaliação subjectiva do conforto, mas que necessitam de um maior desenvolvimento para incluír mais variáveis e consequentemente aumentar a sua validade. Nestas investigações não tem sido considerada a componente psicológica do conforto, mas apenas as componentes fisiológica e física do desconforto. Conclui-se desta análise com base na literatura que o nível de desenvolvimento científico da área do conforto é diminuto, de acordo com a categorização hipotética considerada previamente.

A avaliação da validade dos modelos da área do conforto de assentos baseia-se nos estudos empíricos relatados nos artigos I e II. Estes estudos recolheram informações a partir das estruturas teóricas da antropometria, da física, do conforto, da medição do contacto, da ortopedia e anatomia descritiva e consideram ainda a experiência pessoal e o senso comum dos autores. Da antropometria considera-se a descrição estatística das dimensões humanas, da física consideram-se a aceleração e as forças normais e de atrito no contacto entre assento e ocupante. Da bibliografia sobre o conforto consideram-se estudos experimentais exploratórios àcerca do conforto de assentos, envolvendo os factores seguintes: actividade muscular, postura, pressão interfacial, propriedades da concepção de assentos estáticas e dinâmicas, escalas para a avaliação subjectiva, evolução do desconforto ao longo do tempo, a comparabilidade dos escalonamentos subjectivos e as variáveis que deverão ser controladas de forma a assegurar a repetibilidade dos ensaios em assentos. Da ortopedia e da anatomia descritiva consideram-se aspectos de liberdade de movimento, posturais e de conforto respeitantes à coluna vertebral humana. A experiência pessoal e o senso comum dos autores são usados com vista ao tratamento do propósito pretendido para o apoio lateral do assento e o tipo de utilização dada ao automóvel. O aspecto das medições efectuadas no contacto entre ocupante e assento é tratado com base em relatórios de estudos experimentais que utilizaram tapetes de sensores de pressão ou sensores de binário com esse fim. Refere-se ainda a forma como estes conceitos foram operacionalizados e quais as variáveis efectivamente medidas nos estudos empíricos relatados nos artigos I e II. Não existe, em muitos casos, um fluxo de transformação lógico e directo dos conceitos para os operacionais e chegando aos mensuráveis, mas pode-se usar métodos da prática habitual na derivação dos mensuráveis. Para além destes resultados foram ainda considerados questionários e entrevistas à amostra que participou nos ensaios aos assentos, com os objectivos de rastrear em busca de inconsistências e obter uma visão mais holística sobre cada pessoa que compunha a amostra (parte destes resultados é relatada no artigo IV). O estudo I apenas permitiu a produção de conselhos para a concepção, que não estavam firmemente enraízados nas estruturas teóricas consideradas na elaboração do estudo. A partir do estudo II, por outro lado, foi possível extraír uma directiva de desenvolvimento do produto mais fiável, ainda que houvessem lacunas e deficiências na teoria que apoiou o estudo. Conclui-se assim que as estruturas teóricas identificadas para o conforto não permitem atingir directamente directivas para o desenvolvimento de produtos, muito menos modelos preditivos (o artigo III desenvolve esta problemática da previsão).

O prazer surge como um desenvolvimento a partir da facilidade de utilização (usabilidade), lado a lado com uma abordagem à concepção ergonómica que parte da minimização das perdas para a maximização dos ganhos. Nesta tese o prazer é considerado a partir da perspectiva do desenvolvimento de produtos e da concepção em engenharia. Na prática, considera-se que a área do 'prazer com produtos' foi esturturada por Patrick W. Jordan, que começou a publicar sobre o assunto em 1995 e desde então os seus trabalhos nesta área têm aumentado na sua abrangência e a temática tem vindo também a ser desenvolvida por outros autores. O prazer é visto, na literatura de investigação sobre a concepção, como um benefício emocional que suplementa a funcionalidade e a facilidade de utilização. Este foi sistematizado através sobretudo do quadro teórico dos quatro prazeres de Lionel Tiger, introduzido no artigo IV e aprofundado no artigo V. Este quadro é a base sobre a qual se constroem as especificações dos benefícios dos produtos, recorrendo a uma gama de métodos que incluem as entrevistas, o método da conversação privada com uma câmara, entre outros. A transferência das especificações em termos de benefícios para os requisitos em termos de propriedades do produto é feita na equivalência entre as propriedades experienciais e as propriedades formais, onde contudo ainda poucos progressos foram conseguidos. Considera-se ainda que no presente a teoria e os métodos disponíveis na área do 'prazer com produtos' não apoiam completamente a criação de directivas para o desenvolvimento de produtos, e que a validade das teorias está ainda a ser avaliada, tal como se procede ainda ao desenvolvimento de métodos. Sugere-se assim que o prazer está ainda num nível de desenvolvimento diminuto, de acordo com a hipótese apresentada previamente.

O estudo empírico considerado para a área do prazer é o relatado no artigo V. Este estudo não foca um produto em particular, mas desenvolve aspectos teóricos da área do 'prazer com produtos'. Desta forma, o estudo por si só não poderia constituir-se num veículo para a produção de directivas para o desenvolvimento de produtos. Neste estudo testam-se empiricamente, recorrendo a um questionário, os conceitos seguintes: A aplicabilidade da visão pluralística dos três mundos de Karl Popper (objectos, estados mentais e ideias) ao prazer, a categorização dos quatro prazeres de Lionel Tiger (fisiológico, psicológico, sociológico e ideológico) e a distinção entre prazeres de necessidade e prazeres de apreciação de Clives S. Lewis. O estudo contribui assim para a validação da estrutura teórica considerada como base do prazer com produtos através da decomposição de conceitos, e para elucidar quanto ao nível de compreensão atingido pelas pessoas aquando da comunicação destes conceitos (este nível é considerado elevado no contexto da amostra considerada).

No que concerne aos estudos bibliográficos na área da engenharia cognitiva, consideram-se as perspectivas de três escolas alternativas, mas complementares: a de Don Norman, a de Erik Hollnagel e David Woods e a de Jens Rasmussen e Kim Vicente (desenvolvidas no Anexo B). Ainda que o conceito de engenharia cognitiva não esteja fixo nem seja inequívoco, encontram-se aspectos comuns nestas suas várias expressões.

Para Don Norman os objectivos da engenharia cognitiva centram-se na compreensão dos princípios fundamentais que regem a actividade e o desempenho humanos e que são relevantes para o desenvolvimento de princípios para a concepção em engenharia, bem como para a concepção de sistemas de utilização aprazível. Don Norman considera, entre outros, o conceito da actividade cognitiva motivada que advém da experiência do 'fluxo óptimo', envolvendo factores como a existência de objectivos inerentes à actividade, de retro-alimentação, ou de regras e desafios, que em conjunto encorajam a pessoa a concentrar-se e a envolver-se na tarefa.

A escola de Hollnagel e Woods considera a engenharia cognitiva como uma abordagem à cooperação entre as pessoas e a tecnologia, apartada da aplicação da ciência cognitiva e que é desafiada a desenvolver a sua própria base teórica. Esta escola considera ainda que a abordagem da engenharia cognitiva deve ser conduzida pela resolução de problemas do desempenho de tarefas cognitivas, e não pelo desenvolvimento de tecnologia cada vez mais poderosa. Esta escola põe ainda em causa a possibilidade e a exequibilidade da concepção conduzida por conceitos teóricos. Hollnagel e Woods vêem os desafios principais da engenharia cognitiva como sendo: lidar com a complexidade nos sistemas cognitivos, a utilização de ferramentas cognitivas sofisticadas e os sistemas cognitivos distribuídos compostos de sistemas cognitivos artificiais e naturais (seres humanos). David Woods desenvolve em particular uma metodologia para a investigação e o desenvolvimento na área do trabalho cooperativo suportado por computadores, considerando que o motor de inovação na engenharia cognitiva consiste na sincronização e alimentação mútua dos ciclos da investigação e do desenvolvimento. Esta metodologia baseia-se nos valores da autenticidade, da abstracção, da criação e da participação, por contraste com aspectos de validade e repetibilidade e é desenvolvida no Anexo B.

Apresenta-se o genótipo conceptual do laboratório de Risø, desenvolvido a partir dos anos 60, tal como exposto por Kim Vicente. De acordo com o genótipo de Risø, a engenharia cognitiva trata da concepção de sistemas de informação baseados em computadores destinados à aplicação em sistemas sócio-técnicos complexos. A partir do genótipo de Risø foram desenvolvidos princípios para a concepção, tais como a concepção ecológica de interfaces, para ajudar os operadores a adaptarem-se de forma flexível a eventos imprevistos.

Para complementar esta recolha de aspectos teóricos da engenharia cognitiva, apresenta-se ainda uma lista de problemas, métodos de análise e tipos de acção que são considerados no estudo da cognição na interacção homem-máquina. Considera-se assim a existência de um vasto conhecimento e quantidade de métodos na área da engenharia cognitiva, se bem que o nível a que as diferentes escolas consideram a sua viabilidade varia. Dada a extensão desta área e o debate sobre a sua ontologia, considera-se que esta se encontra num nível intermédio de desenvolvimento, de acordo com a hipótese já apresentada.

O artigo VI descreve um estudo empírico na área da engenharia cognitiva. Descreve-se a metodologia utilizada no estudo, que leva à compreensão dos processos de transformação e adaptação de pontos de mudança que ocorrem naturalmente e que perturbam um sistema (no caso em apreço o sistema de cuidados de saúde a doentes hospitalizados). Um aspecto crítico da elaboração deste estudo é a identificação de padrões de transformação e adaptação, baseada em experiências de estudos anteriores. Os padrões identificados sugeriram efeitos colaterais imprevistos da mudança tecnológica focada (informatização do processo de medicação e utilização da validação por código de barras). Estes indiciaram a geração de conceitos para a concepção, que têm incutidas hipóteses sobre o que seria útil para aumentar a qualidade e a eficiência do sistema. Aponta-se como contribuição deste estudo a demonstração de parte de uma metodologia para a investigação e a concepção centradas na prática, e um aprofundamento da compreensão do impacto da tecnologia sobre a cognição e a colaboração num domínio da actividade humana (cuidados médicos). Enriquece-se assim a base de conhecimentos que poderão ajudar a conduzir observações noutros estudos.

No que diz respeito à pergunta de investigação R.2, esta foi mais completamente elucidada no que diz respeito ao conforto, e somente parcialmente elucidada quanto ao prazer e à engenharia cognitiva. Debate-se ainda as possibilidades de se atingir a previsão nas três áreas, considerando-se como indicador desta possibilidade o nível a que cada área mira os objectivos de desempenho objectivo ou envolvimento emocional como forma de conduzir e avaliar a concepção. A consequência mais importante destes resultados para a concepção na engenharia é a necessidade de se desempenhar a actividade da concepção através de uma abordagem combinada de investigação-concepção para as áreas do conforto, do prazer e da engenharia cognitiva.

Compatibilizar conforto, prazer e engenharia cognitiva

Esboçam-se vários fios condutores da compatibilidade entre a engenharia cognitiva, o prazer e o conforto. A perspectiva da dor e dos ganhos, permitiu o posicionamento relativo das três áreas em relação a duas dimensões: o objectivo na concepção (aliviar a dor e adicionar ganhos) e os aspectos humanos considerados (físico, fisiológico, sociológico, ideológico e do desempenho). Na análise foi ainda introduzida uma terceira dimensão através da consideração do foco actual das três àreas em termos da perspectiva das dores e dos ganhos e dos seus objectivos conceptuais identificados a partir de definições. Sugere-se que os métodos do conforto (aqui confundidos com o termo 'engenharia somática' numa analogia com o termo engenharia cognitiva) e da engenharia cognitiva são métodos que podem ser usados para atingir os objectivos de conforto (alívio da dor) e de prazer (adição de ganhos). Na prática, as semelhanças encontradas a partir destas análises não são completamente suportadas pela análise de similaridade ao nível dos sub-conceitos levada a cabo entre o conforto (engenharia somática) e o prazer (fisiológico) e entre a engenharia cognitiva e o prazer (psicológico). Encontrou-se uma intercepção que é apenas parcial entre estes dois pares, que poderá ser o resultado dos diferentes objectivos na concepção buscados na prática (o prazer buscando a adição de ganhos, enquanto as outras duas áreas buscam o alívio da dor). Para além disso, o prazer visto como uma disciplina recorre à ergonomia tradicional, ao conforto (engenharia somática) e à engenharia cognitiva para atingir o objectivo na concepção do alívio da dor.

Apresenta-se uma descrição da teoria da actividade baseada numa recolha elaborada por Petra Rhodin, visando a sua utilização em estudos aplicados, que se centra nas teorias e modelos desenvolvidos e apresentados graficamente por Lars-Christer Hydén, Yrjö Engeström e MariAnne Karlsson (desenvolvida no Anexo C). Considera-se que a teoria da actividade permite a explanação de um fenómeno em várias dimensões, contextualizando situações e acções. Faz-se a operacionalização da pergunta de investigação R.3 que lida com a aplicação da teoria da actividade. Esta teoria serviu de base ao esboço do processo geral de investigação-concepção aplicável aos estudos I, II e VI, que lidam com a avaliação e o levantamento de informação com vista à concepção de um produto / sistema particular. Este processo poderá ser aplicável a uma gama mais vasta de estudos com o fim de implementar qualidades ergonómicas na concepção, necessitando a sua verificação de uma base mais alargada de estudos empíricos. Para além disso, o quadro da teoria da actividade de Karlsson (1996) foi aplicado aos estudos I, II e VI, colocando-se os operacionais (conforto) e os padrões de transformação e adaptação (engenharia cognitiva) no contexto de utilizador-actividade-artefacto-objectivo. A aplicabilidade do quadro aos dois casos apoia a consideração de uma característica integradora através dos estudos utilizados para ilustrar as duas áreas: a estrutura da actividade subjacente à acção humana.

A avaliação de compatibilização efectuada não está completa uma vez que a integração ao nível dos operacionais não foi ensaiada, nem aquela que diz respeito a métodos de recolha dos dados, ou aos formatos de representação das directivas do desenvolvimento dos produtos. O procedimento de decomposição da teoria aplicado não produziu operacionais para o prazer (devido a uma definição preliminar da teoria e à ausência da sua aplicação). A avaliação da validade dos modelos feita a partir de bibliografia da engenharia cognitiva mostrou que a disciplina é desafiada a desenvolver a sua própria teoria, apartando-se da aplicação directa de conceitos da psicologia experimental. Portanto, a engenharia cognitiva rejeita parcialmente os conceitos considerados pela cognição na interacção homem-tecnologia. Para além disso, as directivas (universais) para o desenvolvimento dos produtos aparentam não ser alcançáveis na área da engenharia cognitiva devido aos problemas que se encontram em assegurar a sua validade em campos da prática complexos e em mudança.

Alcançou-se uma compatibilização parcial entre conforto, prazer e engenharia cognitiva. Esta compatibilização engloba a partilha de objectivos para a concepção (conforto e prazer), as intersecções entre os aspectos humanos focados nas três áreas, algumas semelhanças parciais ao nível dos sub-conceitos e uma estrutura de actividade comum subjacente tanto aos processos de investigação-concepção e às interacções entre utilizador-actividade-artefacto-objectivo em qualquer estudo particular (daqueles estudos considerados). Ainda que as tentativas de compatibilização ensaiadas tenham atingido parcialmente o sucesso, a sua base empírica é estritamente reduzida. Estas tentativas beneficiariam portanto da consideração de um espectro mais alargado de casos empíricos.

Notas conclusivas

Os resultados da avaliação da validade e da maturidade dos modelos das estruturas teóricas mostraram que não existem presentemente métodos universais de concepção nos ramos do conforto, do prazer e da engenharia cognitiva, com a excepção do conforto térmico. A possibilidade de se atingir a previsão nas áreas do conforto de assentos, da engenharia cognitiva e do prazer com os produtos ainda não foi alcançada, mas considera-se que esta é alcançável para algumas das sub-áreas destes ramos, nomeadamente: para a modelação do desconforto físico da pessoa sentada, para a modelação das propriedades aprazíveis dos produtos para sub-grupos culturais e para a modelação dos padrões do impacto da mudança em sistemas cognitivos adjuntos. Considera-se que a possibilidade de previsão não é passível de ser alcançada para outras das sub-áreas destes ramos, gorando-se presentemente a expectativa de se atingir a sistematização desejada pela engenharia. Esta situação impede o desenvolvimento de um método de concepção integrando o conforto, o prazer e a engenharia cognitiva destinado a ser aplicado directamente nos projectos da engenharia. Nestas áreas, os problemas de concepção são portanto abordáveis através de um <u>processo combinado de investigação e concepção</u>. Um processo tal recorre à extracção de conhecimentos das estruturas teóricas relevantes existentes e aplicáveis mas também recorre à investigação contextualizada de forma a preencher as lacunas da teoria e a proceder à avaliação e à evolução iterativas de protótipos.

Alcançou-se um nível moderado de compatibilidade entre as estruturas teóricas do conforto, do prazer e da engenharia cognitiva. Existe um défice em cada uma das três áreas entre aquilo que é a definição do seu espaço de acção e aquilo com que estas realmente trabalham. Se na prática o ramo do prazer procura implementar o objectivo da adição de ganhos, os ramos do conforto e da engenharia cognitiva debatem-se na prática com o objectivo do alívio da dor e da minimização de perdas. O aspecto psicológico do ser humano é comum às três áreas, ainda que na prática este não seja considerado pela área do conforto, nem que a sua componente ligada às emoções seja desenvolvida na prática pela engenharia cognitiva. Foram encontradas semelhanças parciais entre o conforto e o prazer (no que concerne ao aspecto físico) e entre a engenharia cognitiva e o prazer (no que concerne ao aspecto psicológico) ao nível dos subconceitos. Demonstra-se uma estrutura de actividade comum composta por actividade-objectivo-utilizador-artefacto subjacente aos estudos empíricos lidando com o conforto e a engenharia cognitiva. Mostra-se assim para estas duas áreas que se pode derivar variáveis mensuráveis e identificar operacionais a partir do nível das operações da teoria da actividade, uma vez classificados os elementos relevantes para o problema de concepção de acordo com as categorias de actividade-utilizador-objectivo e artefacto. **A teoria da actividade também possibilitou a estruturação e a organização do processo comum de investigação-concepção subjacente à condução de estudos de concepção específicos nas áreas do conforto e da engenharia cognitiva. Sugere-se que este processo também é aplicável à concepção com vista às qualidades ergonómicas para as áreas onde haja lacunas na teoria.**

Apresenta-se também assuntos para investigação futura. Estes incluem o prosseguimento de esforços de investigação com vista a atingir a possibilidade de previsão para alguns dos modelos e uma avaliação mais completa de métodos para colheita, análise e representação de dados para a engenharia cognitiva e o prazer.

Summary

Translation of the Portuguese version

Introduction

In the present times, the mixture of product qualities is a relevant competitive factor. Technological performance is no longer the single most important quality, since the level of importance of other more use related qualities (such as comfort, satisfaction or usability) increases. Branches of ergonomics that are still developing, such as pleasure, comfort or cognitive engineering, have been tentatively considered in the context of this competitiveness, as a means of adding use related value to products. Moreover, other concepts are also considered, such as macroergonomics, participatory ergonomics, or strengthening companies' images.

This dissertation is based on the study of comfort, pleasure and cognitive engineering, in the context of the ergonomic contribution to engineering design. This choice is rooted in the fact that these areas have a direct consequence to the design of products, systems and services. In this perspective, ergonomics is seen as a science that supports engineering design.

A set of common characteristics of various definitions of ergonomics found in literature in the French and English languages is presented, as well as the official definition of the International Ergonomics Association. Its presentation has the purpose of introducing some general aspects of the discipline of ergonomics, as a way of characterizing it shortly. A present tendency in the development of ergonomics' goals of intervention is also sketched; the tendency of moving from the paradigm of only minimizing losses and pain towards also maximizing gains and pleasure.

A short introduction to engineering design and product development, aiming at situating the role of ergonomics in engineering design from the point of view of the latter, is presented. Moreover, a review of sampled literature on the theme of product development / engineering design is reported (Appendix A), in order to demonstrate the relevance of the present research to those matters. In this perspective, ergonomics is seen as one of the many types of information that should feed the process of design or product development. Ergonomics is also one of the requirements that are part of the set of requirements to be used in assessing the result of the design process.

Aiming at branching a holistic perspective, a parallel between the evolution of quality and ergonomics is considered, with regard to products. In one of the intersections between these two disciplines one finds the product's 'use-value', which concerns the aspects of the experience of use of the product by people. This concept was studied and developed throughout the years at the Dept. of Human Factors Engineering of Chalmers University of Technology, in Gothenburg, having lead, among other results, to the creation of an analytical tool for the study of the user-artefact relation. The tool adopts a systematic approach, based partially on activity theory, which relates user-task-goal-artefact and environment. The user properties and the artefact properties are taken into account in order for benefits to accrue from the performing of the activity. An analysis, based on selected definitions of comfort, pleasure and cognitive engineering, enables suggesting intersections and connections between the three areas, from the user and product characteristics that are invoked. These similarities

demonstrate the potential for the integration of the three areas into a single approach to ergonomic design.

The aims and hypotheses of the research are developed adopting a terminology from theory-based research, of which essential aspects are mentioned. The fundamental aim of this dissertation is defined as ‘contributing towards a deepened understanding of the level of development of comfort, pleasure and cognitive engineering, in relation to Ergonomics and for relevance to engineering design’. The theoretical structures of concepts of each of the three focused areas are also sought, in order to expose their integrated relation. It is suggested that the level of scientific development or maturity of the three areas focused is presently different from that of the core of ergonomics (which is treated under the label of ‘traditional ergonomics’). Hence, the hypotheses are arrived at that while traditional ergonomics has reached maturity, cognitive engineering would be at an intermediate stage, and pleasure and comfort would be at a low level of development.

Having demonstrated how the requirements of ergonomic character are only one of the many types of demands imposed on the process of product development, and having suggested aspects that potentiate a possible integration of the three areas focused, an integration attempt, or at least approximation, of their three design methods is sought. This integration attempt is supported by the analysis provided by activity theory, and is considered as beneficial from the point of view of engineering design, given the wide range of design for properties (‘Design for X’ - DFX) tools that are already used (e.g. stress, durability, assembly, disassembly, etc.). Instead of envisaging the creation of three new DFX methods, one would have only one. Activity theory is suggested as a means of attaining compatibility of the requirements on the product developed springing from cognitive engineering, comfort and pleasure. The possibility for the research in these three areas to reap benefits from the compatibility between concepts is also equated. However, due to the antagonist forces of partition and maintaining unity inside scientific disciplines, it is not possible to bring forward a determined prediction of the materialization of such benefits.

A hierarchical presentation of the aims, underlying hypotheses and research questions is made. The research questions are:

R.1 – Do existing theories and methods (for comfort, pleasure and cognitive engineering) produce viable results for assessing the validity of models? To direct product development?

R.2 – Are data collection methods and representation formats adequate for communicating with users and designers?

R.3 – Can activity theory be used as a means of structuring concepts – knowledge – data in an integrated way for the handling of and management of pleasure, cognitive engineering and comfort?

A general view of the organization of the dissertation is presented, which is made of seven chapters, supported by three appendices and by a set of six articles.

Method for answering the research questions

The logics of the process of answering the research questions are presented. For each of the three areas focused, this process consists in assessing the transformations from the theoretical structures towards product development directives. The possibility of attaining predictability is assessed through the transformation of the subconcepts in the theoretical structure into operatives and measured results. Attaining this capacity of systematic predictability corresponds in practice to the creation of predictive models. These would allow, departing from the properties of the technical device (product, system, etc.), giving an estimation of the subjective assessment that would be done by human beings. The existence, or lack of it, in the present, of such predictive models, also supports the characterization of the validity of models that are implicit in the corresponding theoretical structure. Besides this process, the method for answering the research questions also encompasses the application of activity theory for compatibilizing the three areas focused. In pragmatic terms, the actions developed in the process of answering the research questions are the following:

- development of a scale of maturity (based on Kuhn's theory of the evolution of science),
- literature review for assessing theoretical structures and their concepts,
- analysis of empirical studies to assess the viability of the theoretical structures,
- assessment of methods for data collection, analysis and representation, and
- application of activity theory to attain common theoretical structure and concepts.

History of research events

The chronological history of the work involved in the elaboration of the dissertation and the research that supports it, along a period of seven years, are described. Comfort appears as the first domain that was investigated and also the one most deepened. Studies I and II, dealing with comfort, were sequentially elaborated in Sweden, although the contact with cognitive engineering occurred in between these. Article III elaborates on these two studies, and was written afterwards. Article IV, linking comfort and pleasure, uses empirical data collected from the same sample that participated in study II (comfort). Study V, dealing with the field of pleasure, was the last one to be carried out, and is based on data collected in Portugal. Study VI, pertaining to the domain of cognitive engineering, was carried out in the United States, between the time the studies of comfort and the study of pleasure were made. Although the aims of the studies appended to this dissertation are partially detached from the aims of the dissertation, over time the latter aims were already present when designing the empirical studies. Besides the articles appended to the dissertation, the research in which this dissertation is based was also reported in other publications, written in both Portuguese and English. Some reflections on the limitations and restrictions underlying this dissertation are also presented. These spring essentially from the exploratory character of the dissertation, given that it is based on the study of relatively new areas.

Short description of articles appended to the dissertation

The description presented aims at showing the value of the studies for the partner involved in their carrying out (relevant for articles I, II and VI), to emphasize case by case the production of useful results for the design of products and systems and to show the relevance of the studies as sources of answers to the research questions. The level of empirical content varies in the articles. Articles I, II, V and VI have a strong empirical component. Articles III and IV have a more theoretical nature, although article IV includes the results of a small questionnaire.

Article I – evaluation of automobile seat side supports

This study enabled the production of design advice, through a revised problem formulation, despite the inconclusiveness of the experimental results. It was based on the evaluation of four alternative seat prototypes by a sample of 4 persons. The theory of seat design for comfort is not developed to the point of being able to conclusively direct side support design. Additionally the study shows that theory does not yet provide conclusive guidance in selecting scales for subjective rating of (dis)comfort and support.

Article II – increasing seat support to the back

This study involved the definition of the height for an articulation in the upper part of the automobile seat backrest, with the purpose of increasing support and comfort to the cervical region of the vertebral column. Twelve subjects participated in sitting trials both in simulated and real driving conditions. The decrease in discomfort was proven, enabling feeding the product development process that the study supported.

Article III – exploring the possibility of attaining seat comfort predictability

This article discusses comfort's multidimensionality, demonstrating the greater practicability of the creation of (physiological and physical) discomfort indexes, rather than of comfort. It is based on literature studies and also develops on studies I and II. It elicits in part the answer to research question R.1 for comfort.

Article IV – linking comfort and pleasure

The results of this study, supported by theoretical concepts and the answers of 13 people to a questionnaire on automobile and automobile seat use, suggest that comfort can be seen as an aspect of pleasure, although the latter holds dimensions not included in the former. The study also contributes partially to the answer to research question R.3 although activity theory had not yet been considered at the time the study was made.

Article V – empirical confirmation of the foundations of pleasure

This study includes in its objectives the development and empirical testing of a structure of concepts that allows communicating about 'pleasure with products' to users and designers. It also contributes to the characterization of the level of development of this research field, besides suggesting the empirical validation of theoretical premises tested through a questionnaire study involving 82 respondents.

Article VI – the impact of technology change on patient safety

This study demonstrates an approach to cognitive engineering geared for distributed cognitive systems where safety is critical. The study also demonstrates the pertinency of developing cognitive engineering's capacity to proactively anticipate and assess the impact of technology change. Moreover, the need to further develop the discipline's theoretical base is proven. The study was based on non-intrusive observation of clinical practitioners at the sharp-end of patient care, as well as interviews and process tracing methods.

Results

The results presented were extracted from literature review and the empirical studies, aiming at answering research questions R.1 and R.2. The particularities of the areas of comfort, pleasure and cognitive engineering include differences of their level of conceptualization, of the approaches used and of the dimension of established knowledge.

In what concerns comfort, an area pertaining to traditional ergonomics is discussed (thermal comfort) as a means of contrasting its stage of development with other areas considered that are still in a pre-paradigmatic stage (comfort at the human interface and seat comfort). The structure utilized for the analysis of these areas, considers their objective, the relevant existing models, the knowledge relevant for engineering design and an assessment of the quality of predictability and validity of models. Concerning the branch of comfort at the human interface, it is considered that it recurs to people to visualize the distribution of interface pressure, and that the relation between the latter and comfort has not yet been understood, although requirements for health assurance are developed. The analysis of the branch of seat comfort is essentially based on article III, being it considered that the possibility of prediction has not yet been achieved, and that seat comfort continues to be evaluated recurring to the subjective assessment of samples of people. It is also considered that the theoretical structure underlying this field is not fully developed and that the product development directives extracted from it do not assure a design of seats that leads to a guaranteed satisfactory level of comfort. There is however a number of research efforts that seek the modelling of the connection between seat design properties and subjective comfort assessment, but these need further development to include more variables and hence boost their validity. In those efforts, the psychological component of comfort has not been considered, but only the physiological and physical components of discomfort. As a conclusion to this analysis based on literature it appears that the level of development of comfort is low, in accordance with the hypothetical categorization previously presented.

The assessment of model validity of the field of seat comfort is based on the empirical studies reported in articles I and II. These studies collected information from the theoretical structures of anthropometrics, physics, comfort, contact measuring, orthopedics and descriptive anatomy and also consider the personal experience and common sense of the authors. The statistical description of human dimensions is considered from anthropometrics, while acceleration and normal and friction forces in the contact between seat and occupant are considered from physics. Extracted from comfort literature are explorative experimental studies about seat comfort, involving the following factors: muscle activity, posture, interface pressure, static and dynamic seat design properties, scales for subjective assessment, evolution of discomfort over time, comparability of subjective ratings and the variables that should be controlled in order to assure the repeatability of sitting trials. Freedom of movement, postural and comfort aspects pertaining to the human vertebral column are considered from orthopedics and descriptive anatomy. Personal experience and common sense of the authors is used to treat the purpose intended for the seat side support and the type of use given to the automobile. The aspect of measurements made in the contact between seat and occupant is treated on the basis of reports on experimental studies that used pressure sensor mats or torque sensors with that purpose. The way these concepts are transformed into operatives and which variables were effectively measured in empirical studies I and II are also mentioned. In many cases a direct logical transformation flow from concepts to operatives and measurable variables does not exist, but common practice methods can be used in arriving at measurable variables. Besides these results, questionnaires and interviews to the sample that took part in the seat experiments are also considered, with the goals of scanning for inconsistencies and obtaining a more holistic view about each person that was part of the sample (part of these results is reported in article IV). Study I only enabled the production of design advice, which were not firmly rooted in the theoretical structures considered in the conception of the study. From study II, on the other hand, it was possible to extract a more reliable product development directive, despite the existence of shortages and deficiencies in the theory that was available to support the design of the study and the interpretation of the results. It is thus concluded that the theoretical structures identified for comfort do not enable directly attaining directives for the development of products, much less predictive models (article III develops this problem of prediction).

Pleasure appears as a development from usability, hand in hand with an approach to ergonomic design that departs from minimizing losses to maximizing gains. In this dissertation, pleasure is considered from the perspective of product development and engineering design. It is considered that in practice the field of ‘pleasure with products’ was structured by Patrick W. Jordan, who started publishing on the subject in 1995 and since then his work in this area has increased in thoroughness and completeness and the theme has also been developed by other authors. Design research literature views pleasure as an emotional benefit that supplements functionality and usability. It has been systematized mostly through Lionel Tiger’s four pleasure framework, which is introduced in article IV and developed in article V. This framework is the basis on which product benefits specifications are built, making use of a scope of methods that include interviews, the private camera conversation method, among others. The transfer of specifications in terms of product benefits to the requirements in terms of product properties is done in the equivalence between experiential properties and formal properties, where however little progress has been accomplished so far. It is also considered that in the present the theory and methods available in the field of ‘pleasure with products’ do not completely support the creation of product development directives, and that the validity of the theories is still being evaluated, as much as methods are still being developed. It is also suggested that pleasure is still at a low level of development, in accordance with the hypothesis presented.

The empirical study considered for the field of pleasure is the one reported in article V. This study does not focus on a particular product, but develops on theoretical aspects of the field of ‘pleasure with products’. Accordingly, on its own, the study could not constitute itself in a vehicle for the production of product development directives. In this study the following subconcepts are empirically tested, through a questionnaire: the pluralistic view of the three worlds of Karl Popper (objects, mental states and ideas), the four pleasure categorization of Lionel Tiger (physiological, psychological, sociological and ideological) and the distinction between pleasures of need and pleasures of appreciation of Clives S. Lewis. Thus the study contributes to the validation of the theoretical structure considered as a basis for pleasure with products through the transformation into operative form of subconcepts, and to elucidate about the level of understanding attained by people in the communication of these concepts (this level is considered high in the context of the sample considered).

In what concerns literature review in the field of cognitive engineering, the perspectives of three alternative and complementary schools are considered: Don Norman’s, Erik Hollnagel and David Wood’s and Jens Rasmussen and Kim Vicente’s (developed in Appendix B). Although the concept of cognitive engineering is not fixed or unequivocal, common features can be found in these various expressions of it.

For Don Norman, the aims of cognitive engineering are centered in the understanding of the fundamental principles that command human activity and performance and that are relevant for the development of engineering design principles, as well as for the design of systems that are pleasant to use. Don Norman considers, among others, the concept of motivated cognitive activity that incurs from the experience of ‘optimal flow', involving factors such as the existence of built-in goals, feedback, or rules and challenges, which together encourage the person to concentrate and engage in the task (developed in Appendix B).

The school of Hollnagel and Woods considers cognitive engineering as an approach to co-operation between people and technology, and one that is detached from the straightforward application of cognitive science and that is challenged to develop its own theoretical base. This school also considers that the approach of cognitive engineering should be conducted by solving problems in the performance of cognitive tasks, and not by developing ever more powerful technology. This school also questions the possibility and practicability of design that is guided by theoretical concepts. Hollnagel and Woods see the main challenges of cognitive engineering as: coping with complexity in cognitive systems, the use of sophisticated cognitive tools and distributed cognitive systems composed of artificial and natural (human beings) cognitive systems. David Woods develops in particular a methodology for research and development in the field of computer supported cooperative work, considering that the engine of innovation in cognitive engineering consists in synchronizing and interlocking the cycles of research and development. This methodology is based on the values of authenticity, abstraction, creation and participation, by contrast with aspects of validity and repeatability and is developed in Appendix B.

The Risø laboratory's conceptual genotype, developed since the 1960's, is presented, as described by Kim Vicente. According to the Risø genotype, cognitive engineering deals with the design of information systems based on computers and intended for use in complex socio-technical systems. From the Risø genotype, design principles were developed, such as ecological interface design that supports operators in adapting flexibly to unanticipated events.

In order to complement this collection of theoretical aspects of cognitive engineering, a list of concepts is presented, as well as methods of analysis and types of action that are considered in the study of cognition in human-machine interaction. Thus, the existence of a vast amount of knowledge and methods in the area of cognitive engineering is considered, although the level at which the different schools consider their viability varies. Given the extension of this area and the debate about its ontology, it is considered that the area is at an intermediate level of development, in accordance with the hypothesis presented previously.

Article VI describes an empirical study in the area of cognitive engineering. The methodology used in the study is described, one that leads to the understanding of the processes of transformation and adaptation of points of change that occur naturally and disturb a system (in the case under focus the system of health care of hospitalized patients). A critical aspect of the building of this study is the identification of patterns of transformation and adaptation, based on experiences from previous studies. The patterns identified suggested unanticipated side effects of the technology change focused (computerization of the process of medication and use of the validation through bar coding). These seeded the generation of design concepts that have included hypotheses about what would be useful to increase quality and efficiency of the system. A contribution of this study is identified as demonstrating part of a methodology for practice centered research and design, and deepening the understanding of the impact of technology on cognition and collaboration in a domain of human activity (health care). The knowledge base thus gets richer, which may help guiding observations in other studies.

In what concerns research question R.2, this was more completely elicited for comfort, and only partially elicited in what concerns pleasure and cognitive engineering. The possibility of attaining predictability in the three areas is also debated, being it considered that the level to which each area aims for the goals of objective performance or emotional engagement as a means to guide and evaluate design are indicators of the possibility of attaining predictability. The most important consequence of the results for engineering design is the need to pursue design endeavors in the areas of comfort, pleasure and cognitive engineering with a combined research-design approach.

Compatibilizing comfort, pleasure and cognitive engineering

An outline of several threads of compatibility between cognitive engineering, pleasure and comfort is made. The pains and gains perspective is discussed, enabling relatively positioning the three areas in relation to two dimensions: design goal (relieving pain and adding gain) and human aspects considered (physical, psychological, sociological, ideological and performance). A third dimension was introduced in the analysis through the consideration of the present focus of the three areas in terms of the pains and gains perspective and their conceptual aims identified from high level definitions and postulates. It is suggested that the methods of comfort (hereby confounded with the term 'physical engineering' in an analogy with cognitive engineering) and cognitive engineering are methods that can be used to attain the goals of comfort (relief of pain) and pleasure (addition of gain). The similarities in practice explicit in the analyses are not completely supported by the analysis of commonalities at the subconcept level carried out between comfort (physical engineering) and (physiological) pleasure and cognitive engineering and (psychological) pleasure. There is only a partial interception between the two pairs, which may result from the different design goals pursued in practice (pleasure pursuing addition of gain, while the other two pursue relief of pain). Moreover, pleasure as a discipline recurs to traditional ergonomics, comfort (physical engineering) and cognitive engineering in attaining the design goal of relief of pain.

A description of activity theory is presented, based on a collection carried out by Petra Rhodin, aiming at its use in applied studies, which is centered in the theories and models developed and presented by Lars-Christer Hydén, Yrjö Engeström and MariAnne Karlsson (presented in Appendix C). It is considered that activity theory enables understanding a phenomenon in various dimensions, contextualizing situations and actions. Research question R.3 dealing with the application of activity theory was transformed into operatives outlining the general process of research-design applicable to studies I, II and VI, dealing with the evaluation and eliciting of information for design of a particular product / system. This process may be applicable to a wider range of studies meant to design Human Factors and Ergonomics quality, needing a wider spectrum of empirical cases for its verification. Additionally, Karlsson's (1996) activity theory framework was applied to studies I, II and VI, positioning the operatives (comfort) and patterns of transformation and adaptation (cognitive engineering) into the context of user-activity-artefact-goal. The applicability of the framework in both cases supports the consideration of an integrating feature across the studies considered to illustrate the two domains: the underlying activity structure of human action.

The assessment of compatibility made is not complete since integration at the level of operatives was not pursued, neither in what concerns data collection methods, or product development representation formats. The theory breakdown procedure outlined and used did not yield operatives for pleasure (due to a preliminary definition of theory and lack of application). The assessment of model validity based on literature for cognitive engineering showed that the discipline is challenged to develop its own theory, detaching itself from the straightforward application of concepts from experimental psychology. Hence it partially rejects the concepts considered concerning cognition in human-technology interaction. Additionally, (universal) product development directives are not deemed pursuable in the area of cognitive engineering due to the problems of assuring their validity in complex and changing fields of practice.

A partial compatibilization between comfort, pleasure and cognitive engineering has been attained. This compatibilization encompasses the sharing of design goals (comfort and pleasure), the intersections between human aspects focused in the three areas, some partial commonalities at the subconcepts level and a common activity structure underlying both the conduction of research-design processes and the interactions between user-activity-artefact-goal in any particular study (of those considered). Even if the compatibilization attempts essayed were partially successful, their empirical basis is strictly small. These attempts would hence benefit from the consideration of a wider spectrum of empirical cases.

Conclusive Remarks

The results of the assessments of model validity and maturity have shown that universal design methods in comfort, pleasure and cognitive engineering for direct application by engineering design are presently not available, with an exception found for thermal comfort. Predictability in seat comfort, cognitive engineering and pleasure with products has not yet been achieved, but it is deemed feasible for some of their sub-areas: modelling physical discomfort in sitting, modelling pleasurable product properties for cultural sub-groups and predicting patterns of the impact of change on joint cognitive systems. Other sub-areas are not considered worthwhile pursuing for attaining engineering systematization, since predictability in these sub-areas is not deemed attainable. This situation hence precludes the development of an integrated comfort, pleasure and cognitive engineering design method for unaided application by engineering design. In these areas, design problems are thus better tackled using a combined process of research and design. Such process recurs to extracting knowledge from the existing relevant and applicable theoretical structures but also to context based research intended to fill in the gaps of theory and to iteratively evaluate and advance on prototypes.

A moderate level of compatibility between the theoretical structures of comfort, pleasure and cognitive engineering has been attained. There is a deficit in all three areas between what is defined as their scope of action and what is actually worked with. While pleasure pursues in practice the goal of adding gains, comfort and cognitive engineering struggle in practice with relieving pain and minimizing loss. The psychological human aspect is common to all three areas, although it is not pursued in practice in comfort, nor does cognitive engineering pursue in practice the aspect of emotions. Partial commonalities were found between comfort and pleasure (in what concerns physical aspects) and between cognitive engineering and pleasure (in what concerns psychological aspects) at the level of subconcepts. A common underlying activity structure of activity-goal-user-artefact was demonstrated for the empirical studies dealing with comfort and cognitive engineering. This showed, for both areas, that deriving measurable variables and identifying operatives could be done from the operation level of activity theory, once the elements relevant to the design problem are classified according to the activity-user-goal-artefact categories. **Activity theory also enabled structuring and organizing a common research-design process underlying the conduction of specific design studies in comfort and cognitive engineering. This process is also suggested as applicable for designing Human Factors and Ergonomics quality wherever theory gaps are found.**

Issues for future research are also presented. They include the pursuing of research efforts in attaining predictability for some of the models and a more complete assessment of methods for data collection, analysis and presentation for cognitive engineering and pleasure.

Chapter 1

Objectives:

- To introduce the problem domain.
- To describe the overall purpose of the dissertation.
- To present the research questions.
- To show the organization of the dissertation.

(1) Introduction

This dissertation is concerned with the application of three developing branches of ergonomics to engineering design (particularly product and systems design). These branches are comfort, pleasure and cognitive engineering.

The present chapter sets the scene by introducing the problem domain and the holistic view in which it is embedded, by presenting the overall aim of the dissertation leading to the research questions considered and concluding with a reader's guide to the dissertation.

(1.1) Introduction to problem domain

In the present times, technical performance advantages are difficult to sustain, since technological performance is available to most industries and it has reached a level of satisfaction that is quite high. Companies can buy licenses and put together a mix of components and qualities (this goes on both at the level of high technology, e.g. the case of information technology, and at the level of low technology, e.g. the case of bicycles). The mix of product qualities is therefore a relevant competitive factor. As a consequence, other quality advantages besides technical performance are giving competitive advantages. Some of the earlier customer fascination with technical functions has shifted towards requirements for other, more use related, qualities (Karlsson, 1996). Previous values such as functionality, reliability and cost tend to be complemented by others such as comfort, satisfaction or usability (Yamada & Price, 1991). As an example, a few manufacturers produce small maritime diesel engines in Japan, as a general-purpose equipment component. These are then tailored by other manufacturers in Europe with cooling systems, reverse and reduction gearboxes and service kits. To the customer, the difference between the alternatives in the market has mostly to do with price and easiness of oil change, durability of cooling system, reverse and reduction gearboxes and usability of tool kit and serviceability of the power system as a whole (engine and peripheral completing components). Hence, use related qualities are an important decider of purchase choice in this example.

In our present times, concepts such as pleasure, comfort and cognitive engineering are being tentatively considered as competitive qualities. These concepts are developing branches of Human Factors and Ergonomics, but other concepts, such as building a brand name or company image building are also present. Some companies have explicitly made public that they do not use child work, that they are environmentally conscious or that they carefully select what events and public projects they sponsor. These aspects have nothing to do with the quality of the products these companies manufacture, but rather with an image they wish to project in the market. Brand images, ecoquality and social acceptance qualities are also part of the trends of our times, but I will not be dealing with these. Other trends of our times in Human Factors and Ergonomics include Macroergonomics (with the goal of optimizing workplace productivity by recognizing effects of systemic interactions between individuals and environmental, technological and interpersonal variables – Hendrick, 1995) or Participatory Ergonomics (aiming at the development of methods and principles on how to involve the employees in the design of work and workplaces – Örtengren, 1997, or Garmer, 2002).

I have decided to investigate comfort, pleasure and cognitive engineering and not macroergonomics and participatory ergonomics or company images and brand names. This investigation aims at being a contribution to Human Factors and Ergonomics, which I look upon as a support science to Engineering Design. I have chosen comfort, pleasure and cognitive engineering because these have a direct bearing on the physical design of the product, system or service. Table 1, summarizes this discussion, leading to my choice of the factors directly concerned with the design of products, systems and services, which constitute the focus of this dissertation.

Table 1 *– Trends of our times (concepts that are being tentatively considered).*

Condition	Result	Solutions sought	My focus
Technology performance is in practice available to all manufacturers	Technology performance is no longer the single most dominant competitive factor	Developing and strengthening other competitive factors, including: • Cognitive Engineering • Comfort • Ease of assembly • Ecoquality • Participative ergonomics • Pleasure • Macroergonomics • Serviceability • Social acceptance • Usability • Building brand name / company image	Factors directly concerned with the design of product / system / service: • Comfort • Pleasure • Cognitive engineering

Holistic design, such as the one claimed to be pursued by the design and development company IDEO (a big and successful US based design consultancy), considers physical, cognitive, emotional and social wide aspects into the design of products and systems (IDEO, 2000). In terms of the correspondence to the factors selected for my work, comfort covers mostly physical aspects, cognitive engineering covers mostly cognitive aspects; I have concentrated on the emotion of pleasure, in which psychological pleasure comes the closest to emotions. However, the tangibility of the three chosen factors is not the same. Comfort and cognitive engineering are deemed easier to transform to operatives (i.e. questions, measures, data to be collected, methods, representations) than emotional and social (cultural) variables, since the former are so far better defined. Pleasure may not be as systematizable because of its inherent connection to the mind and to emotions. But on the other hand, take the example of low back pain, which is an issue of a biomechanical nature; it is thought that at least half of the causes for aggravation of low back pain have a psychological nature (SUB, 2000). Thus, even when the focus is drawn on physical aspects and consequences of design, psychological factors must be considered too.

Moreover, macroergonomics studies the industry relationships between people, considering psychology, but the effects are measured in terms of pain. Hence body and mind are not separable – in the world of human beings one can study something very narrowly, but cannot detach it from the whole. However, while I recognize that sociological and anthropological variables are of interest to engineering, I have chosen not to focus on socio-anthropological issues[1].

(1.1.1) Human Factors and Ergonomics

Throughout this dissertation Ergonomics and Human Factors are considered as synonyms. This is in accordance with the Executive Council of the International Ergonomics Association (IEA) which in the year 2000 considered that "Ergonomics (or Human Factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well-being and overall system performance". Within the discipline three domains of specialization are highlighted by IEA (2000): physical ergonomics, cognitive ergonomics and organizational ergonomics. This thesis can be seen as an investigation on whether these domains should be complemented or integrated with the aspects of comfort and pleasure.

There are, however, variants of the definition of Human Factors and Ergonomics proposed by diverse scholars. While some authors consider it to be a science (Laville, 1998; Karwoski, 1996), others recognize elements of both scientific and technological nature in the discipline of Human Factors and Ergonomics (Hendrick, 1995; Wilson and Corlett, 1995). Montmollin, (1997) emphasizes systematical and communicative aspects in the definition, while other scholars focus on the question of fitting the machine (or the work) to the human (Sperandio, 1988; Wisner; 1987, Corlett and Clark, 1995; Pheasant, 1991). Despite the differences found in different authors' definitions, the following aspects are common in most of the definitions of ergonomics found in French, British and US literature, as surveyed by Moraes (2000):

- the utilization of scientific data about the human;
- the multidisciplinary origin of these data (from anatomy, physiology, biomechanics, neurophysiology, psychophysiology, psychology, cognitive science, sociology, anthropology, semiotics);
- the interdisciplinarity of Ergonomics (or Human Factors);
- its application to technical devices, to work organization and training and the parameters and recommendations proposed by ergonomics;
- the relationship of ergonomics with the design of machines, artefacts, consumer products, durable equipment, information systems, warnings and signs, documents, computer interfaces and displays, tasks, work organization, instructions and procedures;
- the perspective on the use of these technical devices by the normal population of workers, with their capacities and limitations, without implying a selection that chooses the "right human being";

[1] Sociological and ideological aspects are considered as part of the four pleasure framework devised by Tiger (1992), and used by Jordan (2000) to structure the pleasure with products theory.

- fitting machines, environments and work to the human, and not the opposite;
- the consideration of the capacities, characteristics, skills and limitations of the user population;
- the objectives of safety, comfort and well-being.

In one of the arenas of ergonomics action – companies – continuous company-wide improvement approaches are being designed aimed at linking ergonomics (including macroergonomics and participative ergonomics) with quality, occupational health and safety and natural environment protection aspects of organizational performance. These are duly justified due to the inherent inter-relationships between product quality defects, workplace design defects, and operational defects (Karwoski & Dzissah, 2000). These integration efforts in the management of companies contribute to enhance and promote the awareness, diffusion and application of the discipline of ergonomics.

Within the core of development of the discipline of Human Factors and Ergonomics, a trend towards change has recently been acknowledged and encouraged. As a discipline, ergonomics had been mostly focusing on eliminating human pain and discomfort, both of a physical and cognitive nature, and in so doing, minimizing loss. A recent approach to ergonomic design in the context of consumer products has been brought forward by Jordan and Macdonald (1998) concerning the creation of products that bring positive benefits to users, in terms of pleasures. Such an approach, when extended to the discipline of Ergonomics and Human Factors, could be coined as the maximization of gain and pleasure, as opposed to minimizing pain and loss and focusing on safety and human-system compatibility (Noy, 2000). Asides with pleasure, the approach promotes satisfaction, creativity, personal growth, meaningful activity and human-system symbiosis.

I have chosen to focus on three aspects of Human Factors and Ergonomics: comfort, pleasure and cognitive engineering, differentiating these from Traditional Ergonomics and Human Factors. What I mean by Traditional Ergonomics is the developed part of Human Factors and Ergonomics, the one that has achieved maturity in terms of the creation of product development directives and having attained validation of theory and models. This includes occupational ergonomics. Figure 1, illustrates this conception, and positions Human Factors and Ergonomics in relation to surrounding matters such as Engineering Design, Quality or Industrial Management. While Traditional Ergonomics is in the background for my analysis on comfort, pleasure and cognitive engineering, other recent branches of Human Factors and Ergonomics such as macroergonomics or participatory ergonomics are not focused at all.

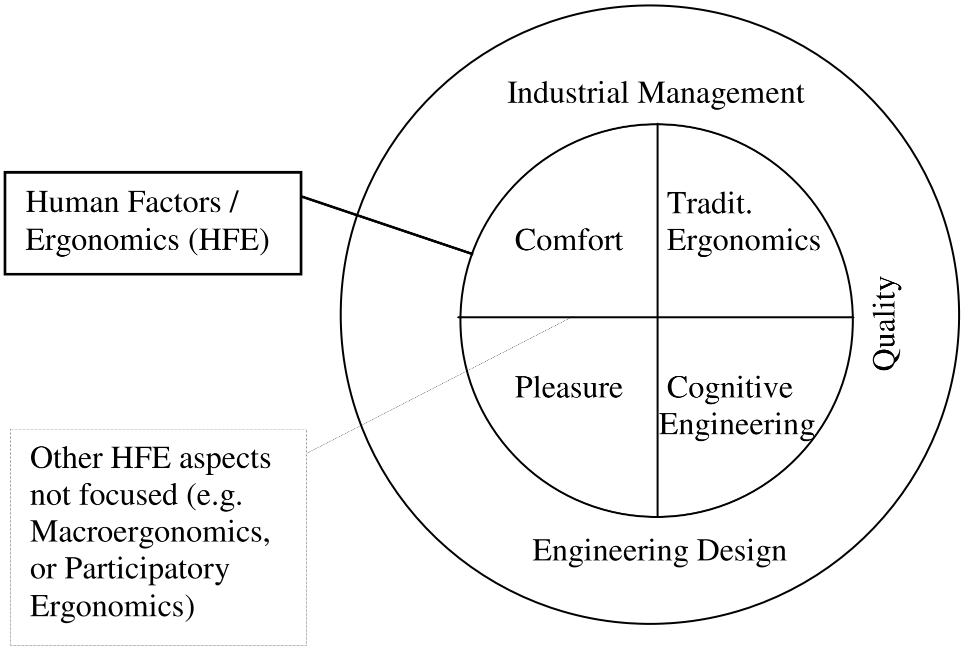


Figure 1 *– Pieces of the HFE 'cake' considered as my focus (cognitive engineering, comfort and pleasure), positioned in relation to surrounding matters.*

(1.1.2) Engineering Design and Product Development

This section is intended to establish a contact between engineering design and the role of ergonomics in product development, clarifying how the contribution of ergonomics is embedded in product development processes. To do this, I have considered Hubka & Eder's (1996) definitions of design in the engineering context, and looked for their positioning of ergonomics in the process of designing. Hubka & Eder (1996) present an overview of the state of design knowledge, arguing for unification and an increase in thoroughness of engineering design knowledge. There are other schools which have systematized parts of engineering design knowledge, although to a lesser degree of completeness. Additions to the present section, concerning a wider scrutiny of Product Development literature, are presented in Appendix A, aiming at further depicting a background framework against which to position the content of he dissertation.

Lundqvist (1996) has distinguished between the meaning of the terms product development, product design and product innovation. Product development focuses mainly on management and organizational issues. Product design deals primarily with the professional designer, design methods and the use context. Finally, product innovation literature approaches the area from an economic perspective and emphasizes issues such as market effectiveness, economic measures and the emergence of radically new technology. Engineering design knowledge covers aspects of product development and product design and mentions the contribution of Ergonomics to product development. Hubka & Eder (1996) use the term engineering design in the context of Lundqvist's notion of product development and product design of technical systems (engineering products, systems, objects or artefacts).

There are two interpretations of the word ‘design’ in the context of engineering, as considered by Hubka & Eder (1996). One of the interpretations is design as a noun, meaning the outward appearance and pattern of (artificial) objects, artefacts, systems or products. This involves studying how and why things look and behave the way they are, including the possibility of mathematics or computer-based analysis. The other interpretation, considered by these authors as probably more important in the context of engineering, is design as a verb. This means a process of establishing which of several alternative ways (and with what tools) things could be done, which of those is most promising, and how to implement that choice, with continual reviews, additions and corrections to the work - designing. These two aspects of engineering design (object and activity) interplay and have to be coordinated. In my view, a correspondence to Lundqvist’s terminology would link product design to the interpretation of design as a noun (object), while product development would be linked to the interpretation of design as a verb (activity).

According to Hubka & Eder (1996), designing is an activity of humans together with tools, performed using information, under direction and with goals delivered from management, in a working environment. All these factors affect the quality of the designed product. Responsibility rests with the designers, but information is needed by and from many others. Designing as a process (activity) accepts input information about the task and the requirements for its output. Designing delivers as its output a set of instructions for implementing or manufacturing the designed system. This system (product) must be able to perform the desired tasks with the demanded performance, operability, sufficiently long life, safety, reliability, adjustability, maintainability and other aspects which together with these are collected under the term functionality. In addition, products must be manufacturable to the appropriate quality, packaged, distributed, and so on. The time scale of planning, designing, manufacturing and delivering must be suitable. Recycling and disposal and other aspects pertaining to sustainability (e.g. life cycle assessment) have recently become more important. Products must be suitable for humans to operate and interact with them (ergonomics) and live with them (aesthetics). They must conform to the laws, regulations, standards, codes and moral and ethical considerations applicable for the place of origin and of use. Cash flow and financing must be considered. They must also be economical, offered at the right price, with appropriate services and support, and acquired at a suitable cost.

Hence, from the engineering design perspective of Hubka & Eder (1996), ergonomics is seen as one of the many types of input information that ought to be considered for the process of designing or product development. Ergonomics is also seen as a requirement on the output of the process of designing that is part of the mix of requirements on the output of the process of designing in engineering. Additionally, it is essential to balance and optimize demands imposed on the product derived from all the important aspects and requirements considered. For example, functional demands, economy-related requirements, demands derived from the environmental field and ergonomics-related demands could give rise to trade-off situations. These need to be dealt with during design. Quantitative measures have been suggested as a fruitful means to handle trade-off situations (Hattori et al., 1996). If it is specified in quantitative terms, which are the most important of the conflicting criteria, a direct evaluation can be done. Methods have been developed to assist in handling trade-offs between conflicting criteria in the field of Design for X. Tichem (1997) suggested that applying methods taking several X:es into consideration simultaneously during product development is more effective than one X at a time.

The notion of design as an activity implies the setting of goals for such an activity. In practice, a technical system is designed so that it is able to perform the desired tasks with the demanded (required) quality with reference to a set of property dimensions. Ergonomics appears as one of such property dimensions (suitability for human operation and interaction) that are dealt with during the process of design. Human requirements may be clearly identified at the start of the process of designing or need to be further elicited in coordination with the conduction of the process. The demands imposed by Ergonomics on the particular design may be in conflict with demands imposed from other dimensions of the quality intended for the technical system. These conflicts can be dealt with by prioritizing the various demands and considering several demands simultaneously during the activity of designing.

(1.2) Overall purpose of the dissertation

This section presents in more detail the aspects that are focused in this dissertation and the research aims. A holistic view is provided as a basis to relate to the derivation of aims and research questions. This view is concerned with what quality is, what its constituting aspects are and with the links existing between product qualities and the aspects of Ergonomics focused in the dissertation (comfort, pleasure and cognitive engineering).

(1.2.1) Holistic view

The discipline of Human Factors has evolved over the years, steadily increasing in importance and maturity and moving towards a systems oriented approach (Brown, 2000). Similarly, in what concerns products, systems, objects, artefacts and services, quality (the mixture and values of properties) is stepping up to include all their constituting aspects. Quality has evolved from a limited role of inspection of material deficiencies and likelihood of technical breakdowns in the early days of manufacturing to the present day concepts of total quality (Bergman & Klefsjö, 1994). In the year 2000, the International Standards Organization reinstated and reformulated the definition of quality, phrasing it as “the ability of a complete set of realized, inherent characteristics of a product, system or process to fulfil requirements” (ISO/DIS 9000:2000).

Hubka & Eder (1996) have distinguished between different aspects of quality that are relevant for consideration in the design of technical systems (quality of design, quality of manufacture and quality of application). They consider a definition of quality that is similar to the one above: “the entirety of properties (features) of a product or an activity which refer to their fitness to fulfill given demands”. This definition of quality implies a total judgement (total value) about a system of properties that make a thing to be that which it is, for what it can serve and how suitable it is to fulfill all partial tasks and the total task. The total value is composed of the individual values of relevant properties, by a simple addition or through a synergistic influence of one property on another (Hubka & Eder, 1996).

A concept that can be included in a broadened view of quality is the product's use-value. The use-value is a special case of the notion of quality, in that it considers the product properties that are valued through use, in interaction with humans. Hubka & Eder (1996) acknowledge that the conditions of usage can affect the actually achieved quality of the product in use, but the product fitness to human interaction and use is dealt with in conjunction with Ergonomics. The Department of Human Factors Engineering (formerly Department of Consumer Technology), at Chalmers University of Technology in Göteborg, has pursued the study of use. Dahlman (1986) identified the observable consequence of use and interaction as an important aspect in the study of use, considering that problems are the consequence of misfits between the user and the equipment. Dahlman (1990) also developed the notion of consequences, in connection with problems (negative consequences) and values (positive consequences). According to Rosenblad-Wallin (1990), a product's use-value is determined in relation to a human being and the environment in which the product is used, i.e. in relation to the user and the use situation. This means that different products have different values depending upon the use situation and the user preferences. The properties of a product, on the other hand, are related to the product itself, its material and parts. This definition of use-value is partially detached from the definitions of quality because it concerns what the user / customer experiences when he interacts with the product, and is not merely a characteristic of the product itself (Karlsson, 1996).

Building upon the work of Dahlman, Rosenblad-Wallin and other scholars, Karlsson (1996) designed a framework for the study of 'use'. The framework is intended to provide a basis for the discussion, description and evaluation of different approaches to the design of the user-artefact relation. In this framework, the unit of analysis is the use activity, and she adopts a holistic approach that includes a system view of user-task-goal-artefact and environment. In this approach aspects such as product features and operations are studied, but the key point is that they must be related to the overall level of analysis. The framework is composed of five factors, each of which is represented in three different levels of analysis (Table 2). In this view of the user-artefact relation, the purpose of employing an artefact (product) is to make use of its functions in order to achieve a goal, but the actual benefit acquired is dependent upon the properties of the artefact and the properties of the user, as well as other local conditions, such as the environment where the activity takes place (Karlsson, 1996).

***Table 2** – A framework for the study of the relation between user and artefact, from Karlsson (1996).*

Goal / Consequence	Activity	User	Artefact	Environment
Motive / need	Activity	Individual / Collective	Alternative technical systems	General environmental conditions
Goal	Action	Individual / user	System: functions and performance Artefact: function and performance	
Fits / Misfits	Operation	The physical and mental properties of the individual / user	The properties / features of the artefact	Local environmental conditions

This interplay between the properties of the artefact / product and the properties of the user is an element of analysis in each of the Ergonomics areas focused in this dissertation (comfort, pleasure and cognitive engineering). Product qualities that are relevant for each of the three areas are considered in relation to specific user characteristics. Simplistically, physical characteristics would be strongly involved in (physical) comfort, mental characteristics would be connected to cognitive engineering and emotional characteristics would be explicitly linked to pleasure. However, this is not a tight comparting, and there are commonalities and intersections on the connections for each of the three branches linking the user characteristics (mental, physical and emotional) and product characteristics (qualities relevant for comfort, cognitive engineering and pleasure) These similarities are explicit (wordwise) when selected definitions of the three areas are analyzed. Such an analysis is tentatively considered in the following sub-section.

(1.2.1.1) Wordwise similarities found in definitions of comfort, pleasure and cognitive engineering

Comfort is defined by Slater (1985) as a pleasant state of physiological, physical and psychological harmony with the environment. This definition encompasses both physical (including physiological) and psychological[2] (cognitive and emotional) aspects that are relevant as consideration of the user characteristics concerning the ergonomic goal of comfort. Products are not mentioned in this definition, but it can be assumed that they are included in the 'environment'. This definition also mentions pleasure (in the expression 'pleasant state of … harmony'); hence it establishes a link to pleasure, which can be considered at the emotional level. Thus, it springs from this definition that comfort considers the user's physical, cognitive and emotional characteristics.

While characterizing the cognitive engineering design problem, Norman (1986) described cognitive engineering as a discipline whose premise is to transform cognitive design by supplying the principles 'that get the design to a pretty good state the first time around'. Norman (1986) stated the following aims for cognitive engineering: "to understand the fundamental principles behind human action and performance that are relevant for the development of engineering principles of design, and to devise systems that are pleasant to use". In these aims, one recognizes aspects of both the user (cognitive) and the product / system characteristics (engineering design) as well as the goal of pleasurable use.

According to Jordan (1997), pleasure with products concerns the emotional, hedonic and practical benefits of product use. The terms hedonic and practical can be thought to include all aspects of both user characteristics and ergonomic goals. The term emotional is also present. This definition places pleasure with products at the summit of the ergonomic goals in product development, adding the emotional aspect (through pleasure) to other approaches that are summoned in this broader approach (these approaches include comfort, cognitive engineering and traditional ergonomics – cf. Jordan, 2000).

[2] The term psychological is deemed to encompass both cognitive (concerned with learning and skills) and emotional aspects of mental behavior.

The three areas (comfort, cognitive engineering and pleasure) are part of the Human Factors / Ergonomics approaches to design, and tend to be taken separately, since they have been applied in different domains. While comfort has been applied to the environment and the human interface (e.g. beds, seats, clothes, environment), cognitive engineering has been concerned with computer software and computer supported work systems. Pleasure, although still in an incipient stage, has been directed mostly towards consumer products, and includes some of the applications considered for comfort and cognitive engineering.

Thus, there seems to be a potential for at least some integration of the three approaches into a combined and integrated ergonomic design approach, judging from the short analysis presented above.

(1.2.2) Research aims

In this section research aims are formulated, taking into account the previous sections of this chapter. The section initiates with a clarification of the theory based research terminology used throughout this discussion, as well as in other chapters of the dissertation.

In his *Handbook for scientific and technical research*, David Beach (1992) characterizes a theory as an explanation of behavioral or physical events that consists of generalizations and constructs. A generalization (or model) is a relationship between two or more events and it can be used to predict events. Constructs (or concepts and subconcepts) are usually defined in operational terms, that is, in terms of the ‘operations’ needed to measure them. The operational measures (or operatives) of constructs are usually variables, with values or numerals assigned to them. While a theory is fairly established, a theoretical structure is less complete and more tentative (Glaser & Strauss, 1967). However, both theories and theoretical structures afford the definition of subconcepts, which given practical restrictions are transformed into operatives. Operatives are directly congruent with subconcepts, but some subconcepts do not get transformed into useful operatives. Thus the transformation influences the quality of the operatives.

The overall purpose of this dissertation is to contribute to an increased understanding of the level of development of comfort, cognitive engineering and pleasure in relation to Human Factors and Ergonomics and to study their relevance or potential relevance to engineering design. The level of development is valued through studying and assessing the three HFE branches, aiming at conceptualization. This conceptualization is attained through the identification of the theoretical structure of concepts embedded in these three branches of ergonomics. Moreover, the conceptualization is also meant to expose and substantiate the integrated relation of the theoretical structures of these three areas. In summary the overall purpose is:

- studying and assessing the level of development of comfort, pleasure and cognitive engineering in relation to Human Factors and Ergonomics and for relevance to engineering design;

and

- in the three cases conceptualizing to identify the theoretical structures of concepts and their integrated relation.

Associated to this purpose rises the question of identifying the concepts and their sub-concepts that are viable for data collection, communication, analysis and representation. Thus, this is a question of which are the concepts that can be transformed into operatives. However, each of the three branches appears to be on a different level of development, and all of the three appear to be less developed than traditional ergonomics. Traditional ergonomics is widely applied and used, in a way it is standard, but the same does not apply to pleasure, comfort or cognitive engineering. Pleasure and comfort seem nevertheless not as developed as cognitive engineering, where much effort is going on in finding methods and developing theoretical background understanding (Dowell & Long, 1998).

The theoretical structure of concepts in each of the three areas is what supports the building of models, and the validity of these models are an indicator of the level of development of each area. Validated models are used to predict outcomes given physical properties. Outcomes include objective symptoms (e.g. health) and subjective assessment (e.g. comfort). Considering this process, departing from the theoretical structure and arriving at the prediction of outcomes given physical properties, I have preliminarily considered the level of development of traditional ergonomics, cognitive engineering, comfort and pleasure. I have categorized the four in terms of mature, semi-developed and at a low level of development, and have also mentioned low back pain (orthopedics) as a term of reference. This hypothetical categorization is presented in Table 3, which also includes examples of models attained or modelling efforts.

Table 3 *– Hypothetical categorization of the level of development of Human Factors and Ergonomics (HFE) branches focused in the dissertation in comparison with orthopedics (low back pain) and asides with examples of models, or modelling efforts.*

Level of development	Field / HFE branch	Examples of models / efforts
Mature	Traditional Ergonomics	(has attained predictability) Jack™ - human modelling and simulation system for anthropometrics (HMS-CIS, 1997); NIOSH (1981) guidelines for manual lifting (biomechanics); Thermal comfort (Fanger, 1972)
Semi-level	Low Back Pain (orthopedics)	Symptoms are empirically described, treatment has been developed, but causes are not fully understood (SUB, 2000)
	Cognitive Engineering	Rasmussen et al.'s (1994) Skills-Rules-Knowledge model; Reason's (1990) error categories; Woods' (1995) design procedures; (prediction is not exact - e.g. article VI)
Low level of development	Comfort	Examples of attempts – Zhang et al. (1996), Goonetilleke (1998) or Ebe and Griffin (2000)
	Pleasure	Example of attempts – article V

Traditional ergonomics is able in some cases to model and / or predict subjective assessments and objective symptoms and therefore it is able to input requirements into design processes. Within traditional ergonomics, there are areas that have attained a level of predictability that makes them a point of reference. But the comparison depicted in Table 3 raises the question of what is the feasibility of attaining predictability for those three other branches of HFE (cognitive engineering, comfort and pleasure). My holistic hypothesis is that pleasure and comfort have the potential to achieve this capacity of modelling and or predicting (cognitive engineering is close to achieving it already). In order to attain that capacity, further development is however needed.

A goal of this thesis is further assessing the predictability of these three branches, and pointing at directions to attain it. This aim includes the following operative aims:

- assess the level of scientific knowledge concerning comfort, pleasure and cognitive engineering

and

- perform field studies to test the feasibility and performance of the theoretical structures, data collection methods and representation formats (how to present the results).

Moreover, establishing the level of scientific development can be done through finding out if the present theory and methods yield workable results for assessing model validity on the one hand, and for directing product development on the other.

An important aspect of ergonomics input into the process of designing is the great number of requirements that coexist with it. Thus, considering a holistic product development perspective, these requirements range from the design for function, stress, manufacturing, assembly, cost, use, quality and service to environment (Meerkamm, 1994). Hubka & Eder (1996) use the expression 'design for properties' to signify the search for suitable design properties in face of design requirements. This is equivalent to 'Design for X' (DFX) where the X stands for a particular phase of the product life-cycle or a specific property (Furuhjelm, 2000). Given my aim of studying and assessing comfort, pleasure and cognitive engineering for relevance to engineering design, the integration of their respective design methods is desirable. Separately working with methods for design for comfort, methods for design for pleasure, methods for design for cognitive engineering, plus many other methods for design for X would overwhelm practitioners, given the wide spectrum and the diverse nature of the DFX tools they would have to cope with (Huang & Mak, 1997). Compartmentalized knowledge is more at risk of becoming bookshelf knowledge, hence not practiced or put to use.

- Thus, how can integration be accomplished?

Activity theory is a psychologists' way of relating people, with things, goals and consequences (e.g. Engeström et al., 1999). It could possibly be a means of unifying these approaches of Human Factors and Ergonomics from an engineering design perspective. Engineering design applies Human Factors knowledge to Product Development, so instead of having several Design for X methodologies, it would be desirable to have a unified approach. In the terms of activity theory, this implies considering the goals and consequences of each approach.

- What are the criteria of integration? What is to be achieved?

The criteria for integration should be attaining compatibility. Activity theory is to be used in an attempt for compatibilizing concepts, words, nomenclature and theory structure. Thus making it possible to talk about and work with cognitive engineering, comfort and pleasure requirements in a compatible way, specifically looking at goals and consequences. The benefit for product development in the long run is analyzing the ergonomic requirements of products with one single approach and method.

The tentative answers given to the three former questions lead to formalizing the following research question:

- Can activity theory be used as a means of structuring concepts– knowledge–data in an integrated way for the handling of and management of pleasure, cognitive engineering and comfort?

While integration is desirable from an engineering design perspective, Moray (2000) predicts that in the future HFE will develop into a collection of sub-disciplines whose practitioners know little of each other's techniques. He foresees that this will occur as a response to the discovery that the range of problems to which HFE can be applied is very great. Thus, besides product development, research might also gain from a convergence, in terms of having a link, or common thread, between these branches of Human Factors and Ergonomics. An acknowledged shared structure that serves as a ground for cross-communication and recognizing common goals might contribute to delay partition, if not avoid it, and facilitate co-operation in research. It would also enable a more holistic view of problems, and abstracting patterns across domains or sub-disciplines.

However, there are strong forces that drive the partition of disciplines as they grow. According to Ziman (2000), research specialties are the local intellectual arenas where knowledge claims are disputed and, in principle, no two academic scientists should be doing exactly the same research. Their competition for notoriety and resources drives them to differentiate their work into distinct fields. To this adds the restriction that recognized research scientists hold the responsibility of being sufficiently familiar with the literature in their field, in order to assess the novelty and plausibility of peer work. Ziman argues that the combination of these two forces is what keeps an active research specialty from growing too large. It will either subdivide, fail to reach consensus and split into competing schools, or simply fade away for lack of interest. These arguments support Moray's prediction of subdivision of the discipline, given the growth of the range of problems suitable for HFE, if it is accompanied by an increase of active researchers. However, according to Ziman (2000), this tendency towards fragmentation is counteracted by an effect of the intra-personal competition between researchers. In a saturated field, many scientists realize that there are more promising problems in 'marginal' areas, where they have to take account of problems and techniques from 'neighbouring' fields. As a result, problem areas get stitched together by researchers whose careers cross the boundaries between specialties. Hence, it is not possible to judge to what extent research would reap benefits from a successful integration of comfort, pleasure and cognitive engineering through the application of activity theory.

Based on his experience of product development and design for pleasure, Jordan (2000) outlined a unifying thread that runs through the ergonomic contributions to product development. This thread is based on the notion that all product benefits contribute to pleasure, which is seen as a goal in human interaction with products. This goal of pleasure came to be empirically supported, as reported in article V. Thus, if activity theory can be used as a means of integrating pleasure, cognitive engineering and comfort, another thread will result, reinforcing the unification, in terms of product development.

(1.3) Summary of research questions

The discussions presented in this chapter led to the formulation of an overall purpose (aim) for the dissertation, two operative aims and a separate research question, as presented in section 1.2.2. These aims and research questions are presented in summary in this conclusion to the introductory discussion. Each aim is presented with an underlying hypothesis and each of the operative aims is associated to a research question. This results in three operative aims and three corresponding research questions. In Figure 2, aims, underlying hypotheses and research questions are presented in a hierarchical relation.

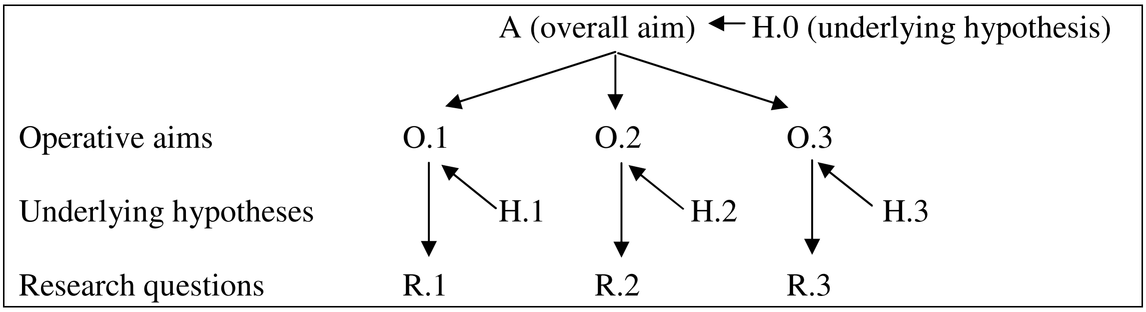


***Figure 2** – Hierarchical representation of the structure of aims, leading to research questions, and considering the underlying hypotheses.*

A (overall aim) – Study and assess comfort, pleasure and cognitive engineering for relevance in engineering design processes and working towards finding or identifying an integrated theoretical structure.

H.0 (underlying hypothesis) – Comfort, pleasure, cognitive engineering are important factors in the process of designing Human Factors quality, a process which would benefit from an integration of design approaches and theoretical structures.

O.1 (operative aim) – Establish level of scientific knowledge concerning comfort, pleasure and cognitive engineering (in terms of development potential and feasibility).

H.1 (underlying hypothesis) – Comfort, pleasure, cognitive engineering (and traditional ergonomics) are at different levels of development, but they have basically a similar potential to achieve predictability.

R.1 - Research question:

- do present theory and methods yield workable results for assessing
  model validity?
  directing product development?

O.2 (operative aim) – Perform field studies to test the feasibility and performance of (level of development in practice):

- theoretical structures found
- data collection methods
- representation formats

H.2 (underlying hypothesis) – Comfort, pleasure, cognitive engineering (and traditional ergonomics) are at very different levels of development in practice, but they have basically the same potential to achieve predictability.

R.2 - Research question:

- are data collection methods and representation formats adequate for communicating to users and designers?

O.3 (operative aim) – Apply activity theory[3] to attempt compatibilizing the three theoretical structures.

H.3 (underlying hypothesis) – Integration can be accomplished and activity theory enables accomplishing that integration.

R.3 - Research question:

- can activity theory be used as a means of structuring concepts–knowledge–data in an integrated way for the handling of and management of pleasure, cognitive engineering and comfort?

(1.4) Organization of dissertation and reader's guide

The primary interest of this dissertation is assessing the feasibility of attaining predictability and essaying compatibility of three newer branches of ergonomics science (comfort, cognitive engineering and pleasure). Accordingly, the dissertation has an explorative and synthesizing character, in which selected issues relating to an engineering design perspective of these three branches are investigated and related to each other. The organization of the dissertation is shown schematically in Figure 3.

Chapter 1 comprises an **Introduction** outlining the problem domain, setting the research aims and presenting the research questions and a reader's guide.

Chapter 2 presents the **Method and Process** used for answering the research questions. By introducing this description I hope the reader will have a more linear structure in the reading process.

Chapter 3 gives an outline of the **History of Research Events** underlying this dissertation and exposing limitations and restrictions of this dissertation.

[3] There could possibly be a number of different approaches for integration (e.g. matrix formulation combined with fuzzy logics – cf. Karwowski & Dzissah, 2000), but I chose this one given its success as a means of understanding a phenomenon in various dimensions (e.g. Karlsson, 1996, Rhodin, 2001). Ergonomics is known as the science of work, and work consists of activities, hence the interest in activity theory in the context of understanding how human beings utilize tools to achieve benefits.

Chapter 4 presents a **Summary of Articles**. The summary includes an extraction of those issues which are relevant for discussing the research questions and for showing the application character for engineering design.

Chapter 5 comprises **Results** concerning the estimation and assessment of model maturity and validity based on literature and the empirical studies. These results are also discussed in the light of research questions R.1 and R.2.

Chapter 6 essays several analyses, including the application of activity theory, for **attaining domain compatibility**. The outcomes of this application are discussed in terms of the answer to research question R.3.

Chapter 7 presents the **Conclusions and Future Research**.

Appendix. The appendices consist of Appendices A (scrutiny of literature on Product Development), B (cognitive engineering schools of thought), C (description of activity theory) and the Appended Articles, which report on investigations that complement the dissertation. They are structured into the three main domains considered:

- articles addressing comfort (articles I, II, III and IV),
- articles addressing pleasure (articles IV and V) and
- article addressing cognitive engineering (article VI).

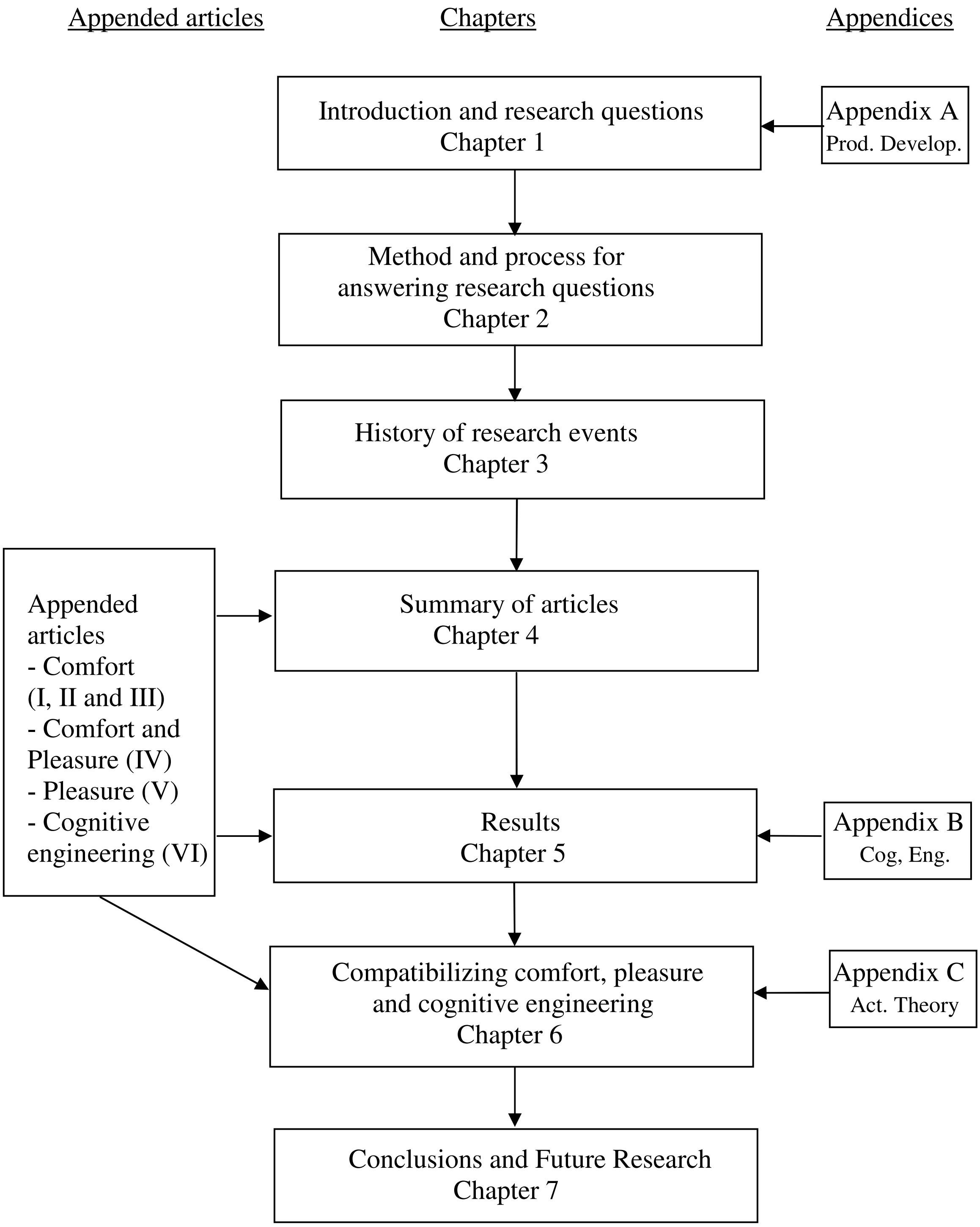


***Figure 3** – Organization of the dissertation.*

Chapter 2

Objectives:

- To introduce the methodological approach followed in the dissertation.
- To present the scale of maturity devised.
- To show the role of literature and empirical studies in estimating the level of maturity.
- To describe the rationale used in assessing methods for data collection, analysis and representation.
- To introduce the approach followed in essaying compatibility (encompassing the application of activity theory).

(2) Method and process for answering the research questions

This chapter presents the logics used for answering the research questions. For each of the three branches of Human Factors and Ergonomics focused, this 'answering' process includes the assessment of the transformations from the theoretical structure into product development directives. As criteria for evaluating the level of development of the three branches, this assessment considers the validity of the existing models[4] and the creation of product development directives. There is one overriding direction in this process as presented in Figure 4. This process consists of extracting the theoretical structure from literature, characterizing its sub-concepts and transforming these into operatives. Operatives then yield measured empirical results, which may lead to product development directives. The transformation from subconcepts to measured results is the portion of the process that can possibly be brought to the level of systematic predictability.

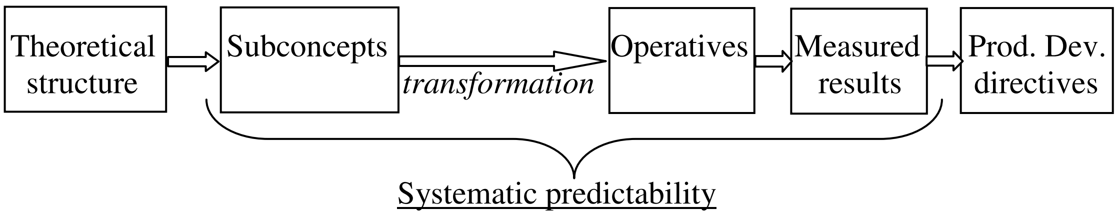


Figure 4 *– Chain process from theoretical structure (literature) to product development directives.*

Examples of operatives are comfort and discomfort (both taken separately, cf. Zhang et al., 1996), which would then figure in the output side of the predictive model depicted in Figure 5, which is an elaboration of Figure 4. As an example of transformation, elasticity, being a property with a believed direct link to comfort (Ebe & Griffin, 2000; Park et al., 1998), has already been defined in general physics. It can also be seen as an operative resulting from the transformation of comfort, since it is hence part of the theoretical structure of comfort. In the case of the main pleasure study performed and appended to this dissertation (article V), a transformation process is depicted from subconceptual hypotheses to operative questions. The measured results in that case spring from the answers to the questions. There is also a difference between wanted operatives and what can actually be measured in practice. Operatives also range in their subjective and objective essence (e.g. discomfort versus elasticity).

[4] Validity is used here to signify the degree to which theory has been verified in the 'real world', hence the extent to which theory has been empirically validated. In particular contexts, such as those of pleasure, comfort and cognitive engineering, validity refers to the degree to which contents of theoretical overviews (containing propositional knowledge, models and hypotheses) have been empirically verified (in a manner based on observations or experiments). The applicability and quality of design methods meant to translate wanted subjective outcomes into product properties can also be thought of as a measure of the validity of such methods, when these are considered as part of the theoretical body of knowledge (which hence includes design tools as applied theory).

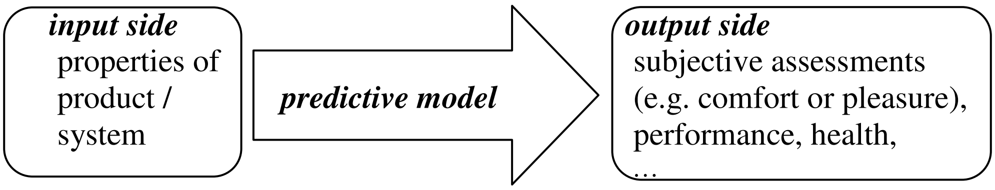


Figure 5 *– Depiction of a wanted operative, i.e. a predictive model, which can be used as a product development directive, or design method. The existence of such models also assists characterizing model validity of the corresponding theoretical structure.*

With the chain process represented in Figure 4, the theoretical structures are used in an empirical context. Production of product development directives and assessment of model validity are the two kinds of entities used to assess the theoretical structures. The measured results establish the link to the empirical world. If we know something about the product or system at hand and we use this process (as depicted in Figure 4), managing to identify or produce predictive models that can deliver useful outputs (Figure 5), then the theoretical structure is good. The process of modelling takes features and properties as inputs and delivers outcomes. The sorts of outcomes are ill health, discomfort, tiredness or subjective pleasure. For the comfort branch, a potential outcome co-variating with comfort is not becoming tired. For the pleasure branch, a potential outcome co-variating with pleasure is being alert and engaged for a long time.

In addition to the chain process depicted in Figure 4, the method to answer the research questions encompasses an analysis on methods used for data collection, data analysis and data representation in my empirical studies in the three areas. This analysis is geared towards feasibility and practicality, as well as towards compatibilizing and integrating these types of methods. Moreover, the application of activity theory is essayed for compatibilizing the three areas of cognitive engineering, comfort and pleasure. The following sections describe in more detail the phases of the method used to answer the research questions.

(2.1) Scale of maturity devised and criteria of assessment

The three areas of HFE under study have different characteristics in several dimensions. Such dimensions encompass the level of conceptualization of the field, the shear size of established knowledge and the level of emancipation from the core of ergonomic science.

In chapter 1, section 1.2.2 – Research Aims, a hypothetical categorization of the level of development of the HFE branches focused in the dissertation was brought forward (Table 3). This hypothetical categorization is to be recalled in chapter 5 for comparison with the results actually attained from the assessment of theoretical structures and concepts. This assessment concerns in particular the level of maturity of each of the HFE branches focused, e.g. the stage of scientific development of the theoretical structures of concepts. This depends on the level of validity of models and the quality of the existing product development directives (see following sections – 2.2 and 2.3).

Kuhn's (1962) theory of the structure of scientific revolutions is used as a background framework from which some of the assessment criteria of the level of maturity are derived. This theory and the criteria used in the assessment of the level of maturity of comfort, cognitive engineering and pleasure are discussed in the following paragraphs.

Kuhn's theory of scientific evolution comprises the following chronological stages: a pre-paradigmatic stage, a normal science stage, and a revolutionary stage. A field of science is described as initially being pre-paradigmatic, then turning to a normal science stage for at some point to enter into the revolutionary stage. After the revolutionary stage the science field is accepting a new paradigm moving into another normal science stage, and so forth. In each of the three stages the community attempts to explore its field with different concepts, theories, methods and instruments.

In the pre-paradigmatic stage, competing schools or even individual researchers are defining their different theories and thoughts as a foundation for carrying through their research activities. They use different concepts, hold to different theories, and use different methods and different instruments in their attempt to achieve insight into their field. Although the pre-paradigmatic stage is not incompatible with significant discoveries and inventions, the patterns for such discoveries and inventions are less organized than in later stages. According to Kuhn (1962), a field first qualifies as a science field when the field is able to support a normal science stage.

When the community is in a normal science stage, the vast majority of researchers work within the same paradigm, sharing consensus on conceptual, theoretical, methodological and instrumental constraints relevant to the field. The shift from a pre-paradigmatic to a normal science stage is however a slow process. Research in the normal science stage can be characterized of puzzle solving activities. The paradigm outlines important research questions and guides researchers to improve the precision of theories and findings in the way laid out by the paradigm. A community enters a revolutionary stage when doubts and anomalies have been encountered for the existing paradigm. This might lead to establishment of a new paradigm as a result of a more appropriate paradigm that manages to describe and include additional aspects of the field in question.

Based on Kuhn's theory of scientific revolutions, I have devised a scale of maturity that considers five criteria of assessment, namely:

- the extent and quality of the theoretical body,
- the models' validity / quality,
- the Kuhnian level of paradigmatic consensus (excluding the revolutionary stage),
- the level of congruence between the theoretical body of knowledge and the practice centered demands of the field, and
- the production of product development directives.

The application of this scale is necessarily imbued of some level of subjectivity, but the use of five criteria of assessment aims at assuring a level of reasonable repeatability and enabling a critical discussion of the conclusions arrived at. Kuhn's 'concepts and theories' are dealt with in the criterium of the extent and quality of the theoretical body of knowledge, while Kuhn's 'methods and instruments' are dealt with in the criterium of models' validity and quality. These two criteria, together with the degree of paradigmatic consensus of the field, can be used to characterize the Kuhnian stage of evolution. I have, however, decided to exclude the revolutionary stage from the latter criterium, since it obviously does not apply to emerging fields. In addition, the level of congruence between theory and practice, which I deem particularly relevant for fields of applied science and engineering, reflects the fact that theoretical overviews have an ambition to be complete, whereas empirical evidence is available for some aspects only. The existence of product development directives is a partial measure of the attractiveness of the field to researchers, as well as of the interest arising from practice in its development. However this criterium is geared here towards the quality of the existing product development directives, rather than their quantity.

Table 4 depicts the scale of maturity devised as well as the levels of each of the criterium used to extrapolate its value for each branch considered. The criterium are equally weighted and the qualitative levels correspond to an ordered numerical scale of low-1, medium-2 and high-3. The resulting scores were arbitrarily set to correspond to: low level of development – $1(=1^5)$ to 16 $(=1^5/2+2^5/2-0.5)$, semi-level of development – 17(=16+1) to 137 $(=2^5/2+3^5/2-0.5)$ and high level of development (mature) – 138(=137+1) to $243(=3^5)$.

Table 4 *– Scale of maturity devised and criteria of assessment (each of which is divided into three levels).*

Scale of Maturity (a product of the values for each criterium)	Low level of development 1-16	Semi-level of development 17-137	Mature (High level of development) 138-243
Kuhnian level of paradigmatic consensus	Low 1	Medium 2	High 3
Extent and elaboration of theoretical body (including existence of models)	Ill-defined 1	Preliminarily defined 2	Well defined 3
Models' validity / quality	Bad 1	Medium 2	Good 3
Quality of product development directives	Very low 1	Mediocre 2	Very big 3
Level of congruence between theory and practice	Highly Dissociated 1	Neutral 2	Highly Congruent 3

The application of this scale of maturity is geared to answer research question 1, which inquires if the present theory and methods yield workable results that can be used to assess model validity and to direct product development. The answers to this research question are embedded in the criteria considered in reaching at the level of maturity.

(2.2) Survey of literature to estimate level of theoretical structures and concepts

This phase concerns the assessment of the level of scientific knowledge, based on literature on comfort, cognitive engineering and pleasure, and using the aforementioned scale. The level of scientific knowledge is seen as the degree to which these branches of science have been able to produce model validation and product development directives. Thus the section includes:

- an inventory of concepts and theoretical structures (refer to second paragraph of section 1.2.2 – Research Aims for a clarification of terminology adopted)

and

- an assessment of the degree to which the former have been able to produce model validation (help in building models) and product development directives (or requirements).

As an example, for pleasure, the theory structuring seems to have hardly started. On the other hand, comfort is deemed in a more advanced but not complete stage, since it is not broken down all the way from theory structures to operatives. For comfort, predictability has not been achieved, not even roughly, but there seems to be a potential to attain modelling.

(2.3) Empirical studies to assess viability of theoretical structures and concepts

This step of the investigation and the previous one are linked, and together they aim at establishing the level of scientific knowledge. They follow the process depicted in Figure 4, using the scale of maturity presented in section 2.1. This process is intended to show what exists and what is missing in the theoretical structures, and what could be done to complete them or pointing out what has potential for further development. These results are then fed into the issues deemed relevant for future research, presented in chapter 7.

This phase of the investigation provides results, based on my empirical studies, that may assist in assessing the validity of the theoretical models, and therefore in assessing scientific development. It also provides results that may be useful for guiding design processes, through product development directives or requirements. The focus of this phase is on operatives (questions, measures, data to be collected and representations). This investigation is also aimed at answering the question:

- To what degree have my empirical studies been able to produce communicable Product Development directives?

(2.4) Assess methods for data acquisition, data analysis and data representation

This analysis deals with what methods used in my empirical studies actually work and those that do not work. The assessment of data representation methods answers questions such as:

- Are these representation formats acceptable to communicate with users, operators and designers?
- Did people understand what I asked them?

As an example, for the side support study (article I) and the premises on pleasure study (article V), verbally eloquent people were needed to be able to deal with the concepts presented. This was not achieved in the first study mentioned above (article I) but it was attained in the second one (article V).

(2.5) Application of activity theory as a means for achieving domain compatibility

This step of the investigation is aimed at applying activity theory in an attempt to reach domain compatibility. It concerns:

- a description of activity theory (presented in Appendix C)

and

- the application of activity theory as a means of reaching domain compatibility (within comfort, pleasure and cognitive engineering).

The application of activity theory is intended to test if it can help in aligning comfort, pleasure and cognitive engineering for relevance to the practice of engineering design. My initial standpoint is that definition-wise, at least, there are commonalities. Maybe one can find more commonalities at the subconcepts and operative levels, further down the chain process presented in Figure 4. Activity theory is to be tried as a tool that may prove to be valuable in assisting in this search process.

Chapter 3

Objectives:

- To describe the background and history of research events.
- To show awareness of limitations and restrictions in pursuing the proposed aims.

(3) History of research events

The empirical work underlying this dissertation is a result of a research process stretched out over seven years, and which can be structured into four domains. In this journey, comfort has been in my baggage for the longest time. This domain, dealing with seat comfort, consisted of two research projects, the first of which started in 1995 and was carried out under the auspices of CTH (Chalmers University of Technology) and Volvo Car Corporation. This study is reported in article I. It deals with the evaluation of automobile seat side supports from a comfort and support perspective, and was part of my Master's project. The second study (reported in article II) was carried out during the academic year 1998/1999 again under the auspices of CTH and in partnership with Autoliv[5]. It deals with the design of a new automobile seat feature (articulation at shoulder level) and its impact on comfort. Article III, on the feasibility of predicting seat comfort, is a theoretical reflection based on the two comfort empirical studies, and was produced at a later stage.

I established contact with the domain of cognitive engineering in the medical technology area in between the first and the second comfort studies. This period started in February 1996 and allowed my familiarization with hospital work environments in two Portuguese hospitals (Covilhã and Porto's S. João). This would later be useful as a background experience for carrying out the cognitive engineering study under the auspices of OSU (Ohio State University), during the fall and winter of 1999/2000, and in partnership with the Veterans Health Administration. This study is reported in article VI, dealing with the impact of a new technology (bar code support to medication administration) on patient safety.

My exploration of the domain of pleasure developed in parallel with the second comfort study and later on its own, after having carried out the cognitive engineering study. The questionnaire study reported in article IV, dealing with links between comfort and pleasure, was carried out at the time of the second comfort study (article II), and both draw on the same group of subjects. The second pleasure study focuses on theoretical premises of pleasure with products and is reported in article V. It was the last empirical study to be preformed. It was carried out under the auspices of UBI (University of Beira Interior), during the academic year of 2000/2001.

The aims of this dissertation are partly different from those of the appended articles, but an overall vision was already present when designing most of those studies. A vision for the aggregation of the three branches (comfort, cognitive engineering and pleasure) came along in 1998. That was when the aims for this dissertation started to become more concrete, at the time the second comfort study was being prepared. However, prior to that, in 1997, the aims for the research had been widely formulated as characterizing human requirements on technology for compatibility with the practice of engineering design. The vision evolved and studies appeared initially as opportunities and later as a choice between opportunities and finally as specially

[5] Autoliv is a Swedish based developer and manufacturer of automobile safety systems and of other automobile sub-systems.

designed studies (only choice). The pleasure studies resulted from an evolving vision trying to see if this area was ready for empirical application. The application of activity theory to attempt compatibilizing the three concepts came at a later stage, when the final part of the dissertation work focused on analyzing, reflecting and compatibilizing theory.

The research that supports this dissertation enabled producing other publications not appended to this dissertation, some of which were presented in different forums, in both Portuguese and English languages, and are listed below.

Coelho, D.A. (forthcoming). Wheel loader seat comfort. In Peter Vink, Michiel de Looze (eds.), Report on the Eurocabin Project, Brussels: European Commission.

Patterson, E.S., Coelho, D.A., Render, M.L., Coyle, G., Woods, D.D., Cook, R.I. (2001). Medication Administration Error and BCMA: Preliminary Findings. Proceedings of the 19th Annual Meeting VA Health Services Research: Improving Access and Outcomes. Washington D.C., February 14-16.

Coelho, D.A., Gonçalves, L.C.C., Dahlman, S. (submitted for publication in "Revista Portuguesa de Ergonomia). As componentes do conforto (Comfort components – in Portuguese).

Coelho, D.A., Render, M.L., Patterson, E.S., Woods, D.D., Cook, R. I., Dahlman, S. (2000) - The impact of new technology on patient safety, in "Ergon-Axia 2000, Ergonomics and safety for global business quality and productivity" ed. by Podgórski, D. and Karwoski, W., Central Institute for Labour Protection, Warsaw, ISBN 83-87354-54-6, pp. 261-265.

Coelho, D.A. and Dahlman, S (2000). Evaluation of methods, approaches and simulation quality in the experimental evaluation of seat comfort and functionality, Proceedings of IEA'2000, San Diego, USA, 2000.

Coelho, D.A., Cook, R.I., Dahlman, S., Patterson, E.S., Render, M.L., Woods, D.D. (2000). Unintended effects of technological change in the process of inpatient care. Paper presented at the Ergonomics in Quality Management conference of the Portuguese Ergonomics Association (APERGO), Costa da Caparica. 8p.

Coelho, D.A., Dahlman, S.; "A Revised Framework for the Development of Safer Medical Technology - Comparing Portuguese and Swedish Hospital Environments", in "Engineering Psychology and Cognitive Ergonomics", Volume Three -Transportation Systems, Medical Ergonomics and Training; edited by Don Harris; Part Five; ISBN 1-84014-546-3; pp 421-428; Ashgate; 1999.

Osvalder, A-L., Dahlman, S., Coelho, D.A., Garmer, K., Liljegren E.; Ergonomic Design and Quality in Handling of Technical Equipment in Medical Care – Development of a Working Model; International Conference on TQM and Human Factors; Linköping, Sweden; June 1999, Vol.2, pp. 453-458.

Coelho, D.A., Dahlman, S., 1999. Articulation at Shoulder Level – A way to improve car seat comfort? Technical report – University of Beira Interior, Covilhã and Chalmers University of Technology, Göteborg, 159 pp.

Coelho, D. A., Dahlman, S. – Development of safer medical technology, comparing Portuguese and Swedish Hospital Work Environments, Proceedings of the II European Symposium on Ergonomics, FMH edições, Lisboa, Portugal, June 1998.

Coelho, D. A., Dahlman, S. - A Pilot Study to Evaluate Car Seat Side Support, Proceedings of IEA'97 (13th International Ergonomics Association triennial congress), ed. by Finnish Institute of Occupational Health, vol 6, pp 299-301, Helsinki, Finland, 1997.

Coelho, D.A., Dahlman, S.; O uso de métodos ergonómicos na avaliação do apoio lateral no assento de automóvel. Comunicação ao I Congresso Nacional de Ergonomia, ed. da APERGO, pp 39-40, Lisboa, Portugal, February 1997.

(3.1) Limitations and restrictions

My knowledge is deeper in the domain of comfort, which is a domain that is fairly small if compared to cognitive engineering. The latter is enormously big even though apparently it is not fully mature. In the case of pleasure, although it appears to be a small subject at an incipient stage, the results that have been produced are spread in a wide array of disciplines; some of the work that has been done in the field has been published in publications pertaining to consumer issues and marketing. I have focused on ergonomic approaches to pleasure with products. Concerning product development, what I have covered are generalities directly concerned with engineering design, but the design methodology and terminology used in chapter 1 (and in Appendix A) is mostly applicable to hard products, as opposed to soft products (the latter can be seen as more relevant to cognitive engineering, while pleasure is applicable to all product categories – cf. article V).

The empirical papers that are appended to this dissertation have a double purpose. They suit the purpose of studying sharp problems for an interestee (e.g. Volvo Car Corporation, Autoliv, Veterans Health Administration) who thus was the definer of the problem. At the same time the papers have been used as vehicles for the analysis contained in the dissertation. This has had the advantage of studying relevant problems in a real world context. On the other hand, the customer interest has governed the design and focus of these studies, which imposes a restriction that strengthens the explorative character of the work. Hence, while the theory overviews provided tend to be overarching, the empirical evidence available is restricted. The main empirical studies from which this dissertation draws results consist of two small features of automobile seats, features of bar coding and a pleasure study that does not focus on any definite product. It is thus envisaged that hypotheses can not be verified or falsified conclusively, although they will be strengthened or weakened and thus indicate paths for future research.

The exploratory nature and the pioneering ambition of this study are a consequence of venturing into new areas (exploring new fields). Research is a process that leads to increasing knowledge. In 'normal' academic science, research problems are formulated and tackled within the bounds of an established discipline (Ziman, 2000). However, the contexts of application where science finds its implementation are not so bounded (as is the case in the empirical studies appended to this dissertation). In this dissertation I am placed in the borderline between the known and the unknown. Research that is done in the known areas has a predictable path. In this case, the assessment of the ability to predict and model is my outcome. Thus, a holistic perspective is deemed necessary to complement detailed depth in reaching at this outcome. This contribution goes to Ergonomics and Human Factors, but this discipline is seen here as a support science for Engineering Design in its activities of designing products, systems and organizations.

Chapter 4

Objectives:

- To show the value of the appended articles as a medium for orienting system and product development.
- To describe selected aspects of the content of each appended article in relation to the dissertation’s aims and research questions.

(4) Short description of appended papers

The level of empirical content in the appended articles varies. While articles I and II report on studies of comfort with a strong empirical component, article III is mainly discursive and theoretical, but relates and develops partially on articles I and II. Article V has again a strong empirical component on pleasure, while article IV, linking comfort and pleasure, draws on the results of a pilot study based on questionnaires, but also has a stronger discursive theoretical component. Article VI, concerning cognitive engineering, has a weighty empirical basis. The short description of appended papers presented below was produced so as to conform to the following two guidelines:

- showing the value of the studies as an application for the interestee involved (if relevant), and whether useful results for system and product design were produced, and
- showing the relevance of the studies to serve as a medium through which aims of this thesis are attained and research questions are answered.

(4.1) Study I – evaluation of automobile seat side supports

Study I is an experimental pilot study that aimed at deepening the understanding of support and comfort in relation to automobile seat side supports. The rationale followed was to vary three design factors that hypothetically had major influence in perceived comfort and support, producing four different seats. These were subjectively assessed during automobile driving in a track secluded from public traffic by 4 male subjects with very similar body widths (performing simple and paired comparison assessments). Comfort and support were subjectively assessed by subjects in graphical rating scales of perceived discomfort and perceived support, which considered several body areas, at intervals of 10 minutes. Overall assessments of comfort were done through paired comparisons between alternative test seats. The study also collected objective data under the presence of lateral acceleration - pressure prints of the contact interface and video recordings of the lateral displacements of the occupants while driving in the curvy track secluded from traffic. The experimental results obtained were inconclusive towards the acceptance or rejection of the underlying hypotheses due to unexpected behavior of the subjects (differing patterns of voluntary postural changes in reaction to lateral acceleration) and consequently low level of agreement of the subjective assessments and data collection problems. Still, a revised understanding of the problem formulation was attained that enabled producing practical design advice for the automobile company that sponsored the study.

The existing theory on seat design for comfort is not developed to the point where it can direct seat side support design. It was necessary to deepen specific knowledge in order to produce design advice for product development. However, given the fragileness of the existing theoretical structure on seat side support and the inconclusive results of the experiments, the advice produced is more of a suggestive character than a proven guideline or directive. Additionally the study shows that theory does not yet provide guidance in selecting scales for subjective rating of comfort / discomfort and support either.

(4.2) Study II – increasing seat support to the back

This is an experimental study that was aimed at assessing if an increase in the support given to the upper back would increase comfort in an automobile seat. This increase in support was possible through the implementation of an innovative articulation in the upper part of the seat backrest. The idea of introducing this articulation sprang from prevention of whiplash injuries occurring in rear end collisions. It was associated to a headrest counter tilting effect, thus resulting in a combined upper backrest and headrest convexity that was aimed at providing enhanced support to the cervical curvature of the vertebral spine. The setting of the exact height of the articulation was based on recommendations from orthopedics for spine posture (considering health criteria) and the natural curvatures of the back, and which was empirically validated. Subjective comfort evaluations took place at 15 minute intervals in static and dynamic settings (in the laboratory and through driving in common roads, though in a standard route) with a group of 12 subjects covering selected anthropometric strata of the accommodation range. Evaluations for both static and dynamic experiments were based on a scale of discomfort adapted from Borg's (1982) RPE scale. Same subject assessments of a seat fitted with the innovation showed a decrease in long-term subjective discomfort in relation to the same seat without the innovation in both static and dynamic settings. Hence, the dynamic trials served as a validation to the more controlled setting of the static trials. The values of the preferred settings for the articulation, head-rest counter-tilt angles were also collected and compared between the laboratory and road trials, with significant equivalence.

This study gave valuable proven input to the product development process of the interestee. The requirements on the articulation height established according to orthopedic and anthropometric criteria had a positive effect on the reduction of discomfort.

Study II was carried out at a later time than study I, and part of the methodology of collecting data was different in study II, reflecting the deeper understanding attained with study I. Completing unstructured interviews were used to scan for inconsistencies in the subjective assessments. Unexpected behavior did also occur in study II, since some subjects were observed not to lean into the upper part of the backrest and to the headrest, hence not seeking that support.

(4.3) Study III – exploring the feasibility of attaining seat comfort predictability

Study III is a discussion paper aimed at exposing and integrating the multidimensionality of comfort and assessing the feasibility of formulating an index of seat comfort. It is based on literature review of theoretical and experimental contributions on the concept of comfort and the area of seat comfort (including studies I and II). The literature survey was the means to extract the level of completeness of the state of knowledge concerning the relationship between objective unidimensional variables and subjective comfort. The goal was to judge where predictability could be attained, and to systematically assess where more knowledge is lacking, hence where the biggest research effort should be applied. The results show that the creation of discomfort indexes will be more feasible than that of comfort indexes; since comfort is presently described as a separate entity from discomfort and it is at present less well understood. The study argues for the need to reach a consensus on concepts, measurements and methodology concerning seat comfort research in order to ease the process of attaining predictability by coordinating research efforts.

The study partially addresses the first research question: Does present theory and methods yield workable results for assessing model validity and directing product development? The study also concludes that the physiological and physical aspects of comfort are the sub-components of comfort where predictability is more likely to be attained, whereas the psychological component of comfort is not yet developed to the same level.

(4.4) Study IV – linking comfort and pleasure

This study essays an integration of comfort and pleasure, based on semantic and conceptual similarities of the definitions of these two concepts. The study also embeds a comparative analysis of descriptors of comfort and concepts of pleasure with products. The results suggest that comfort can be seen as an aspect of pleasure, but pleasure holds dimensions not included in comfort. However, the ambition to clarify and define the overlapping and intersection of these two concepts should be pursued in the light of a spectrum of empirical cases. A small questionnaire study on automobile use and automobile seats illustrates the relationships between these concepts. The questionnaire covers the application of the four-pleasure framework, considering psychological, sociological, ideological and physiological pleasures derived from the subject's interaction with the automobile in general and with the driver's seat in particular. The questions were both open ended and with multiple pre-defined answers. Thirteen persons answered the questionnaire privately (during their leisure time) immediately after participating in the sitting trials of study II. The study also infers, from the questionnaire and the comparative analyses, a relationship between the elimination of discomfort and attaining usability for the case of automobile seats, seeing the former as part of the latter.

This study partially addresses the third research question, since it gives a contribution to compatibilizing comfort and pleasure, even though activity theory was not yet considered at the time of writing.

(4.5) Study V – empirical confirmation of the foundations of pleasure

Study V partially aims at developing and empirically testing a structure of concepts that allows communicating about pleasure with products with both users and with designers. It bases this structure of concepts in the theory assembled and developed by Jordan (2000), and adds some aspects concerned with the context of product use, in line with Rosenblad-Wallin's (1990) notion of a product's use-value. It attempts validation of the underlying theoretical premises on the theory of pleasure with products by considering three theories. These are Popper's (1989) pluralistic view of three worlds of activity, Tiger's (1992) four pleasure categories and Lewis's (1987) distinction between need pleasures and pleasures of appreciation. These theories were broken down into statements that were applied in a questionnaire study, completed by 82 respondents individually in their work or home environments. The statements were assessed in terms of the level of agreement the respondent had with them (four levels: total disagreement, moderate disagreement, moderate agreement and total agreement). Additionally, examples of products were requested to the questionnaire respondents to illustrate their ratings of the statements. The results of the questionnaire support the validation of the theories and shed light on the multitude of product categories for which pleasurable design seems to be relevant.

From the perspective of this dissertation's research questions, this study contributes to the characterization of the level of development of pleasure, and is also an attempt at contributing towards its advancement, in terms of providing empirical evidence to validate the underlying theoretical structure. The article also refers to the shortness of methods and validated models available to guide product development for pleasure.

(4.6) Study VI – the impact of technology change on patient safety

Study VI has very clearly embedded an approach to cognitive engineering, and in particular to Computer Supported Cooperative Work, which is described by Woods (2000), is mentioned in section 5.1.3 – cognitive engineering – and is succinctly reviewed in Appendix B. The methodology followed in the study enables understanding the processes of transformation and adaptation of naturally occurring points of change that disturb a system. The points of change are opportunities to learn how the actual system functions and sometimes mal-functions, and observation at points of change adds to the knowledge base of how changes impact cognition and collaboration.

The object of the study was the computerization and bar coded administration of medication in a large healthcare network in the United States. The study was deeply fielded, with data collection based on attemptedly non-intrusive observations ('shadowing') of practitioners at the sharp-end of the system of patient care. Additionally, practitioners and health-care managers were interviewed at the two hospitals where observations were carried out. Computer system designers and site managers also provided completing information. This was an opportunity to assess *in vivo*, the impact of the technological change on the safety, reliability and performance of the system of patient care. Patterns from previous research carried out in diverse domains were useful in guiding our observations. These patterns concerned automated verification, automated documentation, interface to a supervisory control process, system that changes the distribution of mental and physical workload and system that redistributes priorities of goals. Observation, guided with these patterns, contributed, together with tracing of the process of medication administration, to anticipate the complexities and practitioners' workarounds introduced as side effects of the change. An important complexity resulting from the technological change was raising timely medication administration over other patient care goals. The practitioners' workarounds consisted of adaptation strategies to reduce workload during the medication pass. A new path to failure of the joint cognitive system was identified – missing pending and discontinued medication orders. Additionally, design seeds were developed embedding hypotheses of what would be useful to support planning and increasing efficiency of work. These concerned creating overviews of medication orders according to multiple criteria in the dimensions of time and space.

The study shows the pertinence of developing, through a deepened understanding of how technology impacts cognition and collaboration, the ability to proactively anticipate and assess the impacts of technology change. This ability would enable forestalling new paths to failure before they have the opportunity to occur. This conclusion contributes to characterizing the level of development of cognitive engineering, since it shows that predictability has not yet been attained, although it is within reach.

This study enables more stringently assessing cognitive engineering's level of attained predictability in terms of the impact of computerization on cognition, since the study specifically addresses predictability of the effects of a technological change in a complex and safety critical work domain. It hence assists in providing answers to the first research question. It also shows the value of fielded observations (made through conceptual looking glasses developed with the assistance of patterns of adaptation abstracted from other studies and domains of cognitive systems) as a means of data collection. This method enables extracting a basis for developing hypotheses of what would be useful to advance in the design problem (materialized in terms of design seeds and reusable concepts). These hypotheses spring from the understanding of the complexities and capacities of the joint cognitive system. The study also shows the feasibility and effectiveness of synchronizing the research and development cycles (using prototypes as tools for discovery besides accepting the challenge of prediction) for advancing on design that supports the quality, reliability and safety of joint cognitive systems.

My involvement in this study consisted of several actions, namely:

- Familiarizing myself with the technology that was being introduced, as well as with the domain of work (medication administration for inpatients), and the previous methods of work. Surveying literature on medication 'error' to get some insight on the pre-conditions for the technology change. Prior to the conduction of this study I had initiated familiarization to the hospital work environment in two hospitals in Portugal.
- Observing the process of medication administration, both before and after the technology change. This included 'shadowing' of nurses, pharmacists and

physicians, as well as interviewing health-care managers and practitioners in two US hospitals and in different wards.

- Collecting observations and impressions and communicating them back to the research group for guidance on what to look for in the forthcoming observations and interviews. Key advisors were David D. Woods, Richard I. Cook and Emily S. Patterson.
- Understanding the side effects of change and identifying new paths to failure.
- Collaborating in extracting design seeds[6] for future improvement.

[6] Design seeds (Woods, 2000) are created upon reaching an understanding of the complexities and capacities of the system of people, technology and work. Design seeds do not carry the prescriptive nature of product development directives or guidelines but embody hypotheses of what would be useful.

Chapter 5

Objectives:

- To present the results of literature studies in assessing model maturity.
- To describe the assessment of model validity based on empirical studies.
- To assess methods for data acquisition, analysis and representation used in the empirical studies.
- To elicit the levels of maturity of comfort, pleasure and cognitive engineering.
- To present the answers to research questions R.1 and R.2.
- To discuss the feasibility of attaining predictability for each of the three areas.
- To equate the consequences of the results for engineering design.

(5) Results

This chapter considers the results from surveyed literature and from the empirical studies, in accordance with the descriptions given in sections 2.2, 2.3 and 2.4. It concludes with a discussion of the findings in the light of the research questions R.1 and R.2. The chapter is sub-divided into three main sections, each one dealing with comfort, pleasure and cognitive engineering respectively. Each of these main sections considers the estimation of model maturity based on literature studies and the assessment of model validity based on the empirical studies appended to this dissertation. The scale and criteria described in section 2.1 are applied to each of the three areas, in the light of the previous assessments. Methods for data acquisition, analysis and representation are also assessed with respect to my empirical studies in each of the three main sections.

After having collected an inventory of concepts through the literature studies, the goal has been to assess, for each of the three areas focused in the dissertation, the degree to which theoretical structures have been able to produce model validation (help in building models) and product development directives (or requirements). This assessment enables providing answers to research question 1.

The discussions on the assessment of model validity based on empirical studies follow, to the extent possible for each area, the chain process depicted in Figure 4, but focusing mostly on operatives (questions, measures, data to be collected and representations). These discussions expose the degree to which my empirical studies were able to produce communicable product development directives. The analyses on methods concerning data collection, analysis and representation are also based on the appended empirical studies. These analyses focus on the feasibility and the effectiveness of those methods and are geared to provide answers to research question 2.

While initially I had the ambition of adopting similar structures for the analyses of the three branches, this was not pursued, due to the different levels of knowledge documented and the particularities of the three areas. These particularities manifest themselves in different levels of conceptualization of the fields, and different approaches and on how dispersed and how great the established knowledge is. Also, what is published in literature, and the conscience of an independent field varies considerably. While cognitive engineering stages an active discussion and a number of alternative approaches and focuses can be identified within it, comfort has not gained the visibility and importance of cognitive engineering. Hence, concerning comfort, what it should be studying is not an object of discussion to the extent that it is for cognitive engineering. Pleasure, on the other hand, appears as an emergent field, which has been the object of discussion on what it should study, but is still very short of methods and visibility. Consequently, I have approached the three branches in different ways, conditioned by what was available in literature, and my capacity of navigation. Hence, the sub-section on comfort adopts a tabular and topical format, while the other two (pleasure and cognitive engineering) adopt a more discursive format.

(5.1) Comfort

(5.1.1) Assessment of model maturity based on literature studies

In my literature studies I have found two definitions of comfort at a general level:

- "comfort is that which a particular environmental reality can provide in terms of convenience, easiness and habitability" – Maldonado (1991), and
- "comfort is a pleasant state of physiological, psychological and physical harmony between a human being and the environment" – Slater (1985).

Maldonado views comfort as a property of the environment. Slater sees comfort as a condition or a transient property of the human being, which is, however, influenced by the environment. Hence, Slater's definition is more complete. In my analysis of comfort, the sub-branches of comfort considered can be seen as aspects of the surrounding environment. The sub-concepts included are not an attempt to cover all the instances of comfort but only a few, that are linked to seat comfort (focused in my empirical studies). Missing are aspects of human interaction with the environment which can be situations where discomfort can arise, such as auditory comfort, visual comfort, or ride (movement) comfort. Consequently, the present analysis does not encompass every sub-branch of comfort, but only some of those that have consistently and repeatedly been labeled in literature with the term 'comfort'. Additionally, there could be other bodies of knowledge, or theoretical structures, within the science of ergonomics, which could be seen as sub-branches of comfort, but that have not been denominated with such term. Hence, in practice, psychological aspects of comfort are also absent from the analysis.

The following analysis considers an area of comfort that is part of traditional ergonomics (thermal comfort) and two other I believe are still in a Kuhnian pre-paradigmatic stage (comfort at the human interface and seat comfort, which are covered in my empirical studies). This contrast enables suggesting differences these branches have attained in terms of maturity. Thermal comfort and comfort at the human interface are looked upon as parts of the theoretical structure of seat comfort.

The sub-branch of seat comfort is the one developed most deeply in this analysis. It extracts from the content of article III. I have used a tabular structure to assess the three sub-branches (thermal comfort, comfort at the human interface and seat comfort). This structure considers concepts, their relation to comfort components in Slater's (1985) definition, the objective of the sub-branch of comfort analyzed, relevant existing models, the deliverables of the field with relevance to engineering design and an assessment of prediction quality and model validity. Table 5 and Table 6 present this analysis for the sub-branches of thermal comfort and of comfort at the human interface respectively. The analysis of seat comfort is only partially presented in the form of a Table (Table 7). Some of its topics are developed in the subsequent text, which is organized into sub-sections identified in Table 7. These texts are followed by a concluding discussion on the assessment of comfort based on literature.

The models mentioned in the Tables (5, 6 and 7) have, in some cases, the character of operatives, while in other cases the models characterize relationships between operatives (variables). The operatives implicit in the models referred in the Tables yield deliverables such as those presented in the Tables, which are an extract of those with believed relevance to engineering design. Operatives will be presented in detail in section 5.1.2 with reference to the empirical studies concerned with seat comfort.

Table 5 *– Succinct analysis of thermal comfort using the tabular structure devised for the analysis of comfort sub-branches.*

definition	"a state of mind that expresses satisfaction with the thermal environment" – Fanger (1972)
concepts	heat production by the body, thermal resistance of clothing, air temperature, radiant temperature, air velocity, air humidity (Fanger, 1972)
relating to	perceived physiological and physical aspects of comfort
objectives	health, performance, thermal comfort
models	sweat production, thermal regulation (nervous system), thermal insulation, metabolism and energy expenditure, understanding of thermal influence on health, performance and comfort, subjective thermal discomfort
delivers	indexes that predict an approximate judgement of human thermal sensation for a given thermal environment modelled through six objective measures (Predicted Mean Vote - PMV, Predicted Percentage of Dissatisfied - PPD), requirements for the thermal conditioning of artificial environments, requirements for clothes design, etc.
prediction quality / model validity	predictability has been attained, the models are validated, hence the theoretical structure is good, the level of development is high, it is a branch of comfort that is mature

Table 6 *– Succinct analysis of comfort at the human interface using the tabular structure devised for the analysis of comfort sub-branches.*

definition	a particular category of comfort that focuses on the contact between the human body and the surface of a supporting object (e.g. beds, seats, shoes) (Goonetileke, 1998)
concepts	force distribution, interface pressure, vapor permeability, friction, compression of hard and soft human tissue, circulation, nervous system (pain)
relating to	perceived physiological and physical aspects of comfort
objectives	health and comfort (performance implicit in comfort)
models	physics force theory, thermal comfort, human physiology and anatomy, compression of human tissue, nervous system physiology, subjective discomfort at the human interface
delivers	tentative (hesitant) guidelines for the design of mattress surfaces, seat cushions for wheel chairs, foot support surfaces
prediction quality / model validity	resorts to the use of human subjects to visualize pressure distribution, the relationship between pressure distribution and comfort is not understood, although health requirements are somewhat developed (extreme pressure peaks are not commended, but there is no consensus on the ideal pressure patterns for comfort)

Table 7 *– Partial analysis of seat comfort using the tabular structure devised for the analysis of comfort sub-branches, with an indication of the sub-sections where completing analyses are developed.*

definitions	- a branch of comfort that specializes on comfort of the sitting person, - "comfort defined as the absence of discomfort" – Hertzberg (1972), or - comfort and discomfort seen as two separate entities, discomfort pertaining to physiological and biomechanic 'misfits' and comfort associated with feelings of relaxation and well-being (adapted from Zhang et al., 1996)
concepts	postural comfort (muscular effort, angles of skeleton joints, intervertebral pressure), comfort at the human interface, overall seat comfort assessment
relating to	perceived physiological, physical and psychological aspects of comfort
objectives	health and comfort (performance implicit in comfort)
models	postural comfort models: anatomy and physiology understanding of the human musculoskeletal system, orthopedic (health) understanding of ideal vertebral spine posture, understanding of the limitations imposed by seats on postures that may be attained by people (prescribed posture), the relationship between muscular effort (activity) and electromyography of muscles overall seat comfort models: anthropometry (for accommodation), attempts to identify relationships between seat design properties and subjective comfort, subjective discomfort, subjective comfort, subjective support thermal comfort models (*Table 5*) comfort at the human interface models (*Table 6*)
delivers	- generic design guidelines for health (*section 5.1.1.1*) - understanding of some direct cause-effect relationships that however do not extend to the comfort outcome (*section 5.1.1.2*) - other knowledge with implications on seat design aimed at comfort *(section 5.1.1.3*)
prediction quality / model validity	predictability has not yet been attained, the theoretical structure is not developed, but modelling efforts are underway (*section 5.1.1.4*)

(5.1.1.1) Generic design guidelines for health

The generic seat design guidelines encountered deal essentially with postural comfort. Examples of these include:

- The seat cushion must be contoured and soft at the 'waterfall' under the knee to avoid occlusion of fluids in the leg (Åkerblom, 1954).
- A general recommendation of orthopaedists is that a good seat should support the natural curves of the back; the lumbar spine should be supported in its neutral position (i.e. with a modest degree of lordosis) without the need for muscular effort (Pheasant, 1996).
- Orthopaedists recommend frequent or at least occasional changes of position; this calls for a seat that allows easy changes of sitting posture (Grandjean, 1988).

(5.1.1.2) Understanding of some direct cause-effect relationships that however do not extend to the comfort outcome

Examples of such relationships are listed below and include one relating to postural comfort (i) and two relating to comfort at the human interface (ii and iii):

i. a partial understanding of the relationship between muscular effort and seat design properties, e.g. “frequency of muscular activity was higher in the seats with firmer padding and smaller width” (Reed et al., 1991);
ii. a flatter seat cushion surface will raise pressure under the ischial tuberosities and a contoured surface will distribute pressure under the soft tissues (Pheasant, 1996);
iii. armrests should contact the fleshy part of the forearm, but unless very well padded, they should not engage the bony parts of the elbow where the highly sensitive ulnar nerve is near the surface (Pheasant, 1996).

(5.1.1.3) Other knowledge with implications on seat design aimed at comfort

This kind of knowledge is essentially relevant for the characterization of overall seat comfort. It includes the following propositions:

- Time spent sitting allows identifying the amount of time necessary to stabilize comfort evaluations and therefore establish the difference between short and long term comfort – one and a half hour (Reed et al., 1991).
- Accommodation requirements (for functionality and support, even support is linked to comfort) such as ‘seat cushion size should be dimensioned for accommodation of the seated occupant’s buttock and thigh dimensions’, or ‘lateral space in the seat backrest must accommodate the physical dimensions of the torso’.
- Finding significant correlation between some seat design properties and subjective assessment of comfort (e.g. Park et al., 1998 - level of deformation of the seat cushion and backrest, dynamic constant of elasticity and hardness of foam padding in the seat cushion and backrest, or Ebe and Griffin (2000) - built a mathematical model of sitting discomfort based solely on seat stiffness and vibration dose magnitude).
- Zhang et al. (1996) collected empirical evidence connecting feelings of relaxation and well-being with comfort. Jordan (2000) sees comfort as part of pleasure enabled by seats (this pleasure maybe derived through physiological and physical, as well as psychological, sociological and ideological mediation).
- Goonetilleke (1998) introduced the concept of a threshold value of pressure (the ‘mean tolerance value’) to delineate between the experience of a positive sensation of comfort and discomfort. For the purpose of seat design, this author suggests that if mean contact pressure is below the threshold value it would be best to distribute the forces, while higher pressures, closer to the ‘mean tolerance value’, should be localized to relieve discomfort caused by simultaneous neuron firings over large areas.

The present sub-section and the two previous ones (5.1.1.1 and 5.1.1.2), which develop some of the topics depicted in Table 7, contain pieces of knowledge relevant to seat design. However, this knowledge is fragmented and does not seem to follow a logical thread. Hence, it can be inferred from Table 7 and from the three subsections adding to it that there is fragmentation in the knowledge pertaining to seat comfort. Knowledge is dispersed and it is hence hard to assemble a complete picture of it. This is a characteristic that adds to the incompleteness of the existing knowledge as a hardship in designing for seat comfort.

(5.1.1.4) Prediction quality and the validity of models of seat comfort

Predictability in the field of seat comfort has not yet been attained, and comfort assessment still resorts to the subjective judgement of human subjects. Holistic models have not been developed nor have underlying hypothesis such as ‘high values of pressure or big pressure gradients are indicators of increased discomfort’ or ‘reduced muscular effort promotes sitting comfort’ been proved. Psychological aspects of comfort are not treated concomitantly with physiological and physical aspects, although these are acknowledged in definitions, at a high level of the theoretical structure. Hence the theoretical structure is not fully developed, and product development directives produced do not assuredly guide design to a satisfactory level of seat comfort.

However, research efforts are aiming at modelling, and partial models that link seat design properties with subjective comfort assessment have been unveiled (Park et al., 1998 and Ebe and Griffin, 2000). These still need further development to include more variables and hence boost their validity.

(5.1.1.5) Discussion of the findings pertaining to literature studies on comfort

The definition of comfort presented by Slater (1985) does not have a correspondingly encompassing set of sub-concepts and operatives leading to the creation of predictive models. Research efforts are however underway, but what has been missing in these efforts is the aspect of psychological comfort where little advancement has been made. Research has focused in physiological and physical aspects, but has not yet come to the point of predictability.

(5.1.2) Assessment of model validity based on empirical studies

The empirical studies considered for this analysis of comfort are studies I and II. The analysis is divided into sub-sections, each of which depicts a step in the chain process described in chapter 2 (Figure 4). These studies are a basis for the assessment of theoretical structures that were considered in the studies. The subconcepts of these theoretical structures that were used in the two studies are also described, as well as their transformation to operatives and measured results. To this follows an assessment of the production of communicable product development directives in the two studies. Finally, concluding remarks about the viability of the theoretical structures based on the two empirical studies are made.

(5.1.2.1) Theoretical structure

The theoretical structures from which the studies develop are identified in this sub-section. They are identified with a letter in italic, which is used throughout the remaining sub-sections.

The formulation of study I – evaluation of automobile seat side supports – collected knowledge from the following theoretical structures (in square parentheses are non formally existing structures):

(*a*) anthropometry (for accommodation in between the side supports),
(*b*) physics (discussion of acceleration and normal and friction forces in the seat / occupant contact),
(*c*) comfort (literature consisting of explorative experimental studies dealing with seat comfort – e.g. Thakurta et al., 1995, or Lee & Ferraiuolo, 1993) ,
(*d*) [personal experience and ambitions vis-à-vis side support (as expressed by Volvo development team)] , and
(*e*) contact measuring (literature on experimental automobile seat comfort studies that included contact pressure or contact force measurement – e.g. Reed et al., 1991).

The formulation of Study II – increasing seat support to the back collected knowledge from the following theoretical structures:

(*a*) anthropometry (for designing the articulation height),
(*c*) comfort (literature consisting of explorative experimental studies dealing with automobile seat comfort – e.g. Reed et al., 1991), and
(*f*) orthopedics and descriptive anatomy (understanding the movement, posture and comfort pertaining to the spine based on textbook knowledge and consulting discussions with an experienced orthopedic medical doctor).

(5.1.2.2) Subconcepts of the theoretical structures used in the empirical studies on comfort

The theoretical structures presented in the previous sub-section are now expanded into the subconcepts used in studies I and II. Each theoretical structure is identified according to the convention presented in the above subsection (5.1.2.1).

(*a*) <u>anthropometry</u>

Anthropometry deals with measurements of the human body and its portions. Sub-concepts in anthropometry are the statistical description of the human dimensions, through the use of percentiles that are used to design for a range of human users falling into a range of dimensions. In seat design these issues are very important in defining dimensions, and dimensions are defined taking into account the range of the population that is meant to be accommodated.

(*b*) <u>physics</u> (discussion of acceleration and normal and friction forces in the seat / occupant contact)

Basic seat functionality consists of supporting the occupant in a sitting position. Therefore the equilibrium of forces is a necessary item on the shopping list of seat design. The static and dynamic nature of the forces is also important to distinguish between.

(*c*) <u>comfort</u> (literature consisting of explorative experimental studies dealing with seat comfort)

Such a complex entity as comfort has not been fully understood to date. The discussion of 'objective' factors involved is described in article III. The factors considered are: Muscular activity (not included in empirical studies), posture, interface pressure and static and dynamic seat design properties (dynamics properties were not considered in my empirical studies). From the subjective evaluation side the following 'subconcepts' are considered important: scales for subjective assessment (rating comfort or discomfort), evolution of discomfort over time (short term and long term comfort), comparability of subjects' ratings and variables that should be controlled in assuring repeatability of sitting trials.

(*d*) personal experience and ambitions vis-à-vis side support (as expressed by Volvo development team)
Branching a problem on which there is no theory formulated forces researchers to acquire first hand knowledge of the problem, but also to resort to their personal experience and common sense to attempt tackling it. This results in establishing premises and formulating hypotheses. In study I, the purpose intended for the seat side support was tackled with this tool, formulating the premise that the side support is intended to hold the seat occupant when curving and that driving on the highway would not impose the same need on the securing function of the side support. This understanding can however be dealt with from the knowledge of physics (contact forces), but this relationship was established tentatively and was not backed up by existing theory on seat side supports. A similar rationale applies to the type of use given to automobiles, a kind of knowledge that is likely to pertain to marketing studies, but is also relevant for seat design. However, this knowledge was again not available in the form of a subconcept of seat design for comfort. It is also linked to the problem of the purpose intended for the seat side support, in securing the occupant in the presence of lateral acceleration (thus reducing muscular effort in keeping the posture) or as a trendy design feature intended to give the seat and the car a sporty look for marketing purposes. My judgement of this dichotomy is that seat side supports serve both purposes. However, my interest in study I was to deepen understanding on the securing function and its effect on comfort.

(*e*) contact measuring (literature on experimental automobile seat comfort studies that included contact pressure or contact force measurement)
From the knowledge of general physics, it is possible to derive a number of alternative contraptions to measure interface pressure contact. These include pressure sensing mats (used in study I), and other means, such as torque sensors.

(*f*) orthopedics and descriptive anatomy (understanding the movement, posture and comfort pertaining to the spine)
The data and knowledge borrowed from orthopedics, used in study II, has a similar descriptive nature as that of anthropometrics, and these two are somewhat linked, since joint range motion of the spine vertebrae and the geometrical description of the backshape were considered for the same purpose. This purpose was to serve as a basis on which to establish a technical property (the height of the articulation), and also as a resource on which to search for guidance in improving comfort through added support to the spine / back. Orthopedics did not however produce inputs other than maximum ranges of joint movement and recommendations concerning a healthy posture for the spine. It was not able to produce a prescriptive guideline as to the best posture for attaining comfort.

Hence the need to resort to a tentative approach that falls back on subjective assessment, in order to proceed in tackling the design problem.

(5.1.2.3) Transformation of subconcepts to operatives and measured results

The theoretical structures and subconcepts presented in the previous sub-sections are now corresponded to operatives and measured results in accordance with what was done in studies I and II. The focus is on questions, measures, data to be collected, methods and representations. Each theoretical structure is identified according to the convention already used in the two previous sub-sections (5.1.2.1 and 5.1.2.2). The main purpose of this sub-section is to expose whether there are direct linkages between subconcepts, operatives and measured results.

(*a*) anthropometry

The operatives of anthropometry are measurements of people's physical dimensions. There is no major limitation in attaining these measurements. The restrictions therein are concerned with practical aspects, such as the precision and reliability of the measurement procedure, and the quality of the measuring apparatus. In order to assure the quality of measurements, surface landmarks on the human body are identified for the measurement of specific dimensions (Pheasant, 1996). In both study I and study II, measurements were taken of prospective subjects, to identify those that fitted into the dimensional intervals set up in the experimental design. Additionally, in study I, proportionality between different measurements on any one person was assessed and controlled (shoulder breadth and hip breadth).

(*b*) physics (discussion of acceleration and normal and friction forces in the seat / occupant contact)

Acceleration can be assessed through calculations governed by kinematics laws or measured with accelerometers. In study I acceleration was calculated for both the static laboratory situation and the dynamic situation of real driving. In the latter case, velocity and radius of curves were the parameters used, while in the former case, the angle of tilting of the static platform was used. Normal and friction forces in the seat / occupant contact are concepts from dynamics. While normal forces can be measured through the use of pressure sensor mats, friction forces are evasive, since any apparatus inserted between the seat and the occupant alters the characteristics of the contact (friction forces were not transformed into operatives).

(*c*) comfort (literature consisting of explorative experimental studies dealing with seat comfort)

Literature reporting on experimental studies on seat comfort (e.g. Reed et al., 1991, or Park et al., 1998) provides guidance on the methods that can be used to operationalize comfort sub-concepts. Muscular stress is associated to fatigue, which is thought to be a deterrent of comfort, promoting discomfort. Hence an objective measure that has been used in an attempt to objectively grasp these aspects is the measurement of selected muscle activity through the technique of electromyography. In my empirical studies this method could not be used.

Interface pressure measurement has also been the object of attempts to operationalize discomfort and fatigue, however these have not attained success. The technique however, enables mapping the contact pressure, and since the physiological health limits for pressure peaks are established, it can be used as a health assessment tool, but it falls short in its usefulness to assess comfort, given the multidimensionality of comfort. In article I, I used the technique of contact pressure mapping with a double ambition. On the one hand, identifying the areas of contact with the seat side support under static lateral acceleration, and on the other attempting to co-relate pressure peaks with body areas of major discomfort under straight sitting. My attempts failed, due to various inconsistencies (including improper calibration of a new and untried set of equipment) and due to unexpected behavior of the subjects. Furthermore, subjective assessment problems were also present in the equation. The subjective evaluation scales extracted from similar studies proved to be inadequate, since the selection of subjects did not consider their verbal ability to distinguish between aspects of comfort and seat support.

The subjective impression of comfort is a sub-concept that has eluded reliable transformation into operative form. Several problems persist in this transformation into operative form. There is no consensus on the best way of measuring this subconcept. A multitude of graphical scales have been used in literature. But there have been no successful attempts as far as I can perceive from my literature studies of producing a scale that satisfactorily captures the essence of subjective comfort. For study II, I investigated the perceived sensations of discomfort using a set of alternative scaling methods ranging from graphic scaling methods to Lickert scales. Svensson (1993) supports the finding that verbal scales, and especially ordered categorical scales, are best to obviate the problem of individual differences in perceived intensity of feelings. This process enabled selecting an ordered categorical verbal list of intensity of discomfort (Figure 6).

No discomfort at all
Extremely weak discomfort (just noticeable)
Very weak discomfort
Weak discomfort
Moderate discomfort
Strong discomfort (heavy)
Very strong discomfort
Extremely strong discomfort (almost max)

***Figure 6** – Ordered categorical scale for discomfort rating (adapted from Borg, 1982).*

The data produced from ordered categorical scales cannot, however, be used to make interpersonal comparisons among subjects, but neither can other scales of perceived feelings get around this problem, rooted in the individuality of each human being.

The assessment of comfort for sub-regions of the body has been done combining a rating scale with a body map (Corlett and Bishop, 1976) indicating the boundaries of the regions considered. Again, this is done in a tentative approach, without a proven theory on which to fall back upon. Some tentative methods like this one have become accepted as common practice because of their repeated use, although these methods have not been validated.

The variation of static seat design properties is a means of studying the effect of their change on subjectively assessed comfort. This methodology is thus a technique that assists in the extraction of knowledge that is not covered in the theoretical structures. While in study I, three seat design properties were varied in the seats and established at two levels, in study II two seat angles were varied almost continuously to suit the occupant's preference. For study I, the approach followed the theory of the design of experiments (Montgomery, 1991). For study II, a new approach was followed which was not based on any particular previously established or reported approach.

(*d*) personal experience and ambitions vis-à-vis side support

The securing function of the side support was tentatively transformed into operatives both objectively and subjectively (study I). On the one hand, contact pressure was read for the side support under static lateral acceleration. On the other hand, subjects were requested to subjectively assess the securing function on a graphical scale for different lateral body areas, under real use conditions. Video recorded images were another means to attempt characterizing the securing function of the side support, by analyzing subjects' lateral displacements at the hip and shoulder levels. However, due to the unexpected and differentiated behaviors of the subjects this turned out not to be useful (some subjects leaned into the curve away from the side support, while others leaned against the side support).

(*e*) contact measuring (literature on experimental automobile seat comfort studies that included contact pressure or contact force measurement)

Besides pressure or force sensors, as discussed previously, other means can be utilized to operationalize contact. Photographic images were used in study II to assess the contact of the back of the head with the seat headrest. However, due to the concavity of the headrest, and the hairdo of some subjects, this measure was more effective to definitely identify situations of absence of contact, and it was not useful in assessing definite contact[7].

(*f*) orthopedics and descriptive anatomy (understanding the movement, posture and comfort pertaining to the spine)

While biomechanical aspects are important in the assessment of discomfort, the posture of the spine *per se* does not predict any aspect of discomfort (except for extreme postures). Hence these aspects were not transformed into operatives in my empirical studies on seat comfort.

The assessment of the transformation from subconcepts to operatives and measured results differs within the subconcepts considered. Table 8, provides an overview of these results. It considers subconcepts, operatives and the results that could be measured. For some of the subconcepts depicted in the Table there is a direct

[7] In addition to the operatives described above, study II adopted several questionnaires and interviews along the process of sitting trials both in the laboratory and in real driving and after the completion of this process. These were meant for several purposes. On the one side, scanning for inconsistencies and factors the researchers were unaware of, such as if the person had been bothered in any way by traffic, or bad weather, or dizziness, etc. They also had the purpose of broadening the view on the subject to a more holistic view, which included both aspects of the person's life, relationship to the automobile, and whether pleasure was derived from automobile use (these aspects are reported in article IV).

transformation flow through operatives to measured results. In several other cases, the transformation flow does not formally exist, since it is not reported in literature. Still, in these cases results could be measured resorting to tentative or indirect approaches, using common practice methods with a different purpose from that of their usual application. This assessment of the formality of the transformation flows for each subconcept is represented in the fourth column of Table 8. This Table can be looked upon as a result that in itself contributes to validate the use of the chain process depicted in Figure 4 (chapter 2) as an assessment tool. The use of that chain process enabled discriminating between the quality of the transformations from operatives to measurable results, as shown in Table 8.

***Table 8** – Overview of the transformation of subconcepts to operatives and measured results used in my empirical studies on comfort.*

Subconcepts	Operatives	Measured Results	Transfor-mation
Accommodation	Human dimensions vs product dimensions	Selected human dimensions (mm) / product dimensions (mm)	Direct
Acceleration	Lateral acceleration	(calculations with speed (m/s) and radius of road curves(m))	Direct
Normal forces	(pressure in contact) (force sensing)	Numerical pressure values (Pa) and pressure patterns / gradients	Direct
Friction forces	Friction under the presence of lateral acceleration	(only estimated)	Non existent
Overall discomfort	Subjective assessment	Ratings in ordered scale	Tentative
Discomfort in body areas	Subjective assessment for body areas	Ratings in ordered scale	Tentative
Interface pressure	Interface pressure	Numerical pressure values (Pa) and pressure patterns / gradients	Direct
Effect on comfort of design variables change	Elemental design variables change	Assessment of comfort / discomfort	Indirect
Securing function of side support	Normal and friction forces in contact	Interface pressure	Direct / non existent
	Subjective assessment of securing function	Ratings in ordered scale	Tentative
	Lateral displacements under lateral acceleration	Difference in relative position of surface landmarks (mm)	Indirect
Postural comfort	Joint ranges of motion	Seat angles chosen by subjects	Indirect
	Contact of the back of the seated person with the seat / headrest	Assessed through visual inspection of recorded images	Indirect

(5.1.2.4) Production of communicable product development directives

Rather than producing a product development directive, study I only enabled producing design advice, concerning the envisaged advantages and disadvantages of alternative design changes to the seat side support, and innovative design concepts. However, these design suggestions were not a straightforward outcome of the application of the formal theoretical structures considered in the design of the study. The design suggestions result from a mixture of the breakdown derivation procedure of the theoretical structures, as well as from empirical evidence.

Concerning study II, it was possible to extract a more reliable product development directive from the results of the study. Still, there are a number of deficiencies and empty spaces in the theory that supported the study, which had to be filled in by trial and error and creative approaches.

The level of development in practice of the theoretical structures is assessed through the feasibility of the theoretical structures, of the data collection methods and of the representation formats. The theoretical structures considered in studies I and II, though predominantly at a low level of development, enable devising, in practice, data collection methods that shed insight into the relationship between subconcepts, thus feeding back to theory. However, this process is not decisively structured, or unidirectional. Data representation formats are also fairly unstructured, and no consensus has been reached on the best ways to collect subjective assessments of comfort that are understood by users.

(5.1.2.5) Assessment of methods for data acquisition and analysis and of data representation

The discussions presented in this section (5.1.2) have so far embedded the transformation of subconcepts to operatives, and an analysis of the quality of this transformation, in terms of the feasibility of measurement and the quality of the data collected. The data collected in studies I and II consisted of:

- anthropometric measurements (objective data)
- parameters to calculate acceleration (objective data)
- pressure values and patterns in the seat interface (objective data)
- observation of peoples' lateral displacement in seat through recorded images (still and moving) (objective data)
- observation of peoples' contact with headrest through recorded images (still and moving) (objective data)
- seat angles chosen by subjects (objective data)
- subjective rating of discomfort in delimited body areas through graphical and verbal ordered categorical scales (subjective data)
- subjective rating of support (securing function) through graphical scale (subjective data)
- paired comparison of overall comfort assessments of alternative seats (subjective data)
- overall preference rating between alternative seats (subjective data)
- broadly formulated and inconsistency scanning questionnaires and interviews (subjective data)

Apart from the circumstantial problems encountered with the measurement of interface pressure in study I, the above data collection methods were feasible and practically pursuable. Difficulties arose in the extraction of the information that was sought from some of these data collection methods. This is hence a problem of reduced effectiveness of the methods in serving the purpose intended. It was found that verbally eloquent people were needed to deal with certain aspects of subjective assessment (discomfort and support – study I). Moreover, the collection of subjective data has imbued the problem of its difficult gauging. The data obtained is dependent on the understanding by the person of what is requested, which maybe different from the researchers' concept. Naturally, it cannot be expected that everybody understands every concept. Concepts such as discomfort or comfort are not presently unambiguously communicable. Moreover, attempts to 'instruct' people participating in subjective assessments has the potential danger of biasing the results. In practice, data that is subjectively collected carries a degree of uncertainty about the understanding of the concept by the person and whether the person's knowledge and experience and her or his implicit beliefs bias the assessment made.

Despite the fact that physical design problems are being tackled in the area of seat comfort, the researchers or designers (engineers) need to be aware of the problem of verbal understanding in communicating with users. In addition to the level of understanding of concepts attained by users, it is important to be aware that different groups of users may also have different levels of motivation when collaborating in experiments. As a conclusion, the problems of verbal understanding and motivation must be considered in collecting and using subjective assessments as an input to design.

There are also methodological issues that condition the effectiveness of data collection methods. The threshold between short and long term comfort is one such issue; the settings where sitting trials are performed are others.

The distinction between long term and short term comfort shapes the time duration of the interval between subjective comfort evaluations and the length of the sitting trials. I have experimented with 2 hours duration (study II), and within the second hour of evaluation time no intrapersonal breaks of trend in the development of the discomfort assessment were found (with evaluations at 15 minute intervals). This supports Reed et al.'s (1991) findings that identify the threshold between short and long term discomfort in sitting trials as the end of the first one and a half hour of sitting.

A controlled environment in the conduction of sitting tasks enables standardizing tasks and the use of physical measuring equipment. This supports the choice for experiments in the laboratory. However, in order to have a validation of laboratory results, experiments in real world settings are needed, since the transfer functions between results from laboratory and from fielded situations are not known. Hence there is an interest in investigating the possibilities of developing transfer functions depicting relationships between results collected in laboratory and in fielded experiments. Context and environmental factors do not come into play to the same extent in the laboratory situation as compared to the fielded one (e.g. for automobile seat comfort these factors include: weather, traffic, unfamiliarity with the driving route, ride quality, visual and auditory demands, or psycho-kinetic coordination).

The analysis of the data collected followed a process, encompassing several stages (feasible and effective) namely:

- transformation and condensation of objectively and subjectively originated data through the use of parametric and non-parametric statistical techniques
- search for correlation between transformed and condensed subjective and objective data as a means of testing hypotheses

Representation of data assumed different formats, along the stages of the process of collection, analysis and communication of data and results (Table 9).

Table 9 *– Representation formats of data for the stages of collection, analysis and communication.*

Process stage	Collection	Analysis	Communication
Representation formats	Elemental Graphical ratings Elemental verbal ratings Arrays of numerical values (e.g. pressure) Arrays of logic values (e.g. contact – existence, absence) Preference rating (individual) Questionnaires and interviews	Condensed rankings (order of preference) Cross-contingency tables (correlation of subjective data) Averaged objective data (numerical values, frequencies) Co-relation of objective data (graphics and equations) Co-relation of subjective and objective data	Verbal and propositional (accepted / rejected hypotheses and revised problem understanding) Graphical (design sketches) Numerical (equations)

In what concerns the communication of results to designers, my experience is that these practitioners want directives as clear, universal and definite as possible, and which are formulated in a way that is ready for application to design. Designers prefer numerical values and numerical relationships between design variables, hence predictive models of the type presented in Figure 5 (chapter 2). This desired format of product development directives could not always be achieved, reflecting the level of incompleteness of originating knowledge, and the quality of its transformation to operatives. Product development directives can be presented in the formats listed in Table 9. However, the degree to which designers accept these results varies according to their level of involvement in the studies that were conducted for their creation. For example, an equation that predicts the relationships between seat angles set by seat occupants (study II) is more likely to be applied in design if designers acknowledge the boundaries within which the equation is applicable. These boundaries are a consequence of the simplifications and the assumptions underlying its extraction. Likewise, results that are expressed as hypotheses that have been supported but not conclusively accepted (study I) are also non-universal and hence limited in their applicability. Hence it is a conclusion that the representation formats' adequacy to communicating to designers is dependent on an understanding of the limitations of the data and product development oriented information presented to them.

(5.1.2.6) Conclusions regarding the viability of theoretical structures and concepts based on the assessment from my empirical studies on automobile seat comfort

The theoretical structures identified for comfort do not permit the direct attainment of (universal) product development directives, much less predictive models. Much remains to be studied in the area, hence, from the perspective of engineering design, it is yet not possible to take off-the-shelf knowledge and apply it to the design of seats for comfort. Consequently, a Design for Comfort method cannot be created which can be applied autonomously by engineering design in parallel with other DFX methods. Article III discusses the feasibility of creating an index of predictive seat comfort, pointing at the efforts that have been made, and where these have led, and also suggests possible paths to attain predictability. Predictability seems more likely attainable for physiological and physical causes of discomfort.

(5.1.3) Level of maturity of comfort

The insights gathered from the assessment of the theoretical structure of comfort enable suggesting that model validation is insufficiently attained and product development directives derived are tentative and not definitive. Concerning the scale of maturity presented in section 2.1, the following levels of the five criteria spring from the prior discussions:

- Kuhnian level of paradigmatic consensus: Low (1)
- Extent and elaboration of theoretical body: Preliminarily defined (2)
- Model's validity / quality: Medium (2)
- Quality of Product Development Directives: Mediocre (2)
- Level of congruence between theory and practice: Neutral (2)

This assessment thus results in a score of 16, corresponding to a low level of development, in accordance with the hypothetical categorization presented in Table 3 (chapter 1).

(5.2) Pleasure

(5.2.1) Assessment of model maturity based on literature studies

Pleasure appears as a development from functionality and usability, hand in hand with a revised approach to ergonomic design that departs from minimizing loss towards maximizing gain (Jordan, 2000). The concept of pleasure is taken here from the viewpoint of product development and engineering design. In this regard, 'pleasure with products' is defined by Jordan (1996) as the emotional and hedonic benefits associated with product use. In practice, the field of pleasure with products was structured by Patrick W. Jordan, and his publications on this area date back to 1995, and have been coming out at a steady rate, increasing in thoroughness and completeness. A growing number of studies by other authors have also considered pleasure in the context of design (e.g. Fulton, 1993; MacDonald, 1998; Desmet & Hekkert, 2001; Hauge-Nielsen & Flyte, 2001).

A difficulty of affective concepts such as pleasure or emotion is that they are probably as intangible as they are appealing (Desmet & Hekkert, 2001). Although some interesting and promising studies have been reported, the research field is still short of conceptual clarity and therefore lacks consensus on what the actual subject of study should be. Both the concepts of pleasure and emotion are somewhat undifferentiated, and are used as collective nouns for all kinds of affective phenomena. Design literature tends to refer to these when studying anything that is so-called intangible, non-functional, non-rational, or non-cognitive. Some of the reported studies involve 'experiential needs' (Holbrook, 1982), 'affective responses' (Derbaix & Pham, 1991), 'emotional benefits' (Desmet et al., 2000), 'customer delight' (Burns et al., 2000) and 'pleasure' (Jordan & Servaes, 1995). Naturally it is inherent to any newly emerging research field that the emulsion has not even started to crystallize, but an adequate definition of the subject of study would facilitate fruitful discussions between researchers (Desmet & Hekkert, 2001).

Design research literature refers to pleasure as a product benefit that exceeds just proper functioning. Pleasure is thus seen as an emotional benefit that supplements product functionality and even usability. In this sense, pleasure covers all pleasant emotional reactions, but it is not an emotion in such (Desmet & Hekkert, 2001). Although people differ in their emotional responses to products, general rules may be identified in the underlying process of emotion eliciting (Desmet & Hekkert, 2001).

In his book *Designing Pleasurable Products*, Jordan (2000) brings forward the concept of pleasure as an overriding goal in product design. Pleasure is seen to contain, but also to exceed, many instances of Human Factor goals in Product Development, such as usability, or comfort. Article IV develops this idea to some extent, using the example of automobile seats to show the overlapping character of these goals and concepts, including functionality, usability, comfort and pleasure.

The rationale Jordan devised to systematize building pleasure into products, considers the four-pleasure framework, which was originally devised by Tiger (1992). This framework is introduced in article IV and more deeply covered in article V. The four-pleasure framework is used to build product benefit specifications, using an array of methods that include focus groups, questionnaires, private camera conversation (Vries et al., 1996), co-discovery (Kemp and Gelderen, 1996), experience diaries, reaction checklists, field observations, etc. The transfer from product benefit specifications to product requirements is done through the means of the equivalence between experiential product properties to formal product properties (Jordan, 2000). This is however the area where less knowledge has been unveiled. Still there are some experiential properties which can be transferred to formal properties fairly easily, such as light weight, vivid color, etc., which draw on previously existing notions borrowed from industrial design, concerning product aesthetics, task analysis and culture. An overview of Jordan's design method for pleasurable products is depicted in Table 10.

***Table 10** – Extract of Jordan's (2000) pleasure based approach to design.*

People characteristics relevant for defining product benefit specifications	Methods for use in the creation and evaluation of pleasurable products (experiential properties)	Elements of product design (formal properties of product's elements)
Physiological Special advantages and disadvantages Musculo-skeletal characteristics External body characteristics Body personalization Physical environment Physical dependencies Sociological Status Self-image Social relations Social labels Social personality traits Social lifestyles Psychological Special talents and difficulties Psychological arousal Personality traits Self-confidence Learned skills and knowledge Ideological Personal ideologies Religious beliefs Social ideology Aesthetic values Aspirations	Empirical creation methods Private camera conversation Co-discovery Focus Groups Think aloud protocols Experience diaries Reaction checklists Field observations Questionnaires Interviews Immersion Laddering Participative creation Controlled observation Non-empirical creation methods Expert appraisal Property checklists Evaluation of design prototypes Product benefits specification Product property specification Visual prototypes Models Screen-based interactive prototypes Fully working prototypes	Color Form Materials Sound Interaction design

Given the encompassing character of this concept of pleasure with products, some of the human factor goals included in the concept have come close to attaining predictability (e.g. usability guidelines). This means in practice that it is partially possible to use the four-pleasure framework to attain some product property specifications. But the sum of parts is not equal to the whole, and a lot of work remains to be done in the area, as well as in defining pleasure metrics. Jordan (2000) also considers the distinction between need pleasures and pleasures of appreciation (originally devised by Lewis, 1987) to aid the four-pleasure framework in the process of structuring thoughts about pleasure. Need pleasures and pleasures of appreciation are also discussed in article V.

In light of the above, the structuring of the branch of pleasure is still at an incipient stage. Model building is proceeding but has yet to attain validated results. The field resorts to human subjects to test the achievement of design methods in terms of pleasurability (e.g. product pleasurability questionnaire – Jordan, 2000) and there is yet no predictability attained in understanding the transfer of formal properties to experiential ones. Product development requirements derived from pleasure with products approaches are loosely tied to formal product properties and are very much still in the realm of experiential properties. As an example, consider the following requirement from a fully worked example of a product benefit specification for a photographic camera targeted for a particular sub-group of society: “the camera should confer the impression of high cultural status on the user” (Jordan, 2000).

Prior to the development of ‘pleasure with products’, Nagamachi (2000) developed the methods behind Kansei engineering / Kansei ergonomics. He founded Kansei Engineering 30 years ago at Hiroshima University, choosing the Japanese word ‘kansei’, as it means feeling. Nagamachi (2000) explains that ‘kansei’ means the customer’s psychological feeling as well as physiological issues. The array of methods developed is quite wide, including: Category classification, Kansei Engineering System, Kansei Mathematical method, Virtual Kansei Engineering, Collaborative Kansei Design System and the combination of Kansei Engineering and Concurrent Engineering. The methods include ergonomic experiments and intelligent system inference, which relies on databases built up by peoples’ kansei (people’s reactions to products). The databases contain information about links that have been established between formal and experiential properties of particular products. Nagamachi (2000), states that Kansei Engineering / Ergonomics has been applied to the design of products from many different companies and domains, including automobiles, construction machinery, electric home appliances, office machines, construction tools for the home, clothes and garments and cosmetics.

Kansei Engineering can work in two ways – Nagamachi (1995) refers to these as the two directions of ‘flow’. One direction of flow is termed from design to diagnosis. This involves manipulating individual aspects of a product’s formal properties in order to test the effect of an alteration on the user’s response to the product. The other direction of flow is from context to design. This involves looking at the scenarios and contexts in which the product is used and then drawing conclusions about the implications of this for design. This second direction of flow involves the gathering of qualitative data via field observations[8]. The data is used to help establish the link between the formal properties of a design and the benefits associated with the product.

Nagamachi’s approach to designing products for kansei (feelings) comes very close to Jordan’s approach to pleasure with products. From my perspective, Kansei Engineering can be seen as a method that fits nicely into being an operative of the theoretical structure adopted for pleasure, and finds its justification in that structure. A similar approach has been developed by Desmet et al. (1999), working on product emotion measure, which was applied to exterior automobile aesthetics. It resorts to human subjects to categorize the emotions elicited by alternative product appearances, based on the comparison with 18 emotions. These emotions are represented by animations of a cartoon character presented on a computer interface. The emotion list is composed of: disgusted, indignant, contemptuous, aversive, disappointed, dissatisfied, bored, disillusioned, vulnerable, enthusiastic, inspired, desiring, appreciative, pleasant, attracted, satisfied, fascinated and softened.

[8] The two directions of flow Mitsuo Nagamachi uses in Kansei Engineering have similarities with two approaches for design exposed in the dissertation. The process resulting from the direction of flow from design to diagnosis is alike part of the process resulting from the theory breakdown approach presented in Figure 4, in compensating for *lacunae* in the theoretical structures. The process resulting from the direction of flow from context to design is alike the fielded experiment and observation methods described by Woods (2000) in approaching some of cognitive engineering design problems (this is covered in section 5.3 – Cognitive Engineering).

(5.2.1.1) Concluding discussion of the literature based findings pertaining to pleasure

There appears to be a lack of consensus on what pleasure actually is, and how systematizable this may be across people. Still, there has been some work done in order to create a theoretical structure and corresponding concepts in the field of ‘pleasure with products’. Preliminary work has also been done in categorizing emotions brought up by product appearance, and product benefits such as usability (extensively researched) are considered a source of pleasure. At this stage, the theory and methods available in the field of ‘pleasure with products’ do not support on their own the creation of product development directives. Validity of the theories is also being currently assessed, as well as the development of methods. This suggests that pleasure is still at a low level of development, in accordance with the hypothesis presented in Table 3.

(5.2.2) Assessment of model validity based on empirical studies

The empirical study considered for the pleasure branch is study V. Prior to the discussion about its contribution to the assessment of the viability of theoretical structures and concepts of pleasure, I present a very short analysis of the contribution of study IV towards the establishment of product development directives.

Study IV – linking comfort and pleasure
This study develops on the following elements of theory:

- definitions of comfort (Slater, 1985; Maldonado, 1991) and comfort descriptors in office seating (Zhang et al., 1996), and
- definitions of pleasure with products (Jordan, 1996), hierarchy of user needs (Jordan, 1997) and the four-pleasure framework (Tiger, 1992).

The applicability of this knowledge for the cases of automobile use and automobile seats is partially tested through empirical data collected through a small questionnaire study (13 respondents). The study does not produce any product development directives *per se*, although it points in some directions, particularly concerning attributes of seats judged by relative importance (the respondents judged comfort at the top of the list).

Study V – empirical confirmation of the foundations of pleasure
This study did not focus specifically in a particular product; instead it develops on theoretical aspects of the field of ‘pleasure with products’. Hence, in itself it could not be a vehicle for the production of product development directives. However, it gives a contribution to the validation of subconcepts, since it provides an indication of their relevance to people.

(5.2.2.1) Subconcepts considered from the theoretical structure of pleasure

Study V collected the following concepts and empirically tested their viability as a means of communicating about pleasure:

- Popper's (1989) pluralistic view of the three worlds (objects, mental states and ideas),
- Tiger's (1992) categorization of the four pleasures (physiological, psychological, sociological and ideological), and
- Lewis's (1987) distinction between pleasures of need and pleasures of appreciation.

These concepts were explicated, to suit the purpose of study V, by the means of breaking them down into statements. This breakdown approach stands in agreement with the approach pursued in breaking down theoretical structures, as presented in the chain process depicted in Figure 4 (chapter 2). The statements were assessed by questionnaire respondents in terms of their level of agreement or disagreement with the statements. In addition, respondents were requested to suggest examples of products to illustrate their judgements of the statements. In such, it was possible to assess the scope of applicability of these concepts, which resulted in a wide applicability covering personal products, consumer products used in the home, office products, professional products and artistic (and hobby supporting) products. A list of the people characteristics considered relevant by Jordan (2000) in defining product benefit specifications (Table 10) and covered in the breakdown into statements considered in the questionnaire (study V) is shown in Table 11. The results of the questionnaire support the acceptance of these characteristics as enablers of pleasure.

Table 11 *– People characteristics covered in the questionnaire in study V with reference to Table 10.*

Physiological	Sociological	Psychological	Ideological
Musculo-skeletal characteristics Physical environment	Status Self-image Social relations	Special talents and difficulties Psychological arousal Learned skills and knowledge	Personal ideologies Aesthetic values

Additionally, the questionnaire covered the three worlds (Popper, 1989) from where pleasure can be derived (objects, mental states and ideas), seen as a predecessing stance for the application of the four-pleasure framework. The questionnaire results support the applicability of pleasure in these three worlds. Finally, Lewis's (1987) dichotomy of need and appreciation pleasures was tested in the questionnaire, the results of which show that the respondents support that distinction. The questionnaire results thus suggest that the concepts considered as a basis for its creation are viable.

(5.2.2.2) Assessment of methods for data acquisition and analysis and of data representation

The data collected in studies IV and V consisted of:

- demographic data of questionnaire respondents (studies IV and V)
- answers to open ended questions concerning automobile use (study IV)
- multi-choice answers to questions concerning seat attributes (study IV)
- multi-choice answers to questions concerning pleasure in automobile use (study IV)
- rating of statements about 'people' in relation to the derivation of pleasure (study V)
- examples of products that enable pleasure (study V)

The data described above is essentially subjective, with the exception of demographic parameters (e.g. age, education, household size). The practical feasibility in collecting these data categories is high, once a group of respondents has been identified and is willing to participate. The fact that these data are essentially subjective implies the consideration of issues that lead to subjective biases, as was previously discussed in section 5.1.2.5 for comfort. For the data collected through the means of a questionnaire in study V, there was a deliberate attempt in targeting a cultural sub-group of society, which hypothetically had a level of culture and verbal ability that would enable discussing pleasure sub-concepts. This deliberate restriction to a sub-group of society was the means found to increase the possibility of understanding of the concepts discussed, but I acknowledge that pleasure is an issue of relevance to all human beings. Moreover, restricting to a sub-group of society carries the risk of introducing systematic biases, which would lessen the validity of extrapolations made from the results for people in general.

The analysis of the data consisted mainly of aggregation of the subjective ratings and the statistical assessment of the significance of the overall results. These are provenly feasible and effective ways of data analysis.

The communication of results derived from studies IV and V, did not assume the form of product development directives, but it was done in the form of the analysis of the subjective assessments, and in terms of their underlying hypotheses. Hence, representation formats adopted were verbal and propositional, expressed in terms of hypotheses, examples given and level of agreement with statements attained. It is assumed that the level of understanding attained by respondents (users) of the concepts covered in the questionnaire is equal to that of designers.

(5.2.2.3) Contribution of the empirical study on pleasure with products towards assessing the viability of theoretical structures and concepts

Study V contributes to the validation of the theoretical structure considered as a basis for pleasure with products. The assessment by the questionnaire respondents of the statements derived from the theoretical structures resulted in significant agreement in general. It can thus be inferred that these concepts produced a frame of resonance in people's minds and are hence relevant in the form presented in the questionnaire. Since the questionnaire dealt with people in general[9], and not individually, the fact that emotions are an individual thing, relating to people's personalities and past experience, does not preclude the possibility of the existence of a common level across people. The existence of such commonalities supports the investment of efforts in pursuing the study of pleasure with products, and could enable some level of predictability to be attained in the future. At the same time, this empirical study indicates that pleasure, as a concept, can be brought deeper than its overriding level,

[9] The statements included in the questionnaire were not formulated using the pronouns me, I or myself, but were phrased using the collective noun 'people'. This displacement of 'personna' was intentionally sought with the purpose of leaving the respondents at ease allowing a less compromised attitude in answering. However, it carries the potential disadvantage that some respondents might have rated the statements of the questionnaire with reference to their idea of people in general, which could be different from their own personal positioning towards the matters covered in the statements. However, this shortcoming was not deemed to outweigh the envisaged advantage of this way of formulating the statements.

given the significantly high level of agreement resulting from the assessment of the broken down theory.

The study thus gives a positive assessment of the viability of the theoretical structure and the concepts considered in pleasure with products. This assessment is however not complete, with reference to the chain process depicted in Figure 4 (chapter 2), since the study does not consider all the people characteristics (subconcepts) depicted in Table 10, nor does it follow this chain process down to the creation of product development directives.

(5.2.3) Level of maturity of pleasure

The insights gathered from the assessment of the theoretical structure of pleasure enable suggesting that model validation has been attained to some extent, but the theory is incomplete (hence underdeveloped). Product development directives considered in the body of knowledge embraced by pleasure with products stem essentially from other areas encompassed in the approach, and emotional outputs are not attained in these. However, Kansei Engineering (Nagamachi, 2000) has advanced as a method for design that considers feelings, although in a less holistic approach when compared to Jordan's (2000) conception of pleasure with products.

The assessment of maturity made herein considers the 'added value' of pleasure with products beyond the encompassed concepts of usability, comfort, and other sub-branches of ergonomics. Concerning the scale of maturity presented in section 2.1, the following levels of the five criteria spring from the above discussion:

- Kuhnian level of paradigmatic consensus: Medium (2)
- Extent and elaboration of theoretical body: Preliminarily defined (2)
- Model's validity / quality: Medium (2)
- Quality of Product Development Directives: Very low (1)
- Level of congruence between theory and practice: Neutral (2)

This assessment thus results in a score of 16, corresponding to a low level of development.

(5.3) Cognitive Engineering

(5.3.1) Assessment of model maturity based on literature studies

Several expressions are used to identify this area, such as human factors, engineering psychology, cognitive engineering, cognitive systems engineering, computer supported cooperative work or cognitive ergonomics. According to Lambie (2001), the concept of cognitive engineering is not fixed and unequivocal, but in its various expressions certain common features are found. Norman (1987) writes that he invented the term 'cognitive engineering' to emphasize cognitive aspects of human-machine interaction. Norman (1986) writes:

"(…) the aims of cognitive engineering are:

- to understand the fundamental principles behind human action and performance that are relevant for the development of engineering principles of design,
- to devise systems that are pleasant to use. - the goal is neither efficiency nor ease nor power, although these are all to be desired, but rather systems that are pleasant, even fun: to produce what Laurel (1986) calls 'pleasurable engagement'[10].
(…) The critical phenomena of cognitive engineering include: tasks, user actions, user conceptual methods and system image. The critical methods of cognitive engineering include: approximation and treating design as a series of trade-offs including giving different priorities to design decisions."

In parallel to Norman's postulates on cognitive engineering, cognitive systems engineering was developed by Rasmussen, Hollnagel, Woods, etc. and was concerned with systems that were safety critical or complex (Lambie, 2001). As their work developed it attracted attention, because it offered better means to design. This version of cognitive engineering is forward looking to precision and testing of models and representations, rather than backward looking towards its epistemological roots. A succinct description of the schools of thought of Erik Hollnagel and David Woods and of Jens Rasmussen and Kim Vicente is provided in Appendix B, which also contains a description of Norman's postulates on motivated cognitive activity.

For Dowell and Long (1998), Human Factors (engineering psychology) is largely a craft, the heuristics it possesses being either 'rules of thumb' derived from experiences or guidelines derived informally from psychological theories and findings, with the latter representing the science applied. It has been found increasingly that addressing design problems in Human Factors, Human-Computer Interaction or Computer Supported Cooperative Work, necessitates turning attention away from the research with a psychological, computational or sociological nature (Lambie, 2001). This kind of research aims at universality, and instead one should focus on the problem posed by the target artefact, including the constraint that it meets given requirements.

Dahlman (2001) collected some of the problems, methods of analysis and types of consequent action that have been considered in the area where cognitive engineering acts. These are reproduced in Table 12, which gives a pragmatic definition of what cognition in human-machine interaction presently considers. Stops, mistakes, stress and performance are the consequences we want to do something about, and which are due to a number of conflicts between the characteristics of human beings and the properties of technology, systems, work, etc. that is handled. Thus we have perception limitations, attention limitations, and so on. In a particular working or use situation these can be identified and understood by using combinations of the exemplified methods and others. This understanding can then be used to redesign the design, modify or set up training programs and so on. These actions stand in line with Woods' (2000) notion of observing people in actual settings and Vicente's (1998) focus on testing alternative proposals. There are theories about perception, attention, information perception and others (e.g. signal detection theory – Green & Swets,

[10] Aristotle, who claimed that a measure of quality by which a work of fiction could be judged was the extent to which the audience became engaged by the story, first identified the concept of engagement. Laurel applied it to computers, claiming that a sense of engagement with the 'world' of the program that the person is using can be a central factor in determining whether he or she experiences a positive joy. Attaining pleasurable engagement would thus be a means of making a system pleasant to use, although there are other envisaged means (compare with previous section on pleasure).

1966) that support the understanding of the situation analyzed. Methods also exist that have been able to produce design guidelines (e.g. Woods, 1995 – display design). Whereas Woods (2000) goes into an introduction of a new technology used in an existing system as the starting point of a process which is geared to deliver design seeds for further development, the process described by Dahlman (2001) steps into a steady state of an existing system. The outcome of the latter process aims at suggesting a new generation system and getting at it with design iterations towards the end of the process.

***Table 12** – Cognition in man-machine systems: limiting conflicts, consequences, methods of analysis and types of action (Dahlman, 2001). The methods of analysis imply a prior collection of data, using methods such as observation, verbal protocols, interviews or reports (Liljegren, 2001). An example of a reference is given for each of the methods mentioned in the Table. The 'limiting conflicts and concepts' are covered in textbooks (e.g. Wickens and Hollands, 2000).*

Concepts	Methods of analysis	Types of action
<u>Limiting conflicts</u> Perception Attention Processing Long Term Memory Retrieval Simultaneous demands Response capacity Arousal, sustainment Schemas, 'strong but wrong' <u>Consequences</u> Stops Mistakes Stress Performance	Task analysis (Kirwan & Ainsworth, 1992) Cognitive Task Analysis (Klein, 1997) Activity theory (Karlsson, 1996) Incident Reports (Donchin et al., 1995) Error analysis (slips-mistakes taxonomy - Reason, 1990) Human reliability (Kirwan, 1995) Failure Mode and Effects Analysis (FMEA) (Fritz, 1989) Cognitive walkthrough (Lewis et al., 1990) Usability studies (Nielsen, 1993)	Redesign Information design Design for guessability and / or learnability Choice and design of support media Personnel choice Teamwork design Training Expertise building Culture creation A learning system

Despite the large number of methods available, the lack of predictive power is a persistent complaint of engineers about the limitations of typical human factors input into design (Hockey & Westerman, 1998). In his *Presidential address to the Human Factors and Ergonomics Society*, David D. Woods (1999) claimed that over the last five decades the profession has been developing and handing over validated guidelines so that others can carry out its professional practice. The process of literal design and "table lookup" is seen by Woods (1999) as an oversimplification that leaves discovery, insight and innovation out of the profession's description of design. He says with some irony that the profession has been "sweeping up at the rear of the parade" ("reacting after-the fact, […] called in only when others reach impasses, respond to calls for help with 'I can test that …', miss windows of opportunity [and] best work in the aftermath of surprises"). As a better alternative, Woods (1999) brings forward another perspective, that of complementarity, where research and practice are mutually reinforcing and where field settings are viewed upon as natural laboratories for long term learning. From this perspective, design is seen as "balancing understanding, usefulness and usability".

Hockey & Westerman (1998) acknowledge that measurement in the area of cognitive engineering is complex, claiming that various components of usability – performance, quality and cognitive user costs – are essentially incommensurate. Usability handbooks, such as Nielsen (1993), refer to crude, context free measures of performance that include time to complete task and number of errors in completing it. These measures, however, can assist in evaluating usability improvements between alternative systems used in the same task and context. On the other hand, subjective assessments refer to concepts such as motivation or satisfaction, but are generally not considered in practice in the methodologies for cognitive engineering. However, Norman (1993) considers the concept of motivated cognitive activity in his writings about cognitive engineering (this concept is characterized in Appendix B). This concept does not however seem to pass on visibly to research.

(5.3.1.1) Concluding discussion of the literature based findings pertaining to cognitive engineering

Whether cognitive engineering is viewed from a perspective of safety critical systems or from a general perspective; literature does not provide any definite methods to assuredly attain the goal of pleasant use, nor does this goal visibly pass on to research literature. However, the knowledge on cognition, and the availability of methods of analysis are quite big, leading to a number of possible actions as described in Table 12. However, this process so far leans on an iterative approach, since predictive evaluation of the outcomes of action is still being developed.

The field of cognitive engineering adopts in its name the noun ‘engineering’, which detaches it from a ‘pure’ science approach. However, one of cognitive engineering’s schools (Woods, 2000) specifically addresses the issue of predictability, but tackles predictability from a practice centered perspective. It does not rely on theory to attempt validating models derived from it, but it rather adopts the pragmatic view of reinforcing the knowledge base (theory) and the technological development cycle in a closed loop, given that it acts in a changing world (an overview of this approach is covered in Appendix B).

A vast amount of knowledge and methods accrue in the field of cognitive engineering. However, there are a number of alternative schools and focuses in the field, and the level to which these consider the existing methods and theoretical structures valid varies. Given the size of the field, and the existence of an ongoing heated discussion of what it should study, and how this should be done, with some level of success in design endeavors, it seems though that in terms of level of development it is not at the same stage of comfort or pleasure. Rather, it seems to be closer to achieving maturity, as hypothesized in Table 3, where cognitive engineering is suggested to be at a semi-level of maturity.

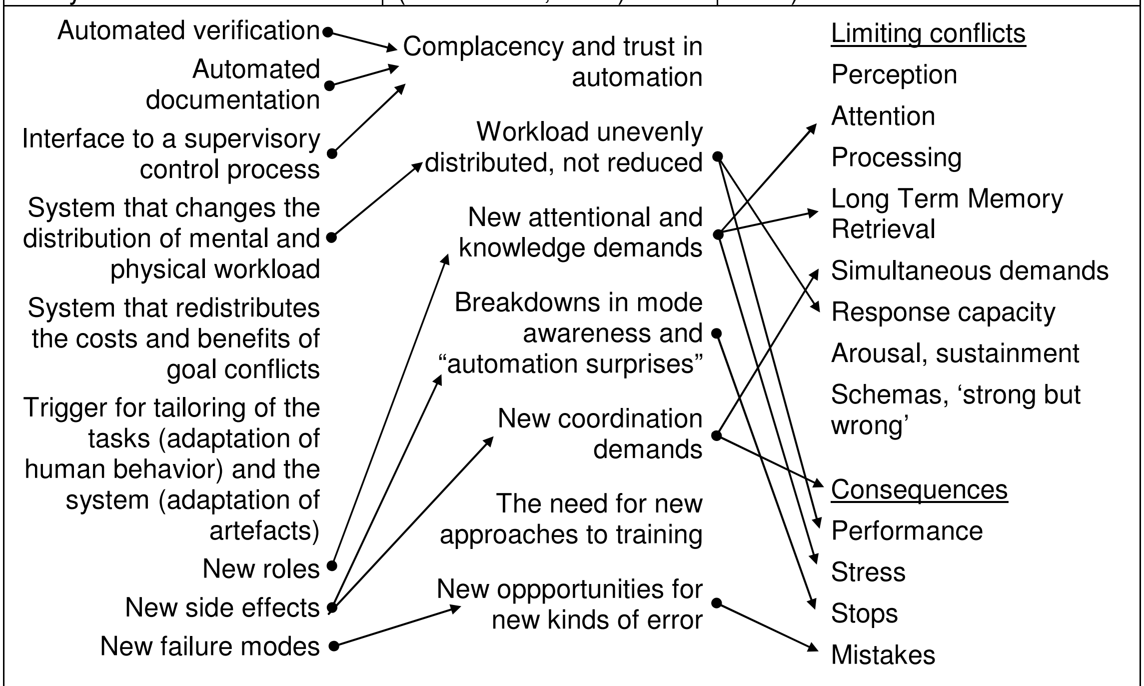
(5.3.2) Assessment of model validity based on empirical studies

Article VI describes an empirical study in the domain of cognitive engineering. The study appears as the result of a demand from a safety critical environment – patient care. Its goal encompasses the assessment of the impact of a technological change (bar coded administration of medication) on the reliability, safety and quality of the system of patient care.

The study follows a methodology that enables understanding the processes of transformation and adaptation of naturally occurring points of change that disturb a system. In order to guide our observations, knowledge of patterns of transformation and adaptation was accessed from previous research (e.g. Woods et al., 1994). This was used to develop conceptual 'looking glasses' that prepared the observers to recognize suprising patterns as departures from anticipated patterns. The bar coding technology used in the medication administration process studied was thought to trigger the elements leading to transformation and adaptation depicted in Table 13. These elements partially embed concepts (limiting conflicts and consequences) from cognition in man-machine systems (Dahlman, 2001). This partial correspondence is tentatively explicated in Table 13 with the mediation of general unexpected problems with human-automation interaction (Sarter et al., 1997). Hence, even if concepts that are part of engineering psychology or cognition in man-machine systems were not considered as elements of analysis in this study, they are partially embedded in the patterns of adaptation and transformation elicited.

***Table 13** – Partial and tentative correspondence between the elements of transformation and adaptation instantiated by study VI and concepts of cognition in man-machine systems, attained with mediation of general unexpected problems of human-automation interaction.*

Elements leading to transformation and adaptation instantiated by study VI	General unexpected problems with human-automation interaction (Sarter et al., 1997)	Limiting concepts and conflicts considered in cognition in man-machine systems (Dahlman, 2001)



It is questionable if such a study could yield results about the understanding of the complexities and capacities in the interplay between people, technology and work, had it been handled with the breakdown process described in chapter 2 (Figure 4). According to Sarter et al. (1997), new user and practice oriented design philosophies and concepts are needed to address deficiencies in human-machine coordination. One goal is to provide the basis to design integrated human-machine teams that cooperate and communicate effectively as situations escalate in tempo, demands, and difficulty. Another goal is to help developers identify where problems can arise when new automation projects are considered and therefore help mobilize the design resources to prevent them. Hence, in assessing the impact of the technological change considered in study VI, the methodology followed appears as part of ‘a design philosophy’ that is needed in place of a traditional theory driven approach, in order to satisfy the two goals stated by Sarter et al. (1997). For this study, this methodology appears as more effective, although it does not totally disregard concepts from previously established theory.

Following the chain process described in Figure 4 would lead to the collection of data of a number of variables of interest. This process is more effectively applied to problems where a reasonable level of understanding has been reached. This understanding cannot be sustained or derived from theory, since cognitive engineering is called in to deal with design problems in a world that is evolving, hence not static. With the methodology followed in study VI, observation guided with patterns of adaptation and transformation yields a contextual understanding of the complexities and capacities of the system of people, technology and work, that is applicable for the present moment. As time advances, this understanding loses its relevance, given the inevitable changes in fields of practice. The understanding enables generating hypotheses of what would be useful, in terms of design seeds and reusable concepts. These are then embedded in prototypes, to be used as tools for discovery. A breakdown derivative process may be applicable in the concurrent process of refining the prototype at the usability level, where collection of data on variables of interest is deemed necessary. Such variables derive from the breakdown of the concept of usability. Woods (2000) looks upon this process of refining the usability of a prototype as embedded in the technology development cycle as opposed to the research cycle.

(5.3.2.1) Perspectives on the production of product development directives (design seeds and re-usable concepts) from the empirical study

Based on our investigations, several patterns emerged that provided insight into gaps between the system designers’ implicit models of performance and the actual nature of practice. New vulnerabilities were identified as a result of missing information about pending or discontinued medication orders. The increase in documentation activities during high-tempo periods encouraged adaptations that bypassed the bar coding system. The automated collection of data about the time a medication was administered artificially raised timely medication administration over other patient care goals. This insight enabled tentatively generating design seeds or reusable concepts (Woods, 2000), which embody hypotheses of what would be useful to increase system efficiency and quality, namely:

- Geographically based overviews of patient location and corresponding medication orders.
- Longshots of medication orders to support planning of work, according to multiple criteria, such as patient, care ward, type of medication / administration route, or scheduled time for administration.

These design seeds are very specific to the technology and domain of practice observed in the study, and do not constitute generalizable (universal) product development directives. However, the enlarged understanding of how technologies impact cognition and collaboration in a field of practice attained through the study enriches the knowledge base. This understanding can be useful in guiding observations in other studies. If similarities are found in other domains and cognitive systems, these design seeds may be reusable in those particular contexts, but they do not hold the universal character intended in establishing product development directives.

(5.3.2.2) Assessment of methods for data collection and analysis and data representation

The data collection and analysis methods used in the empirical study consisted of fielded observations guided with patterns and complementing interviews as well as process tracing methods for the study of cognition outside of the experimental psychology laboratory (Woods, 1993). The effectiveness of fielded observations guided with patterns is dependent on developing conceptual looking glasses that prepare the observer to recognize suprising patterns as departures from anticipated events. These possible patterns (extracted from the research base) calibrate the observer to the specific design issues with the particular technology in the particular setting. Interviews are intended to provide information that is not elicited through non-intrusive observation. Process tracing of the events in the system of people, technology and work is an effective way of providing factual data that can be useful as corroborating evidence of the patterns of adaptation and transformation encountered through fielded observations. Hence, the effectiveness of these data collection and analysis methods is deemed high in providing an understanding of the patterns of transformation and adaptation as a result of a technological change. The feasibility of these methods of data collection is dependent on a positive and encouraging attitude of the 'host' organization at its various levels (from top management to the practitioners at the sharp-end) towards the researchers. Study VI does not follow the principle driven design approach, hence it does not support the assessment of other methods used within this approach.

Representation formats of the results of study VI adopted verbal propositional (patterns of transformation and adaptation) and graphical forms (process traces in the dimension of time). The question 'did users understand what was asked to them?' is not applicable to this study since questions derived from theory concepts were not posed to users. However, implicit in the method of immersion in the system used, is the condition that researchers acquaint themselves with the culture and terminology of the field of practice, in order to have a better understanding of the observed activities. Hence, the user is not challenged with understanding the researchers' theoretical concepts nor are biases introduced from the arising of different interpretations of the concepts. The study also shows the shortcomings and simplifications of the system designers' implicit beliefs (concerning models of performance and the actual nature of practice). It enabled deriving design seeds formulated in a way that should be implicitly understood by designers (in terms such as of what features to develop, or systems glitches that should be addressed).

(5.3.2.3) Contribution of the empirical study towards assessing the viability of theoretical structures and concepts

Performing a study in the area of cognitive engineering allowed me to understand how vast this area is, and how little of it I have actually used in contributing to this empirical study. From this perspective, it seems that the contribution of the study towards theory is the demonstration of part of a methodology for practice-centered research and design that was presented by Woods (2000) and is described in Appendix B, and one which fits into being a design philosophy previously sought by Sarter et al. (1997).

At a lower level of analysis, it is possible to indirectly identify some of the concepts that are part of the theoretical structure of cognition in man-machine systems (Table 13). Aspects such as long-term memory retrieval are invoked to cope with the observed system's idiosyncrasies, and can explain some of the problems ocurring in the joint cognitive system. Simultaneous demands are also present in the process of medication administration, and in the work environment *per se*. However, the study did not depart from subconcepts such as these as a means of following the chain process explained in chapter 2, Figure 4. There may be several aspects that can be tentatively considered as an explanation for this, and which are inherently seen as measures of immaturity of the field. There appears to be a relative 'divorce' between experimental research and naturally occurring experiments. To some extent, the results and achievements of laboratory research on cognition and engineering psychology are not considered relevant for complex fields of practice. Aspects such as validity, or repeatability are considered irrelevant, when the problems of situated cognition in changing fields of practice are so critical and urgent to be addressed. Hence, authenticity leading to design seeds and reusable concepts is favoured in deterrence of attaining validity and creating (universal) product development directives. Moreover, since new technology is a kind of experimental investigation into fields of ongoing activity, the experimenter functions as designer and the designer functions as experimenter (Woods, 1999). This complementarity perspective stands in contrast to writings on the systematization of engineering design (Hubka & Eder, 1996), which clearly separate the design activities from research, advocating for the imposition of requirements on design. However, it is important to note that the types of products these authors focus on have very different characters. While Hubka & Eder's perspective springs from the mechanical design of hardware, Woods' perspective springs from the design of software in the computer medium, aiming at safety and performance in joint cognitive systems. It is thus logical that the latter needs to focus on procedures, behaviors and managing risk, using fielded observations, process tracing methods and others. On the other hand, the design problems faced by Hubka & Eder cannot be tackled with those methods, and a specification is needed in the first place. It is hence envisaged that both perspectives, with their implicitly alternative and apparently conflicting approaches, are important, but should be used for tackling product (or system) design problems of different characters, in agreement with the type of problems from which they spring.

(5.3.3) Level of maturity of cognitive engineering

The insights gathered from the assessment of theory enable suggesting that model validation of experimental psychology concepts is not sought by cognitive engineering. Instead, cognitive engineering is challenged to develop its own theoretical approach, detaching itself from the straightforward application of cognitive science. Significant advancements are being made, however, validity (universality) is not sought, but authenticity is given that cognitive engineering acts in a complex and changing world. Supporting product development is at the core of cognitive engineering's aims, however design seeds and reusable concepts are favoured as outputs of research endeavors. Principle design is not deemed viable in a changing world, for the level of understanding and usefulness, although it may be applicable for attaining usability.

Concerning the scale of maturity presented in section 2.1, the following levels of the five criteria spring from the prior discussions:

- Kuhnian level of paradigmatic consensus: Medium (2)
- Extent and elaboration of theoretical body: Well defined (3)
- Model's validity / quality: Medium (2)
- Quality of Product Development Directives: Mediocre (2)
- Level of congruence between theory and practice: Highly dissociated (1)

This assessment thus results in a score of 24, corresponding to a semi-level of development.

(5.4) Discussion of the results

This chapter fulfils the aim of assessing the level of scientific (theoretical) development of comfort, pleasure and cognitive engineering, as well as their level of development in practice. The answers to research questions R.1 and R.2 are presented in this section, which also discusses the possibility of attainment of predictability in the three areas. Finally, the relevance of the results for application by engineering design is discussed.

(5.4.1) Answers to research questions R.1 and R.2 and the feasibility of attaining predictability

The analyses previously presented in this chapter were geared to satisfying operative aims O.1 and O.2 and to provide answers to research questions R.1 and R.2. The former was framed as 'do present theory and methods yield workable results for assessing model validity and directing product development?'. Table 14 summarizes the answers to research question R.1 for the three areas considered.

***Table 14** – Summary of the insight gathered from the results from literature and my empirical studies towards answering research question R.1 'do present theory and methods yield workable results for assessing model validity and directing product development?'.*

Assessment of:	model validitation	directing product development
Comfort	Yes, but with insufficiencies of the scope covered by models and incomplete transformation of operatives	Yes, but tentative and not definitive
Pleasure	Yes to some extent – model validation is commencing, but theory is underdeveloped for the illusive aspect of emotions	Yes, but only through other areas encompassed in the pleasure with products approach (usability, comfort and other branches of HFE), although emotional outputs are not attained in these. However, Kansei Engineering has advanced in a less holistic approach
Cognitive Engineering	Yes, partially at the level of usability, but for understanding and usefulness it is challenged to develop its own theoretical approach, detaching itself from the straightforward application of science, in particular the mother discipline of cognitive psychology	Yes although debate exists around whether principle design is possible in a changing world

Another result found from the investigations that support answering research question R.1 was a complementarity perspective that has risen within the field of cognitive engineering. This perspective departs from the stance that new technology is a kind of experimental investigation into fields of ongoing activity, where the experimenter functions as designer and the designer functions as experimenter (Woods, 1999). This stands in contrast to a presently widely accepted perspective, which advocates for the imposition of requirements on design (Hubka & Eder, 1996). However, the types of products focused on by each of these perspectives have very different characters. While the complementarity perspective springs from the design of new systems based on the computer medium, the other one springs from the mechanical design of hardware. It is hence envisaged that both perspectives, with their implicitly alternative and apparently conflicting approaches, are important, but should be used for tackling product (or system) design problems of different characters, in agreement with the type of problems from which they spring.

Concerning research question R.2 – 'are data collection methods and representation formats adequate for communicating to users and designers?' – it was more completely addressed in what concerns comfort, and only partially addressed in what concerns pleasure and cognitive engineering. This came as a consequence of the degree of completeness of the empirical studies on which the analysis of data collection methods and representational formats was based. Table 15 summarizes the results of these analyses for the three areas in terms of the answers to research question R.2.

***Table 15** – Summary of the insight gathered (and the degree of completeness of the assessments) from the empirical studies towards answering research question R.2 – ‘are data collection methods and representation formats adequate for communicating to users and designers?’.*

	Degree of completeness of the assessments	Assessment of data collection adequacy with users	Assessment of representation formats’ communicability to designers
Comfort (study I and study II)	Almost complete coverage of data collection methods (missing is electromyography and cross-modality matches) and of representation formats of product development oriented information	The subjective data obtained is dependent on the understanding by the person of what is requested, which maybe different from the researchers’ implicit concepts	The representation formats’ adequacy for communicating to designers is dependent on their understanding of the limitations of the data and product development oriented information presented to them
Pleasure (study IV and study V)	Incomplete coverage of data collection methods, focusing on understanding of users and not reaching at representation formats at the product development directives level	Restricting to a more verbally eloquent sub-group of society is a means of increasing the possibility of users understanding the concepts tested (at the risk of introducing systematic biases)	It is assumed that the level of understanding attained by users about the concepts covered in the questionnaire is extensive to designers
Cognitive Engineering (study VI)	Incomplete coverage, since data collection methods used only concern the attainment of understanding that enables suggesting what would be useful and consequently product development orientation for the level of usability was not assessed (the principle driven design approach was not assessed)	The user (practitioner at the sharp end) is not challenged with understanding the researchers’ theoretical concepts nor are biases introduced from the arising of different interpretations of the concepts	The design seeds are formulated in a way that should be implicitly understood by designers (in terms such as of what features to develop)

The analyses of literature and the insight gathered from the empirical studies support the acceptance of the hypothetical categorization in terms of level of development of the three branches, which had been presented in the introductory chapter of this dissertation. Hence, while comfort and pleasure have so far attained a low level of development, cognitive engineering is at a more advanced stage of development, although it is not yet fully mature. Moreover, cognitive engineering encompasses a broader range of design problems (software, interfaces, new systems, system redesign, training) than comfort (focusing on some categories of products at the physical human interface). Pleasure has focused essentially on consumer products, and hence its range of application is also more restricted than that of cognitive engineering.

For cognitive engineering there is dissociation between a vast academic and theoretical body of knowledge and the practice-centered demands of the engineering work that needs to be done. Pleasure is fairly well defined theory wise, although preliminarily, but it is yet very little researched. Pleasure is also linked to the illusive aspect of emotions, an area where theory seems to be weaker and necessarily more complex. The area of comfort encompasses several aspects of the environment of which some have reached a very high degree of maturity and predictability (e.g. thermal comfort). Some other aspects of comfort have not attained such a level of maturity (e.g. seat comfort) apparently mostly because of a lack of research effort, considering their development potential. In addition, some of the tentative methods used in the assessment of comfort have become accepted as common practice given their repeated use, although these have not been validated.

The underlying hypotheses for research questions R.1 and R.2 considered that comfort, pleasure and cognitive engineering are at very different levels of development (both theoretically and in terms of level of development in practice) but that they have basically a similar potential for attaining predictability. This attainment of predictability is however deemed more feasible within certain subconceptual areas (Table 16).

Table 16 – *Sub-areas of comfort, pleasure and cognitive engineering where attaining predictability is deemed pursuable and sub-areas where it is not deemed pursuable, springing from the results.*

	Areas where predictability has been achieved	Areas where predictability is deemed pursuable	Areas where predicatabilty is presently deemed as not being within reach
Comfort	Thermal discomfort models (with a margin for individuality)	Physiological and physical discomfort models (relating to seats) (with a margin for individuality)	Psychological comfort models
Pleasure	–	Modelling the transfer from experiential product properties into formal product properties for groups or niches of society and culture (using the approach followed in building Kansei Engineering databases)	Universal models of the transfer from experiential to formal product properties
Cognitive Engineering	–	The impact of change on joint cognitive systems (through a research method using abstracted patterns from several domains)	Principle design (attaining universally valid product development directives)

Maybe the psychological component of comfort cannot be objectively predicted, but the physiological and physical components of comfort are closer to reaching the point of attaining predictability. However, these efforts are coming closer to predict subjective discomfort (with some margin for individuality), but not to the ability of designing comfort (seen as as an aspect of pleasure – cf. article IV) into seats. Although people are common in many ways, and that is what enables attaining predictability, emotions relate to past personal experience. Hence, since in pleasure the emotions are an important part, the attainment of predictability may face greater hardships.

The commonalities across humans are deemed bigger for physiological and physical aspects, but decrease in number as we move towards cognitive, motivational and emotional aspects. However, although there are individuality and culturally rooted differences, there might still be commonalities to be found. Predictability may possibly be directed towards groups or niches.

Concerning cognitive engineering, efforts have been made and a robust methodology has been developed that aim at predicting the impact of changes in joint cognitive systems. These efforts and methodology also enable an extraction of design seeds embedding hypotheses of what would be useful to advance in design problems. This methodology, however, implies a research process. Thus it cannot be transformed into a method to design suitable for direct application by engineering design. Moreover, Woods (1999) questions the approach of handing over validated guidelines for others (engineering design) to carry out in practice, arguing that in the field of cognitive engineering researchers function as designers and designers function as experimenters. For the usability level of technological products, not discussed in my empirical study on cognitive engineering, the process of theory breakdown is deemed applicable. However, there are problems of measurement in this area (Hockey & Westerman, 1998), which have to be overcome before predictability can be deemed attainable.

The goals of motivation and pleasurable engagement are mentioned in the aims set by Norman (1986) for cognitive engineering. However, these goals do not pass on with visibility on to ongoing research themes. This can be a sign of the urgency in dealing with more critical issues concerning functionality and safety. The goals of motivation and pleasurable engagement may become more visible in the future, when the presently more pressing problems are solved. However, Noyes & Littledale (2001) acknowledge that strong emotions are often perceived negatively in that they are thought to impair rational decision-making. Hence, interactions resulting in high levels of emotional involvement are not deemed suited to safety and performance critical applications.

It seems there are two dimensions that condition the attaining of predictability, on the one hand objective performance and on the other one emotion. The degree to which each of the three branches aims at goals of objective performance or emotional engagement to evaluate and guide design can thus also be an indicator of how attainable predictability is, and how much input into design processes presently comes from objective measures and from subjective assessment. Figure 7 springs from this reflection. The interceptions in the Figure are not intended to represent an overlapping of content, although this may exist, but they only concern the abstracted dimensions shown in the Figure. Health and tiredness are included for the sake of providing a term of reference and because these are part of the goals of ergonomic design (e.g. assuring and protecting good health and avoiding tiredness).

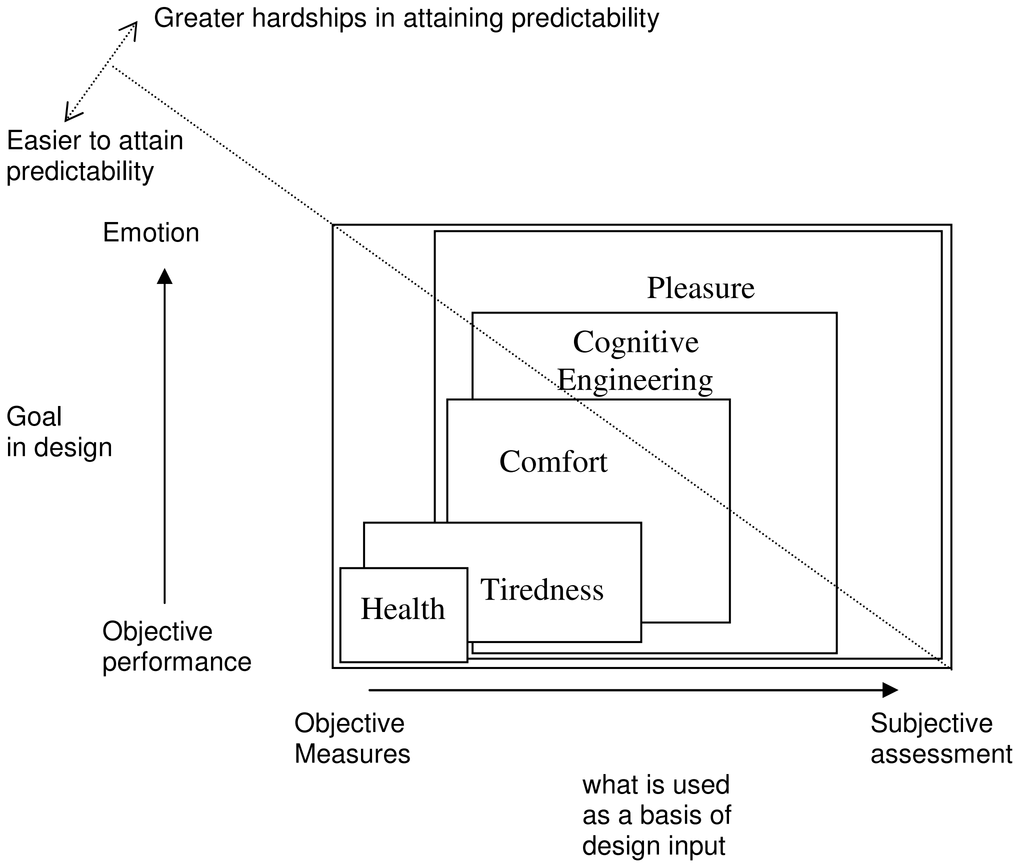


***Figure 7** – Dimensions judged important in the assessment of the possibilities of attaining predictability for comfort, pleasure and cognitive engineering.*

(5.4.2) Consequences of the results for engineering design

The current state of affairs has consequences for engineering design and for research efforts. While engineering design hence falls short of off-the-shelf methods to transfer desired outcomes into product properties, research efforts should be geared towards filling the empty spots of the theoretical structures. Presently, principle driven design is not totally feasible. Hence, innovative design endeavors in the areas of comfort[11], pleasure and cognitive engineering must resort to adopting a combined research-design approach with at least some of the following characteristics:

- understanding what would be useful by unveiling and precising the human requirements on the technology design problem at hand beyond those that are already generally accepted in the field of practice as viable and valid product development directives;
- the use of prototypes as tools for discovery, embedding hypotheses about what would be useful to advance in the design problem;
- the vehicles for the assessment of the prototypes (hence hypotheses) in terms of higher goals of the three areas (pleasant states) rely on 'subjective' assessments, whereas 'objective' measures are not presently transferable into the subjective ratings (the theoretical structures are not able to deliver predictive models and are hence not good – cf. introduction of chapter 2); and

[11] Thermal comfort is an exception, since predictability of the subjective assessment of thermal discomfort has been attained (Fanger, 1972).

- iterations are necessary to advance in the design problem, with the fielding of the product in a system of people, technology and work / tasks and / or recurring to assessments by subjects from use or trial of the product / prototype.

The results of the combined research-design approach for the purpose of a specific design are typically not universal (although results may eventually be fed back to the body of knowledge of the field in question), because they are valid only for a particular set of constraints (situation context). The research in this approach is geared to the specific design problem. This is a combination of research with a pure top-down approach (starting from theory using the chain process described in Figure 4 – chapter 2) and with a bottom-up approach (starting from the design task and the context of use).

Despite the fact that research-like approaches are necessary to complete the design process, the justification for the creation of a single human factors design approach still holds. However, presently it would be feasible only as a framework to assist in guiding or directing the research parts of the combined research-design process intended for specification of human requirements and for attaining product or system properties.

Chapter 6

Objectives:

- To essay compatibilizing comfort, pleasure and cognitive engineering.
- To relatively position the three areas in terms of design goals, human aspects considered and domains of application in practice.
- To search for commonalities in the theoretical structures.
- To apply activity theory in eliciting a common structure of the research-design processes.
- To apply activity theory for identifying operatives and deriving measurable variables in individual design problems.
- To present the answer to research question R.3.
- To discuss the level of compatibility attained.

(6) Compatibilizing comfort, pleasure and cognitive engineering

As an aim for this work, the integration and compatibilization of theoretical structures and methods for comfort, pleasure and cognitive engineering was set forth. This aim derives from exploring and assessing the potential for creating a single DFX method for comfort, pleasure and cognitive engineering, instead of one for each of the three. The problem of integrating or compatibilizing the three branches of Ergonomics considered can be viewed from several levels of analysis. At a higher level, stand the objectives of the ergonomic intervention. The concepts of the theoretical structures used in attaining those goals are considered in another level. Operatives and measurable results are seen in another level. In parallel to these stand the methods for data collection, and in subsequent phases one encounters methods for data analysis. Compatibility and integration ambitions stated in the aims of this work also concern the format of representation of product development directives. Research[12] was also suggested as a potential beneficiary of these integration and compatibilization efforts.

In pursuing the aim of compatibilizing the three areas the perspectives of relief of pain and of addition of gain, introduced in the first chapter as approaches to ergonomic design, are recalled and expanded in the following section. To this follows an analysis of similarities at the subconcept level. The chapter also introduces an analysis based on activity theory with a double purpose. It has a purpose of showing commonalities between the three areas in terms of the underlying goal-activity structure. It also has the purpose of assisting in the identification of what information is needed (operatives) thus allowing the derivation of measurable variables in particular problems. Finally, a concluding discussion is made about the level of compatibility attained with these analyses.

(6.1) A pains and gains perspective

This section considers the perspectives of relief of pain and of addition of gain as a criterium for comparison of the three areas of comfort, pleasure and cognitive engineering at the higher level of the theoretical structures.

The definition of comfort brought forward by Slater (1985) considers physical (and physiological) as well as psychological aspects, but the application and research domains where the ‘label’ of comfort has been used are overall linked to the physical aspects. The four-pleasure framework devised by Tiger (1992) and used by Jordan (2000) as a basis to conceive product benefit specifications adds the sociological and ideological aspects of the human being. In the advent of cognitive engineering Norman (1987) emphasized cognitive aspects of human-machine interaction. While

[12] Three research approaches can be identified: research adopting a top-down approach departing from theory seeking high validity, research departing from application contexts in a bottom-up approach towards the formulation of theory at the cost of lower ‘universalism’, and research which departs from both the theory and application perspectives.

Slater's definition of comfort and the four-pleasure framework are increasingly overarching, Norman delimits the field in terms of its application domain and its focus on learning and skills of the human being (and human action and performance). The application domains where these branches of ergonomics found their 'niche'[13] have shaped their comprehension in terms of focus on particular human aspects. However, their goals in practice can be seen to be partial expressions of the objectives of Ergonomics, e.g. the objectives of safety, comfort and well being (Moraes, 2000). Pleasure approaches to design can be seen from the perspective of Ergonomics as included in the goal of maximizing gain and pleasure, as opposed to minimizing pain and loss (Noy, 2000).

In my opinion, the bulk of practice in the fields of cognitive engineering (particularly in what concerns safety critical systems applications) and comfort have not yet gone over the threshold of minimizing pain and loss (in terms of discomfort, or inadequacy and bad usability quality). The pleasure approach to design of consumer products presented by Jordan (2000) assumes that usability deficiencies, discomfort and interaction inadequacies have been eliminated through the use of methods and techniques which are part of the older ergonomic goal of minimizing loss and pain. An important difference between the three HFE branches seems to be the state of their evolution in terms of success in erradicating inadequacies or adding gains in their domains of application. Table 17 depicts this state of affairs succinctly.

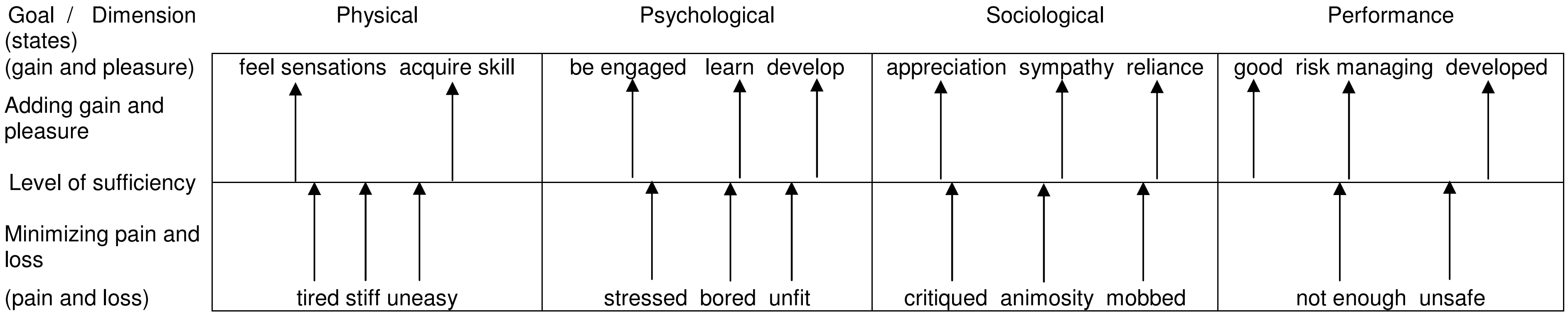
***Table 17** – State of application domain dependent focuses of present <u>approaches to design</u> of pleasure, comfort and cognitive engineering.*

	Pleasure	Comfort	Cognitive Engineering
Domains of application in practice	Consumer products ('hard' and 'soft')	'hard' products (at the human physical interface)	'soft' products and cognitive work systems (human-machine interaction)
Aspects of the human being considered in practice in domains	Physiological and physical, sociological, ideological and psychological	Physical (and physiological)	Cognitive (part of psychological)
Approach to design: minimizing loss and pain	Assumes inadequacies have been eliminated using usability and comfort approaches	Eliminating discomfort	Eliminating inadequacies in cognitive systems, attaining usability, coping with complexity
Approach to design: maximizing gain and pleasure	Creating supplemental benefits	–	–

Hence, striking differences among the present state of the three areas result from the consideration of their actual domains of application and their approach to design in terms of the dichotomy of minimizing loss versus maximizing gain. However, there are common features in the goals identified for the three areas (pleasurable

[13] Woods (1999) claimed that Human Factors and Ergonomics has already become a group of "fragmented imperialist communities", while Moray (2000) predicted that in the future HFE will develop into a collection of sub-disciplines whose practitioners know little of each other's techniques.

engagement – cognitive engineering, pleasant harmony – comfort, attaining pleasure – pleasure with products). Hence, at an overriding level of the design goals pursued and definition-wise, the three areas share commonalities. Moreover, design goals can be considered in several dimensions and in terms of their quality of removing losses and pain or of adding gains and pleasure. Figure 8 presents an analysis considering the physical (including physiological), psychological (including cognitive but not emotional), sociological and performance dimensions. Within each of these dimensions states are depicted in relation to the goals of eliminating pain and loss and of adding gain and pleasure. The states depicted are some of those that spring from a general understanding of what is aimed by Ergonomics in design in its several expressions (e.g. Traditional Ergonomics, Comfort, Pleasure, Cognitive Engineering, or Macroergonomics). This Figure is a hypothetical personal exploration towards a possible theoretical understanding.



Note: There is a specific meaning in the positioning of the arrows. These are positioned centrally in relation to the respective words and are not straightforwardly continued from the level of pain and loss to the level of adding gain and pleasure, suggesting discontinuity between many of the goals in each level.

***Figure 8** – Goals in Human Factors design for physical, psychological, sociological and performance aspects and how improving a negative state to a state of neutrality or attaining a positive state can achieve these. This is a hypothetical personal exploration towards a possible theoretical unerstanding.*

The partial analysis depicted in Figure 8 shows three levels of states in four dimensions. The lower level, of pain and loss, is that where discomfort, inadequateness, unfitness and displeasure are in existence. In the intermediate level, well-being, adequateness and neutrality are achieved by the elimination of pains and losses of the level below. It is hence a level of sufficiency. In the upper level, additional gains and pleasure are achieved, beyond the level of sufficiency below it. In this respect, pursuing comfort (seen as a goal in design) can be seen as the equivalent of pursuing the goal of minimizing pain and loss – achieving a state of harmony, while pleasure corresponds to the goal of adding gains and pleasure[14]. As stated by Noy (2000), the latter goal finds its expression in promoting pleasure, satisfaction, creativity, personal growth, meaningful activity and human-system symbiosis, as opposed to a focus on promoting safety and human-system compatibility (minimizing pain and loss). The polarity in the design for relief of pain (eliminating discomfort) and the design for the addition of gain (achieving pleasure) is reflected in Lewis's (1987) distinction between need pleasures and pleasures of appreciation. This was embraced by Jordan (2000) in outlining the theory supporting his constructs on pleasure with products.

Viewed from this perspective, traditional ergonomics, macroergonomics, cognitive engineering, seat comfort and pleasure with products are methodologies that can be used to achieve these goals of comfort and pleasure. These goals are in themselves embraced by Human Factors and Ergonomics at a general level, although comfort has been considered for a longer time than pleasure. Their domains of application shape the differences between these so-called methodologies, together with the consideration of a partial or complete extract of physical, psychological, sociological, performance and ideological aspects. Cognitive engineering is thus viewed as a way of eliminating discomfort and achieving pleasure[15], and one that focuses essentially in cognitive (psychological) and performance aspects.

The area of comfort is confounded with the goals of eliminating discomfort and achieving comfort, but this label only appears frequently and consistently linked to physical (and physiology) aspects. Moreover, comfort can be seen as an aspect of pleasure (article IV). Macroergonomics, which is not my focus, has the goal of optimizing workplace productivity (Hendrick, 1995), hence focusing on performance. Pleasure with products aims at pleasure, considering physical, psychological, sociological and ideological aspects. Viewed as a whole, Ergonomics and Human Factors has the goal of optimizing human well-being and overall system performance in its physical, cognitive and organizational domains of specialization (IEA, 2000). Armed with this understanding, it is clearer how comfort and pleasure both have the triple role of being goals for ergonomic design, bodies of knowledge (seat comfort,

[14] As reported in article IV, comfort and discomfort are not a continuous, but two separate entities. Article IV shows how comfort in seats can be seen as an aspect of psychological and ideological pleasure, while discomfort in seats is linked to physiological and physical inadequacies.

[15] In addition to the three level distinction of pain/loss, neutrality and gain/pleasure, a parallel dimension in design has been outlined by Woods (2000), which embeds a mixture of elements of research and design. It considers the levels of understanding, usefulness and usability. Understanding corresponds to an enabling precursor to establishing hypotheses about what would be useful. The output of the level of usefulness may require further work in order to overcome pains and losses, hence attaining the quality of usability (at the level of adequateness and neutrality). Additionally, Norman's (1993) concept of motivated cognitive activity can be seen as pertaining to the level of addition of gains, asides with his purpose of designing for pleasant use (Norman, 1986).

thermal comfort, comfort at the human interface, pleasure with products) and methods for eliminating discomfort and achieving pleasure[16]. Conversely, cognitive engineering is seen as having the double role of being a body of knowledge and a method for eliminating discomfort and achieving pleasure.

Hence, there is an obvious dissociation between the areas of comfort and cognitive engineering in what concerns the aspects focused. While the former focuses on physiological and physical aspects, the latter focuses on cognitive (included in psychological) aspects as well as performance. Pleasure with products and comfort share the focus on physiological and physical aspects. Cognitive engineering shares with pleasure with products the focus on psychological aspects, although not including the emotional aspects.

In addition to the commonalities and dissimilarities considered above, a similarity between comfort and cognitive engineering can be outlined, although it is not visible in practice in the comparison of material produced in the two areas. It concerns the psychological aspect, which is covered by Slater's (1985) definition of comfort and is reflected in Norman's (1987) postulates on cognitive engineering (emphasizing cognitive aspects of human-machine interaction). This cognitive dimension can be seen to fit into the psychological aspect, falling short however of the emotional dimension in fulfilling the full scope of the psychological aspect. The psychological aspect of comfort is however not developed. Studies that develop on this facet of human-machine interaction are considered in cognitive engineering and in pleasure approaches to design, but do not portray the label of 'comfort'.

An analysis is made in this chapter about the commonalities between comfort and pleasure with products and between cognitive engineering and pleasure with products at the subsequent level of subconcepts. The analysis is described in the following section.

(6.2) Commonalities at the subconcepts level

The analysis of commonalities between comfort, pleasure and cognitive engineering is based on the subconcepts and operatives identified in chapter 5. The analysis of pleasure with products, presented in chapter 5, was brought to the level of people characteristics considered in defining product benefit specifications. It is found that establishing a correspondence between these and the theoretical structures of comfort and cognitive engineering, is viable at the level of subconcepts, but not on lower levels since pleasure with products was not broken down to that level. The first analysis presented below considers the degree of similarity between the subconcepts (further explicated with the assistance of operatives) in seat comfort and the

[16] Zhang et al.'s (1996) descriptors of comfort, cited in article IV, can thus be seen as linked in one set to the goal of relieving pain/loss/discomfort (refresh, relief, relaxed, cozy, restful, at ease, calm, safe, agreeable, well-being) and in another set to the goal of adding gain/pleasure (pleased, pleasant, happy, softness, spacious, plush, luxurious). This correspondence is compatible with the reflections presented in article IV. Additionally, displeasure can be seen as pertaining to the pains and losses level, and it is hence confounded with discomfort, although it may carry a character even more negative than the latter. However, my purpose is in designing for comfort and pleasure, hence exploring the distinction between discomfort and displeasure is not deemed important.

physiological people characteristics extracted from pleasure with products. The second analysis considers the degree of similarity of subconcepts in cognition in man-machine interaction[17] and the psychological people characteristics considered in pleasure with products.

In chapter 5, subconcepts and operatives pertaining to seat comfort (including thermal comfort and comfort at the human interface) were identified as well as people characteristics used as a basis for reaching at product benefit specifications. Table 18 depicts the former subconcepts and operatives and the physiological aspects of people characteristics considered by pleasure with products. There is a partial correspondence between the people characteristics in the last column of the table and the subconcepts and operatives in the first two columns. These concern musculo-skeletal characteristics (marked with an asterisk) and external body characteristics (marked with a double asterisk).

***Table 18** – Commonalities between subconcepts and operatives considered in seat comfort and physiological people characteristics considered in pleasure with products (marked with asterisk and double asterisk).*

Seat comfort - subconcepts	Seat comfort - operatives	Pleasure with products - physiological people characteristics
Heat balance of the body Accommodation Forces and pressure at the human interface Subjective assessment Overall discomfort Discomfort in body areas Thermal environment** Static and dynamic force balance Acceleration**	Thermal regulation model Thermal insulation model Metabolism and energy expenditure model Subjective thermal discomfort model Compression of human tissue reaction and behavior Nervous system physiology Human dimensions* Physiology and anatomy of musculo-skeletal system* Joint ranges of motion* Subjective discomfort Subjective comfort Subjective support Subjective assessment for body areas Acceleration** Elasticity of seat** Product dimensions** (pressure in contact) (force sensing) Friction under the presence of lateral acceleration Lateral displacements under lateral acceleration Contact of the back of the seated person with the seat / headrest	Special advantages (e.g. strength) and disadvantages (e.g. a disability) *Musculo-skeletal characteristics External body characteristics Body personalization (e.g. hairstyle) **Physical environment Physical dependencies

In chapter 5, subconcepts pertaining to cognition in man-machine interaction (cf. footnote 17) were also identified. Table 19 depicts the former subconcepts and the psychological aspects of people characteristics considered by pleasure with products.

[17] One of the results stated in chapter 5 is that the subconcepts derived from experimental psychology research are not deemed applicable to the design problems tackled by cognitive engineering. The latter is challenged to develop its own theory base. However, the former subconcepts are not totally irrelevant for cognitive engineering, since they are partially present in the theory that has been developed (cf. Table 13).

There is a partial correspondence between the people characteristics in the last column of the table and the subconcepts in the first column. These concern psychological arousal (marked with an asterisk) and learned skills and knowledge (marked with a double asterisk).

Table 19 *– Commonalities between subconcepts considered in cognition in man-machine interaction and psychological people characteristics considered in pleasure with products (marked with asterisk and double asterisk).*

Subconcepts in cognition in man-machine interaction	Pleasure with products - psychological people characteristics
Perception Attention Processing Long Term Memory Retrieval Simultaneous demands Response capacity Arousal, sustainment* Schemas, ‘strong but wrong’** Skill-based, rule-based, knowledge-based behavior** Stops Mistakes Stress Performance	Special talents and difficulties Psychological arousal* Personality traits Self-confidence Learned skills and knowledge**

Hence, the degree of similarity between comfort and pleasure with products (Table 18) and between cognitive engineering and pleasure with products (Table 19) has been assessed at the level of subconcepts. The assessments show that pleasure with products encompasses a vast area of knowledge, part of which is common to what is considered in comfort, and another part is common to what is considered in cognitive engineering. There are also themes considered in cognitive engineering which are not considered in pleasure with products, e.g. sustained alertness and safety (which I view as pertaining to the relief of pain side of the design goals dichotomy). Similarly, the theme of emotions is encompassed by pleasure with products but it is not seen in practice in application studies of cognitive engineering or comfort. In my view, the theme of emotions is something that should be dealt with in designing for addition of gains and achieving pleasure, but there is not such a stringent need in tackling it when designing for relief of pain and eliminating discomfort.

Besides the differences in the pains / gains dichotomy among the three areas (comfort and cognitive engineering pursuing in practice the goal of relief of pain, and pleasure pursuing the goal of addition of gain), there is another qualitative difference: the knowledge contained in comfort and cognitive engineering has more vertical depth, while pleasure with products is more spread horizontally. By vertical depth I mean the level of detail of knowledge, whereas by horizontal spread I mean the amount of different themes encompassed. The encompassing nature of pleasure with products is a consequence of its purpose of considering hedonic (and practical and emotional) benefits of products. For engineering design purposes it needs the support of disciplines that have attained more detailed depth (such as cognitive engineering or seat comfort) in detailing the subconcepts (people characteristics) considered.

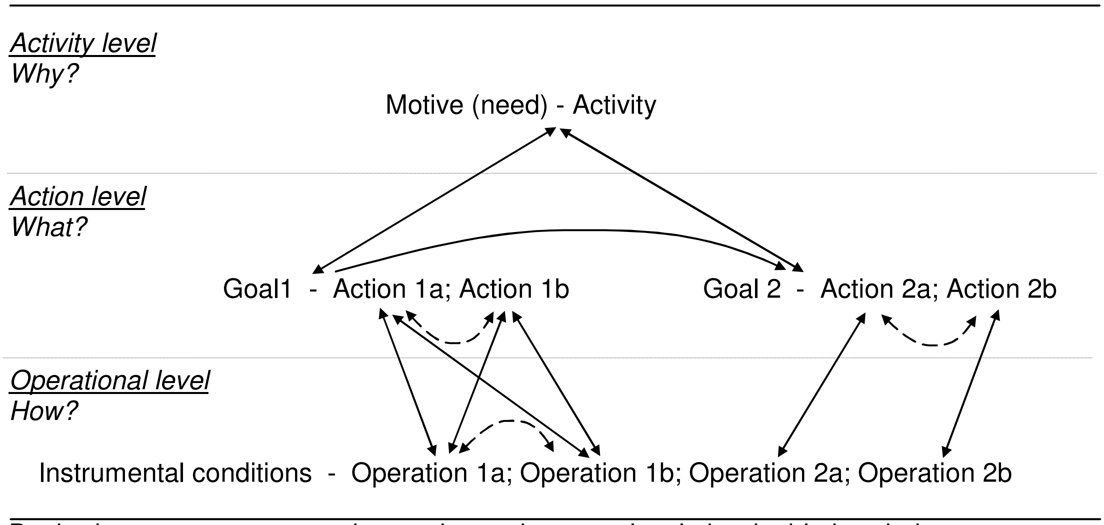
(6.3) Application of activity theory

Appendix C provides a succinct description of activity theory. Activity theory was devised to create understanding of how human beings utilize tools to achieve benefits. It can hence be applied to create understanding of how people interact with techology to perform work, or users use artefacts to perform activities, satisfying a need or pursuing a goal. Additionally, activity theory can function as a framework for developing a picture of a phenomenon in several dimensions, and to put situations and actions into context (Rhodin, 2001). The hierarchical structure of three levels of analysis of activity theory (Leont'ev, 1978, cited in Engeström, 1999) – activity-motive, action-goal and operation-instrumental conditions – has a parallel in the theoretical structures presently at hand: theory-motive/objective, concepts-goals, operatives (and measured results)-instrumental conditions. Thus analyzing the three theoretical structures at these levels is a possible manner of devising compatibility, through the shaping of the levels in terms of sharing objectives, goals and instrumental conditions. The graphical representation of Karlsson's (1996) framework, a development considering activity theory, can be used as a basis to perform these three level analysis applied to empirical studies, seen case by case. At a more general level, of research-design approaches, activity theory enables outlining a broken down process. This process is deemed applicable to the three areas of comfort, pleasure and cognitive engineering, and possibly to Human Factors design studies in general.

The following section presents a process, broken down with the support of activity theory, which represents a subjective hypothetical understanding of the general activity of designing for humans. This process is an extrapolation from the understanding attained from the exploration made in the previous chapter. To this follows a section that essays the application of Karlsson's (1996) activity theory framework to the appended empirical studies as a tool that assists in identifying operatives and measurable variables.

(6.3.1) Common activity structure in the research-design process

The analysis of results, presented in chapter 5, supports outlining a general process underlying the conduction of studies that aim at supporting design endeavors in the areas of comfort, pleasure and cognitive engineering. Activity theory enables the decomposition of this process, considering the levels of activity, action and operations. The process is schematically presented in Figure 9 together with Table 20, which develops on the meaning of the terms used in the Figure. The process springs from a subjective hypothetical understanding attained from the exploration made in the areas of comfort, pleasure and cognitive engineering.



Dashed arrows represent an interaction at the same level, the double headed arrows are used to represent feedback between levels.

***Figure 9** – Schematic presentation of the application of activity theory to a three level breakdown of the process of designing Human Factors quality. This figure is complemented with Table 20.*

***Table 20** – Explicitation of motive (need), activity, goals, actions, instrumental conditions and operations depicted in Figure 9.*

<table>
<tr><th>Level of analysis</th><th>Goal /consequence</th><th>Activity</th><th>Constraints guiding interaction between elements of the activity structure</th></tr>
<tr><td>Activity level (Why?)</td><td>Motive (need) – Designing to meet human needs (through the approaches of relief of pain and addition of gain)</td><td>Activity – Designing functional / usable / pleasurable technology for humans to perform tasks</td><td rowspan="3">Prior to the conduction of actions 1a or 1b it is necessary to consider the task setting (purpose of task, the level of novelty of the task in a context, the level of complexity of the environment, the level of safety criticality of the environment) delivering an understanding of the level of importance of physical, cognitive, emotional, sociological, ideological and performance adequateness of the task.

Actions 1a and 1b (leading to operations 1a and or 1b) can both take place in a design problem, or only one of them, depending on the level of development of the theoretical structures (knowledge base) and the degree of novelty of the field / product / task relationship (whether the context of application is new or it is a redesign of an existing and documented application).

Actions 2a or 2b are carried out in sequence to actions 1a or 1b.
The choice between actions 2a and 2b (leading to operations 2a or 2b) is controlled by the levels of domain complexity and domain safety criticality.

The overall feedback between the lower and higher levels of the activity structure represents the enrichening of theory or knowledge bases</td></tr>
<tr><td>Action level (What?)</td><td>Goal 1 – Understanding and satisfying human needs (Physical, Psychological, Sociological, Ideological and Performance)

Goal 2 –
Check if needs have been satisfied (using evaluation methods)</td><td>Action 1a – Generate design seeds (departing from a practice-centered perspective generating hypotheses)
Action 1b – Perform principle driven design (requirements are delivered by theory)

Action 2a – Perform evaluation of design prototype (fielded and / or simulated)
Action 2b – Predict outcomes (based on application domain knowledge or across domains reported in the knowledge base)</td></tr>
<tr><td>Operation level (How?)</td><td>Instrumental conditions –
prototype (product) properties, human properties</td><td>Operation 1a – Transfer experiential properties (requirements) into formal product / system properties (using existing knowledge)
Operation 1b – Transfer experiential properties (requirements) into formal product / system properties (based on hypotheses)

Operation 2a – Measure / assess response for the human (in terms of experiential properties) and the task
Operation 2b – Predict the response concerning human aspects and task performance</td></tr>
</table>

The following Figures (10 and 11, together with Tables 21 and 22, respectively – these Tables are a repetition of Table 20 in a smaller font, and with highlighting of some parts, in accordance with the Figures) demonstrate which branches of the process described in Figure 9 and in Table 20 were followed in the empirical studies reported in appended articles I, II and VI. These studies deal with the design and evaluation of a particular product / system. Study V does not focus on the design of a particular product or system, but it aims at empirically verifying theory from which pleasure with products constructs are derived. It embeds actions that can be seen to satisfy goal 1 and goal 2. The empirical part of study IV is small, but the questionnaire is deemed as contributing to the satisfaction of goal 1, focusing on automobile use and automobile seats. Study III, has no empirical content per se, nor does it deal with a particular design case, although it exposes achievements that theory has so far attained and which can be used in carrying out action 1a and operations 1a and 1b in what concerns seat comfort.

Studies I and II (Figure 10 and Table 21) portray action 1b (principle driven design based on theory and hypotheses) and action 2a (performing evaluation of design prototypes in both a simulated environment and a fielded environment). Operations 1a and 1b were carried out for both studies I and II since the transfer of desired experiential properties into formal product properties was based on both existing knowledge and on formulated hypotheses. In terms of evaluation of the existing design, the human responses were measured and subjectively assessed (operation 2a).

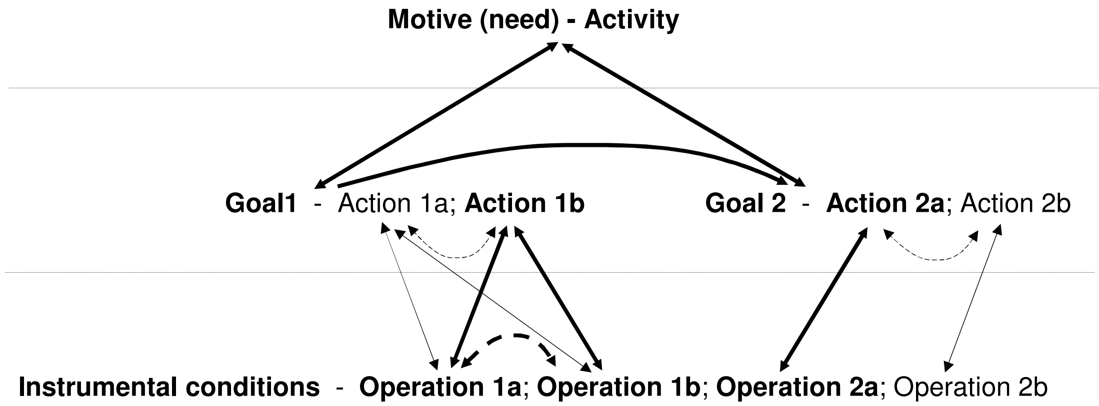


***Figure 10** – Depiction of the process possible to be used in designing Human Factors quality with highlighting of the parts used in studies I and II.*

***Table 21** – Highlighting of motive (need), activity, goals, actions, instrumental conditions and operations in agreement with Figure 10.*

Level of analysis	Goal /consequence	Activity	Constraints guiding interaction between elements of the activity structure
Activity level (Why?)	**Motive (need) – Designing to meet human needs (through the approaches of relief of pain and addition of gain)**	**Activity – Designing functional / usable / pleasurable technology for humans to perform tasks**	Prior to the conduction of actions 1a or 1b it is necessary to consider the task setting (purpose of task, the level of novelty of the task in a context, the level of complexity of the environment, the level of safety criticality of the environment) delivering an understanding of the level of importance of physical, cognitive, emotional, sociological, ideological and performance adequateness of the task. Actions 1a and 1b (leading to operations 1a and or 1b) can both take place in a design problem, or only one of them, depending on the level of development of the theoretical structures (knowledge base) and the degree of novelty of the field / product / task relationship (whether the context of application is new or it is a redesign of an existing and documented application). Actions 2a or 2b are carried out in sequence to actions 1a or 1b. The choice between actions 2a and 2b (leading to operations 2a or 2b) is controlled by the levels of domain complexity and domain safety criticality. The overall feedback between the lower and higher levels of the activity structure represents the enrichening of theory or knowledge bases
Action level (What?)	**Goal 1 – Understanding and satisfying human needs (Physical, Psychological, Sociological, Ideological and Performance)** **Goal 2 – Check if needs have been satisfied (using evaluation methods)**	Action 1a – Generate design seeds (departing from a practice-centered perspective generating hypotheses) **Action 1b – Perform principle driven design (requirements are delivered by theory)** **Action 2a – Perform evaluation of design prototype (fielded and / or simulated)** Action 2b – Predict outcomes (based on application domain knowledge or across domains reported in the knowledge base)	
Operation level (How?)	**Instrumental conditions – prototype (product) properties, human properties**	**Operation 1a – Transfer experiential properties (requirements) into formal product / system properties (using existing knowledge)** **Operation 1b – Transfer experiential properties (requirements) into formal product / system properties (based on hypotheses)** **Operation 2a – Measure / assess response for the human (in terms of experiential properties) and the task** Operation 2b – Predict the response concerning human aspects and task performance	

Study VI (Figure 11 and Table 22) embeds the carrying out of action 1a leading to the derivation of design seeds to improve the next generation of the system studied. These design seeds are derived from hypotheses about what would be useful, hence recurring to operation 1b. It also portrays actions 2a and 2b (and hence operations 2a and 2b) since there is a fielded evaluation of the existing design (action 2a leading to operation 2a), asides with a prior prediction of its impact on the joint cognitive work system (action 2b leading to operation 2b).

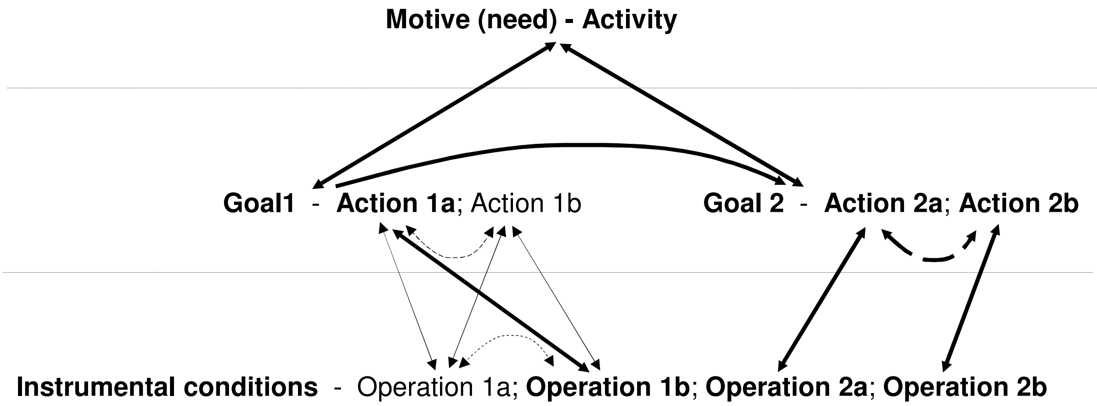


Figure 11 *– Depiction of the process possible to be used in designing Human Factors quality with highlighting of the parts used in study VI.*

Table 22 *– Highlighting of motive (need), activity, goals, actions, instrumental conditions and operations in agreement with Figure 11.*

Level of analysis	Goal /consequence	Activity	Constraints guiding interaction between elements of the activity structure
Activity level (Why?)	**Motive (need) – Designing to meet human needs (through the approaches of relief of pain and addition of gain)**	**Activity – Designing functional / usable / pleasurable technology for humans to perform tasks**	Prior to the conduction of actions 1a or 1b it is necessary to consider the task setting (purpose of task, the level of novelty of the task in a context, the level of complexity of the environment, the level of safety criticality of the environment) delivering an understanding of the level of importance of physical, cognitive, emotional, sociological, ideological and performance adequateness of the task. Actions 1a and 1b (leading to operations 1a and or 1b) can both take place in a design problem, or only one of them, depending on the level of development of the theoretical structures (knowledge base) and the degree of novelty of the field / product / task relationship (whether the context of application is new or it is a redesign of an existing and documented application). Actions 2a or 2b are carried out in sequence to actions 1a or 1b. The choice between actions 2a and 2b (leading to operations 2a or 2b) is controlled by the levels of domain complexity and domain safety criticality. The overall feedback between the lower and higher levels of the activity structure represents the enrichening of theory or knowledge bases
Action level (What?)	**Goal 1 – Understanding and satisfying human needs (Physical, Psychological, Sociological, Ideological and Performance)** **Goal 2 –** **Check if needs have been satisfied (using evaluation methods)**	**Action 1a – Generate design seeds (departing from a practice-centered perspective generating hypotheses)** Action 1b – Perform principle driven design (requirements are delivered by theory) **Action 2a – Perform evaluation of design prototype (fielded and / or simulated)** **Action 2b – Predict outcomes (based on application domain knowledge or across domains reported in the knowledge base)**	
Operation level (How?)	**Instrumental conditions – prototype (product) properties, human properties**	Operation 1a – Transfer experiential properties (requirements) into formal product / system properties (using existing knowledge) **Operation 1b – Transfer experiential properties (requirements) into formal product / system properties (based on hypotheses)** **Operation 2a – Measure / assess response for the human (in terms of experiential properties) and the task** **Operation 2b – Predict the response concerning human aspects and task performance**	

The applicability of this activity structure of the process of designing Human Factors quality to studies I, II and VI, enables suggesting that this framework captures their essential stages. The framework combines actions and operations springing from a theory breakdown approach and a practice centered approach. For studies I and II, action 1a, action 2b and operation 2b were not carried out. For study VI, action 1b and operation 1a were not carried out. However, both goal 1 and goal 2 apply to studies I and II and to study VI. Additionally, at least one action and one operation of those depicted in the framework was applicable for studies I and II and for study VI. All of the elements considered in the framework were applicable for at least one of the studies of those considered. The consideration of the framework's general applicability should be tested through a wider spectrum of empirical studies. These tests would reinforce or weaken the proof of the framework's ability as a depiction of the possible and alternative paths to follow in conducting HFE quality research-design studies aimed at supporting engineering design.

(6.3.2) Identification of operatives and derivation of measurable variables

The underlying activity structure within research-design cases can be made explicit with the use of Karlsson's (1996) framework. The applicability of this framework for research-design cases in different domains adds another thread of compatibility. Included in the present section is the application of this framework to the studies on seat comfort (Figure 12) and on cognitive engineering (Figure 13).

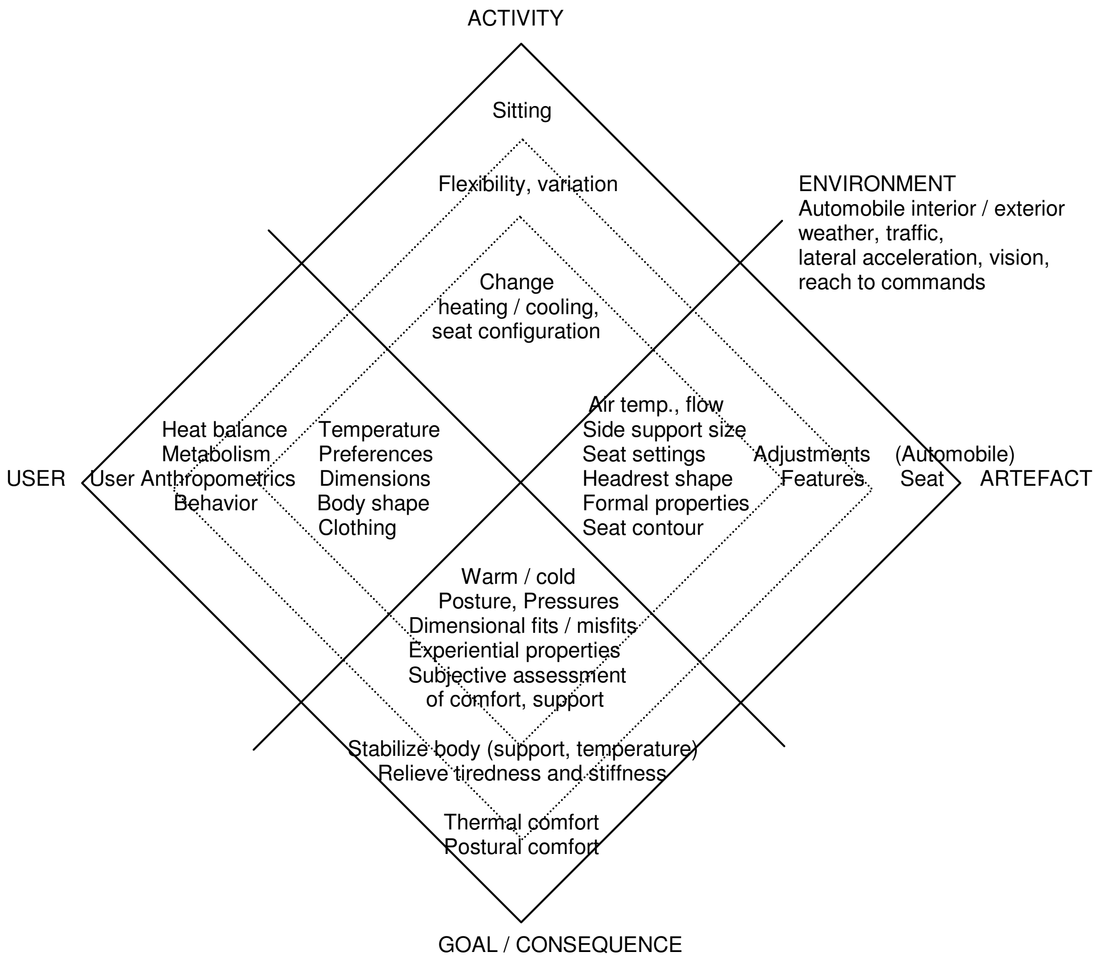


Figure 12 *– Application of Karlsson's (1996) activity theory framework to studies on automobile seat comfort (studies I and II), and considering thermal comfort.*

The elements included in Figure 12 are a mixture of those resulting from a derivative process of breaking down theory (e.g. thermal comfort) and others resulting from the design context (e.g. side support size). The user-artefact relation is ruled by the goal that is to be achieved with the activity in an environment, which poses further constraints on the relation besides the user and artefact properties. The elements depicted in the framework, at its lower level of analysis (user properties – artefact properties – operation – fits/misfits), are operatives that are possible of being measured.

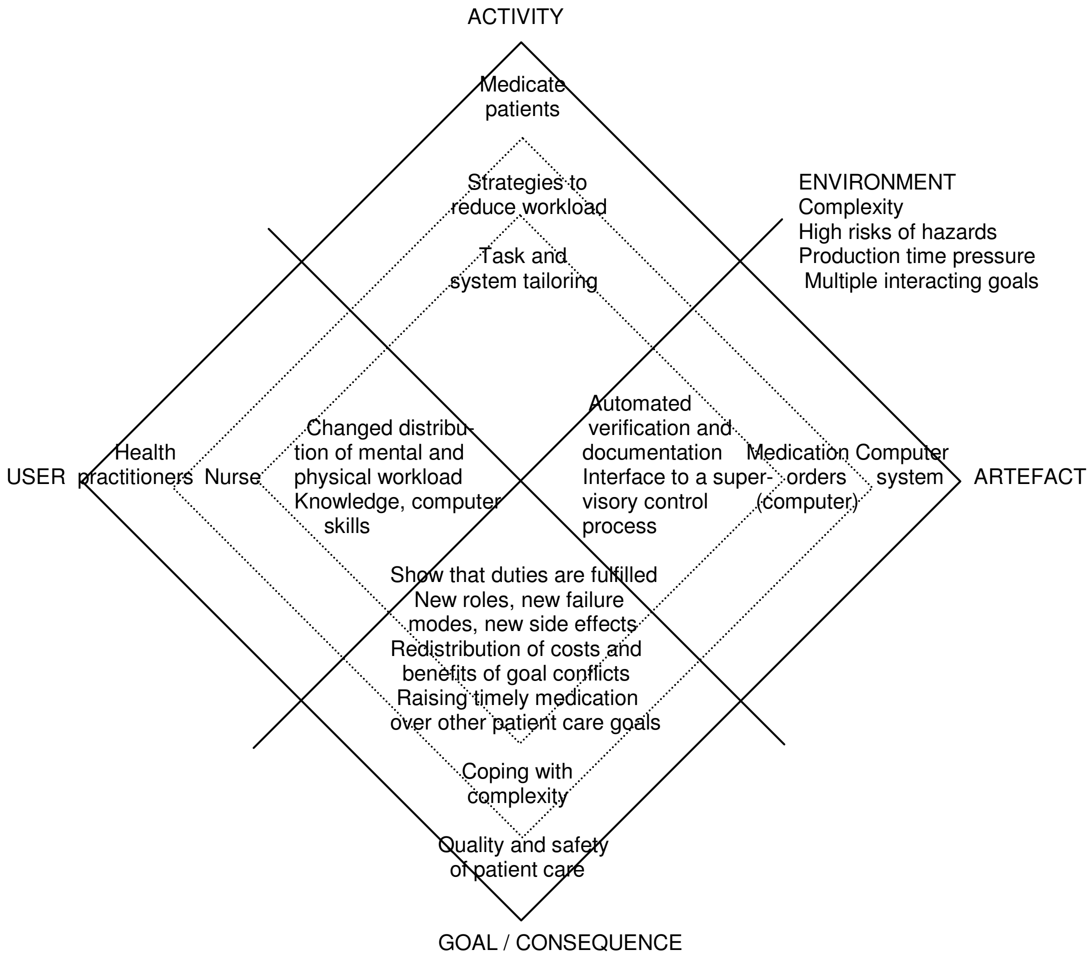


Figure 13 *– Application of Karlsson's (1996) activity theory framework to the study on cognitive engineering (study VI).*

The conduction of study VI relied essentially on observations guided with patterns and process tracing of medication administration before and after the introduction of the technological change focused. At the lower level of analysis of the framework are the elements of transformation and adaptation instantiated by the technological change focused in the study. Although this study did not collect data based on a derivative breakdown process of theory, the patterns of transformation and adaptation were initially predicted, based on previous research, and later verified through the observations. Hence, although these are not formally considered as operatives, they were used in guiding the data collection process. In this case Karlsson's (1996) activity theory framework is beneficial as a means of separating the elements of transformation and adaptation and classifying these according to the dimensions of the framework (Figure 13). This can be advantageous in the process of guiding observations, in a similar manner as the framework can be used to identify operatives and measurable variables for seat comfort (Figure 12).

The two examples of application of activity theory essayed in this section demonstrate the power of activity theory in assisting the identification of measurable variables from the lower level of analysis of Karlsson's framework. This conclusion reinforces the relevance of activity theory as a means of analysis in studies aimed at designing Human Factors quality. Its successful application to my empirical studies on seat comfort and cognitive engineering suggests yet another thread of compatibility between the two areas.

(6.4) Conclusive discussion of the level of compatibility reached

This chapter contains an outline of several threads of compatibility between cognitive engineering, pleasure and comfort. The pains and gains perspective discussed in the first section of the chapter enabled relatively positioning the three areas in relation to two dimensions: design goal (relieving pain and adding gain) and human aspects considered (physical, psychological, sociological, ideological and performance). A third dimension was introduced in the analysis through the consideration of the present focus of the three areas and of their aims identified in definitions of the areas in terms of the pains and gains perspective. These three dimensions are depicted in Table 23.

Table 23 *– Comfort, Pleasure and Cognitive Engineering positioned in relation to three dimensions considered in the analysis of compatibility: goal in design, human aspects considered and present focuses versus definition-wise focuses.*

		Human aspects				
		Performance	Psychological	Physical	Ideological	Sociological
Design goals	Adding gain	Cognitive Engineering (**D**)	Comfort (**D**) Cognitive Engineering (**D**) Pleasure (**D**,**P**)	Comfort (**D**) Pleasure (**D**,**P**)	Pleasure (**D**,**P**)	Pleasure (**D**,**P**)
	Relieving pain	Cognitive Engineering (**D**,**P**)	Comfort (**D**) Cognitive Engineering (**D**,**P**) Pleasure (**D**)	Comfort (**D**,**P**) Pleasure (**D**)	Pleasure (**D**)	Pleasure (**D**)

D – Positioning resulting from high level definitions and postulates
P – Positioning resulting from the areas' focus in practice as explicit in research literature
Verbal example – comfort: Definition-wise comfort concerns both the design goals of adding gain and relieving pain for the psychological and physical human aspects; in practice it only concerns the design goal of relieving pain for the physical human aspect.

The analyses leading to the formulation of Table 23 enable suggesting that the methods of comfort (hereby confounded with the term ‘physical engineering’ in an analogy with cognitive engineering) and cognitive engineering are methods that can be used to attain the goals of comfort (relief of pain) and pleasure (addition of gain). The similarities observed in practice and shown in Table 23 are not completely supported by the analysis of commonalities at the subconcept level carried out between comfort (physical engineering) and (physiological) pleasure and cognitive engineering and (psychological) pleasure. There is only a partial interception between the two pairs, which may result from the different design goals pursued in practice (pleasure pursuing addition of gain, while the other two pursue relief of pain). Moreover, as a discipline, pleasure resorts to traditional ergonomics, comfort (physical engineering) and cognitive engineering for attaining the design goal of relief of pain.

Research question R.3 was framed as “can activity theory be used as a means of structuring concepts – knowledge – data in an integrated way for the handling of and management of pleasure, cognitive engineering and comfort?”. Activity theory was used to outline the general process of research-design applicable to studies I, II and VI, dealing with the evaluation and eliciting of information for design of a particular product / system. This process may be applicable to a wider range of studies meant to design Human Factors and Ergonomics quality, needing a wider spectrum of empirical cases for its verification. Additionally, Karlsson’s (1996) activity theory framework was applied to studies I, II and VI, putting the operatives (comfort) and patterns of transformation and adaptation (cognitive engineering) into the context of user-activity-artefact-goal. The applicability of MariAnne Karlsson’s framework in both cases supports the consideration of an integrating feature across those studies: the underlying activity structure of human action.

A partial compatibilization between comfort, pleasure and cognitive engineering has been attained. This compatibilization encompasses the sharing of design goals (comfort and pleasure), the interceptions between human aspects focused in the three areas, some partial commonalities at the subconcepts levels and a common activity structure underlying both the conduction of research-design processes and the interactions between user-activity-artefact-goal in any particular study (of those considered). Even if the compatibilization attempts essayed in this chapter were partially successful, their empirical basis is strictly small. These attempts would hence benefit from the consideration of a wider spectrum of empirical cases.

The assessment of compatibilization made is not complete since integration at the level of operatives was not pursued, neither in what concerns data collection methods, or product development representation formats. The theory breakdown procedure outlined in chapter 2 and applied in chapter 5 did not yield operatives for pleasure (due to a preliminary definition of theory and lack of application). The assessment of model validity based on literature for cognitive engineering showed that the discipline is challenged to develop its own theory. In so doing it intends detaching itself from the straightforward application of concepts from experimental psychology. Hence it partially rejects the concepts considered in cognition in human-technology interaction. Additionally, (universal) product development directives are not deemed pursuable in the area of cognitive engineering due to the problems of assuring their validity in complex and changing fields of practice.

Chapter 7

Objectives:

- To condense the conclusions of the dissertation.
- To summarize the answers to the research questions.
- To summarize concluding remarks dispersed throughout chapters 5 and 6.
- To suggest areas for future research.

(7) Conclusions

An overall aim of studying and assessing comfort, pleasure and cognitive engineering for relevance in engineering design processes and working towards finding or identifying an integrated theoretical structure has been pursued. From this overall aim, three operative aims were formulated to direct the analyses, with three research questions springing from those aims. These questions and a summary of the answers that were brought forward in the dissertation are summarily presented below. Other conclusive remarks, springing from the results and the compatibility analyses essayed in the dissertation, are presented in the following sub-section. A number of issues which would benefit from consideration in future research are listed in the last sub-section.

> R.1 – Do present theory and methods yield workable results for assessing model validity and directing product development?

In all three areas model validation is attained, although only partially. For comfort there are insufficiencies of the scope covered by models and incomplete transformation of operatives. For pleasure, model validation is commencing, but theory is underdeveloped for the illusive aspect of emotions. For cognitive engineering, model validation is attained for the level of usability. For the levels of understanding and usefulness[18], the field is challenged to develop its own theory, detaching itself from the mother discipline of cognitive psychology. In all three areas product development directives are also attained, but with some limitations. For comfort, these directives are tentative and not definitive. For pleasure, the directives attained derive from other areas encompassed in the pleasure with products approach (such as usability or comfort), although emotional outputs are not attained in these. In the pleasure area, Kansei Engineering has managed to advance in directing product development, but it is a less holistic approach than pleasure with products. For cognitive engineering, the direction of product development is attained, but debate exists around whether principle design is possible in a changing world.

> R.2 – Are data collection methods and representation formats adequate for communicating to users and designers?

The degree of completeness of the assessment of data collection methods and representation formats made varies for the three areas, since it was based on the empirical studies appended to the dissertation. For comfort, the coverage of data collection methods was almost complete (although electromyography and cross-modality matches were missing), and the same degree of completeness was attained with representation formats of product development oriented information. For pleasure, the set of data collection methods covered was incomplete, and was only concerned with the stage of understanding of users. The stage of product development directives was not reached, and hence representation formats were not assessed. For cognitive engineering there was also an incomplete coverage of data collection

[18] The concepts of usability, usefulness and understanding are used by Woods (2000) as a three level dimension of the degree of materialization of prototypes.

methods, focusing on the stage of understanding, which enables suggesting what would be useful. Consequently, product development oriented information was not assessed for the level of usability. Additionally, the methods used in pursuing principle driven design were not assessed for cognitive engineering.

In terms of the adequacy of the data collection methods for communicating with users, it was found, for both comfort and pleasure, that subjective data might be biased due to different interpretations of concepts arising between subjects and researchers. Hence, the problems of verbal understanding and motivation must be considered in collecting and using subjective assessments as an input to design. Moreover, the restriction on a more verbally eloquent sub-group of society, although at the risk of introducing systematic biases, is a means of increasing the possibility of users attaining understanding. For the data collection methods covered from the cognitive engineering side, the user is not challenged with understanding theoretical concepts. In terms of the representation formats' communicability to designers, it was found for comfort that it is dependent on the understanding of the limitations of the data presented (concerning validity and scope of applicability). For pleasure, it is assumed that the level of understanding attained with users is equal to that which would be attained with designers. For cognitive engineering, it is considered that designers implicitly understand the design seeds formulated at the level of usefulness, since these are expressed in development terms.

R.3 – Can activity theory be used as a means of structuring concepts – knowledge – data in an integrated way for the handling and management of pleasure, cognitive engineering and comfort?

A partial compatibilization between comfort, pleasure and cognitive engineering was attained. This compatibilization encompasses the sharing of design goals (eliminating discomfort and achieving pleasure), the interceptions between human aspects focused in the three areas, some partial commonalities at the subconcepts levels and a common activity structure underlying both the conduction of research-design processes and the interactions between user-activity-artefact-goal in any particular study (of those considered).

Activity theory was used to outline the general process of research-design applicable to appended studies I, II and VI, dealing with the evaluation and eliciting of information for design of a particular product / system. This process may be applicable to a wider range of studies meant to design Human Factors and Ergonomics quality, needing a wider spectrum of empirical cases for its verification. It is also suggested that this process is applicable for designing Human Factors and Ergonomics quality wherever theory gaps are found.

Additionally, Karlsson's (1996) activity theory framework was applied to studies I, II and VI, putting the operatives (comfort) and patterns of transformation and adaptation (cognitive engineering) into the context of user-activity-artefact-goal. This showed, for both areas, that it enables deriving measurable variables and identifying operatives from the operation level of the framework, once the elements relevant to the design problem are classified according to the activity-user-goal-artefact categories. The applicability of MariAnne Karlsson's framework in both cases supports the consideration of an integrating feature across those studies: the underlying activity structure of human action. Even if the compatibilization attempts essayed in this work were partially successful, their empirical basis is strictly small. These attempts would hence benefit from the consideration of a wider spectrum of empirical cases.

(7.1) Concluding remarks

The results of the assessments of model validity and maturity based on literature and empirical studies have shown that universal design methods in comfort, pleasure and cognitive engineering for direct application by engineering design are presently not available, with an exception found for thermal comfort. Predictability in seat comfort, cognitive engineering and pleasure with products has not yet been achieved (except for thermal comfort). Attaining predictability is however deemed feasible within certain sub-areas. For comfort (for which holistic models of seat discomfort have so far not been developed) this includes physiological and physical models of discomfort in sitting. For pleasure this includes modelling the transfer from experiential product properties into formal product properties for groups of society and culture, using an approach similar to Kansei Engineering. For cognitive engineering this includes the prediction of the impact of change on joint cognitive systems, using a research method based on abstracted patterns of transformation and adaptation from several domains.

To aim at predictive models and relationships between operatives is a common approach for advancing in science. This has a parallel in the top down-approach used in tackling engineering design problems (departing from theory and pursuing principle driven design) (Hubka & Eder, 1996). However, it is shown that this approach is not always practical, since several problems can arise in implementing it.

In the case of cognitive engineering, there is a fair amount of psychologists' originated data describing mental processes, which lacks predictive power when applied to an engineering design problem. As a solution to this problem, a complementarity perspective has risen within the field of cognitive engineering (Woods, 1999). This perspective departs from the stance that new technology is a kind of experimental investigation into fields of ongoing activity, where the experimenter functions as designer and the designer functions as experimenter. This stands in contrast to a widely accepted perspective – imposing requirements on design. However, the types of products focused in each of these perspectives have very different characters. While the complementarity perspective springs from the design of systems based on the computer medium, the other one springs from the mechanical design of hardware. It is hence envisaged that both perspectives, with their implicitly alternative and apparently conflicting approaches, are important, but should be used for tackling product (or system) design problems of different characters, in agreement with the type of problems from which they spring.

For seat comfort, some of the common practice methods used to operationalize subconcepts lack validity and have only become accepted because of their repeated use. Moreover, it was shown that the transformation process from theoretical structures, through subconcepts, to operatives and leading to measured results, used in the dissertation, is effective as an assessment tool of the quality of those transformations.

In general, for the three areas, theoretical structures are not complete, and some of their sub-constituents are illusive or not constant (given that the world is changing). Such parts are hence not worthwhile pursuing for attaining engineering systematization, since their predictability is not deemed attainable. This situation hence precludes the development of a complete integrated comfort, pleasure and cognitive engineering design method for off-the-shelf application by engineering design. In these areas, principle driven design is not totally feasible. Hence, design problems are thus better tackled using a combined process of research and design, which recurs to the existing theoretical structures but also to context based research intended to fill in the gaps of theory. This process is characterized by understanding what would be useful by unveiling and precising the human requirements on the technology design problem at hand beyond those that are already generally accepted in the field of practice as viable and valid product development directives. The process resorts to the use of prototypes as tools for discovery, embedding hypotheses about what would be useful to advance in the design problem. In this process, the vehicles for the assessment of the prototypes (hence hypotheses) in terms of higher goals of the three areas (pleasant states) rely on 'subjective' assessments, since 'objective' measures are not presently transferable into the subjective ratings (given that the theoretical structures are not able to deliver predictive models). Finally, the process is characterized by the need for iterations to advance in design problems, with the fielding of products in a system of people, technology and work (or tasks) and (or) recurring to assessments by subjects from use or trial of the product (prototype).

Despite the fact that research-like approaches are necessary to complete the design process, the justification for the creation of a single human factors design approach still holds. However, presently it is only feasible as a framework to assist in guiding or directing the research parts of the combined research-design process intended for specification of human requirements and for attaining product or system properties. A tentative framework with such character was delivered in respect to research question R.3, in the form of a framework developed with the support of activity theory's three level breakdown.

A moderate level of compatibility between the theoretical structures of comfort, pleasure and cognitive engineering was attained, with intersections found between the three areas in terms of design goals (relieving pain and adding gains) and human aspects considered. There is a marked difference between what is defined into comfort, pleasure and cognitive engineering and what is actually worked with, the former being broader in scope. While pleasure pursues in practice the goal of adding gains, comfort and cognitive engineering struggle in practice with relieving pain and minimizing loss. The psychological human aspect is common to all three areas, although it is not pursued in practice in comfort, nor does cognitive engineering pursue in practice the aspect of emotions, as pleasure does. Commonalities were also found between comfort and pleasure (in what concerns physical aspects) and between cognitive engineering and pleasure (in what concerns psychological aspects) at the level of subconcepts. However, these sets of commonalities only cover part of the subconcepts considered in each of the areas.

In what concerns operative aims and research questions, these were pursued and answered with different levels of completeness and definiteness. A number of issues remain to be assessed, which would benefit from consideration in future research, as suggested in the following section.

(7.2) Future research

Below are some examples of issues that would benefit from further investigation:

- Developing models of physiological and physical discomfort applied to sitting.
- Modelling the transfer from experiential product properties into formal product properties for cultural groups or niches of society, to be used as a resource for designing pleasurable products.
- Developing the predictability of the impact of change on joint cognitive systems through the collection of patterns abstracted from several domains of practice.
- Investigating the possibilities of developing transfer functions depicting relationships between results pertaining to seat comfort collected in laboratory and in fielded experiments.
- Assessing more completely data collection methods and representation formats used in pleasure with products through studies that aim at specific designs, aiming at compatibilizing the methods with cognitive engineering and comfort.
- Assessing more completely data collection methods and representation formats used in cognitive engineering through studies that bridge the three levels of design seeds / prototype / product materialization: understanding, usefulness and usability, aiming at compatibilizing the methods with pleasure with products.
- Testing the applicability of the research-design process developed on the basis of activity theory to a wider spectrum of empirical cases, including specific Human Factors quality design cases in pleasure with products, traditional ergonomics, cognitive engineering and comfort.
- Demonstrating the underlying activity structure of activity-goal-user-artefact within a wider spectrum of Human Factors quality design cases in the areas of comfort, pleasure and cognitive engineering, reinforcing this thread of compatibility within the three areas.
- Pursuing integration and compatibilization attempts as theoretical structures become more complete and more thoroughly broken down, aiming at a unified approach to designing Human Factors and Ergonomics quality from the perspective of engineering design.

References

The list of references includes:

- references from the summaries,
- references from the main text of the dissertation, and
- references from Appendices A, B and C.

(8) References

Åkerblom, B, 1954. Chairs and sitting, in Floyd, W.F., Welford, A.T. (eds.) Human Factors in Equipment Design, H. K. Lewis & Co. Ltd., London, pp. 29-35.

Andreasen, M.M., Hein, L. (1987). Integrated Product Development. London: IFS Publications / Springer-Verlag.

Beach, D.P., Alvager, T.K.E. (1992). Handbook for Scientific and Technical Research. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Bergman, B., Klefsjö, B. (1994). Quality – from customer needs to customer satisfaction. Lund: Studentlliterature, 478 p.

Borg, G. (1982). A category scale with ratio properties for intermodal and interindividual comparisons, in H-G. Geissler, P. Petzold (eds.), H. Buffart, Yu. Zabrodin (co-eds.), Psychophysical judgement and the process of perception, pp.24-34, Berlin: VEB Deutscher Verlag der Wischenschaften.

Brown, O.J. (2000). Editorial: XIV Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Society: 'Ergonomics for the new millenium'. Ergonomics, 43(7), pp. 829-832.

Burns, A., Barret, R., Evans, P. (2000). Delighting customers through empathic design. Luleå University.

Corlett, E. N. and Bishop, R. P. (1976). A Technique for Assessing Postural Discomfort, Ergonomics, 19/2, pp. 175-182.

Corlett, E.N.; Clark, T.S. (1995) The ergonomics of workspaces and machines: a design manual. London, Taylor & Francis, 1995. 2nd ed. 128pp.

Dahlman, S. (2001). Personal communication.

Dahlman, S. (1990). Att hantera behov (in Swedish; To handle needs), In: Produktutveckling – Behov ovch krav. (Product development – needs and requirements), Department of Consumer Technology, Chalmers University of Technology, 1990, p. 42-55.

Dahlman, S. (1986). User requirements. A resource for the development of technical products. Doctoral thesis from Department of Consumer Technology, Chalmers University of Technology, Göteborg.

Derbaix, C.M., Pham, M.T. (1991). Affective reactions to consumption situations: a pilot investigation. Journal of Economic Psychology, 12, pp. 325-355.

Desmet, P.M.A., Hekkert, P. (2001). The basis of product emotions. in Pleasure with the use of products, ed. Patrick W. Jordan and William S. Green, London: Taylor and Francis.

Desmet, P.M.A., Tax, S.J.E.T., Overbeeke, C.J. (2000). Designing products with added emotional value; development and application of a 'research through design' approach. Delft University of Technology.

Desmet, P.M.A., Hekkert, P.P.M., Jacobs, J.J. (1999). When a car makes you smile: development and application of an instrument to measure product emotions. In S.J. Hoch, R.J. Meyer (eds.) Advances in Consumer Research, vol. XXVII.

Donchin, Y., Cotev, S., Gopher, D., Olin, M., Badihi, Y., Biesky, M., Sprung, C.L., Pizov, R., Cotev, S. (1995). A look into the nature and causes of human errors in the intensive care unit. Critical care medicine 22(2).

Dowelll, J.; Long, J. (1998). Conception of the Cognitive Engineering Design Problem, Ergonomics, 41 (2), pp. 126-139.

Ebe, K., Griffin, M.J. (2000). Qualitative prediction of overall seat discomfort. Ergonomics, 43(6), pp. 791-806.

Engeström, Y. (1999). Activity theory and individual and social transformation. In Engeström, Y., Miettinen, R., Punamäki,R.-L. (eds.) Perspectives on activity theory – Learning in doing: social, cognitive and computational perspectives. Cambridge, UK: Cambridge University Press.

Engeström, Y., Miettinen, R., Punamäki, R.-L. (eds.) (1999). Perspectives on activity theory – Learning in doing: social, cognitive and computational perspectives. Cambridge, UK: Cambridge University Press.

Fanger, P.O. (1972). Thermal Comfort: Analysis and applications in environmental engineering. McGraw-Hill, New York.

Fritz, C. (1989). Feleffektanalys (FMEA) för svensk industri – En introduktion för mindre och medelstora företag (In Swedish - Failure Mode and Effects Analysis for Swedish Industry – an introduction for small and medium companies). IVF- resultat 89632. Göteborg: IVF.

Fulton, J. (1993), "Physiology and design new human factors," American Center for Design Journal, 7(1).

Furuhjelm, J. (2000). Incorporating the end-of-life aspect into product development – analysis and a systematic approach. Doctoral dissertation. Department of Mechanical Engineering. Linköping University, Sweden.

Garmer, K. (2002). Doctoral dissertation. Department of Human Factors Engineering, Chalmers University of Technology, Göteborg, Sweden.

Glaser, B.G., Strauss, A.L. (1967). The discovery of grounded theory: Strategies for qualitative research, New York: Aldine Publishing Company.

Goonetilleke, R.S. (1998). Designing to minimize discomfort. Ergonomics in Design, 6(3), 12-19.

Grandjean, E. (1988). Fitting the task to the man – as textbook of occupational ergonomics. London: Taylor & Francis.

Green, D.M. & Swets, J.A. (1966). Signal detection theory and psychophysics. New York: Wiley (Reprinted 1988, Los Altos, California: Peninsula).

Gyi, D.E. and Porter, J.M. (1999). Interface pressure and the prediction of car seat discomfort, Applied Ergonomics, 30, pp. 99-107.

Hattori, M., Inoue, H., Numora, N. (1996). Design strategies for ecologically conscious products. Proceedings of CIRP 3rd International Seminar on Life cycle engineering, Zurich.

Hauge-Nilsen, A.-L. and Flyte, M. G. (2001), “Understanding attributes that contribute to pleasure in product use,” in Pleasure with the use of products, ed. Patrick W. Jordan and William S. Green, London: Taylor and Francis.

Heidegger, M. (1992). Varat och tiden. (Being and time), Lund: Doxa Press.

Hendrick, Hal W. (1995) Future directions in macroergonomics, Ergonomics, Vol. 38 (11), pp. 1617-1624.

Hertzberg, H.T.E. (1972). The human buttock in sitting: Pressures, patterns and palliatives. American Automobile Transactions, No. 72, pp. 39-47.

HMS-CIS: Center for Human Modeling & Simulation, Department of Computer & Information Science, University of Pennsylvania (1997). Jack™ - The Human Modelling and Simulation System.
http://www.cis.upenn.edu/~hms/jack/flyer_510.html

Hockey, G.R.J., Westerman, S.J. (1998). Advancing human factors involvement in engineering design: a bridge not far enough? Ergonomics 41(2), pp. 147-149.

Holbrook, M.B. (1982). The experiential aspects of consumption: consumer phantasies, feelings and fun. Journal of Consumer Research, 9, pp. 132-140.

Hollnagel, E.; Woods, D.D. (2001). Cognitive Systems Engineering, In W. Karwowski (ed.) International Encyclopedia of Ergonomics and Human Factors, London and New York: Taylor & Francis, pp. 1768-1770.

Huang, G.Q., Mak, K.L. (1997). Developing a Generic Design for X Shell. Journal of Engineering Design. 8(3), pp. 251-260.

Hubka, V., Eder, E. (1992). Enfürung in die Kostruktionswissenschaft. Springer Verlag, Berlin (In German).

Hubka, V. and Eder, W. E. (1996). Design Science: introduction to the needs, scope and organization of engineering design knowledge, 2nd Rev. ed., London: Springer-Verlag, 251 p.

Hydén, L.-C. (1981). Psykologi och materialism: Introduktion till den materialistika psykologin, Stockholm: Prisma.

IDEO (2000). Advertisement brochure. IDEO, Palo Alto, California.

IEA – International Ergonomics Association’s Executive Council (2000). IEA Definitions of Ergonomics. In W. Karwowski (ed.) International Encyclopedia of Ergonomics and Human Factors, London and New York: Taylor & Francis, pp. 102.

ISO/DIS 9000:2000, “Quality Management Systems – Fundamentals and vocabulary”, 2000.

Jordan, P.W. (2000). Designing pleasurable products – an introduction to the new human factors. London: Taylor & Francis, 216 p.

Jordan, P.W., 1997. “A vision for the future of human factors”, in K. Brookhuis et al. (eds.), Proceedings of the HFES Europe Chapter Annual Meeting 1996, (University of Groningen Centre for Environmental and Traffic Psychology), The Netherlands, pp.179-194.

Jordan, P. W. (1996), “Displeasure and how to avoid it,” in Contemporary Ergonomics 1996, ed. S. Robertson, London: Taylor & Francis.

Jordan, P.W.; Macdonald, A.S. (1998). Pleasure and product semantics. In: Contemporary Ergonomics 1998. Ed. by M. A. Hanson. London, Taylor and Francis. 609pp., pp264-268.

Jordan, P.W., Servaes, M. (1995). Pleasure in product use: beyond usability. In S. Robertson (ed.) Contemporary Ergonomics 1995. London: Taylor & Francis.

Karlsson, I.C.M. (1996) User Requirements Elicitation – A framework for the study of the relation between user and artefact. Doctoral dissertation. Department of Consumer Technology, Chalmers University of Technology, Göteborg, Sweden.

Karwoski, W. (1996). IEA facts and background. Louisville, Kentucky. IEA Press, January 1996. 43 p.

Karwowski, W. Dzissah, J.(2000). Design and evaluation of system integration efforts for occupational & environmental safety and health, ergonomics and quality management. Paper presented at the Ergonomics in Quality Management conference of the Portuguese Ergonomics Association (APERGO), Costa da Caparica. 12p.

Kemp, J.A.M., Gelderen, T. van (1996). Co-discovery exploring: an informal method for iteratively defining consumer products. In P.W. Jordan, B. Thomas, B.A. Weedmeester, I.L. McClelland (eds.) Usability Evaluation in Industry, London: Taylor & Francis, pp. 139-146.

Kirwan, B. (1995). Human reliability assessment. In Wilson, John R.; Corlett, E. Nigel (eds.). Evaluation of human work; a practical ergonomics methodology. London: Taylor & Francis.

Kirwan, B.; Ainswort, L.K. (1992). A guide to task analysis. London: Taylor & Francis.

Klein, G. (1997). Applied Cognitive Task analysis.

Kuhn, T.S. (1962). The Structure of Scientific Revolutions. Chicago, Illinois: The University of Chicago Press, Third edition, 1996.

Lambie, T. (2001). Cognitive Engineering. In W. Karwowski (ed.) International Encyclopedia of Ergonomics and Human Factors, London and New York: Taylor & Francis, pp. 22-24.

Laurel, B. K. (1986). Interface as Mimesis. In Norman and Draper (eds.) User Centered System Design, Hillsdale, NJ: Erlbaum, pp.67-85.

Laville, A.. L'ergonomie (in French – Ergonomics). Paris. PUF Presses Universitaires de France, 1998. 6ème ed. cor. 128p.

Leont'ev, A.N. (1978). Activity, conciousness and personality. Englewood Cliffs: Prentice Hall.

Lewis, C.S. (1987). The four loves, Glasgow: Collins.

Lewis, C., Polson, P., Wharton, C., Rieman, J. (1990). Testing a walkthrough methodology for theory-based design of walk-up-and-use-interfaces. Proceedings ACM CHI90 Conference, (Seattle, Washington, April 1-5), pp. 235-242.

Liljegren, E. (2001). A Human Factors Approach for Medical Device Design. Thesis for the degree of licenciate of engineering, Department of Human Factors Engineering, Chalmers University of Technology, Göteborg.

Lundqvist, M. (1996) Organizing Product Development: Formalizing the Informal. Doctoral dissertation. Department of Work Organization and Operations Management. Chalmers University of Technology, Göteborg, Sweden.

MacDonald, A. S. (1988), “Developing a qualitative sense,” in Human Factors in Consumer Products, ed. N. Stanton, London: Taylor & Francis, 175-191.

Meerkamm, H. (1994). Design for X – A core area of design methodology. Journal of Engineering Design, 5(2), pp. 145-163.

Montgomery, D. C. (1991). Design and Analysis of Experiments. New York: John Wiley & Sons.

Montmollin, M. (1997). Vocabulaire de l’ergonomie (in French – Ergonomics vocabulary). Toulouse, Octares, 1997. 2ème ed. Ver. 287pp.

Moraes, A. (2000). Ergonomia: Arte, Ciência ou Tecnologia? (In Portuguese – Ergonomics: Art, Science or Technology?). In: Anais do I encontro Pan-Americano de Ergonomia e X congresso brasileiro de ergonomia. Rio de Janeiro, Abergo, 2000, CD-ROM.

Moray, N. (2000). Culture, politics and ergonomics. Ergonomics, 43(7), pp. 858-868.

Muckler, F.A. and Seven, S.A., 1992. Selecting Performance Measures: “Objective” versus “Subjective” Measurement, Human Factors, 34(4), pp. 441-455.

Nagamachi, M. (2000). Kansei Ergonomics as the advanced technology for product development. In D. Podgórski and W. Karwowski (eds.) Ergon-Axia 2000 – ergonomics and safety for global business quality and productivity. Warsaw: Central Institute for Labour Protection, pp. 39-44.

Nagamachi, M. (1997). Requirement identification of consumers’ needs in product design. In Proceedings of IEA’97, Helsinki: Finnish Institute of Occupational Health, pp. 231-233.

Nielsen, J. (1993). Usability Engineering. San Diego, California: Academic Press.

NIOSH: National Institute for Occupational Safety and Health (1981). Work Practices Guide for Manual Lifting. Cincinnati, Ohio: NIOSH.

Norman, D.A. (1993). Things that make us smart – defending human attributes in the age of the machine. New York: Addison-Wesley Publishing Company.

Norman, D.A. (1987). Cognitive Engineering ~ cognitive engineering. In Caroll (ed.) Interfacing through thought, Cambridge, Massachussets: MIT Press.

Norman, D. A. (1986). Cognitive Engineering, in D. A. Norman and S. W. Draper (eds.), User Centered System Design, Hillsdale, New Jersey: Erlbaum, pp. 31-61.

Noy, Ian (2000). IEA Presidential Address - Opening speech of the President of the IEA, XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Society, July 29- August 4, 2000. San Diego, California, USA.

Noyes, J., Littledale, R. (2001). Computer Playfulness , in Pleasure with the use of products, ed. Patrick W. Jordan and William S. Green, London: Taylor and Francis.

Örtengren, R. (1997) Ergonomics. In Brune D., Gerhardsson G., Crockford G.W. and D’Auria D. (eds.), The workplace. Vol. 1, pp.206-220. CIS, International Occupational Safety and Health Information Centre.

Pahl, G., Beitz, W. (1996). Engineering Design – A systematic approach, 2nd ed., London: Springer Verlag.

Park, S., Lee, Y., Nahm, Y., Lee, J., Kim, J. (1998). Seating Physical Characteristics and Subjective comfort: Design Considerations. SAE Technical Paper No. 980653.

Pheasant, S, (1996). Bodyspace, 2nd ed., Taylor & Francis, London.

Pheasant, S. (1991). Ergonomics, work and health. London, MacMillan, 1991. 358pp.

Popper, K.R. (1989). Epistemology without a knowing subject, in K. Popper, Objective Knowledge: An Evolutionary Approach, Clarendon Press, Oxford, pp. 106-152.

Pugh, S. (1990). Total design – Integrated methods for successful product engineering. Addison-Wesley Publishing Company.

Rasmussen, J., Pejtersen, A., Goldstein, L. (1994). Cognitive Systems Engineering. New York: John Wiley & Sons, Inc.

Reason, J. (1990). Human Error. New York: Cambridge University Press.

Reed, M.P., Saito, M., Kakishima, Y., Lee, N.S., Shneider, L.W, (1991). An investigation of driver discomfort and related seat design factors in extended duration driving. SAE Technical Paper No. 910117.

Reynolds, H. M., 1993. Automotive Seat Design for Seating Comfort, in Peacock, B. and Karkowski, W. (eds.), Automotive Ergonomics, Taylor & Francis, London.

Rhodin, P. (2001). Resurseffektivisering från ett brukarperspektiv. Licenciatuppsats, Chalmers Tekniska Högskola, Göteborg.

Roozenburg, N.F.M., Eekels, J. (1995). Product design: Fundamentals and methods. Chichester: Wiley.

Rosenblad-Wallin, E. (1990) Brukarorienterad Produktutveckling – En introduktion (in Swedish; An introduction to user-oriented product development). Department of Consumer Technology, Chalmers University of Technology, p. 28-41.

Sarter, N.B., Woods, D.D. and Billings, C.E. (1997). Automation Surprises. In G. Salvendy (ed.) Handbook of Human Factors/Ergonomics (Second Edition). New York: John Wiley & Sons, Inc., pp. 1926-1943.

SBU - Statens beredning för medicinsk utvärdering – The Swedish council on technology assessment in health care (2000). Back pain, neck pain – an evidence based review, summary and conclusions. Available online at http://www.sbu.se

Slater, K. (1985). Human Comfort. Springfield, Illinois, USA : Thomas Books.

Sperandio, J.-C. (1988). L'ergonomie du travail mental. (In French – The ergonomics of mental work). Paris, Masson, 1988. 2nd ed. 140pp.

Suh, N. (1990). The principles of design. Oxford series on advanced manufacturing. Oxford University Press.

Svensson, E., 1993. Analysis of systematic and random differences between paired ordinal categorical data, Almqvist & Wiksell International, Stockholm.

Tichem, M. (1997). A design coordination approach to design for X. Technical University of Delft, Delft.

Tiger, L. (1992), The Pursuit of Pleasure, Boston, MA: Little Brown and Company.

Ullman, D. (1997). The mechanical design process. New York: McGraw-Hill.

Ulrich, K.T., Eppinger, S.D. (1995). Product design and development. New York: McGraw-Hill.

Vicente, K.J. (1998). An evolutionary perspective on the growth of cognitive engineering: the Risø genotype. Ergonomics, 41(2), pp. 156-159.

Vicente, K.J., Pejtersen, A.M. (1997). Cognitive Work Analysis: towards safe, productive and healthy computer-based work. Mahwah, New Jersey: Erlbaum.

Vicente, K.J., Christoffersen, K., Hunter, C.N. (1996). Responde to Maddox critique. Human Factors, 38, pp. 546-549.

Vries, G. de, Hartevelt, M., Oosterholt, R. (1996). Private Camera Conversation Method. In P.W. Jordan, B. Thomas, B.A. Weedmeester, I.L. McClelland (eds.) Usability Evaluation in Industry, London: Taylor & Francis, pp. 147-155.

Wheelright, S.C. and Clark, K.B. (1992). Revolutionizing Product Development. New York: The Free Press.

Wickens, C.D., Hollands, J.G. (2000). Engineering Psychology and Human Performance, 3rd ed. Upper Saddle River, New Jersey: Prentice Hall.

Wilson, J. R.; Corlett, E. N. (1995). Evaluation of human work; a practical ergonomics methodology. London, Taylor & Francis, 1995. 1134 pp.

Wilson, C., Kennedy, M., Trammell, C. (1996). Superior Product Development – Managing the process for innovative products. Oxford: Basil Blackwell Ltd.

Wisner, Alain (1987). Por dentro do trabalho; ergonomia, método & técnica. (In Portuguese – Inside work – ergonomics, method & technique). São Paulo, FTD/Oboré, 1987. 189 pp.

Woods, D.D. (2000). Complementarity and synchronization as strategies for practice-centered research and design. Keynote speech presented at the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Society, July 29- August 4, 2000. San Diego, California, USA.

Woods, D.D. (1999). W^3: Watching Human Factors Watch People at Work. Presidential Address, 43rd Annual Meeting of the Human Factors and Ergonomics Society, September 28, 1999. Multimedia Production (D.D. Woods & D. Tinnaple) at http://csel.eng.ohio-state.edu/hf99/

Woods, D.D. (1995). Towards a Theoretical Base for Representation Design in the Computer Medium: Ecological Perception and Aiding Human Cognition. In J. Flach, P. Hancock, J. Caird and K. Vicente (eds.) An Ecological Approach to Human Machine Systems I: A Global Perspective. Hillsdale, New Jersey: Erlbaum.

Woods, D.D. (1993). Process tracing methods for the study of cognition outside of the experimental psychology laboratory. In G. Klein, J. Orasanu and R. Calderwood (eds.) Decision making in action: models and methods. Norwood, NJ: Ablex Publishing Corporation.

Woods, D.D., Johannesen, L., Cook, R.I., Sarter, N. (1994). Behind human error: Cognitive Systems, Computers and Hindsight. Crew Systems Ergonomic Information and Analysis Center, Dayton, Ohio: Wright Patterson Air Force Base.

Woods, D.D., Roth, E.M. (1988). Cognitive Systems Engineering, in M. Helander (ed.) Handbook of Human Computer Interaction (Amsterdam: Elsevier North-Holland) pp. 3-43.

Woods, D.D., Sarter, N., Graham, J., Decker, S. (1999). Predicting how technological change may create human error. Institute for Ergonomics / Cognitive Systems Engineering Laboratory Report, ERGO-CSEL 99-TR-02, The Ohio State University, Columbus, Ohio.

Yamada, S. and Price, H.E. (1991) The Human Technology Project in Japan, Proceedings of Human Factors Society 35th Annual Meeting, p. 1194-1198.

Zhang, L., Helander, M.G., Drury, C.G. (1996). Identifying factors of comfort and discomfort in sitting, Human Factors, 38(3), pp. 377-389.

Ziman, J.M. (2000). Real science: what it is, and what it means. Cambridge, United Kingdom: Cambridge University Press.

Appendix A

Scrutiny of Product Development Literature

(Appendix A) – Scrutiny of product development literature

This appendix reviews selected literature on product development[19], aiming at providing a framework for an enlarged understanding of the positioning of the contribution of this dissertation in relation to product development and engineering design methodology theories. It adds to the introductory description made in section (1.1.2) concerning engineering design and product development and throughout chapter 1 (Introduction). This appendix considers general outlines of product development, starting with presenting different models of product development with the associated activities. The appendix also considers product development from an organizational perspective.

(A.1) Models of Product Development

Even though the development of products can be carried out in many different ways there are generic characteristics that cut across the alternative procedures (Furuhjelm, 2000). Product development can be defined as the set of activities beginning with the perception of a market opportunity and ending with production, sale and delivery of a product (Ulrich and Eppinger, 1995). According to Suh (1990), the design process begins with the establishment of functional requirements to satisfy a given set of needs, and ends with the creation of an entity that satisfies these requirements. Product development can be seen as part of a company's industrial innovation process (Roozenburg and Eekels, 1995). Industrial innovation includes all activities preceding the launch of a new product into the marketplace, such as basic and applied research, design and development, market research, production, distribution and sales. According to Roozenburg and Eekels' model, product development consists of two phases: product planning and strict development. During product planning the company wanting to put new products on the market identifies in explicit terms what it wants to achieve. Derived from the overall goals and strategies, Roozenburg and Eekels suggest the formulation of a policy regarding coming products. With this policy in mind the idea finding commences. One or more promising ideas for a new product are generated. During the strict development the new business idea with its plans for product, production and sales is being developed. Finally, in the last part of the innovation process, which Roozenburg and Eekels call realization, the outcome of the strict development is further evaluated and realized. This phase includes activities such as production, distribution and sales.

Pahl and Beitz (1996) developed another well-accepted model of the product development process, with many similarities to Roozenburg and Eekels' model. According to the former, product development consists of the four following phases:

- product planning and clarifying the task,
- conceptual design,

[19] References for this appendix are listed in the Reference list.

- embodiment design and
- detail design.

A cornerstone in the building up of the theory of product development was laid by Hubka and Eder (1992) in their *Einführung in die Konstruktionswissenschaft*. They present a structure similar to that of Pahl and Beitz. Hubka and Eder, in their 1996 English version, specified the following phases with their respective outputs:
- Elaborate and clarify the assigned task. Output: the design specification.
- Establish the function structure. Output: the function structure.
- Establish the organ structure. Output: the concept.
- Establish the component structure. Output: the layout.
- Establish component structure on more detailed level. Output: representation and description of technical system.

(A.2) Product planning and clarifying the task

The first part of the product development process, what Pahl and Beitz (1996) call product planning and clarifying the task, specifies what products to develop, when and how. In many companies product planning concerns a whole range of products referred to as the product mix or product-market plan (Roozenburg and Eekels, 1995). The product planning is influenced by factors stemming from outside as well as inside the company (Wilson et al., 1996). As an external source the market demand is of course of major importance. In the initial stage of product development it is essential to gather information on customers' behavior and preferences and let these act as a determining factor.

From within the company, influence on the product planning could stem from results of the company's own research, e.g. an improved technology applicable in new products or processes (Wilson et al., 1996). Influence from other sources is also important, such as, economic or political changes, e.g. increase of oil price or changing legislation. Specific examples are raising environmental awareness and imposed recycling demands as mentioned by Pahl and Beitz (1996). These authors present a systematic structure for product planning:
- Analyzing the situation.
  The current product mix and respective market shares are investigated. The company's competence is identified, as well as future developments in areas such as customer behavior, technological trends, and environmental requirements.
- Formulating search strategies.
  This activity includes identifying strategic opportunities as well as new consumer needs and market trends.
- Finding product ideas.
  Ideas could be generated through e.g. brain-storming sessions or intuitive methods.
- Selection of product ideas.
  The best ideas are then selected taking into account the company's goal and the product's functional advantages.
- Product definition.
  The most promising ideas are elaborated in more detail. The outcome of this

task, as well as of the whole product planning phase, consists of product proposals together with a preliminary list of product requirements.

Parallel to product planning, a clarification of the task takes place. Information is acquired concerning constraints imposed on the product to be developed. Among objects of investigation, is finding out what technical demands the product must comply with, in order to fulfill its intended targets. This work is performed from a general to a more detailed level in an iterative process (Pahl and Beitz, 1996). The requirements are compiled into a design specification and as work progresses this becomes more detailed (Roozenburg and Eekels, 1995). On a technical level the design specification should cover areas such as geometry, materials, production, etc. The specification must reflect the customers' needs and differentiate the product from competing ones (Wilson et al., 1996). Other authors refer to the design specification as the product design specification (e.g. Pugh, 1990) or specification of requirements (e.g. Wilson et al., 1996). Pugh (1990) provides a list with more than 30 areas that need to be addressed when setting up the product design specification. One of the areas mentioned with an effect on the product to be designed is ergonomics.

(A.3) The product design phases

After having decided on proceeding with the development of the generated product idea, as well as having established the tareget in form of overall design requirements, the actual design work begins. The product idea is to be elaborated into physical products with high possibilities of becoming successful on the market. This takes place in different phases (Pahl and Beitz, 1996):

- conceptual design,
- embodiment design and
- detail design.

(A.3.1) Conceptual design

Conceptual design aims at generating a preferable concept or concepts meeting all requirements in the specification. A concept is an idea that is sufficiently developed in order to evaluate the physical properties governing its behavior (Ullman, 1997). The first activity in this design phase is to raise the design efforts to a more abstract level (Pahl and Beitz, 1996). In search for the optimal solution it is important to release the mind-set of the designers from prejudices stemming from previous experience. This is done by generallizing the overall function demands and other restraints on the product. Generating a single statement of the overall function on the basis of the customer requirements could be a fruitful way to proceed (Ullman, 1997). This opens the door for generation of a larger number of possible conceptual solutions.

The general function of the product could be described in a simple input / output model (Roozenburg and Eekels, 1995). This may in turn be elaborated in further depth with similar models on a sub-functional level. For each sub-function, working principles can be found. These could in a subsequent step be combined into general working structures for the whole product and lead to full solution principles. After having elaborated the concepts and gathered more information on each of them, for example through rough calculations or modelling, it is time for evaluation and selection. Pugh (1991) underlines that this process should take place in a way restraining creativity but positively stimulating the emergence of new concepts. The evaluation is generally carried out with the requirements in the design specification as a basis.

As work proceeds and knowledge related to the product becomes more enhanced, the design specification generally needs to be revised (Ulrich and Eppinger, 1995). The list of requirements initially laid forth could be too generic in its character, preventing the document from functioning as a guiding tool when starting designing on a practical level. Requirements hence need to be formulated in explicit terms to provide assistance during design.

(A.3.2) Embodiment and detail design

The next step in the product development process, in accordance with Pahl and Beitz's methodology, is the embodiment design phase. During embodiment design the concept is advanced from a vaguely described conceptual solution to a well-defined product model. The overall layout design is determined, as well as the shapes and materials of the parts. The embodiment design phase includes several iterative steps. Many interlinked activities need to be carried out in parallel in this phase. Generally, a large number of changes take place, complicating the relation between different work groups during embodiment design.

There are many different aspects to be considered during embodiment design. The product must be given a design enabling cost-efficient production, be safe to use, have an attractive appearance, and so on. Trade-off situations have to be managed, aiming continuously at finding a balance between different demands. As in the conceptual design phase, different alternatives are evaluated in accordance with the criteria set up in the design specification (Pahl and Beitz, 1996).

In the detail design phase the last steps are taking in finalizing the product before production commences. Final decisions are taken regarding for example layout, dimensions and materials. The elaboration of production documents and detailed drawings is also important in this phase. For example, assembly instructions for production are laid down, as well as manuals for maintenance and opertation. Pahl and Beitz (1996) also state that 'corners must not be cut' in the detail design phase. This could have serious adverse effects on the technical feasibility and increase the likelihood of errors in production. The product's possibility of becoming a success in the market is very dependent on production costs and product quality, which to a large extent is determined by the way the detailed design is carried out.

(A.4) Organizational aspects

Product development generally involves a whole set of different activities, such as management, research and development, and design. Given the complexity of product development, many alternative organizational structures have been devised. The activities described in the previous sections of this chapter could possibly be carried out in a straight sequence. However, concurrent engineering and integrated product development have gained major recognition, leading to having activities taking place in a parallel organisational structure.

(A.4.1) Concurrent engineering

Research has been carried out aiming at a more effective and efficient product development process. To reduce the time to develop a product, it has proven efficient to carry out activities in parallel. Andreasen and Hein (1987) suggested that the preparation for manufacturing and marketing should be carried out concurrently with the design of the product. Apart from reduced development times, applying a work structure where activities are efficiently integrated leads to products more cost-efficient to produce and with higher quality. This is a result of an intensive interaction between people involved with production, marketing and design. In the different phases of the product development process, staff numbers and type vary considerably (Ulrich and Eppinger, 1995). For example, in the earliest phase when identifying the market demand, the marketing department is generally the most important actor. In later stages, designers and production technicians could be the group of staff spending more time on the project.

(A.4.2) Product development projects

After a product idea with potential for becoming successful on the market has been generated, a project plan is set up. This plan determines the time frame and the economic restrictions of a project that is to realize the project idea into a commercial product (Ulrich and Eppinger, 1995). A project assignment is generally the output of the product planning, and is the starting point of the subsequent design project. During the start-up, a project leader is assigned to carry out the task of managing the project. Depending on the size of the project, a certain number of people are allocated to the product development team. Several authors (e.g. Wheelright and Clark, 1992, or Wilson et al., 1996) emphasize the importance of forming groups where people from different functions work together. As an example, having production technology and marketing experts in the teams reduces the risk of the products becoming difficult to produce and later on to sell (Furuhjelm, 2000).

Appendix B

Cognitive Engineering Schools of Thought

(Appendix B) – Cognitive Engineering Schools of Thought

This appendix sheds light into two parallel schools of thought in cognitive engineering: the school started by Erik Hollnagel and David Woods and the school of Jens Rasmussen and Kim Vicente[20]. It complements the descriptions given in section 5.3.1 – Assessment of model validity based on literature studies – for cognitive engineering. Additionally, this appendix characterizes Don Norman's concept of motivated cognitive activity.

(B.1) The school of Erik Hollnagel and David Woods

Woods and Roth (1988) describe cognitive engineering as an approach to the interaction and co-operation of people and technology. Significantly, it is not to be taken as an applied cognitive science, seeking to apply computational theories of mind to the design of systems of cognitive work. Rather, cognitive engineering is challenged to develop its own theoretical base. Further, cognitive systems are distributed over multiple agents, both people and machines, which co-operatively perform cognitive work. Hence the unit of analysis must be the joint and distributed cognitive system. The question that cognitive engineering addresses is how to maximize the overall performance of this joint system. Woods and Roth (1988) state that this question is not answered simply through amassing evermore powerful technology; they contrast such a technology-driven approach with a problem-driven approach wherein the 'requirements and bottlenecks in cognitive task performance drive the development of tools to support the human problem solver'. Yet whether such an approach may be developed remains an open question: whether designers might be provided with the 'concepts and techniques to determine what will be useful, or are we condemned to simply build what can be practically built and wait for the judgement of practice?' (Woods & Roth, 1988). This is ultimately a question of whether principle driven design is possible.

Hollnagel and Woods (2001) consider the following main issues in cognitive systems engineering:

- Coping with complexity. The complexity is due to the multiple demands of information and control and to the possibily conflicting goals that characterize the working situation. People usually try to cope with complexity by reducing it, for instance by structuring the information at a higher level of abstraction with less resolution and making the required decisions at that level. The development of information technology has made it possible to provide computerized tools which to some extent accommodate the operators' needs and thereby help their coping. This kind of support clearly involves a replication of parts of human cognition, hence the use of an artificial cognitive system.

[20] References for this appendix are listed in the Reference list.

- The use of tools. Tools are artefacts that are used with a specific purpose to achieve a specific goal. Tools have traditionally been used to amplify human capabilities – in terms of physical performance (reach, force, speed and precision), and in terms of performance and discrimination. More recently, tools have been introduced which are aimed at amplifying cognition. Although some cognitive tools have existed for ages, the use of computers has made it possible to design tools for more sophisticated functions, for instance decision making and planning.
- Joint cognitive systems. Cognitive Systems Engineering recognizes that technological systems gradually have become more 'cognitive', in the sense that they are goal-driven and make use of cause-based (feedforward) regulation. Technological systems can thus be seen as artificial cognitive systems that interact with natural cognitive systems (i.e. humans). It is therefore appropriate to develop a view of joint cognitive systems, i.e. of cooperating systems which are described using a common set of terms – neither as machines nor as humans, but as cognitive systems.

Woods (2000) presented a framework for research and development (R&D) in the area of Computer Supported Cooperative Work (CSCW). He places R&D at the intersection of the components of CSCW – people, technology and work (in other words, the world, the agents and artefacts, and the strategies, demands and capabilities). The domain of CSCW is one where multiple people coexist with machines, and where complexities, adaptations and failure appear. While cognitive engineering was founded two decades ago, today, as then, Human Factor specialists are called in too late to participate in development projects. Hence there is the need to accept the challenge of predicting. It is necessary to anticipate the side effects of technological change, to be able to cope with complexity in a work domain (Woods et al., 1999). However, associated to this task is the problem of the envisioned world, which may fallaciously be considered as static and unchanging (Woods considers this is the case in the Cognitive Task Analysis methodology). Instead, the real world is one where there is plurality (multiple versions of possible changes) and underspecification, and one that is ungrounded and where there is overconfidence. So the question Woods raises is 'how do we study a current world when it is being changed?'. It is necessary to consider the cycles of research and development.

Woods (2000) considers that the engine of innovation in cognitive engineering consists in interlocking the cycles of research and development so that they reinforce each other. From the knowledge of patterns in cognitive systems, hypotheses are generated about what would be useful, to which follows observation and analysis. From these, design seeds (not design requirements or guidelines) and reusable concepts are generated. Due to pressures and demands from the environment where this research cycle is inserted, prototypes are also generated, but as tools for discovery (if we are not willing to throw the prototype away, it becomes a product already at this stage). The cycle of development is concerned with the design of a technological product. A third cycle, of technology base knowledge should also be connected to the cycle of development, in support of the creation of the technological product. Woods considers that academics have a role to play in synchronizing these complementary cycles and reinforcing them. Each of the cycles is developed between two of three levels of artefact materialization. The levels are understanding, usefulness and usability. The research cycle develops between the levels of understanding and usefulness, while the development cycle develops between the levels of usefulness and usability. The level of understanding produces a model that incorporates the complexities and capacities of the system of people, technology and work. The level of usefulness delivers hypotheses and design seeds. Finally, the level of usability delivers an object or artefact. Artefacts, thus, embed hypotheses of the interplay between people, technology and work.

Work domains also work as experimental fields where patterns are abstracted across domains, with the support of peer researchers and academics (Woods, 2000). These patterns feed the research cycle, hence providing help to anticipate and prepare for new domains of work. Unfortunately, most of the academic institutions are not structured to support interdisciplinary work. Woods considers that what is critical in abstracting patterns is escaping the details of a specific technology. To do this, he considers the need to be practice-centered, in the following way:

- observing people / technology / work (P/T/W) in their actual setting;
- abstracting patterns (predictable regularities in the interplay of P/T/W and adaptations);
- understanding the sources of expertise and failure (and also what explanations are offered by the actors); and,
- generating hypotheses about what is useful, stimulating innovation with design seeds, reusable concepts and techniques.

Finally, David D. Woods suggests four fundamental values to guide this process: authenticity (instead of validity), abstraction (how patterns can be found), generative (to anticipate the side effects of change in the work domain), participative (instead of detached and neutral, and involving all stakeholders). Woods (2000) suggests these are the guiding values to follow on the first twenty years of cognitive engineering.

(B.2) The school of Jens Rasmussen and Kim Vicente

According to Vicente (1998), cognitive engineering is at an early stage of evolution. He considers that in order for it to flourish and mature, a diverse conceptual gene pool of alternative proposals is needed, that can feed into a natural selection process. Vicente (1998) considers that only by generating and critically testing the comparative fitness of alternative proposals will the discipline of cognitive engineering be thriving, mature and cumulative. He describes one such proposal based on the conceptual genotype originating from Risø National Laboratory in Roskilde, Denmark since the 1960s. From the Risø perspective, cognitive engineering is about designing for adaptation. A number of design principles have emerged from the Risø genotype (Vicente, 1998). As an example, ecological interface design (EID) is a theoretical framework for designing interfaces for complex socio-technical systems (Vicente et al., 1996). EID represents the functional and physical constraints in a work domain with an abstraction hierarchy and presents those constraints in a form that exploits human perception and action. EID tries to help operators adapt flexibly to unanticipated events. It is based on work domain constraints rather than on a task analysis defining the ‘one right way’ to perform (only) anticipated tasks.

According to the Risø conceptual genotype, cognitive engineering is concerned with the design of computer-based information systems to support work in complex, sociotechnical systems (Vicente, 1998). This overarching design problem can be parsed into five classes of behavior-shaping constraints that define a unique framework for cognitive work analysis (Rasmussen et al., 1994). First, the functional structure of the work domain imposes a fundamental set of constraints that can be represented as an abstraction hierarchy. Second, product constraints are also imposed by the decision activities that must be performed during the various modes of system operation. These can be represented using the decision ladder. Third, the categories of processes that can be used for each decision activity impose further constraints on behavior that can be represented as mental strategies. Fourth, operators' competencies impose another layer of constraint that can be represented using the skills, rules, knowledge taxonomy. Fifth, organizational constraints impose a final layer of constraint that can be represented as the content and form of work organization. These distinctions, which according to Vicente (1998) define the ontology of the Risø genotype, are described in a detailed, pedagogic form by Vicente and Pejtersen (1997).

(B.3) Don Norman's postulates on motivated cognitive activity

In my literature studies I came across the concept of motivation in the explanation of what Norman (1993) calls 'optimal flow': Motivated cognitive activity, challenging and rewarding, whether experiential or reflective. Norman (1993) explains that the experiential mode of cognition leads to a state in which we perceive and react to the events around us, efficiently and effortlessly. This is the mode of expert behavior, and it is a key component of efficient performance. The reflective mode of cognition is that of comparison and contrast, of thought, of decision-making. This is the mode that leads to new ideas and novel responses. In the state of 'optimal flow' the mind is captured, and the experience exhilarating. "This focused concentration is easiest to sustain when in an experiential mode, when the experience is driven by the events. (...) [It] can also be reached during reflection, the major difference being that the state is now self-controlled, no longer dependent upon continual external simulation. The trick in both cases is to avoid interruption." This interruption (caused by an outside source or self-induced) then results in the disruption of the focused attention, disruption of the trancelike state of concentration. Norman (1993) considers that the factors involved in the experience of 'optimal flow' are the ones embodied in activities which have: " built-in-goals, feed-back, rules and challenges, all of which encourage one to become involved in one's work, to concentrate and lose oneself in it." Furthermore, Norman (1993) proposes a checklist of the characteristics of the environment leading to an optimal experience:

- provide a high intensity of interaction and feedback;
- have specific goals and established procedures;
- motivate;
- provide a continual feeling of challenge, one that is neither so difficult as to create a sense of hopelessness and frustration nor so easy as to produce boredom;
- provide a sense of direct engagement, producing the feeling of directly experiencing the environment, directly working on the task;
- provide appropriate tools that fit the user and task so well that they aid and do not distract;
- avoid distractions and disruptions that intervene and destroy the subjective experience.

Appendix C

Description of Activity Theory

(Appendix C) – Description of Activity Theory

This description of activity theory is based on the theoretical part of an essay by Petra Rhodin, included in the course ”Activity Theory and Human Factors” taught by the department of Human Factors Engineering (CTH) during Spring 2001. This work was later developed as part of her licenciate dissertation (Rhodin, 2001). I have familiarized myself with her main references[21]. This description covers parts of activity theory perceived by Petra Rhodin as to be most important, and relevant for Human Factors research. It is an enabling piece of knowledge for the application of activity theory essayed in Chapter 6.

(C.1) Activity and the activity hierarchy

It is important to emphasize that the greatest accomplishment that may be promoted by activity theory appears to be that it can function as a framework for developing a picture of a phenomenon in several dimensions, and to put situations and actions in to context (Rhodin, 2001). According to Activity theory, the analysis of a situation is based on human activity. Leontyev (cited in Hydén, 1981) has defined activity as ”the processes through which man creates some form of relation to reality and which answer to that need”. Activity is the transmitting body between man and his surroundings, and therefore it is activity that transmits the characteristics of reality to the individual. Through his activity and actions, man can perceive parts of reality but can also create parts of his reality. Activity can be both outer behavior and inner, psychological actions. All activities are aimed at something and have some kind of motive or objective. It is the objective of the activity that decides the form and structure of the activity. This also means that it is the characteristics of the objective that govern the activity. The objective of an activity can be either something concrete or abstract. The activity’s objective / motive can exist in two forms, on the one hand the actual and objectively existing objective or motive, and on the other hand the subjective perception (the psychological reflection) of this objective.

In specific situations, man has not only one but usually many motives for his activities. These are sometimes in harmony and sometimes counteractive. This means that activities can be contradictive. The motives for an activity are not something created by separate individuals, but rather a product of human activities throughout history. Motives for activities are linked to human needs, which are based on biological needs. Apart from these, social needs have emerged and develop constantly through activities. This implies that activity theory is based on the fact that the structure of human needs is well developed and cannot be reduced to any simple biological and physiological needs. Needs are constantly developing and are influenced by the objectives that they are aimed at. However, an objective does not become a motive before it becomes incorporated in an activity, when it then becomes a motive linked to a need for a specific human being. Thus, there is a dialectical connection between needs and objective / motive which develops through activity.

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[21] References for this appendix are listed in the Reference list.

Activities are realized through target-related actions. One or more actions can contribute to an activity. However, it is the activity that gives meaning to the actions, eventhough actions have their own goals and can be included in different activities. Thus there is independence between the activity level and the action level. Actions are carried out within a unit of time and space and have specific intentions (What should be done) and the goal of actions can be consciously reflected by the individual. This is not necessarily the case with the motives of the activity, which can be unclear, or even unknown, to the individual. Actions are aimed at conscious goals where an objective can be clearly and consciously conceptualized. It is thanks to the intentional aspects of actions and activities that we can communicate about the instrumental side (What is the intention?) of our activities (Karlsson, 1996).

Every action carried out by a human being also has an operational aspect. The operational aspects of actions are implemented by a series of operations. We could say that operations answer the question of how a certain action should be carried out. Every activity is linked to concrete, local physical and social terms in order to carry out the actions and they are triggered by the specific terms at a certain point in time. Operations are sensomotorical units carried out by a person in a specific situation without conciously thinking about them. The purpose of operations is to induce the action that the person is aware of. Initially, we can carry out operations conciously as if they were actions, but through learning and experience we transform them into operations, i.e. actions can be transformed into operatives. Due to several reasons we can also start reflecting over what earlier were operations, and try to carry out earlier operations as actions. This change of level is called conceptualizing. Conceptualizing concerns articulating to oneself something that would otherwise be taken for granted. The process that starts with a reason and ends with a conceptualisation is called breakdown. This concept of breakdown belongs to Heidegger (1992) as reported by Karlsson (1996). Changing between levels also means changing the objective of the action, e.g. from writing a letter to choosing or spelling a word, or vice versa. Conceptualising can occur in situations where some unforeseen change in the material terms for a specific operation causes a breakdown. An unarticulated conflict arises between the presupposed terms for the operations on one side and the actual terms on the other. Activity, action and operation form a hierarchy that should not be taken as static and immutable, because there is mobility between levels in the activity hierarchy. Transformations between operations and actions and between activity and actions occur all the time in actual situations. Regulation (feedback) of the different levels also occurs. Operations are immediately and unconsciously evaluated together with the direct, local conditions. Actions are evaluated on a more abstract level together with the goals or the plan they are included in. Activity is also evaluated together with motives and needs. Regulation thus becomes more abstract and indirect the higher in the hierarchy we go. The fact that the motive for an action can be unclear or hidden means that regulation can also become unclear. Regulation also occurs in consideration to the physical / material preconditions and to the individual's interpretation of social rules and norms. The interpretation of social rules and norms is based on an interpretation of other people's expressions and behavior in that specific situation, and on the norm system we have created which states how we should act.

Moreover, the individual's relation to the surrounding world is influenced by the individual's awareness. The awareness of a human being is the psychological, subjective reflection of reality, which comes to govern activity. Every human being creates his or her own combination of individuality forms and therefore has his or her very own relation to the surrounding world. Different people can thus have their own, qualitatively different, understanding of the same objective reality. This can lead to different people acting differently within the same activity under the same outer social and material conditions. Awareness arises when outer activities are internalized and become internal activities. The outer activities that are internalized have developed historically and socially exist. The outer activities that are internalized have different shapes - practical actions as well as different kinds of pictures and pretensions, and above all language.

However, Hydén (1981) states that conscience does not necessarily correspond to the social existence. Thus, while studying human actions, we cannot solely base the studies on humans' own awareness of their actions. We must also conduct an objective analysis of man's social existence, and in the light of that analysis view his awareness and actions. It is therefore not enough to presuppose that man acts according to his perception of the world. Instead, Hydén says that we have to deal with a complex dialectical relation between man's subjective and objective existence. Furthermore, man's perception of the world develops in coordination with the surrounding reality.

A central expression within the psychological part of activity theory is, besides activity and consciousness, personality (Hydén, 1981). It is personality that characterizes a certain concrete human being. An important concept linked to personality is identity. In accordance to Hydén, identity is the total system of rules and norms that every human being develops. This identity system is composed of what in daily language is called the way a human being views the world. Identity tells us how the world is and how we should act. The identity system also includes notions on how things should be, e.g. moral, and how things could be, e.g. dreams and imagination. The individual rule / norm system is not something that is developed by every individual on their own. Instead the individual acquires various systems in society: moral, political, social ideologies, etc. Every individual acquires complete or parts of various systems and blends these to a system specific to that individual. It is according to the identity system that interaction with the surrounding world occurs. Specific actions / behavior are generated according to an interpretation of the situation, yielding a transformation of certain rules, whereafter the action is carried out. It is also compared to the planned action through a regulation loop.

(C.2) Representation of Activity

What aspects are relevant to include in studies of activity? Petra Rhodin chose to deal with three models that in different ways represent frameworks that can be used in applied studies. These are Hydén's (1981) model of activity, Engeström's (1999) representation of activity systems (which deals mainly with the activity level but also somewhat with the action level), and finally Karlsson's (1996) framework. The latter model has been developed mainly for studies of the relation between user and artefact and it deals with all three levels in the activity hierarchy.

Hydén (1981) considers that the objectives / motives of the activity, the social and material / physical perceptions, and the motives and needs determine the activity and its structure (Figure C1). The means for carrying out the activity include for example techniques and skills, procedures, artefacts, of which language is often considered to be central. By analyzing activities we can determine what relation man has to the material and social reality, and therefore also which consequences the material and social reality will have for the individual.

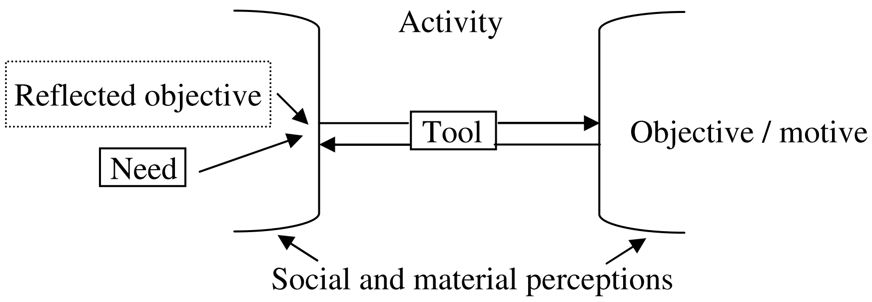

Figure C1 *– Model of activity, based on Hydén (1981).*

Engeström (1999) considers that researchers need to create and test models that clarify the components and the internal relations in an activity system in order to make full use of the activity concept in concrete research. Engeström suggests a triangular representation of separate actions, and also of complete activity systems. On the action level, Engeström (1999) brings up the subject, who is often an individual, the mediating artefact or the tool to carry out the action, the objective or the goal that the action is meant for and also the results of the action. The mediating artefact can be a physical object, but also, for example, different praxis or procedures. Language is often claimed to be one of our most important artefacts in activities (Hydén, 1981). According to Engeström (1999), the model of the action level is limited by the fact that it does not clarify the social and cooperative nature of actions. The motive behind actions is not clarified either. In order to capture these aspects too, Engeström suggests a model for complex activity systems (Figure C2).

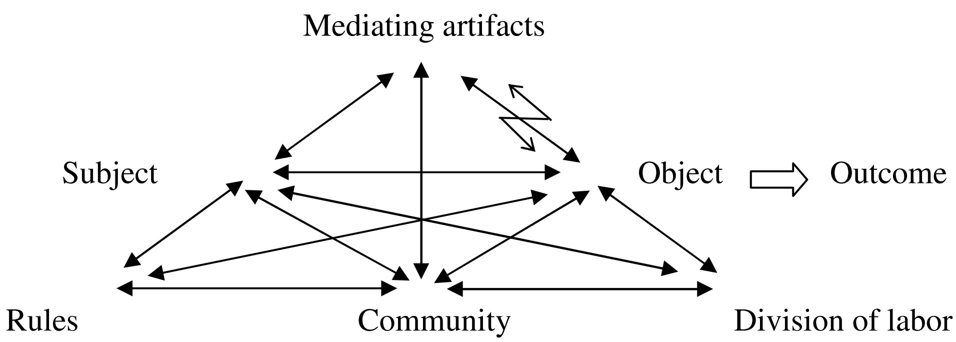

Figure C2 *– A complex model of an activity system, according to Engeström (1999).*

This model includes rules, group and work division. Rules, norms and conventions affect the activity, which is also affected by the social group linked to the activity. Work division within the group is also included. The subject no longer has to be an individual person on the activity level. It can also be a group of individuals. There can also be contradictions between central components of an activity system. These are marked in the model with lightning-shaped arrows; see the example in Figure C2. In this example there could be a contradiction between a challenging motive and the means at hand to fulfill the motive.

In her doctoral dissertation, Karlsson (1996) developed and presented a framework to study the relation between user and artefact. This is to be used as a tool for reflection and discussion during planning and evaluation of studies concerning user requirements on artefacts, mainly technical artefacts. The framework resulted from a synthesis of mainly the activity theory, the concept of use, Heidegger's breakdown concept and experiences from 8 empirical studies carried out at the Department of Consumer Technology (currently Department of Human Factors Engineering, CTH) during the years 1992-1996. The framework is presented in Figure C3 in graphical form (it is also presented in Table 2 – chapter 1 – in the form of a matrix).

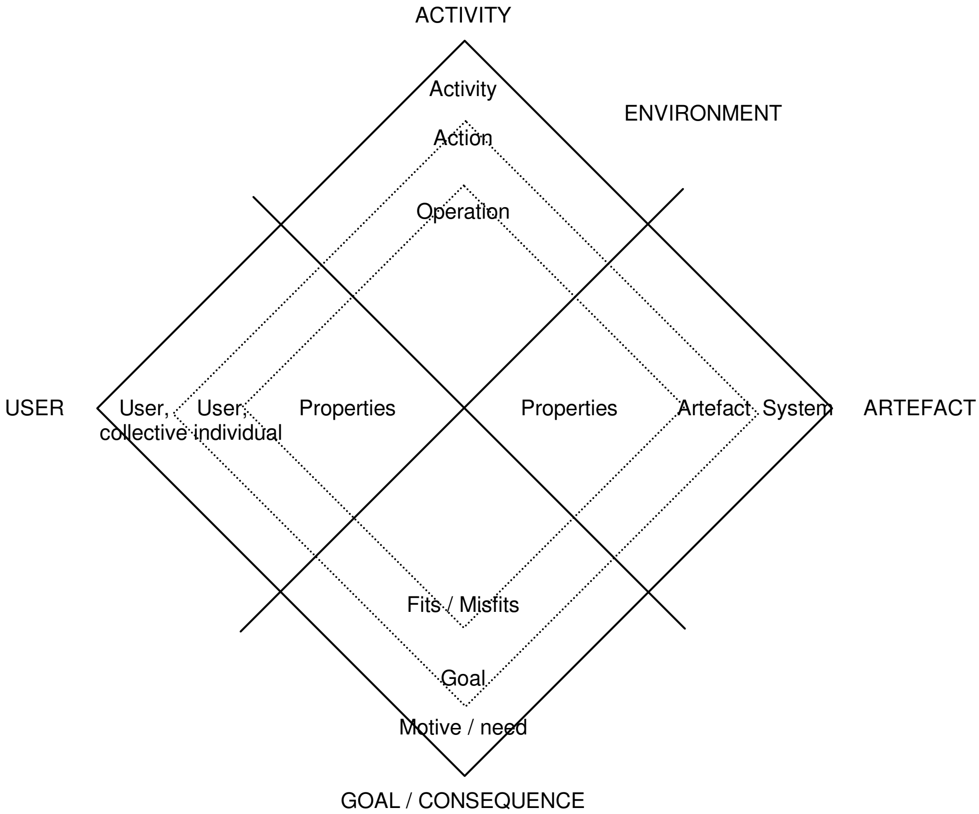

Figure C3 *– A graphical representation of the framework for the study of the user-artefact relation created by Karlsson (1996).*

The user perspective in Karlsson's framework indicates that the focus is on the individual and his / her relation to the objective and the mediating artefact. Furthermore, Karlsson considers that use implies a goal (use for what?), an instrument (use what?), a user (used by whom?) and an environment and a context (used where?). These aspects represent different dimensions of the concept of use. The framework Karlsson brought forward to study the relation between user and artefact states that five different dimensions should be adressed and analyzed at various levels, in order to fully understand the role of an artefact and the demands on an artefact in a use situation. The analysis follows the activity hierarchy and shifts between 'higher' levels of analysis related to motive and goal, and 'lower' levels related to the specific and local conditions that affect specific operations. .

Article I

Coelho, D.A., Dahlman, S. (1999). A pilot evaluation of car seat side support: Leading to a redefinition of the problem. International Journal of Industrial Ergonomics, 24 (1999) - pp. 201-210.

A pilot evaluation of car seat side support
- Leading to a redefinition of the problem

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Abstract
Little published research exists about car seat side supports. The objective of the experimental study, here reported, is apprehending the levels at which selected design factors better contribute to the side support's utility. Three seat design factors were manipulated: the cover's friction properties, the distance between the opposing side supports and the side support's size at the hip-lower torso level. Four subjects, with similar body widths, evaluated the test seats, in a standard driving task. Pressure prints were taken, with varying lateral acceleration levels. Video recording of the driving task aimed at characterising shoulder and hip displacements. The seats were rated for comfort, support, egress / ingress characteristics and seat preference. The setting of recommendations for future studies followed the theorising of the reasons for the inconsistency and low level of association of the individual data. The authors' subjective impressions from performing driving evaluations are confronted with the assumptions and hypotheses underlying the experimental design, resulting in strong agreement. Practical design advises are outlined and design concepts worth future study highlighted. A deeper understanding of how the seat provides lateral support is attained, with the building of the problem understanding along the process – a typical pilot study outcome.

Relevance to industry
The framework and findings presented may serve as a basis for further evaluating the car seat side support. Considerations of the methodological process are presented, with relevance given to having found sense despite the inconclusive results, due to a revised problem understanding.

Keywords: *lateral support, seat comfort, methodology*

1. Introduction
The variety of human dimensions is a capital concern in car seat design. The introduction of side supports may aggravate the problem of designing a seat to fit every human being in the range of accommodation targeted in the seat's design. The side support is built in both sides of the seat and people with varying body widths must be accommodated in between. Additionally to the accommodation issue, other reasons might justify the inclusion of adjustment in the side support. Each particular seat occupant might, in different situations, desire a different level

of performance of the side support. The definition of the side support's location and dimensions must take into account the issues of: Adjustment of the side support, purpose intended for the side support and car utilisation type, the design constraints from general car seat design and the anthropometric variations. Our judgement of this is that, from the issues involved, the anthropometric variations and the purpose intended for the side support will be of superior importance.

This paper reports on a study, Coelho (1996), aimed at revealing the design factors relevant to the car seat side support's utility.

2. Literature study

An extensive literature search was performed for references on car seat side support generally and its relation with comfort and support particularly. Many references were found covering research on automotive seat comfort, but only one dealt with side support, Gamache (1994). He gives a short description of an automatically articulating seat, which compensates for lateral acceleration. The setting of a theoretical background and frame of analysis had then to be analytically derived, and without much literature support. The issues found to be of main interest to the problem under concern are the phenomenon of lateral acceleration, the perceived comfort and long term use of the seat with side support, the modelling of the seat / occupant interaction (as illustrated in Figure 1) and the securing function of the side support. The various design factors related to the side support, and its adjusting and static or dynamic features (see Figure 2), are expected to restrict the effectiveness of the securing function.

3. Objective, research questions and hypotheses

The objective of this study is to apprehend the levels at which selected design factors of side supports in the seat of the car driver contribute to the utility of the side support in the dimensions of support and comfort. Friction and pressure in the side support and in the seat were identified as the decisive factors, but dependent on others.

Since the evaluation of improvement must have some reference start point, an analysis of different design configurations of the side support must be done, taking into consideration a basic design configuration and starting the changes from there. The approach of our research is performing changes on a design basis and evaluating them from the aspects of support and comfort. The research questions meant to be answered by this study are:

- In what direction must the design changes occur to provide an improvement in the securing function and / or an increase in perceived comfort of the occupant?
- Can a fixed and static configuration offer a uniform level of support and perceived comfort to different occupants, within the accommodation range?
- Is there a conflict between comfort and securing effect, in the seat with side support?

The hypotheses related to these questions, considered relevant and practically testable were:

- The distance between the occupant and the side support (or rather the slack between these) conditions the support performance and the feeling of comfort. (Hypothesis 1)

- The greater the area of the side support that the occupant gets in contact with, the higher the values of lateral acceleration permitted for the same support effectiveness, and the less the discomfort in extended duration use. (Hypothesis 2)
- The higher the friction coefficient between the seat cover material and the occupant, the more support is sensed by the occupant, even if the side support is called into play at only higher levels of lateral acceleration. Less discomfort on the side areas of the occupant is sensed, but with more discomfort on the areas in contact with the seat cushion and the seat backrest. (Hypothesis 3)

4. Experimental method

4.1. Preliminary considerations

Before the presentation of the reasoning leading from the previous discussion and hypotheses established to the actual experimental design, a few remarks are made. Valid indicators of the aspects of support and comfort related to the side support are sought. How the adjustability issue, concerned with the side support, will be treated, regarding the experimental design at hand, is also presented.

4.1.1. An indicator of the functionality of the side support

A valid indicator of the functionality of the side support should unequivocally show the action of the side support. Once the action of the side support is securing the occupant against lateral acceleration, and in this process a distributed action-reaction force exists between occupant and side support, the monitoring of the value of this force, viewed against the level of lateral acceleration, should be elucidating towards the degree of functionality of the side support. The evaluation of the functionality aspect inherent to the side support in the seats must necessarily occur under the presence of lateral acceleration.

The measurement of contact pressure has been documented in several studies of sitting comfort, ex.: Lee and Ferraiuolo (1993), by the use of a pressure transducer net. A relatively dense net of pressure transducers on the side support areas of the seat would elucidate about the contact area's size and shape and the value and distribution of the contact pressure. However, the characterisation of friction is not possible with an equally objective measurement, as the one available for the pressure. Although the higher values of friction forces are likely to occur where the pressure values are higher, this is not a direct relation, since areas of high pressure may register lower values of friction forces than areas with lower pressure.

4.1.2. Indicators of (dis)comfort

The feelings of comfort and discomfort are seen as an aspect of underlying physiological processes in the human being. However, the relation between the feelings of comfort and discomfort and physical indicators of the underlying physiological processes has not yet been firmly established. Still, some researchers have reported a significant correlation between subjective assessment of discomfort and the measure of pressure in the seat / occupant contact. Thakurta et al. (1995) designed an experiment involving thirty-six subjects, who evaluated five similar cars, by completing a comfort assessment questionnaire and being pressure mapped before and after a 128 km highway drive. They found that the effect of distribution of pressure to subjective comfort is significant, with lumbar support and ischial support appearing to be more significant than shoulder and thigh support. A significant difference between the five seats was also reported.

The evaluation of seat comfort has been performed in a combination of contact pressure measurement (or other measurements such as EMG - electromyography) with subjective evaluation of the perception of comfort, Reed et al. (1991), Lee and Ferraiuolo (1993), and Thakurta et al. (1995). However, no reference was found to the inclusion of the side support, in this evaluation, under realistic conditions of use, that is, under the effect of lateral acceleration.

The availability of equipment for pressure measurement caused the choice of an objective measure, in this experimental design. This objective indicator was to be correlated to subjective comfort, apprehended through subjective comfort evaluation questionnaires, enabling a characterisation of the seat occupants' perceived comfort.

4.1.3. Treatment of the side support's adjustability

The manipulation of the design configuration of the side support in the experimental design is meant to test the hypotheses drawn in the previous chapter, and is based on a fixed configuration (non-adjustable static side support).

4.2. Trial persons (subjects)

4.2.1. General considerations

First is the question of defining a criterion for recruiting the subjects. Would we have subjects covering the variation of the accommodation range of the seats, or would we try to keep to a "standardised" subject dimension. It was also necessary to define if every subject should evaluate every seat, or only some of the seats, and how much time each trial person would be requested to spend with this study. It became clear that subjects would have to be recruited and offered some monetary compensation for the time they would spend conducting the driving sessions.

4.2.2. Subjects for the experiments: With varied dimensions covering the accommodation range, or with similar dimensions?

The advantages of having trial persons in these experiments as persons of varied body dimensions, covering the seat accommodation range were identified as: providing a more representative sample of the user population, and permitting a stronger validation of the results of the experiments. The disadvantages were seen as: a greater complexity being introduced in the data analysis, and a greater number of subjects being needed, or else the results would be very dependent on the subjects' characteristics, since they would not be evaluating the same dimensional relation (anthropometric / seat dimensions).

On the other hand, recruiting middle sized persons with close dimensions amongst themselves would bear the advantages of: providing a greater repeatability of measurements than the one possible with subjects of varied dimensions and providing a better chance of having consistent judgements between the trial persons, since they would be judging approximately the same thing. This concept for recruiting the trial persons is, however, not free of disadvantages, mainly: the validity of results is dependent on an extrapolation between groups with similar slack, but differing anthropometric dimensions.

The interest in testing the effect of slack variation between occupant and side support was the decisive argument in the choice for the second alternative - closely dimensioned subjects. If this factor was to be tested with subjects of varied dimensions, with test seats based on a fixed (non-adjustable) configuration of the side support, the number of test seats necessary would increase beyond the quantity of 4, which had been set as a practical (economical) limit.

By having "standard" dimensioned subjects and including in the experimental design test seats with two seat widths, we get assessments of two cases of the dimensional relation occupant / seat side support dimensions: "tight fit" and "loose fit". We can assume that an "undersized" fit is never good, neither in terms of comfort nor in terms of support. If one gets a strong difference between the "tight" and the "loose" test seats, it indicates that this factor is of importance. If a small, or no difference is found, then this factor is unimportant. With this procedure, we are able to make an assessment of the criticality of the dimensional horizontal fit between the seat occupant's body and the side support.

Nakaya and Okiyama (1993), present a series of cross section curves of the human back, at different levels. From a group of 31 subjects, they divided them in to three groups according to anthropometric characteristics: small, average and big. They then plotted the average curves for the back cross sections referred for each of the groups. The averaged curves are similar in shape, for the three groups. These facts presented in Nakaya and Okiyama's paper, may support the pretension of extrapolating the results achieved with much similarly dimensioned subjects to the whole accommodation range.

4.2.3. Setting up of the actual subject recruiting criteria

Once the choice of the conceptual alternative for recruiting subjects was settled, it was necessary to establish which anthropometric dimensions would be the control variables for the recruiting of the trial persons. We were looking for four trial persons with similar body widths, weights and heights, for whom the physical phenomena, taking place when they are driving with lateral acceleration and with side support in the seat, would be very much the same. For the purposes of subject recruiting, the value of the hip breadth of the subjects was set to around 350 mm. The measurements of both the hip and shoulder widths of prospective subjects were taken. The problem of the conicity of the subjects hip-torso segments, lead to the choice of having subjects of only one sex. For reasons of availability males were used. The age of the trial persons was allowed to vary between 20 and 40 years. Finally, another condition was that the trial persons should have had a driving license and some driving experience for a few years.

4.3. Test seats

The four test seats were based on the existing configuration of the reference seat. Each seat was to be the result of the manipulation of this basic configuration in three combinations of factors of variation at two levels (o – standard, + - additional): Slack between the occupant and the side support at the hip level(A), friction of the cover of the seat(B) and relative size of the side support in the hip-torso area(C). In all the test seats the foam in the side support areas of the seat was to be replaced with harder than standard foam. This is a way of overcoming the difficulty presented by the relative softness of the foam present in the reference seat. It was assumed that harder foam would highlight the differences in the geometry of the side support of the four test seats. The seat cushions of the four seats were to be kept as in the reference configuration, but the cover material of each seat cushion was to match the cover material of that seat's backrest. Table 1 presents the configuration of the test seats that was reached at, concerning the level of the three factors of variation included. Figure 3 depicts the actual test seats used in the experiments.

4.3.1. Practical decisions and limitations concerning the test seats

The seats were set as based on one seat model corresponding to a car model, so that the driving sessions could be carried out with only one car model and with specially built seats. The possibilities of factor modifications were studied under this initial period of the experimental design. A group of design factors was prioritised in terms of the interest in that group of factors and the possibilities of practical implementation of the modifications under the conditions available. The three design factors chosen are directly related to the testing of hypotheses 1, 2 and 3, which were then reformulated, as presented in section 8.2 ("Summary of the findings with practical relevance").

The adjusting of the side support was left out from the experimental design in an earlier stage of this study, but the inclusion of the factor of slack between the occupant and the side support had been confirmed when choosing the conceptual alternative for the definition of the subject recruiting criteria.

4.3.2. Design of experiments using the fractional factorial approach

Using a fractional factorial approach, Montgomery (1991) to the design of experiments, three factors of variation at two levels can be included in the four test seats, as presented in Table 1. The full factorial approach of testing three factor variations at two levels would involve 2^3 (eight) different runs (test seats). However, using only half of the runs, corresponding to $2^{(3-1)}$ (four) different test seats, allows the identification of the main effects, although aliased with two factor interactions. The use of four subjects, would, translated to the design of experiment terminology, imply having the runs replicated four times. In terms of results, the main effects will be confused with two factor interactions, but that is the price to be paid for having half the number of runs of the full factorial design. This approach to an experimental design is recommended when the cost of including all the factors in the experimental design is too high, or the number of runs necessary to test all the factor combinations included is also great. In the present situation, both conditions apply.

4.4. Data collection

How should the aspects of support and comfort be apprehended from the subjects' interaction with the test seats in the driving sessions? To enable this apprehension, the trial persons completed two kinds of subjective evaluations. The first concerns the subjective impressions of the aspects of securing effect and discomfort in the various body regions in contact with the seat side support, or with the whole seat.

The second requires an overall judgement of the seats in terms of support and comfort.

The readings of interfacial pressure between seat and occupant were meant to characterise the support and comfort aspects from an objective point of view. Video recordings of the subjects during the driving sessions were also made with the aim of characterising the support aspect of the side support.

4.4.1. Video recording for evaluation of seat / occupant displacement

Video recording, along one complete lap of the standardised driving task, provides a basis for further understanding of the differences in support offered by the different test seats, assuming a control function in the data analysis.

4.4.2. Readings of the pressure distribution over the seat / occupant contact with lateral acceleration

Pressure sensor equipment was used to register pressure prints of the subjects in the seats at simulated levels of lateral acceleration. Due to restrictions of the portability of the pressure sensor equipment available, we were not able to perform the readings of the pressure values in a dynamic car-road situation. A tilting device that enables the simulation of lateral acceleration, but only statically, was the solution found to deal with the limitations of the pressure measuring equipment.

4.5. Driving sessions

The driving with remarkable lateral acceleration was performed on a special car track with many "interesting" curves (see Figure 4). The driving sessions could be seen as a standard task. The track was secluded from other traffic and was rented. In this way, the speeds and trajectory could be precisely defined and repeated with each subject for each seat evaluation. As to the time length of the individual driving sessions and the timing of the questionnaires, our reference was a study by Reed et al. (1991). Grandjean (1988), studying office seating, showed some relevance for the definition of the duration of the seat evaluations, while Reed's study dealt with automotive seating. Each seat evaluation was performed for 50 minutes, with questionnaires being answered after the first 20 minutes and in the end of each driving session.

4.6. Summary of the experimental design reached at

Four subjects with similar body widths evaluated the test seats, in a standard driving task, in terms of support and comfort in different body regions. Subjects were driving at fixed standard speeds. They were then pressure mapped in the same seats, with varying levels of simulated lateral acceleration. Video recordings of the driving task were taken, aiming at characterising the subjects' shoulder and hip displacements in the curves. The seats were subjectively rated, in terms of overall comfort and support and in terms of egress / ingress characteristics and seat preference. The data from the questionnaires was to be correlated with the data from the pressure measurements.

5. Results

The results showed very low degree of agreement among the judgements of the subjects. The data resulting from the video recordings were not useful in the characterisation of the support features of the seats, due to inconsistency with the assumptions underlying the experimental design. It turned out that there were different driving behaviors. Drivers taking hold of the wheel and leaning into the curve and drivers allowing themselves to lean completely against the side supports. The pressure measuring equipment was new and not yet perfectly calibrated to give valid pressure distribution results.

6. Conclusions drawn from the experimental study

The results of the experiments were inconclusive towards the acceptance or rejection of the hypotheses formulated. They do not contradict the assumptions underlying the experimental design. A thorough review of the experimental design in the light of the inconclusive results, enabled the setting of the following recommendations for future experiments:

- Selection of subjects with a verbal ability to distinguish between aspects of judgement used: comfort and support.
- Reduction of the number (10) of body areas in the subjective evaluation of comfort.
- Distinction, in the questionnaires, between lateral support by normal and by friction forces.
- Increase in the number (2) of anchored expressions in the graphic scaling of the subjective evaluations.
- Redesign of driving task to include separate driving scenarios (highway, city and bending road).

Our subjective impressions, from performing driving evaluations with the test seats, were confronted with the assumptions and hypotheses underlying their design, resulting in strong agreement. A deeper understanding of how the side supports and the seat provide lateral support, and how different lateral support modes are connected to different levels of perceived comfort was attained with this study. As an example, we consider that the slack between the occupant and the side support causes bending of the spine and displacements in the head and shoulders of the occupant, before the contact with the side support occurs (in the presence of lateral acceleration).

7. Methodological overview

Following a thorough problem analysis, a careful study of the restrictions of the problem, and the setting up of the experimental design, we conducted the experiments, collecting all the data as planned. However, we ended up, due to data collection problems and unexpected behavior of the subjects, with results of the experiments that were inconclusive towards the acceptance or rejection of the hypotheses formulated in the sequence of the problem analysis.

The subjective impressions we gathered from our own driving evaluations of the test seats, plus the video recording of the subjects in their driving task, gave us a first hand knowledge of the problem. We consider this knowledge extremely valuable, since it was used as a basis for the redefinition of the problem, enabling us to understand the relevance of factors that had not been considered initially. Thus, an apparent failure, due to the occurrence of some unexpected situations, was made useful in re-evaluating the problem analysis. In a methodological sense, having kept ourselves open minded to the unexpected, enabled us to see beyond the inconclusive set of results: the test of hypotheses did not work out well, but we

gathered practical information which allowed us to create a solution (refer to the following section for an example drawn from the set of solutions produced in the sequence of this study) and to draw valuable conclusions.
What we can prove from this methodological process is that one should not expect results to always come out exactly as planned, but instead, an open mind should be kept through out, in search for valuable and useful information, concerning the characterisation of the problem at hand.

8. Practical Design Advice

Proving or rejecting the hypotheses provides no basis for practical design advice. However, based on our subjective impressions, which are in agreement with the hypotheses underlying the design of the experiments, and thus of the test seats, a few extrapolations may be made for the practical design of car seat side supports, of which we present an example bellow.

8.1. Introduction of adjustment in the side support

We are highly in favour of the introduction of adjustment in the side support, as a means of allowing seat occupants, in the whole accommodation range of the seat, to tailor the characteristics of lateral support received. The design of the test seats, and our subjective impressions of their use, enable us to make the advice of the introduction of adjustment in the distance between the opposing side supports (see Figure 5), according to the range of accommodation of the seat.

Considering altogether the friction properties, the mobility of the occupant in the seat and the maximisation of the lateral support in the adjustable side support, implies comparing the “tight” fit seats (seats C and A). The characteristics of C (excluding the greater size of the side support due to the egress/ingress problems) are probably adequate to the sporty vehicle, because of the higher friction. However, the reduced mobility inherent in that type of cover material would misadvise using the characteristics of C for the luxurious high end vehicle, where long journeys require the mobility provided by the lower friction cover material of A. Notice that the differences between A and C (with side support adjustment included) are more in terms of mobility of the occupant in the seat and eventually, of thermal comfort. The return to the central position of the occupant after passing a bend is not that important, since the adjustment allows the tight fit, where these displacements are minimised.

8.2. Summary of the findings with practical relevance

Hypothesis 1: The existence of slack between the occupant and the side support affects the perceptions of comfort and lateral support.

Acceptance or rejection inconclusive based on the results.

Accepted, based on authors’ subjective judgement. The slack causes bending of the spine and displacements in the head and shoulder of the occupant, before the contact with the side support occurs.

Hypothesis 2: The relative size of the side support in the hip - lower torso level affects the perceptions of comfort and lateral support.

Acceptance or rejection inconclusive, based on the results.

Accepted based on authors' subjective judgement. (Relevant only for non-existence of slack). Larger side support areas provide more evenly distributed and "imperceptible" lateral support.

Hypothesis 3: The friction properties of the seat cover affect the perceptions of comfort and lateral support.

Acceptance or rejection inconclusive based on the results.

Accepted, based on authors' subjective judgement. Friction differences (more notorious when slack is present) affect the level of lateral acceleration, for which there is contact with the side support. Higher friction with the existence of slack, allows bending and displacement effects on the occupant, for higher values of lateral acceleration. The lower friction facilitates the return to the central position, after the end of the bend.

Acknowledgements

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References

Coelho, D.A., 1996. An Experimental Pilot Study to Evaluate Car Seat Side Support. Master of Science thesis - Chalmers University of Technology, Göteborg, 82 pp.

Gamache, S. T., 1994. Development of a Lateral Acceleration Compensating Seat. Society of Automotive Engineers, paper no. 940216.

Grandjean, E., 1988. Fitting the Task to the Man. Taylor and Francis, London, 373 pp.

Lee, J. and Ferraiuolo, P., 1993. Seat Comfort. Society of Automotive Engineers, paper no. 930105.

Montgomery, D. C., 1991. Design and Analysis of Experiments. John Wiley & Sons, New York, 432 pp.

Nakaya, H. and Ohiyama, H., 1993. A Development of Statistical Human Back Contour Model for Backrest Comfort Evaluation. Society of Automotive Engineers, paper no. 930114.

Reed, M. P., Lee, N. S., Saito, M., Kakishima, Y. and Schneider, L. W., 1991. An Investigation of Driver Discomfort and Related Seat Design Factors in Extended-Duration Driving. Society of Automotive Engineers, paper no. 910117.

Thakurta, K., Koester, D., Bush, N. and Bachle, S., 1995. Evaluating Short and Long Term Seating Comfort. Society of Automotive Engineers, paper no. 950144.

Figure and Table Captions

Figure 1 - a) Schematic representation of forces involved in seat cushion / occupant interaction, when seat cushion has side support. b) Diagram of the bending moments occurring because of the uneven distribution of friction forces in the occupant's body and seat, when subjected to lateral acceleration.

Figure 2 – Conceptual alternatives for the principle of action of the side support.

Table 1: Test seats configuration, according to the level of each factor of variation at two levels (o/+): Slack between the occupant and the side support at the hip level (A), friction of the cover of the seat (B) and relative size of the side support in the hip-torso area(C).

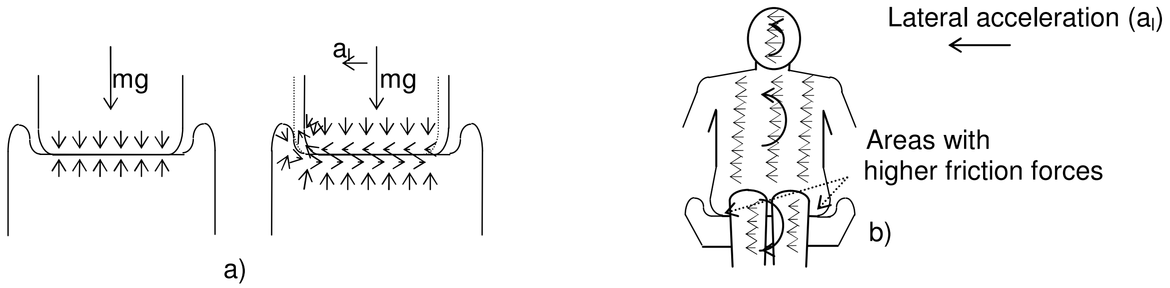
Figure 3: Photographs of the actual test seats used in the experiments. From the top right and clockwise: seats A, B, C and D.

Figure 4: Portion of the "Stora Holm" track where the driving sessions were performed, with a length of about 2000m per lap. The trajectory chosen provided a balance between curves to the right and to the left.

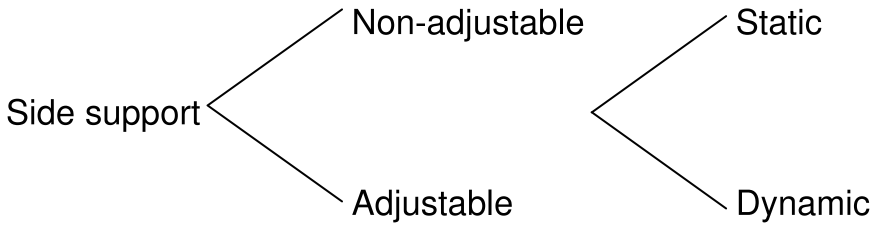
Figure 5: Adjustable side support in the dimension of the distance between the opposing side supports.

	Factor A	Factor B	Factor C
Seat ref. A	o	o	o
Seat ref. B	+	+	o
Seat ref. C	o	+	+
Seat ref. D	+	o	+

Table 1: Test seats configuration, according to the level of each factor of variation at two levels (o/+): Slack between the occupant and the side support at the hip level (A), friction of the cover of the seat (B) and relative size of the side support in the hip-torso area(C).

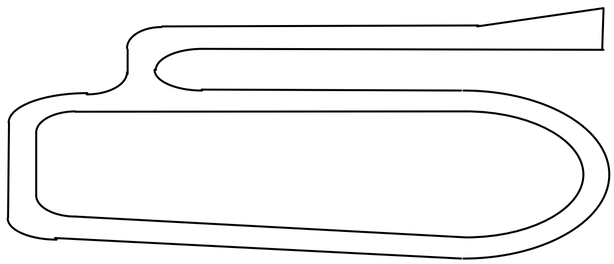

mg
a_l
mg
a)
Lateral acceleration (a_l)
Areas with
higher friction forces
b)

(Figure 1)

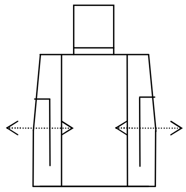


(Figure 2)

(Figure 3)



(Figure 4)



(Figure 5)

Article II

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Articulation at Shoulder Level
- an experimental study on car seat comfort

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Abstract
This article reports on an experimental study aimed at evaluating the introduction of an articulation in the upper part of the seat backrest. The idea of introducing this articulation sprang from prevention of whiplash injuries and this study assesses its potential for improvement in comfort. This was done considering a pre-defined articulation height. A height for the articulation of a distance d above the H-point of a reference seat was theoretically deducted based on a population with an average sitting height of 88cm. Subjects evaluated the articulated seat in comparison with the reference seat. Twelve subjects were divided into three groups of sitting height. In a laboratory environment subjective comfort evaluations and preferred values of deployment of the articulation and of counter-tilting of the headrest were registered. Driving in the roads completed and validated the laboratory assessments. The reference seat was less comfortable for the subjects with short and medium sitting height than for the tall ones. There was a notorious improvement in comfort for most of the medium and short sitting height subjects when using the articulated seat. The articulation was fully deployed by most subjects.

Relevance to industry: Anthropometric strata, analysis of cross contingency Tables and the comparative rationale form the basis of the method of evaluation of improvement in subjective comfort presented. Its use in other studies on car seat comfort is suggested, especially those evaluating the impact of introducing new seat features.
Keywords**:** Comfort, Redesign, Car seat backrest, Experimental study, Road driving, laboratory

1. Introduction
New safety enhancements have been introduced in car seats aiming at protecting occupants from whiplash injuries in rear end collisions. Distinct technical solutions for these enhancements exist with the common denominator of reducing the clearance from the occupant's head to the seat headrest, on the event of an impact. The introduction of an articulation in the upper part of the seat backrest is derived from this safety perspective. The question that this study is meant to answer is if such an articulation can also be used on a day to day basis to improve comfort. The underlying hypothesis being that bringing the contour of the upper part of the seat backrest closer to the curvature of the concavity of the neck and thoracic region of the spine (through

the deployment of the articulation and headrest counter-tilting compensation), improves comfort through added support to the natural curves of the back (see Figure 1).

1.1 Aim

In order to test the hypothesis stated above, it is necessary to position the articulation at a height that would be compatible with supporting the cervical curvature of the back, and to evaluate its impact on subjective comfort of the seated person. The aims of the study are therefore twofold: defining a height for the articulation in the upper part of the seat backrest, and evaluating the impact of the articulation (positioned at the defined height) on subjective comfort.

2. Deduction of a height for the articulation

This section is concerned with the rationale followed to reach at an articulation height. The goal was to increase the support to the upper back, without changing its natural posture. Two alternative approaches for attaining this goal were initially considered and assessed for feasibility, leading to a process that combined parts of these approaches and allowed inferring a value for the height of the articulation. A car seat of a car model from the high end of the market, that was deemed very comfortable, was used as a basis for the development.

2.1 Alternative ways of reasoning

Two alternative ways of reasoning were considered as starting points to define a height for the articulation. These are characterised in the sections below, considering the availability of the following data as starting points:

- the joint range of motion of the vertebrae (1);
- the curvatures of the vertebral column (2).

2.1.1 Joint range of motion of vertebrae

Ranges of simple and combined joint motion characterize motion in the sagittal plane of the vertebral column (Snyder et al., 1971; Foust et al., 1973; Kapandji, 1974; Lind et al., 1988; Stubbs et al., 1993). Snyder et al. (1971) consider that the vertebral column has three zones of distinct mobility. The mobility is rather big in the lumbar region and diminishes in the thoracic area, increasing again in the cervical region. The thoracic spine is rather stiff up to T4 (fourth thoracic vertebra). From there upwards the mobility increases to a maximum at the interface between C4 and C5 (5^{th} cervical vertebra), and then decreases again. Within the maximum range of motion of the joints, it may be possible to find narrower ranges for comfort and according to orthopedic criteria. Hypothetically, the comfort range might still be divided into short-term and long-term comfort ranges and the joint range of motion for long-term comfort might coincide with the orthopedic recommendation (Figure 2). Literature search and expert consulting proved such comfort recommendations are not established. Therefore, this way of reasoning (1) would lead to positioning the articulation pivot for compatibility with the mobility maximum in the saggital plane, which is between vertebrae T4 and C4-C5.

2.1.2 Analysis of the curvature of the vertebral column

From the geometrical representation of the curvature of the spine, overlapped to the seat backrest contour, a pivot point for the articulation would result (Figure 1).

The spine in standing position at rest is as close to the orthopedic optimum as possible (Nordwall, 1998). Branton (1984) did a survey on the backshape of British railway workers. The variability found is comparable to the dimensional variability in terms of sitting height, which differs greatly among subjects. Following this way of reasoning (2) would lead to superimposing the average back shape at rest as reported by Branton, to the seat backrest profile. This would lead to positioning the articulation pivot at the level of the highest contact point between the occupant's back and the seat backrest, providing a larger area of support to the upper back when rotating the upper part of the backrest forward.

2.1.3 The various possibilities for setting the articulation height
For alternative (1), the mobility of the spine is the main concern, while for alternatives (2) it is its shape. The highest values of joint range of motion occur in the cervical column. This however corresponds to a very high level in the seat backrest, which is not technically feasible. Therefore approach (2) was followed by superimposing Branton's statistical description of the human back to the seat contour.

2.2. The procedure followed to determine a height for the articulation
Branton's (1984) statistical and geometrical description of the average back shape was scaled to reference values of sitting height. Data were taken from Pheasant's (1996) table of anthropometric data of British adult population (19 to 65 years old). The values used were the fifth percentile female sitting height (795 mm), the 95th percentile male sitting height (965 mm) and an average of these two (880mm). The goal was to estimate the range of articulation heights resulting from considering the female 5th percentile and the male 95th percentile of sitting height, as well as a middle value. Superimposing these three backshapes to the seat contour in the saggital plane results in a series of upper contact points (one for each of the scaled average backshapes).

The backshape profiles were positioned in relation to the H-point (SAE, 1990) of the seat, allowing half of an estimated average thigh thickness to stand below the H-point quota. The H-point is intrinsic to the seat and simulates the pivot center of the human torso and thigh. It provides a landmark reflecting where people sit in the seat. The average thigh thickness considered was 157,5mm (from Pheasant, 1996), of which half is 78,75mm, the value of the displacement of the base line below the H-point where the backshapes were set. No allowances were made for deflection, neither of the seat cushion, nor of the seat backrest. The middle back shape yielded a contact point, which is a distance $\underline{d}$ above the H-point in the vertical reference direction of the seat backrest. The value of a distance $\underline{d}$ above the H-point is the articulation height that was tested in the experimental part of this study. The 5th percentile female backshape and the 95th percentile male backshape yielded values of the contact point height respectively smaller (a distance $\underline{d}_s$) and bigger (a distance $\underline{d}_b$) than the value referred for the middle sitting height considered. The resulting range from $\underline{d}_s$ to $\underline{d}_b$ was 90mm.

2.2.1 Value reached at and prediction of implications across the accommodation range
The effects on the accommodation range of an articulation height with an adjustable range of 100mm around the central value (a distance $\underline{d}$) were analyzed. A predictive analysis was made in terms of hypothesizing the benefits in terms of head to headrest clearance reduction and increased upper back support along the accommodation range, given this range of articulation height. The accommodation range was divided

into 5 categories of sitting height (extremely short, short, middle, tall, extremely tall). The backshapes were classified into straight, regular and bent. In this prediction no provision was made for the benefit of an articulating headrest, with counter-rotation, although this was to be included in the comfort assessment experiments. Benefit from the use of the articulation was expected to leave out the extremely tall subjects, most of the tall and some of the middle sized in terms of sitting height. The actual prototype seat to be used in the experiments was, however, fitted with an articulation at a fixed height (a distance d above H-point), and with adjustable counter-tilting headrests.

3. Design of experiments

Experiments aimed at testing the suitability of the articulation height and its effect on sitting comfort. A test seat was fitted with the articulation at a distance d above the H-point and with headrest counter-tilting to compensate the rotation of the headrest.

3.1 Research questions

The following research questions guided the design of experiments:

1. What is the preferred setting of the articulation?
2. What is the preferred setting of the headrest?
3. How is discomfort rated for the reference seat configuration?
4. How is discomfort rated for the articulated seat with preferred settings?
5. What is the effect of sitting height on the answer to the previous questions?
6. Can the preferred settings of headrest and articulation be correlated to seat backrest inclination?
7. Is it possible to correlate discomfort with the distance from head to headrest?

3.2 Method

The method used was to compare the results from the sitting trials using the articulated seat (seat B) with a non-articulated reference seat (seat A). The experiments were carried out in two stages. A laboratory experiment, in a controlled environment, where 12 subjects each evaluated seat A and seat B, and a road based experiment (7 out of the 12 subjects that tested in the laboratory – seat B) testing the validity of the laboratory set up.

3.2.1 Duration of the sitting trials and articulation adjustment

Reed et al. (1991) identified the threshold between short and long term discomfort at the end of the first one and a half-hour of sitting. The evaluations in the laboratory and in the road were designed to have duration of 2 hours and 5 minutes, thus enabling sufficient time for long term discomfort to be perceived. Subjects were given the first 1 hour and 5 minutes of the evaluation to find their preferred settings in the seats. Evaluations were made every 15 minutes. The first 5 minutes of the trials were used for briefing of subjects, major adjustments and familiarization with scales and procedures. At the end of each evaluation, during the first 1 hour and 5 minutes, subjects were given the choice to change the articulation angle and associated headrest counter-tilting. The changes were made with fixed increments of 5º, in the range from 0 to 25º (for the articulation angle). The headrest countertilting angles varied from 0 to 50º with increments of 10º. No adjustment changes were made in the last hour of the sitting trials. This corresponds to the four last discomfort evaluations, which were the data actually analyzed. The previous evaluations were not considered because of the changes in the configuration of the seat.

3.2.2 Laboratory experiments

An articulated seat, fitted into a stationed car, served as a basis for the conduction of the laboratory sitting trials. The subjects simulated driving while watching light entertainment films projected on a screen in front of the car (arguments for this choice of task are given in Coelho and Dahlman, 2000).

3.2.2.1 Measurements made in the laboratory experiments

In the laboratory experiments, subjective measurements of comfort were taken. Objective indicators (photographic records of postures and positions – Figure 3) were collected. These provided a control variable for the differences found in the subjective comfort evaluations between different regulations (angles) of the articulation, headrest and backrest.

3.2.3 Real driving experiments

The real driving experiments were used to validate the findings of the laboratory sessions and involved car driving in different road settings.

3.2.3.1 Patterns of driving

Since driving attitude and posture in the seat might change with the road setting, these trials were designed to include driving in alternative environments. Each subject performed driving experiments in a standardized route combining highways, city traffic, and curvy roads. Video and photographic images, taken throughout the trials, along with comfort evaluations done every 15 minutes, were the measurements performed.

3.2.4 Headrest counter-tilting

An issue concerning the articulated seat (B) used in the experiments was concerned with the tilting of the headrest and part of the backrest in relation to the rest of the seat. Occupants should be able to maintain a comfortable horizontal line sight, even when the tilted part of the seat is deployed in an extreme position. To assure this, the headrest was suited with a counter-tilting effect (see Figure 4).

3.2.5 Subjects

Prospective subjects were measured to enable the selection of subjects according to a range of established anthropometric dimensions. In order to have a group with a significant size, and to allow breaking down the total into three groups (with different characteristics) a number of subjects of 12 to 30 was considered feasible, given practical and economic limitations. Each subject would participate in two or three experiments. The actual number of subjects came to be 12, divided into three groups of sitting height, equally distributed between sexes and aged between 30 and 65 (Table 1). Attempting to represent the whole accommodation range would lead to the need of a much greater number of subjects. A selection of three groups each with a short interval of sitting height dimension enables a smaller number of subjects to be used. The groups were extracted from the distribution of sitting height of the population: one from the left tail of the distribution, another from the middle of the distribution and a third from the right tail of the population. The effect on the intervals not covered by the sitting height of the three groups can be estimated from interpolation. The left tail group (short) represented sitting height values around the 5^{th} percentile female. The right tail group (tall) represented sitting height values around the 95^{th} percentile male. The middle group (medium) represented sitting height values around the 50th percentile of the combined distribution for females and males of the distribution of sitting height (Figure 5). Each subject evaluated the two seat configurations (A - non-articulated and B - articulated) in the laboratory. Seven of the subjects further evaluated the B seat configuration while driving in roads. The experiments were divided into the laboratory experiments and the driving trials, each of these requiring about two to 3 hours of each subject's time.

4. Results

Selected results of the study are presented in this section, whereas the complete set can be found in Coelho and Dahlman (1999). Profiles of discomfort are presented, with intra-personal comparisons of discomfort for the last hour of the 2 hour and 5 minute long evaluation sessions. Angle values reached at and several cross contingency Tables relating the data are used to present the data and its analysis. Given the small number of subjects (12 in the laboratory, and 7 in the road trials) individual subject results have a heavy weight in the overall results. Non-parametric statistics are indicated for this analysis due to the following:

- small samples (number of subjects is 12, but within groups and sub-groups goes down to 2);
- use of ordered categorical scales (for example, the scale used for perceived discomfort);
- use of stepped (non-continuous) numerical variables (headrest and articulation angles).

4.1 Discomfort data

Subjects using an ordered categorical scale, adapted from Borg's (1982) CR-10 scale evaluated discomfort. Since the correspondence between the ordered categories of discomfort in the rating scale and a numerical scale is not defined, the analysis is made using the ordered verbal categories.

The method chosen to pursue the analysis of the discomfort ratings was to calculate a median value for the individuals rating of discomfort for each evaluation period. The median values for each subject and each evaluation period were calculated by two separate ways:

a) taking into account only the ratings given for the head, neck and shoulders (the body areas hypothetically more affected by the new articulation);
b) taking into account all the body areas rated (head, neck, shoulders, arms, back, buttocks and legs).

Figure 6 shows an example of a plot of median values of discomfort for one subject and all of the body areas rated. The plot concerns the result of a subject in the Younger group (30-44 years old), with a Medium sitting height (87-89 cm) and of Male sex, hence the designation of YMM. Throughout the remaining text and Tables, the subjects are identified by a code, where the first letter identifies the age group (Younger or Older), the second identifies the sex (Female or Male) and the third letter identifies the sitting height group (Tall, Medium or Short) (compare with Table 1). A number is added in the cases where further distinction between subjects is necessary (e.g. OFS1 and OFS2).

In the analysis of the aggregated discomfort ratings of the last hour of each evaluation session this separation was made again. Cross contingency tables are used to support the analysis of agreement / disagreement in subjective judgements (Svensson, 1993).

Table 2, shows that 7 subjective evaluation cross matches result in higher discomfort ratings in session type A when compared to session type B. Four of the 12 subjects are placed in the diagonal, where no difference between sessions was found. One subject is placed under the diagonal, having rated seat A more comfortable than seat B. The McNemar’s Sign test (Siegel and Castellan, 1988) was applied to this data. The conclusion being that, based on the detailed discomfort evaluations for 3 areas (head, neck and shoulders) the test seat with the preferred articulation and headrest angle settings is more comfortable than the reference configuration with a confidence level < 0,05.

In terms of sitting height groups, what can be seen is that all the subjects in the medium group have lower reported discomfort in the articulated sessions. This should not be dissociated from the fact that the subjects in the medium group had between 87 and 89 cm of sitting height and that the height of the articulation had been based on a sitting height of 88 cm. All but one of the short subjects (with 82 to 84 cm in sitting height) also had lower reported discomfort in the articulated sessions. One of the tall subjects reports higher discomfort in the articulated configuration, compared to the reference configuration.

Table 3 was constructed considering the discomfort ratings for all the body areas. It shows that 7 subjective evaluation cross matches indicate higher discomfort ratings for seat configuration A than for B. Five of the twelve subjects are placed in the Table’s diagonal, marked in black, where no difference between seats A and B was found. No subjects are placed under the diagonal.

4.1.1 Comparison between seat configurations A and B

Upon the completion of the evaluations of both seat configurations A and B, subjects were asked to indicate which of the two seats was more comfortable. Table 4 shows how the subjects answered the question. Nine subjects consider seat configuration B more comfortable than A. The answer to this question was given in terms of one of the two alternatives shown, with no in between answers allowed. However, some subjects gave the comment that they were not sure about their answer (this is indicated in parentheses in Table 4).

4.1.2 Judgements of change in discomfort

As part of the subjective evaluations of discomfort, subjects rated the change in comfort for each body area in relation to the previous evaluation. The categories were “more comfortable than last time”, “unchanged” and “less comfortable than last time”. In the debriefing questions, posed after the conclusion of both laboratory evaluations, subjects were asked whether absolute discomfort or change in comfort had been harder to evaluate. Several subjects reported it was harder to judge change in comfort, because sometimes they did not remember what had been their previous rating of discomfort. Despite this, subjects gave consistent evaluations of trend in discomfort.

4.1.3 Discomfort data from the real driving experiments

Table 5 is a cross match between medians of discomfort ratings from the laboratory and real driving experiments (seat configuration B only) concerned with the ratings for the three upper body areas (head, neck and shoulders). The Table shows that all the subjects are placed next to the diagonal, or on the diagonal. Moreover, all the subjects are in or around the cell of "no discomfort at all”.

4.2 Angles reached at in the experiments

Table 6 presents the preferred angle values reached at in the experiments. Figure 7 illustrates these angles. The subjects are ordered in sitting height groups. The values of angles of the articulation and headrest set in the laboratory experiments are shown in the 2nd and 3rd columns. The 4th and 5th column show the values reached at in the real driving experiments. In the 6th column the value of headrest angle reached at in the real driving experiments is converted to an equivalent angle, if the articulation angle of the laboratory experiments had been correct in the real driving experiments. Finally, the last column shows the algebraic difference between the headrest angle values in the 3rd column and in the 6th. This difference is the change in preferred setting of the headrest from the laboratory to real driving.

4.2.3 Backrest inclination angles

The values for the B sessions of the laboratory experiments are plotted in Figure 8 with articulation angle as parameter and headrest angle as dependant variable. Polynomial equations were fit to the data, yielding low determination coefficients (R^2).

Further plots of the data can be made, but high determination coefficients cannot be found by fitting reasonably low level polynomial expressions to the data. A multiple linear regression analysis using the method of least squares was performed to the angle data from the B type laboratory sessions. The headrest counter-tilting angle was considered dependent from the backrest inclination (br) and articulation at shoulder level (art) angles. The estimation expression used was [hr=28,4 + 1,7*art -1,1 *br]. The headrest angle (hr) is the angle extended beyond standard between headrest and upper seat backrest (Figure 7).

The standard deviation of the error in the estimated values of headrest angle was 10,8°. This is not a value high enough to validate the regression model, but the real values of headrest angles were distributed in a non-continuous range at 10° intervals. The plot shown in Figure 9 represents the real and estimated values of the headrest angle.

It seems though that more data points would be necessary to define a better regression model. On the other hand, since subjects were not primarily worried with safety, some of them had preferred headrest angles that would not be recommended from a safety perspective.

The linear regression model presented should not be considered a pure mathematical abstraction. In fact, the linear relation between headrest and articulation and backrest angles has a physical validation. It may be argued that the driver needs to keep to a horizontal line of sight. If the head is leaning against the headrest, when increasing the backrest angle, the headrest follows and so does the head. In such a situation the line of sight would be tilted upwards, if the head would follow the headrest, or additional tension would be created in the muscles of the neck. Therefore the angle of headrest to upper backrest should decrease when the backrest angle increases, justifying the negative coefficient in the expression given. Similarly, keeping the backrest angle constant and increasing the articulation angle would lead to an increase in the headrest counter-tilting. This explains the positive coefficient associated with the articulation angle in the regression expression.

4.3 Head clearance from headrest

The discomfort ratings were to be correlated with the distance from head to headrest. An exhaustive listing of measured head to headrest clearances and discomfort ratings for the head, neck and median of upper body was assembled for that purpose. The inspection of that data revealed the impossibility of establishing such a correlation with significance. It was the case that some subjects always kept their head against the headrest but still reported discomfort. Other subjects mostly kept their head away from the headrest but did not report discomfort.

5. Discussion

This section presents the conclusions from the experimental part of the study. The research questions are taken up and comments are made concerning how well they were answered. Suggestions are given on aims for studies complementing the knowledge unveiled with these experiments.

5.1 Main conclusions from the experiments

The strong conclusions that can be made from the experimental studies are:

- The reference seat configuration was less comfortable for the subjects with short and medium sitting height than for the tall ones. There was a notorious improvement in comfort for the short and medium sitting height groups when using the articulated seat configuration.
- The articulation was fully deployed by most subjects.
- The laboratory experiments were validated by the real driving experiments.
- The number of subjects was not big enough to enable establishing significant models of the relation between backrest inclination, articulation and headrest angles.

5.2 Answers to the research questions

Seven research questions were formulated to guide the design of the experiments (section 3.1). The level to which they were answered is assessed in this section.

Research questions 1 and 2 have been answered by the experiments, the illustrating data and development can be found in section 4.2.

The discomfort data presented in section 4.1 answers research questions 3 and 4, although in a partial form. This is because the data is shown in aggregated from (for a complete set of data see Coelho and Dahlman, 1999). A general trend in the evolution of discomfort data over time is not obvious when all subjects are considered.
Answers to research question 5 are presented in a separate sub-section, given below.

- Can the preferred settings of headrest and articulation be correlated to seat backrest inclination? (6)

Section 4.2.1, dealing with this problem, is where a linear regression between the three variables was established, resulting in a high standard deviation of the estimation error.

- Is it possible to correlate discomfort with the distance from head to headrest? (7)

In section 4.3 this correlation was sought, however, in only two sessions did it seem possible to establish such a correlation, leaving out the remaining 29 sessions.

5.2.1 Discussion of research question 5

- What is the effect of sitting height on the answer to questions 1,2,3 and 4? (5)

The answer to research questions 1 and 2 was resolved to sitting height in Table 6, shown in section 4.2. Sitting height did not appear to influence the preferred settings of headrest and articulation angles.

The answer to questions 3 and 4, resolved to sitting height, is presented in section 4.1. Generally, it can be inferred that subjects in the Short and Middle Sitting height group have less discomfort in the articulated seat configuration. Subjects in the tall group do not consider the articulated seat configuration more comfortable than the reference configuration. Could the "floor" effect of the discomfort rating scale explain this overlapping of judgements of the tall subjects? Since the lowest value of the scale was "no discomfort", subjects could not distinguish between the two seats if they thought that one was comfortable, but the other was simply not uncomfortable.

The subjects for whom A is more comfortable or equal to B did not act into setting the articulation in session B towards the angle it had in A (angle zero). The inspection of the complete discomfort profiles for these subjects shows that, for some of them, discomfort in the B sessions only arose after the first 1h and 5 minutes, when no changes could be made. However, similar phenomena occurred for subjects in other sitting height groups without influencing their preference of seat configuration.

5.3 Completing studies suggested

If more individuals had been used, the evidences might have been greater for a significantly different behavior of the three sitting height groups, the taller being the most outlying. An adjustable articulation height might be needed to improve the conditions for the taller persons.

Possibly, being this a study with a small number of subjects, another study could be suggested with more individuals. In such a study the articulation, headrest and backrest inclination angle values would be used in order to calibrate the model of the relation between these three angles, for product development purposes. This is justified because if the relations between the three angles are established, adjusting two of them would set off the third, possibly making the product more easy to use and pleasurable.

From the three sitting height groups studied (82-84, 87-89 and 92-94 cm) the group with more unexpected results was the tall one. However, the choice of sitting heights was based on an average population, and does not cover the whole spectrum for which the reference seat was designed. Therefore, a completing study is suggested exploring the effects of the introduction of articulation for the tall (92-94 cm) and the very tall (above 94 cm).

6. Conclusion

In this study, an articulation height of a distance d was defined for an occupant with an average backshape and 88 cm of sitting height. The articulation was fitted into a standard car seat, designed for a population with a different average sitting height. While most of the shorter (82-84 cm) and medium (87-89cm) subjects reported less discomfort when using the articulation and associated counter-tilting headrest, most of the tall subjects (92-94cm) were equally comfortable in both the standard and articulated seats. The preceding facts do not establish sufficient evidence to argue for a placement of the articulation in relation to an occupant with a sitting height above the average for the population accommodated in the seat. This is not obvious from the experimental results, since the results of the tall subjects were not thoroughly understood. However, this topic would benefit from completing research.

Since relief of discomfort was the phenomenon discussed, the tall subjects, who had no discomfort in the reference seat configuration, had no discomfort to be relieved by the use of the articulation and counter-tilting headrest. Therefore, the results of the experiments included in this study are very dependent on the seat platform used and the sitting height chosen to define the articulation height that was tested. This does not exclude the potential for a general improvement in comfort given an adjustable height of the articulation. However, the increase in the number of seat adjustments calls for a simplification of the adjustment controls (by associating several of the controls). This would contribute to the user friendliness of the seat adjustments, without limiting the possibilities to improve comfort.

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References

Borg, G., 1982. A category scale with ratio properties for intermodal and interindividual comparisons. In: H.-G. Geissler and P. Petzold (Eds.), H.F.J.M. Buffart and Y.M. Zabrodin (co-eds.), Psychophysical judgement and the process of perception, VEB Deutscher Verlag der Wischenschaften, Berlin, pp.24-34.

Branton, P., 1984. Backshapes of seated persons – how close can the interface be designed? Applied Ergonomics, 15(2): 105-107.

Coelho, D.A. and Dahlman, S., 1999. Articulation at Shoulder Level - A way to improve car seat comfort?, Technical report - University of Beira Interior, Covilhã, Portugal and Chalmers University of Technology, Göteborg, Sweden, 159 pp.

Coelho, D.A. and Dahlman, S., 2000. Evaluation of methods, approaches and simulation quality in the experimental evaluation of car seat comfort. Proceedings of the International Ergonomics Association 14th triennial congress and of the Human Factors and Ergonomics Society 44th annual meeting, San Diego.

Foust, D.R., Chaffin, D.B., Snyder, R.G. and Baum, J.K., 1973. Cervical Range of Motion and Dynamic Response and Strength of Cervical Muscles. Proceedings of the 7th STAPP Car Crash Conference, pp 285-308.

Kapandji, I.A., 1974. The physiology of the joints: annotated diagrams of the mechanics of the human joints; translated by L.H. Honore, Vol. 3 - The trunk and the vertebral column. E. & S. Livingstone, London, 256 pp.

Lind, B., Sihlbom, H., Nordwall, A. and Malchau, H., 1988. Normal range of motion of the cervical spine: A clinical and radiographical study. In Bengt Lind

(Ph.D. thesis). The halo-vest in the treatment of unstable cervical spine injuries; University of Gothenburg and Dept. of Orthopaedics, Sahlgren Hospital, pp. 61-68.

Nordwall, A., 1998. Personal communication.

Pheasant, S., 1996. Bodyspace - Anthropometry, Ergonomics and Design. Taylor & Francis, London, 244 pp.

Reed, M.P., Saito, M., Kakishima, Y., Lee, N.S. and Schneider, L.W., 1991. An investigation of driver discomfort and related seat design factors in extended duration driving, Society of Automotive Engineers Technical Paper No. 910117, Warrendale, PA.

Society of Automotive Engineers, 1990. SAE J826 recommended practice. In, 1990 SAE Handbook, on Highway Vehicles and Off Road Highway Machinery; Vol. 4, Warrendale, PA.

Siegel, S. and Castellan, Jr., J.N., 1988. Nonparametric statistics for the behavioral sciences. Mc Graw-Hill, New York, 399 pp.

Snyder, R.G., Chaffin, D.B. and Schutz, R.K., 1971. Link System of the Human Torso. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, Report No. AMRL-TR-71-88.

Stubbs, N.B., Fernandez, J.E. and Glenn, W.M., 1993. Normative data of joint ranges of motion of 25- to 54-year-old males. International Journal of Industrial Ergonomics, 12: 265-272.

Svensson, E., 1993. Analysis of systematic and random differences between paired ordinal categorical data. Almqvist & Wiksell International, Stockholm, 480 pp.

Captions (Figures and Tables)

Figure 1: Concept of the articulated seat meant to increase the support given to the back in its natural posture, showing the pivot in the upper part of the backrest and associated headrest counter-tilting.

Figure 2: Schematic representation of the mobility of the spine (hypothesizing the distinction between maximum, orthopedic and short or long term comfortable ranges).

Figure 3: Evaluation in the laboratory.

Figure 4: Sketch of headrest configuration alternatives to correct for a horizontal line of sight, especially when tilting of the headrest is pronounced.

Table 1: Actual panel of subjects performing the laboratory experiments (F-female, M-male).

Figure 5: Graphical representation of the rationale for setting the sitting height of the three subject groups.

Figure 6: Example of plot for evaluations of discomfort of one subject in the laboratory, for both seat configuration A and B (highest discomfort – 6; no discomfort – 0).

Table 2: Cross match of medians of aggregated discomfort ratings for laboratory sessions A and B. The Table refers to the three upper body areas rated (head, neck and shoulders).

Table 3: Cross match of medians of aggregated discomfort ratings for laboratory sessions A and B. The Table refers to all the body areas rated (head, neck, shoulders, arms, back, buttock and legs).

Table 4: Subject answers to the direct question “which seat is more comfortable?” after completing the last of the two laboratory evaluations.

Table 5: Cross match of median of discomfort ratings between laboratory and real driving, based on three ratings (head, neck and shoulders).

Figure 7: Representation of the headrest, articulation and backrest angles in the seat.

Table 6: Preferred angles.

Figure 8: Headrest angles (hr) plotted as a function of backrest inclination angle (br) and parameterized to articulation angle (art). All the values shown are in degrees.

Figure 9: Estimation of headrest angles, based on improved estimation expression, compared with real experimental values (laboratory).

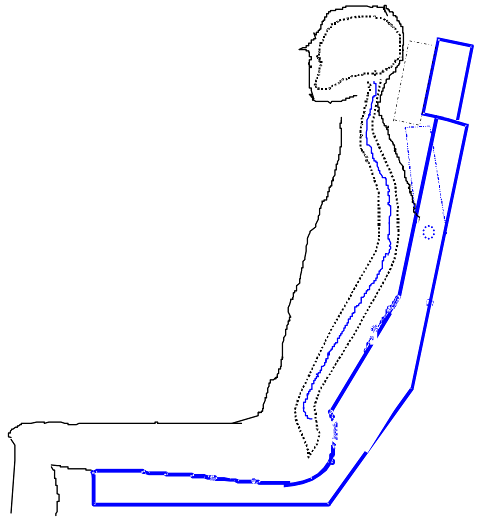
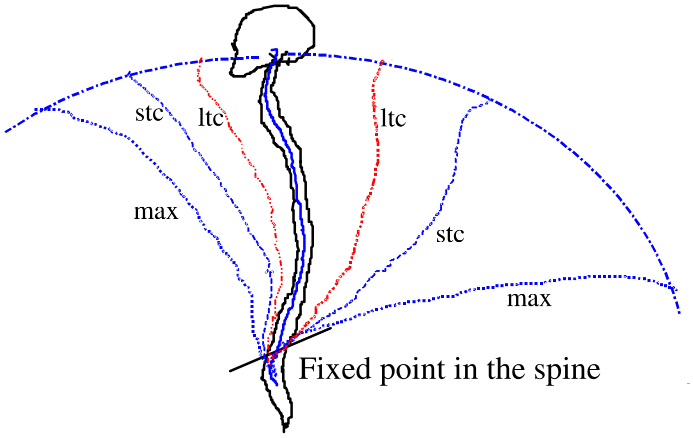


Figure 1: Concept of the articulated seat meant to increase the support given to the back in its natural posture, showing the pivot in the upper part of the backrest and associated headrest counter-tilting.



max - Limits of the maximum spinal posture range
stc - Hypothetical limits of the spinal posture range for short-term comfort
ltc - Hypothetical limits of the spinal posture range for long term comfort (coinciding with the orthopedical limits)

Figure 2: Schematic representation of the mobility of the spine (hypothesizing the distinction between maximum, orthopedic and short or long term comfortable ranges).

Figure 3: Evaluation in the laboratory.

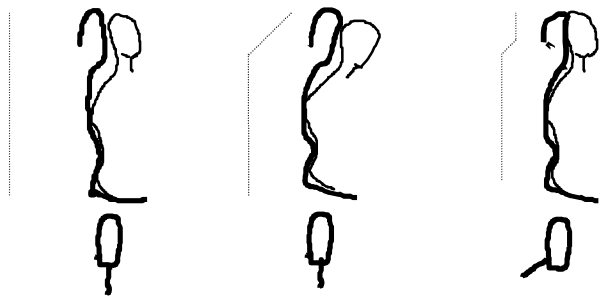


Figure 4: Sketch of headrest configuration alternatives to correct for a horizontal line of sight, especially when tilting of the headrest is pronounced.

Age	Sitting Height (cm) 82-84 (Short)	87-89 (Medium)	92-94 (Tall)	Total
31-44 (Young)	2F	1F + 1M	2M	3F + 3M
50-65 (Old)	2F	1F + 1M	2M	3F + 3M
Total	4F	2F + 2M	4M	6F + 6M

Table 1: Actual panel of subjects performing the laboratory experiments (F-female, M-male).

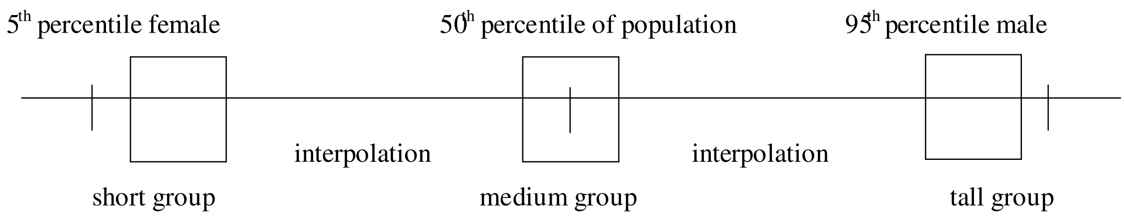


Figure 5: Graphical representation of the rationale for setting the sitting height of the three subject groups.

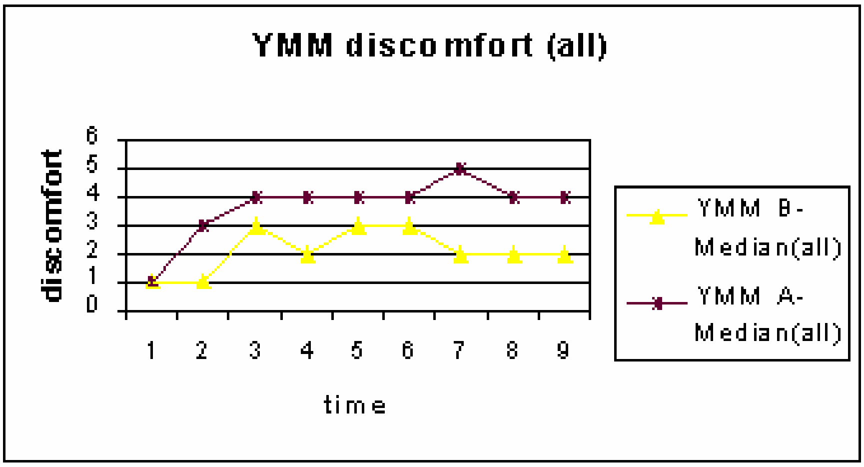


Figure 6: Example of plot for evaluations of discomfort of one subject in the laboratory, for both seat configuration A and B (highest discomfort – 6; no discomfort – 0). The letters YMM refer to the designation of the subject: Y - Young, M – male, M - medium.

median 6-9

B/A (3)	none	extremely weak	very weak	weak	moderate	strong	…	Session A
none	**YMT1, YMT2, YFS2**		**OMM, OFM, YFM**	**OFS2**				
extremely weak		**OMT2**				**YMM**		
very weak	**OMT1**			**YFS1**				
weak					**OFS1**			
moderate								
strong								
…								
SessionB								

Table 2: Cross match of medians of aggregated discomfort ratings for laboratory sessions A and B. The Table refers to the three upper body areas rated (head, neck and shoulders).

median 6-9

B/A (all)	none	extremely weak	very weak	weak	moderate	…	Session .
none	**YMT2, OMM, YFS2**	**OMT1**	**YFM**	**OFS2, OFM**			
extremely weak		**OMT2, YMT1**		**YFS1**			
very weak					**YMM**		
weak					**OFS1**		
moderate							
…							
SessionB							

Table 3: Cross match of medians of aggregated discomfort ratings for laboratory sessions A and B. The Table refers to all the body areas rated (head, neck, shoulders, arms, back, buttock and legs).

Seat B is more comfortable than A	**Seat A is more comfortable than B**
OMT2 (unsure), YMT2, OMT1, OMM, YFM, YMM, OFS1, OFS2, YFS1	YMT1, YFS2, OFM (unsure)

B – articulation and headrest angles set to the subjects' choice. A – test seat set to reference configuration (no use of non-standard adjustments).

Table 4: Subject answers to the direct question "which seat is more comfortable?" after completing the last of the two laboratory evaluations.

lab/road (3)	none	Extremely weak	Very weak	…	road
none	YMT2, YFM, OMM, OFM	**OFS2**			
Extremely weak	**OMT2**				
Very weak		**YFS1**			
…					
lab					

Table 5: Cross match of median of discomfort ratings between laboratory and real driving, based on three ratings (head, neck and shoulders).

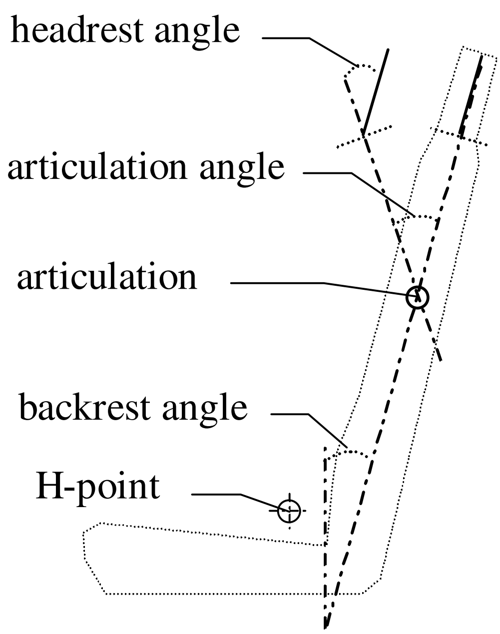


Figure 7: Representation of the headrest counter-tilting, articulation and backrest angles in the seat.

Sub-ject	Laboratory experiments art (°)	Laboratory experiments headrest (°)	Real driving experiments art‡ (°)	Real driving experiments headrest (°)	Lab. eq. to R.d.e. headrest (°)	Change (°)
OMT1	20	40	-	-	-	-
OMT2	25	50	22,5	45	50	0
YMT2	20	10	22,5	15	10	0
YMT1	15	30	-	-	-	-
YMM	20	50	-	-	-	-
OMM	20	20	22,5	25	20	0
OFM	20	40	22,5	40	35	-5
YFM	25	50	22,5	45	50	0
YFS1	20	50	22,5	45	40	-10
OFS1	25	40	-	-	-	-
YFS2	25	50	-	-	-	-
OFS2	25	50	22,5	50	55	+5

(‡) The articulation was not adjustable in the real driving experiments, but set to a value of 22,5°.

Table 6: Preferred angles.

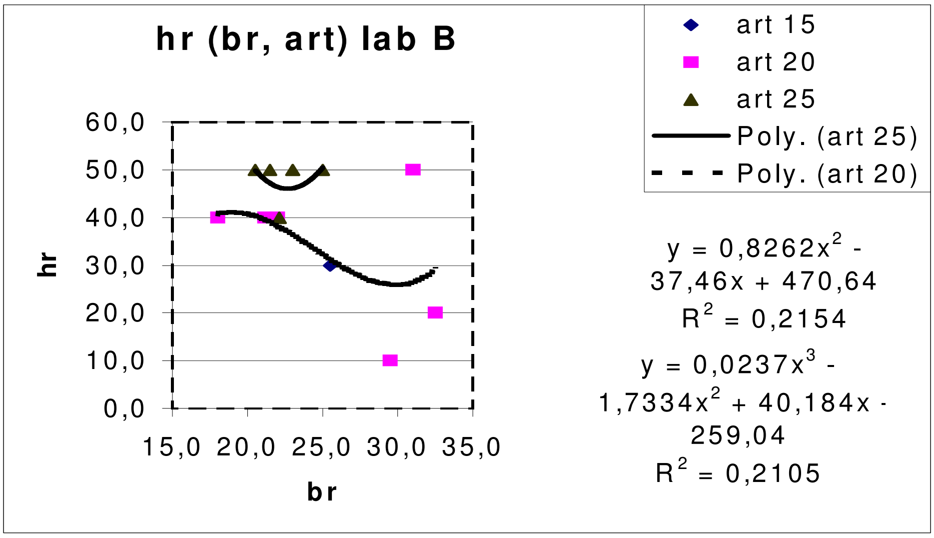


Figure 8: Headrest angles (hr) plotted as a function of backrest inclination angle (br) and parameterized to articulation angle (art). All the values shown are in degrees.

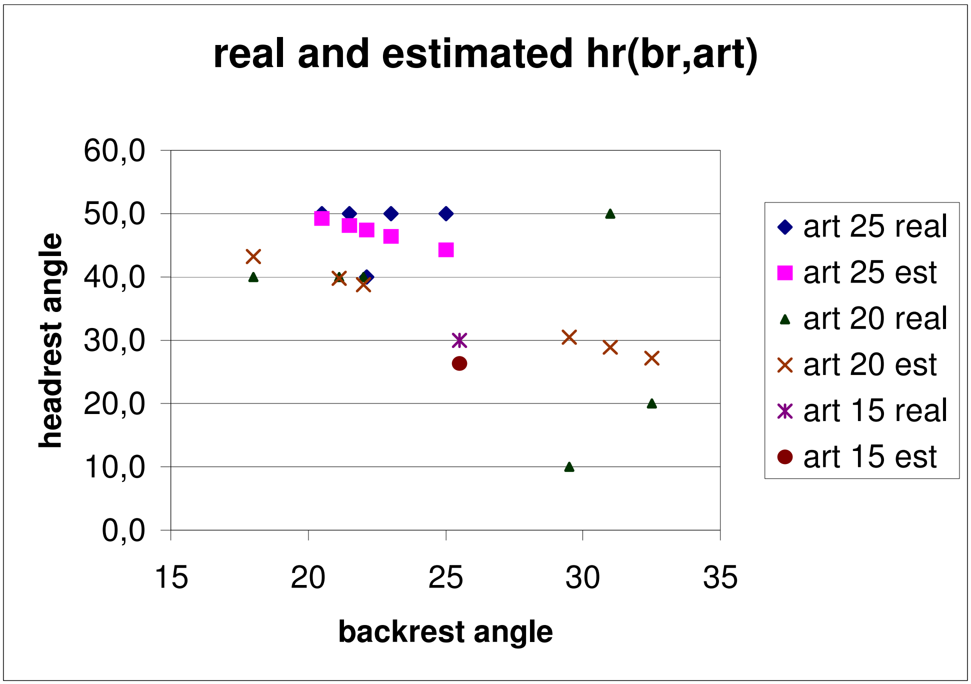


Figure 9: Estimation of headrest angles, based on improved estimation expression, compared with real experimental values (laboratory).

Article III

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Seat Comfort
– an evaluation perspective on the feasibility of index formulation

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Abstract
This study aims at exposing and integrating multiple aspects of comfort, which is seen as a concept and as a branch of ergonomics science, and to analyse the feasibility of formulating an index for seat comfort (in analogy with established indexes for thermal comfort). Having identified automobile seat comfort as an encompassing illustration of comfort, and one that has been the object of a substantial amount of research, the analysis is based mainly on experimental studies in this area. These are critically analyzed in terms of their approach to seat comfort evaluation. The review yielded the inference that the field of seat comfort has yet to attain, among the researchers, a theoretical and methodological consensus. Given the great number of factors identified that may contribute to seat discomfort and comfort, the formulation of a predictive index of seat (dis)comfort would require a coordinated effort in research, at a large scale.

Keywords: Multidimensionality; Design; Methods; Predictive Indexes.

1. Introduction

Comfort is a concept that is receiving growing interest from consumer product manufacturers. Sawaki and Price (1991) consider that factors such as comfort, pleasure and usability increased the relative importance for consumer products. Ergonomic design, in general, and comfort in more specific cases, is used as a marketing argument for many products. The development of measurements that could be used to assess these claims is in many cases still ongoing. In the case of comfort, there are no indexes available to evaluate the degree of comfort offered by a product in interaction with people (to the exception of thermal comfort, which however relates to the thermal environment). The need to create an index of comfort, that can be used to compare the level of comfort mediated through differing products, is justified with the convenience of valuing and predicting comfort. On the other hand, if the present shortening in design and market placing lead times of new products is taken into account, it is self-evident how this type of predictive tools would ease design aimed at achieving comfort both in terms of cost and time.

In this report, the idea that comfort is a multidimensional concept (Karlsson and Rosenblad, 1998) is taken as a basal premise. This statement is illustrated with definitions found in several fields of knowledge (thermal comfort, general comfort), eventhough in the core of the present analysis lies the comfort of seats (namely, automobile seats). Experimental research (Coelho and Dahlman, 1999a, 1999b) was the departing point over which a categorized and multidimensional understanding of comfort in automobile seats was established along with an overview of relationships between objective unidimensional measures and subjective (dis)comfort.

2. Aims and method

Besides illustrating the multidimensionality of comfort, using the example of automobile seats, this study aims at exposing and integrating diverse aspects of comfort. Moreover, its intent includes giving a contribution to the exploration of the possibilities for creating an index of seat comfort, in order to evaluate and compare the level of comfort offered by different seats. This would bring seat comfort to the level of thermal comfort, which has had for three decades integrative tools that can predict thermal (dis)comfort and the percentage of people dissatisfied with the thermal environment (Fanger, 1972), without having to resort at every occasion to human subjects as assessment tools. In short, the aims of the work are:

a) to expose and to integrate the multidimensionality of comfort
 and
b) to assess the feasibility of formulating an index of seat comfort.

3. The concept of comfort

In this article, a human centered view of comfort as a human requirement on engineering design is embraced. This section is aimed at presenting several generic definitions of comfort. According to Maldonado (1991), comfort is a modern idea, diffused in the period following the Industrial Revolution, associated with quality of life. This author defines comfort as that which a particular environmental reality can provide in terms of convenience, easiness and habitability. These considerations are reflected in Maslow's (1970) hierarchy of human needs, since comfort can be related with various levels of this hierarchy. It can be seen as catering to physiological needs (e.g. through shelter from cold), to needs of safety (e.g. through physical aspects), or to needs of self-respect (e.g. through consolation). Comfort is also defined, in a simple manner, as the absence of discomfort (Hertzberg, 1972), and has more recently been associated to the sensations of relaxation and well being (Zhang *et al.*, 1996).

Since comfort is a multidimensional entity, it is hard to find a definition of comfort that is sufficiently holistic, but at the same time categorized, although several definitions can be found in literature. According to Slater (1985), comfort is a pleasant state of physiological, psychological and physical harmony between a human being and the environment. These definitions, albeit in different wordings, presume, as a preceding stance, the division of the concept of comfort into a number of parcels that together form the perceived sensation of comfort. Interestingly, Slater's definition leaves out emotional, social and cultural variables, focusing on behavioral and experience aspects linked to the body (physiological, physical) and to the mind (psychological or cognitive). From this perspective, pleasure with products can be seen as a continuation of comfort, since it is considered as the emotional, hedonic and practical benefits of the interaction with products (Jordan, 1997).

4. Comfort categories

Different categories of comfort are considered in the following discussion: thermal comfort, comfort at the human interface and automobile seat comfort. Notice that thermal comfort may be a part of the latter, and that automobile seat comfort is an encompassing illustration of both seat comfort and of comfort when it is seen from the perspective of the task of driving.

4.1. Thermal comfort

Thermal comfort, one of the examples of comfort categories, was defined by Fanger (1972) as a state of mind that expresses satisfaction with the thermal environment. Compare this with Slater's definition and notice that the difference pertains to the multidimensionality of the comfort outcome side (physiological, physical and psychological as opposed to thermal). In the thermal comfort case, the multidimensionality of comfort is also present in the conditions established for thermal comfort (depending on six variables – see Figure 1). The correlation between objective measures and indicators of subjective (thermal) comfort is well established and is widely used to condition artificial environments for thermal comfort.

4.2. Comfort at the human interface

An area that has been the object of more recent research is comfort at the human interface (with e.g. seats, beds, footwear), using pressure measurement and subjective rating of (dis)comfort (Goonetilleke, 1998). Several attempts have been made to correlate these two measurements for the specific case of automobile seats (Kamijo *et al.*, 1982; Lee and Ferraiuolo, 1993; Coelho and Dahlman, 1999b; Gyi and Porter, 1999). However, given the general multidimensionality of comfort, also present in the category of comfort at the human interface, these attempts have not attained success, since the following hypothesis has not been proved: 'high values of pressure or big pressure gradients over time are indicators of increased discomfort'.

4.3. Automobile seat comfort

Automobile seat comfort, as an application class of seat comfort, has a level of complexity that exceeds many instances of seat comfort (e.g. office seats). This is due to the multitude of demands that are imposed on the driver of an automobile and the combination of restrictions that add to the complexity of the design and use situations. However, many other applications have analogous sets of complex demands: lorry driver seats, earth moving equipment cabin seats, control room operator seats, crane cabin seats, lumbering machine seats or flight cockpit seats. The particularities of automobile seats are linked with the restrict work space and the need to provide extra seat functionality and adjustments to suit a wide population range, while assuring an efficient and comfortable interface between the human and the machine and supporting the safe and efficient performance of the driving task. It can be argued that such an enterprise of attempting to grasp and characterize the sitting comfort dimension of comfort would be easier if one were to start from a lower level of complication of seats, say an office chair, or at a simpler level, a kitchen chair or a wooden stool. The opening of the problem to multiple variables from its conception may be advantageous to enable the universality of methods subsequently developed, safeguarding their wide applicability. The development of methods and its progress, however, might benefit from departing from the simpler level of complexity of seats in the direction of a growing complexity.

In the case of automobile seat comfort, several factors contribute to the composite subjective impression that is comfort. This set of factors can be divided between factors pertaining to the human body, factors pertaining to the seat and the result of the interplay between these two entities. The factors identified by Shen and Galer (1993) were the force applied to the body, the prescribed and the preferred posture of the sitting person, the freedom of movement of the body in the seat and the time spent in the same posture by the seated person. There are also characteristics of the seat interface to consider (its area, contour, stiffness, thermal isolation and friction properties). The design of the side supports, the contour of the backrest and the possibilities for adjustment are also influencing factors (Coelho and Dahlman, 1999b). Thus, the development of a model of subjective comfort in seats should consider factors of the three different types mentioned.

Should we focus on a concrete case, the driving workstation of an automobile vehicle, we would be able to elucidate the three components of the definition that Slater (1985) gives of comfort (Figure 2). In this manner, we will have, on the one side, the aspect of comfort in the human interface based on the seat (Reynolds, 1993), having a physiological nature (contact pressure, seat hardness, thermal comfort); on the other side, the postural and biomechanical aspects (and those of reach, vision, anthropometrics, mobility, equilibrium, dynamics and ride quality) that condition the component of physical comfort; and finally, we will have the psychological aspects, related to the execution of the driving task (traffic conditions, meteorological conditions, familiarity with the route and the vehicle) and to the psychological context in which the driver is inserted. Some of the factors of the composition of comfort that derive from the psychological situation of the driving context can be linked to pleasure. In this field, some work has been done in considering aspects of comfort that intercept pleasure (Coelho and Dahlman, in press). Although the comfort definition considered (cf. Slater, 1985) is quite broad, it does however leave out the aspects of emotion and pleasure.

4.4. Comfort and discomfort

The study of Zhang *et al.* (1996) considers that comfort and discomfort are two variables that complement each other but that do not constitute a continuum. Furthermore, these authors concluded that poor biomechanical conditions promote discomfort in sitting, but the absence of discomfort is a necessary but not sufficient condition for the existence of comfort. This perspective clashes with Hertzeberg's (1972) simple definition of comfort ("the absence of discomfort"), but makes sense when comfort is taken beyond the physiological and physical components of Slater's (1985) definition.

5. Unidimensional objective measures and subjective (dis)comfort in seats

According to Muckler and Seven (1992), the distinction between "objective" and "subjective" measures is neither significant nor useful in human performance studies.

This statement is presented supported on the argument that all measurements in science and technology have implicit subjective elements. Generally, however, literature on seat comfort embraces this implicit convention to distinguish between two types of measures (pertaining to subjects evaluation and to data that is measured through physical equipment), and this convention is adopted in this report. Objective measures are typically unidimensional, while the general ratings and preference are multidimensional.

In order to proceed in tackling the problem of creating a predictive index of seat discomfort, we will mention basic seat design guidelines for accommodation and health and studies that aim at unveiling relationships between objective variables and subjective comfort. We consider studies dealing with the following unidimensional objective measures, used in the evaluation of seat comfort: Muscular activity (EMG – electromyography), posture (postural angles), interface pressure and elasticity and dampening of the seat. Time sitting and frequency of posture changes are also considered.

5.1. Basic accommodation and health requirements

There is a set of basic accommodation and health requirements associated with seats. The seat cushion size should be dimensioned for accommodation of the seated occupant's buttock and thigh dimensions. The cushion must be contoured and soft at the 'waterfall' under the knee to avoid occlusion of fluids in the leg (Åkerblom, 1954). Lateral space in the seat backrest must accommodate the physical dimensions of the torso. Horizontal adjustments (common in vehicle seats) should accommodate differences in leg length that are associated with seat cushion height and preferred knee angle. Seat back angle adjustments are intended to accommodate differences in occupant preferred hip angle, and have an effect on intervertebral disc pressure. Orthopedists have studied low back pain and the exposures that might possibly be the cause for it, without, however, reaching at a conclusive understanding of the causal mechanisms (SBU, 2000). Our extrapolation to seat design is that the connection between seat design properties and low back pain is not thoroughly understood either. A general recommendation of orthopaedists is that a good seat should support the natural curves of the back. Pheasant (1996) corroborates this opinion and recommends that, in designing a seat, the lumbar spine should be supported in its neutral position (i.e. with a modest degree of lordosis) without the need for muscular effort. This can be achieved by a semi-reclined sitting position with a backrest contoured to the form of the user's lumbar spine. However, seat back inclination was proven to have less effect on lumbar lordosis than the supporting surface (Porter and Norris, 1987). These guidelines illustrate knowledge that has been gathered as human requirements on seat design, and that is commonly faced as pre-conditions for seat comfort.

5.2. Muscular activity (EMG – electromyography)

The interest in studying muscular activity to characterize seat comfort is based on the hypothesis that reduced muscular effort promotes sitting comfort. In order to assess the relationship between these two variables, Reed *et al.* (1991) carried out an electromyography study of the activity in the torso muscles of a sample of 8 people of the male sex. The subjects performed sitting trials in four different automobile seats, during a period of 3 hours in each seat. The study reveals that EMG measurements were confounded with subjects' voluntary motions, hence preventing assessment of variance in the levels of muscle activity. Still, episodes of more higher muscular activity were more frequent in seats with firmer padding and smaller width, corresponding to posture shifts. The study does not conclude in terms of the relationship of muscular activity with subjective comfort. The study by Reed *et al.* (1991) also identified a threshold sitting time of about one and a half hour separating short term from long term subjective comfort impressions. In another study, Lamotte *et al.* (1996) used surface electromyography to investigate the headrest comfort in automobile seats, with the participation of 8 volunteers. The study assumed that the automobile seat used was more comfortable when suited with a headrest than without one. However, differences found between experiments with and without headrests were weak. Only half of the subjects exhibited lower surface electromyography with a headrest. The study advocates the need for the development of inductive methods (comprehensive analysis of events in data using accelerometer data and video of the subject) to explain unexpected results. Our experience from field studies in automobile seat comfort (Coelho and Dahlman, 1999a) shows that many people do not use the headrest as a support for the back of the head but use it either as a support for the neck or do not use it at all; we also observed people who get into contact with the headrest occasionally, as a result of posture changes.

5.3. Posture (postural angles)

The amount of posture change that occurs during sitting has been sought for use as an aspect of behavior and indicator of seat comfort. However, difficulties have been found with using this concept – it is generally agreed that some changes in posture are desirable, and of course some are necessary due to task demands (Corlett, 1990). Orthopaedics, as well as ergonomics, recommends frequent or at least occasional changes of position. This calls for a 'dynamic' seat that allows easy changes of sitting posture (Grandjean, 1993). Seat dimensions, contour, stiffness and cover materials should enhance the occupant's ability to change positions, since comfortable support for many postures is essential. In an experiment using a static adjustable platform, simulating the automobile driving workstation, Porter and Gyi (1998) aimed at finding the optimum posture that would promote comfort in automobile driving, by recording the preferred posture angles of the participating subjects. These authors present the aggregated ranges of joint angles adopted by the subjects when requested to find a comfortable posture in long term sitting evaluations (two and a half hours). This kind of data is clearly useful to define the ranges of adjustment of seats, but it cannot be used to prescribe the exact seat configuration that leads to postural comfort given the wide variation in individual body sizes, shape and preferred postures.

5.4. Interface pressure

Interface pressure results from the contact between the human body and the seat, and is influenced by the physical characteristics of both. The body is composed of soft and hard tissues that have different load-deflection characteristics. The seat contour, the presence of upholstery seams, the different foams used in the padding and the seat suspension combine in promoting a heterogeneous load-deflection relationship throughout the seat area which gets in contact with the occupant. Thus, the distribution of interface pressure represents a complex interaction between the occupant and the seat. Experiments have shown that a flatter seat cushion surface will raise pressure under the ischial tuberosities and a contoured surface will distribute pressure under the soft tissues (Pheasant, 1996). However, Gyi and Porter (1999) demonstrated that the simple quantification of interface pressure as an indicator of discomfort is not satisfactory, precluding the feasibility of establishing a direct cause and effect relationship between pressure and discomfort in seats. Furthermore, Goonetilleke (1998) introduced the concept of a threshold value of pressure (the 'mean tolerance value') to delineate between the experience of a positive sensation and discomfort. For the purpose of seat design, this author suggests that if mean contact pressure is below the threshold value it would be best to distribute the forces, while higher pressures, closer to the 'mean tolerance value', should be localized to relieve discomfort caused by simultaneous neuron firings over large areas.

5.5. Elasticity and dampning of the seat

Exposure to vehicle vibration has been linked to the occurrence of low back pain (Troup, 1978). Thus, seat design must consider seat dynamic properties, the vibration transmitted to the seat occupant and their effect on comfort (and health) of the occupant. A study by Park *et al.* (1998) found significant correlation between subjective comfort of the seated person and some technical properties of seats. The sample was composed of 35 male subjects, with sitting trials lasting 30 minutes in 7 different seats. The main variables significantly associated with comfort were the level of deformation of the seat and its backrest and also the dynamic constant of elasticity and the hardness of the foam padding in the seat and backrest. Moreover, Ebe and Griffin (2000-a) have shown that subjective judgements of overall seat discomfort (in flat seat cushions made of foam and wood, without any upholstery, contour or backrest) are influenced by both static seat characteristics (e.g. seat stiffness) and dynamic seat characteristics (e.g. vibration magnitude). In a subsequent report Ebe and Griffin (2000-b) presented a predictive equation of overall subjective seat discomfort based solely on seat stiffness and vibration magnitude variables, and assuming the form of Steven's psychophysical law. These results indicate a certain tolerance to vibration caused by discomfort, which however decreases with the further increase of vibration dose and the increase of seat stiffness.

5.6. Literature critique

The experimental studies mentioned in the four previous sub-sections (5.2 through 5.5) tackle the problem of predicting subjective seat comfort from different ends, but none aims at investigating and obtaining results on the combined effects of the four classes of unidimensional variables, presented above, on overall seat comfort / discomfort. This literature review yielded the inference that the field of seat comfort has yet to attain, among the researchers, a theoretical and methodological consensus. Lack of consensus at the theoretical level can be found in the apparent dispersion of efforts in studying objective variables that explain subjective perceived comfort. Methodologically, the approaches to evaluation design also differ substantially, independently of the aims of the studies (basic research or design development). This lack of methodological consensus is obvious in the scales used for subjective rating of comfort / discomfort. In some cases comfort is rated as good or bad, in others, discomfort only is rated, others still, consider a comfort / discomfort continuum with a neutral point in between. Finally, in the case of paired comparisons, comfort or discomfort are rated incrementally.

The results of Park *et al.* and of Ebe and Griffin, quoted above, give some enlightenment towards creating an index of subjective comfort / discomfort of the seated person. However, the aforementioned authors do not include postural, pressure interface or muscular activity variables in their studies of static and dynamic factors affecting seat comfort. The use of the paired comparisons method by Ebe and Griffin to subjectively rate different seats has the consequence that the ratings of overall seat discomfort predicted from their equation are not absolute and represent increments of the level of discomfort. Their approach to the experimental design is however in agreement with the reflection presented earlier in this report advocating for a growing level of seat design complexity to proceed in tackling the problem of seat comfort prediction (see section 4.3).

5.7. Towards a seat comfort index

Researchers in the field of seat comfort have made efforts in laying the foundations for the development of a predictive index of seat comfort / discomfort. Work has been done separately considering different unidimensional objective measures, but no index has been produced and validated. Refering to Figure 2, the index that is sought, concerns the integrated perception of comfort. This integrated perception, however, springs from the combination of comfort mediated through physiological, physical and psychological processes. In our opinion, indexes pertaining to the physiological and physical components of seat comfort appear to be within reach, considering the efforts that have been made, as reported in the literature review presented above, an index for physiological comfort seems to be attainable in the near future.

The results of Zhang *et al.* (1996) lead to considering it more difficult to empirically deduct an index for comfort than one for discomfort. This conclusion is analogous to the manner Fanger (1972) encountered to synthetise an index of thermal comfort (in light of Zhang *et al.*'s findings this is rather an index of thermal discomfort), referring to the proportion of people dissatisfied with the thermal environment – the Predicted Percentage of Dissatisfied (PPD) indicator. However, the complexity of seat comfort and discomfort has not yet been understood. There is a considerable amount of research that identifies relevant factors to consider in modelling the subjective assessment of seat comfort. This research is centered in physiological and biomechanical aspects. However, the correlation between the multitude of identified factors and subjectively assessed comfort is not yet established. For this reason and for the time being, the pragmatic and industrial evaluation of seat comfort has to rely on subjective judgements of humans performing sitting trials.

6. Conclusion

The absence of discomfort is a necessary condition but not a sufficient one for the existence of comfort. On the other hand, discomfort is primordially associated to physiological and physical factors. The creation of discomfort indexes will be more feasible than that of comfort indexes, since comfort is a more complex phenomenon and even less understood than discomfort. Furthermore, the modelling of physiological and physical processes underlying these components of seat comfort's integrated perception are within closer reach than the modelling pertaining the psychological component.

A coordinated effort of research on seat comfort is necessary to elicit an encompassing predictive index of seat discomfort, one that is functionally dependent on objective dimensions. This task must resort to using subjective assessments to construct a model and to validate it, and once validation is attained, the model should allow prediction of subjective assessments within an acceptable error margin (taking account of variable human preferences). An important concern in setting such a coordinated effort is to overcome the obstacle of poor inter-subject comparability of subjective seat discomfort assessments. Methods for 'calibration' of perceived feelings are available that are based on subjective comparison between stimulus of different nature (e.g. comparing seat discomfort with pain in a cross-modality arrangement – Reed *et al.*, 1991). Without a consensus on the method and procedures to calibrate feelings intensity, these elemental studies are bound to be of a comparative nature, applicable only to relative improvements on existing seat designs. It seems though that researchers approaching seat comfort have been lacking a unified consensus on concepts, measurements and methodology. Reaching a consensus in terms of attaining a common framework to allow coordination of efforts towards the goal of understanding subjective discomfort, would allow the field to enter the Kuhnian normal science stage (Kuhn, 1970). In such a stage, researchers activity can be characterized as consisting of puzzle-solving around a paradigm that outlines important research questions and provides guidance towards improving the precision of theories and findings, in the way laid out by the paradigm.

References

Coelho, D.A., Dahlman, S., 1999a. Articulation at Shoulder Level - A way to improve automobile seat comfort? Technical report - University of Beira Interior, Covilhã and Chalmers University of Technology, Göteborg, 159 pp.

Coelho, D.A., Dahlman, S, 1999b. A pilot evaluation of automobile seat side support: Leading to a redefinition of the problem. International Journal of Industrial Ergonomics, 24 (1999. pp. 201-210.

Coelho, D.A., Dahlman, S, *in press*. Comfort and pleasure. in “Pleasure in product use”, ed. by P.W. Jordan and B. Green, Taylor & Francis, London.

Corlett, E.N, 1990). The evaluation of industrial sitting. In J. R. Wilson and E. N. Corlett (eds.) Evaluation of human work, 2nd ed., Taylor & Francis, London, pp. 621-636.

Ebe, K., Griffin, M.J, 2000-a) – Qualitative models of seat discomfort including static and dynamic factors. Ergonomics, 43(6), 771-790.

Ebe, K., Griffin, M.J, 2000-b) – Qualitative prediction of overall seat discomfort. Ergonomics, 43(6), 791-806.

Fanger, P.O, 1972. Thermal Comfort: Analysis and applications in environmental engineering. McGraw-Hill, New York.

Grandjean, E, 1993. Fitting the task to the man, 4th ed., Taylor & Francis, London.

Goonetilleke, R.S, 1998. Designing to minimize discomfort. Ergonomics in Design, 6(3), 12-19.

Gyi, D.E., Porter, J.M, 1999. Interface pressure and the prediction of automobile seat comfort. Applied Ergonomics, No. 30, 99-107.

Hertzberg, H.T.E, 1972. The human buttock in sitting: Pressures, patterns and palliatives. American Automobile Transactions, No. 72, pp. 39-47.

Jordan, P.W., 1997. “A vision for the future of human factors”, in K. Brookhuis et al. (eds.), Proceedings of the HFES Europe Chapter Annual Meeting 1996, (University of Groningen Centre for Environmental and Traffic Psychology), The Netherlands, pp.179-194.

Kamijo, K., Tsujimura, H., Katsumata, M, 1982. Evaluation of seating comfort. SAE Technical Paper No. 820761.

Karlsson, I.C.M., Rosenblad, E.F.S, 1998. Evaluating functional clothing in climatic chamber tests versus field tests: a comparison of quantitative versus qualitative methods in product development. Ergonomics, 41(10), 1399-1420.

Kuhn, T.S, 1970 – The structure of scientific revolutions, 2nd ed., Chicago, University of Chicago Press.

Lamotte, T., Priez, A., Lepoivre, E., Duchêne, J., Tarrière, C, 1996 – Surface electromyography as a tool to study the head rest comfort in automobiles. Ergonomics, 39 (5), 781-796.

Lee, J., Ferraiuolo, P, 1993. Seat comfort. SAE Technical Paper No. 930105.

Maldonado, T, 1991. The idea of comfort. Design Issues, 8(1), 35-43.

Maslow, A, 1970. Motivation and Personality. 2nd ed., Harper and Row, New York.

Muckler, F.A., Seven, S.A, 1992. Selecting Performance Measures: "Objective" versus "Subjective" Measurement. Human Factors, 34(4), 441-455.

Park, S., Lee, Y., Nahm, Y., Lee, J., Kim, J, 1998. Seating Physical Characteristics and Subjective comfort: Design Considerations. SAE Technical Paper No. 980653.

Pheasant, S, 1996. Bodyspace, 2nd ed., Taylor & Francis, London.

Porter, J.M., Gyi, D.E, 1998. Exploring the optimum posture for driver comfort. International Journal of Industrial Ergonomics, 19 (3), 255-266.

Porter, J.M., Norris, B.J, 1987. The effects of posture and seat design on lumbar lordosis, in Megaw, E.D, ed.) Contemporary Ergonomics 1987, Taylor & Francis, London, pp. 191-196.

Reed, M.P., Saito, M., Kakishima, Y., Lee, N.S., Shneider, L.W, 1991. An investigation of driver discomfort and related seat design factors in extended duration driving. SAE Technical Paper No. 910117.

Reynolds, H. M, 1993. Automotive Seat Design for Seating Comfort. in "Automotive Ergonomics" edited by Peacock, B. and Karkowski, W., Taylor & Francis, London, pp. 99-116.

Sawaki, Y., Price, H, 1991. The Human Technology Project in Japan. Proceedings of the Human Factors Society 35th Annual Meeting - 1991, Santa Monica, California, USA, pp. 1194-1198.

SBU - Statens beredning för medicinsk utvärdering – The Swedish council on technology assessment in health care (2000). Back pain, neck pain – an evidence based review, summary and conclusions. Available online at www.sbu.se

Shen, W., Galer, I.A.R, 1993. Development of a pressure related assessment model of seating comfort. Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting, October 1993, Vol. 2, pp. 831-835.

Slater, K, 1985. Human Comfort. Springfield - lllinois: Thomas Books, pp. 1-11.

Troup, J.D.G, 1978. Driver's back pain and its prevention. A review of the postural, vibratory and muscular factors, together with the problem of transmitted road shock. Applied Ergonomics, 9, 207-214.

Zhang, L., Helander, M.G., Drury, C.G, 1996. Identifying factors of comfort and discomfort in sitting. Human Factors, 38(3), 377-389.

Åkerblom, B, 1954. Chairs and sitting, in Floyd, W.F., Welford, A.T. (eds.) Human Factors in Equipment Design, H. K. Lewis & Co. Ltd., London, pp. 29-35.

Captions

Figure 1: Influencing factors of the perception of thermal comfort.
Figure 2: Comfort components in the task of automobile driving.

Graphics (text with drawings)

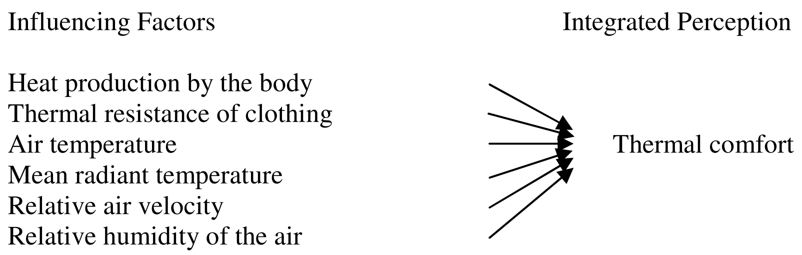

Figure 1: Influencing factors of the perception of thermal comfort.

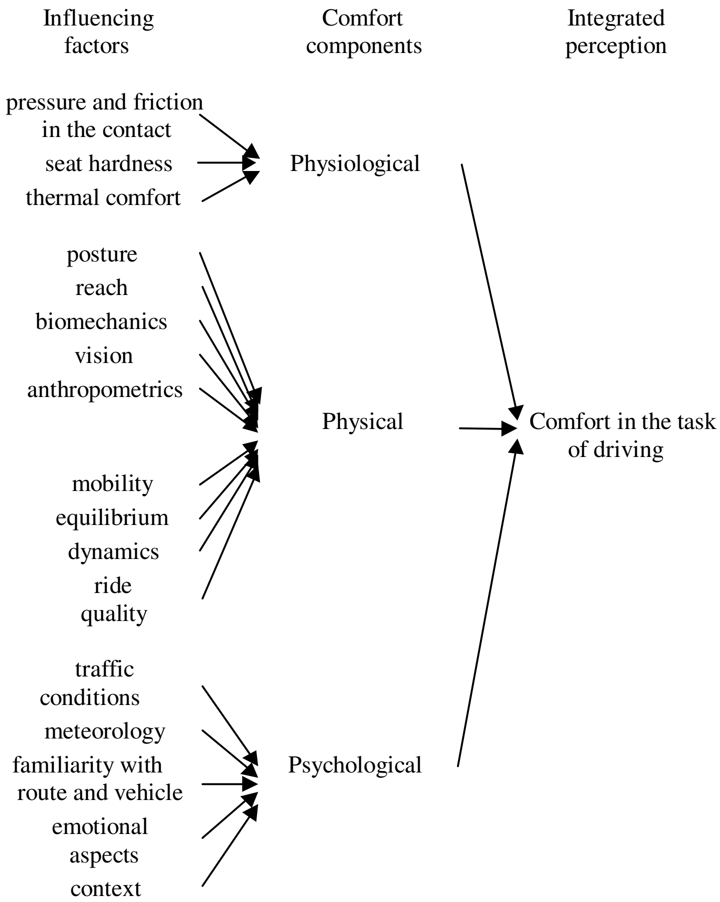

Figure 2: Comfort components in the task of automobile driving.

Article IV

Coelho, D.A., Dahlman, S., (2002). Comfort and pleasure. In Pleasure in Product Use, ed. by Patrick W. Jordan and William Green, Taylor & Francis, pp. 321-331.

COMFORT AND PLEASURE

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Abstract

The ambition of the paper is to position the concepts of comfort, pleasure and usability in relation to each other, using as a basis the theoretical framework on pleasure with product use. The theme for this chapter is the relationship between comfort and pleasure in product use. The starting point considered is that pleasure with products goes beyond usability. In this context, comfort can be considered as an aspect of both usability and pleasure. The distinction between comfort and pleasure, what differentiates them and also how and where these two concepts intersect is one focus. The empirical background for this study comes mainly from the context of car seat comfort, where the authors have performed two experimental studies. A wider interpretation of the concept of comfort is also brought into the discussion, based on a study of office seating and work on human comfort. Furthermore, a small questionnaire study about pleasure and comfort related to cars and car seats was conducted. This provided data to illustrate the relationship of comfort with pleasure in the context of the evaluation of the design of automobiles and their seats. The studies performed allow us to suggest hypotheses about the interrelation between comfort, pleasure and usability. Implications for industry include the findings that interpretations of these concepts are overlapping nd would benefit from more distinct understanding. Practitioners are working with and need these concepts in order to create good, worthwhile and succesful products. A final section argues the role of Human Factors in product development considering comfort and pleasure in the light of environmental sustainability.

1. INTRODUCTION

Comfort and pleasure both are concepts that are receiving growing attention as a possible means of adding value to products. Sawaki et al (1991) reported on the Human Technology Project in Japan, showing that factors such as comfort, enjoyment (a synonym for pleasure) and usability have increased in relative importance as part of product quality. Usability-comfort-enjoyment constitutes a new paradigm in the goal of product development, adding to the functionality-reliability-cost paradigm.

In historical terms, Ergonomics' role in product development has shifted and widened over the last half of the 20th century. The history of Human Factors and Ergonomics (Meister, 1999) shows that in its early stages ergonomic intervention was meant to assure safety, health and performance for the users of products (e.g. the design of World War II aircraft cockpits, radar systems, etc). To this followed a stage where functionality was a goal of ergonomic studies in product development, initially through enabling increased performance and later by enhancing the usability of products. Comfort came as the next stage, although in some domains it might be regarded as an aspect of usability (e.g. software development). However, comfort may also be seen as an independent goal in itself, as is the case in car seat development. Finally, the emergence of pleasure, as a goal in ergonomic product development, so far completes the progression.

The boundaries between the different goals for Human Factors interventions are not clearly established, and a single intervention may of course accommodate several of these goals. Moreover, these boundaries may be subjective, or domain specific, creating variants of the distinction between these goals and concepts. As an example of this, usability may in some cases be seen as an aspect separate from performance. For other domains, usability may instead be seen as an aspect of performance.

2. AIMS, RATIONALE AND METHOD OF APPROACH

- This study aims at positioning the concepts of comfort, pleasure and usability in relation to each other, using as a basis the theoretical framework on pleasure with product use (Tiger, 1992; Jordan, 1997).
- The study also aims at positioning comfort in the hierarchy of user needs (Jordan, 1997), which relates functionality with usability and pleasure (Figure 1).

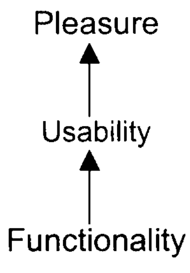

Figure 1: Hierarchy of user needs (fr. Jordan, 1997).

A revision is proposed to this hierarchy, under the light of environmental sustainability. This aspect should not be forgotten in a review of the present role of Human Factors in product development, given the urgency of placing environmental concerns among the highest corporate priorities (ISO/DIS 14004). The focus of this study is on the distinction between comfort and pleasure and their intersection.

This being a first venture into a new area it is our ambition to generate hypotheses about the interrelations of comfort, pleasure and usability, and later to test the hypotheses suggested with empirical data in studies to come.

This analysis is based on referenced definitions of comfort and pleasure. The case of pleasure and comfort in car use and car seats illustrates the relationships between these concepts, backed up by the results of a questionnaire.

3. LINKS BETWEEN COMFORT AND PLEASURE

Comfort and pleasure are linked and intersect each other as concepts, as can be extrapolated from the views and definitions presented below. Slater (1985) defined comfort as “a pleasant state of physiological, psychological and physical harmony between a human being and the environment". From an evolutionary point of view, comfort and pleasure, as well as pain and discomfort, have been receiving great attention by human beings since the birth of the species. Tiger (1992) defends this idea with the following argumentation: "our ancestors found comforting pleasure in nothing more complex than sitting by a fire and watching its ever varied motion. (...) our pleasures are as much related to our history as a species and products of it as they are products of our invention. (...) Ancient parts of the brain constantly monitor the comfort of the body and obviously seek to reject pain and seek pleasure." It comes, therefore, as no surprise that contemporary Human Factors approaches to product development are giving greater emphasis to comfort and pleasure, adding up to previously established goals, i.e. safety and health, performance and usability.

Tiger (1992) distinguishes among four categories of pleasure: physiological, psychological, sociological and ideological pleasures. Jordan (1997) reinstated these and illustrated them with case studies of product use, defining pleasure with products as the "emotional, hedonic and practical benefits of product use". In a similar manner, comfort can be considered to have three different categories: physiological, physical and psychological (Slater, 1985). While physiological pleasure is clearly linked to physiological and physical comfort, psychological comfort may be linked to psychological pleasure. However, sociological and ideological pleasures cannot be directly linked to comfort, except in the case where comfort is considered as an aspect of the quality of life (Maldonado, 1991).

Zhang et al (1996) identified factors of comfort and discomfort in office sitting. The following descriptors of sitting comfort were brought forward in the study, based on a survey of 42 office workers:

agreeable,	at ease,	calm,	content,
cozy,	happy,	luxurious,	not think about workplace,
pleasant,	pleased,	plush,	refreshed,
relaxed,	relief,	restful,	safe,
softer,	spacious,	supported,	warm

and well-being.

These descriptors of comfort reinforce the idea that comfort and pleasure are intersecting concepts. The hedonic benefit from comfortable sitting is conveyed by "well-being, safe, pleased, pleasant, content". Physiological pleasure can be linked to the descriptors that are related to physiological or physical comfort, such as "cozy, plush, refreshed, relaxed, relief, softer, spacious, supported, warm". Psychological comfort may be reflected in the terms: "agreeable, at ease, calm, happy, not think about workplace, restful". Sociological and ideological pleasure are the most unlikely to be linked to the above descriptors, although the term "luxurious" might be thought of in such context.

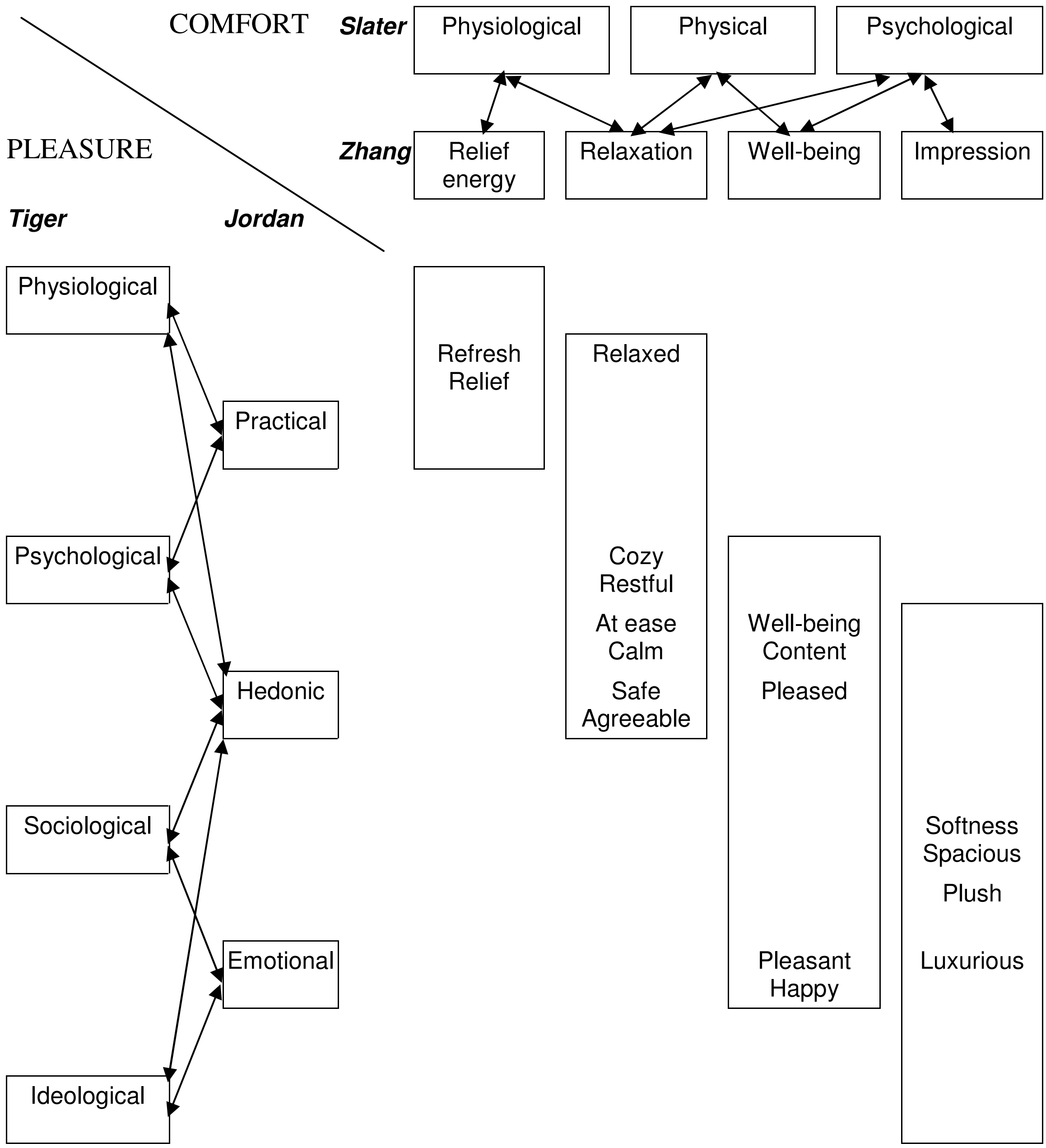

Table 1: Links between comfort and pleasure found from the definitions of Slater (1985), Tiger (1992), Jordan (1997) and from the study of Zhang et al (1996).

Table 1 describes a subjective interpretation of the authors, trying to bring together models of pleasure (Tiger, 1992 and Jordan, 1997) and relating them to models of comfort (Slater, 1985 and Zhang et al, 1996). Tiger and Jordan suggest ways of breaking down ‘pleasure’ into separate dimensions. Similarly do Slater and Zhang with ‘comfort’. In the figure, we have interpreted the definitions of the dimensions and tried to relate them within comfort and pleasure respectively but also between comfort and pleasure. A frame indicates a suggested relation. The comfort descriptors described by Zhang have then been positioned in the comfort dimensions according to the results of Zhang, and by us subjectively in the pleasure dimensions. This exercise suggests that the descriptors of comfort derived by Zhang et al (1996) all seem to be relevant from a pleasure point of view. We further suggest that comfort is a constituting part of pleasure and it seems that pleasure holds dimensions not included in comfort: performance pleasures, skill pleasures, esthetical pleasures to mention some. The exercise also triggers the idea of performing an analogy to the Zhang study, but focused on pleasure, to more stringently grasp the dimensions of pleasure.

The exercise suggests that the boundaries between comfort and pleasure in product use are blurred and would benefit from more strict consideration in the light of a spectrum of empirical cases. Table 1, summarizes the links found between comfort and pleasure. One may as well consider a similar exercise relating discomfort and displeasure in sitting, which is the discussion presented in the following paragraph.

We believe it is not a straightforward cause-effect relationship that discomfort in sitting leads to displeasure. An uncomfortable seat may not allow a pleasurable sitting experience, since sitting in that seat is an unpleasant experience, but the seat might be pleasurable in other aspects. The seat may have a nice looking design, or a soft touch, that would enable other pleasures (sociological), but not physiological pleasure, since physiological or physical comfort are absent. A distinction between pleasurable products and pleasure derived from activities can be made in this example. The seat (product) although pleasurable to look at and to touch does not enable pleasurable sitting (activity). A negative emotional response to the physiological or physical discomfort occurring during the sitting activity may be present as physiological displeasure.

One can analyze displeasurable sitting and can it to sitting discomfort, but can pleasurable sitting be related to sitting comfort? To distinguish between seats that are comfortable one must look at the pleasurable aspects of each seat. This idea is supported by Zhang et al (1996) that suggests that comfort-discomfort are two interrelated variables, although not a continuum. This has a bearing on the hypothesis that pleasure is something more than comfort. Seats can be comfortable in many different ways, as with different assumed postures, or with different seat cushion stiffness, or different seat fabric properties, or different seat contours, or different seat styling, aesthetics, and so on. Different seats (although comfortable) will enable distinctly different pleasurable sitting experiences, since pleasurable can take the form of any or all of its four categories: physiological, sociological, psychological and ideological.

4. INTEGRATING FUNCTIONALITY, USABILITY, COMFORT AND PLEASURE - the case of car seats

This section applies Jordan's (1997) hierarchy of user needs to an example of a product, i.e. car seats. Car seats are commonly evaluated in terms of comfort. In this section the argument is brought forward claiming that car seat comfort is built upon basic seat functionality and usability of the seat and its controls. The section presents arguments supporting the intersection of comfort with functionality, usability and pleasure, in the case of car seats.

The comfort of a car seat depends on the characteristics of the seat, and in general terms, for a car seat to be comfortable it must provide functionality. This can be seen as adjustment features, such as height of the seat, reclining the backrest, adjusting the distance from the pedals, and so on. However, the inherent functionality of a car seat is also supporting the occupant at ease in a driving posture. One can judge if it is easy to adjust the seat settings, and this would be part of evaluating the usability of the seat. But being easy to adjust the settings is not the only way the seat can be easy to use. Being easy to use it (e.g. its usability) also means it is easy to get in and out of the seat (egress/ingress characteristics), and that it is easy to use the seat in all that it is used for. Focusing the attention on the driver seat of the car, as there are more demands on its functionality than in the other seats in the car, the seat is used primarily for sitting while driving. Reynolds (1993) considers the car seat as an interface between the car and the driver. Therefore, besides the usability of the seat adjustments, being easy to use that interface (the seat) means it is easy to drive, to see the road and to reach commands while sitting in that seat. Ultimately, usability of the seat means it is easy to sit in it or stay seated on the seat while performing the task of driving. In other words, part of the usability of the car driver's seat is that it is comfortable. We have also seen how the functionality of the seat is linked to comfort, since basic functionality, such as the adjustment possibilities available, has an impact on comfort in the seat.

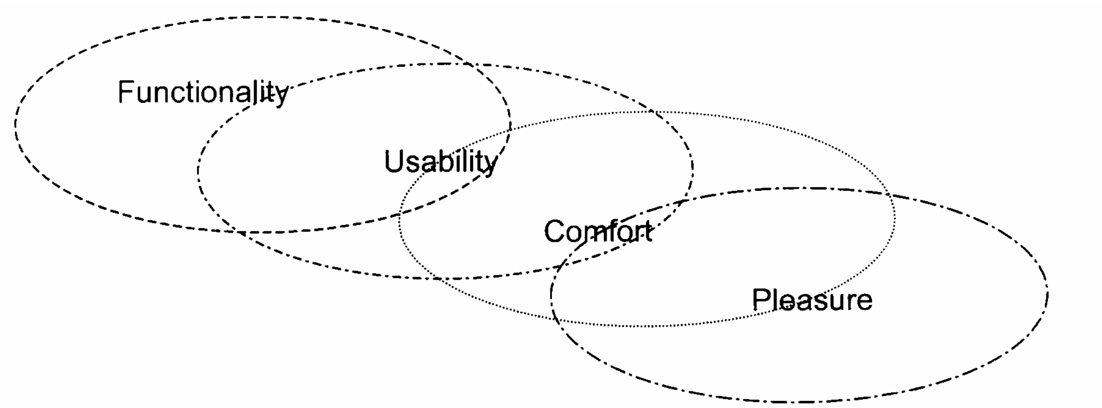

Figure 2: The blurred boundaries and intersections of functionality, usability, comfort and pleasure - the case of the driver's car seat.

In the previous section, a study of comfort in office seating (Zhang et al, 1996) led us to suggest that comfort could be seen as an aspect of pleasure. This analysis of the usability of the driver's car seat suggests that comfort may also be seen as an aspect of usability, defined as the effectiveness, efficiency and satisfaction with which users can achieve tasks with a product (ISO DIS 9241-11). Assuming that Zhang et al's (1986) descriptors of comfort can be applied to the driver's car seat, one concludes that functionality, usability, comfort and pleasure in the driver's car seat are concepts that intersect each other, and that do not have strict boundaries (as shown in Figure 2). Furthermore, the element of satisfaction in the definition of usability may be linked to pleasure.

5. EMPIRICAL OBSERVATIONS

Comfort and pleasure have been discussed and links have been emphasized between these two concepts in the preceding sections, crossing the boundaries of functionality, usability, comfort and pleasure. A structured questionnaire was designed to test the applicability of Tiger's (1992) "Four pleasure" classification and Jordan's (1997) "Hierarchy of user needs" for driving, cars and car seats. The results of the questionnaire behold evidence to support the links exposed between comfort and pleasure and the inter-relationships in the levels of user needs. The methods used and the results of the questionnaire are presented in the following paragraphs.

Thirteen Swedish automobile drivers answered the structured questionnaire, which had both open ended and multiple-choice questions. The subjects were 7 men and 6 women, aged from 30 to 65 years old that had driven regularly, for at least 5 years, a distance between 5 and 20 thousand kilometers per year. The questionnaire administration was integrated in a larger research study on car seat comfort (Coelho and Dahlman, 1999). A further selection criterion of the subjects was their sitting height. There were 4 subjects in each of the following sitting height intervals: 82-84cm and 92-94cm. There were 5 subjects in the 87-89cm sitting height interval. Each subject responded to the questionnaire during his or her leisure time, after performing two 2 hour long sitting trials in the laboratory, separated by approximately a week. A telephone number was indicated in the questionnaire header for support, however, none of the subjects called to clarify questions in the questionnaire.

Selected results of the questionnaire are presented in the following paragraphs. The question "Do you find driving pleasurable?" yielded the following results:

"Not at all"	8%
"Somewhat"	46%
"Rather lot"	38%
"A lot"	8%

These results show that the vast majority of the subjects considered driving as a pleasurable activity. This does not directly imply that the product that supports the activity (the car, the seat) is pleasurable. A sugested hypothesis (see above) is that the pleasure derived from the interaction with a product can either originate in the activity, or from the product qualities. In the case of car driving a combination of both seems to apply, as can be seen from the results of this question and from the following few ones.

To the question "Do you think driving is hard?" subjects answered as follows:

54%	"Never"
31%	"In adverse conditions"
15%	"Driving is hard in adverse conditions, but it is pleasurable to succeed in doing it".

The 15% of the total of 13 subjects that gave the last answer seem to enjoy a sort of psychological pleasure in completing a hard driving task in adverse conditions. This may lead one to suggest the hypothesis that pleasure with an activity may exist even though psychological discomfort is present.

The 13 subjects participating in the study were probed about the pleasurability of the interiors of their cars. This yielded the following results:

54% considered that the interior of their car was "somewhat pleasurable"

23% thought it was "pleasurable"

23% thought that it was "not pleasurable at all"

0% considered it to be "very pleasurable"

Although the subjects had cars of different makes, size and age, these answers show that pleasure seems to be a relevant attribute for the design of car interiors.

When asked to describe pleasurable attributes of their car, the subjects mentioned (number of subjects mentioning the attribute is indicated in parentheses):

comfortable (5)
performance (3)
lovely road handling (2)
nice looking design (2)
safety (2)
automatic transmission (1)
gives me freedom (1)
strong construction (1)
well built (1)
well equipped (1)
quick (1)
sportiness (1)
big car (1)
comfortable seats (1)
good seats (1)
cozy (1)

This question had open ended possibilities for the subjects' answers, which might explain the spread in the results. Still, the answers show that 5 of the 13 subjects answering the questionnaire considered that their car was comfortable and that this contributed to make it pleasurable. This result supports formulating the hypothesis that comfort enables pleasure. It also shows that people understand the separation between a pleasurable activity (driving or socializing in the car) and pleasurable attributes.

Subjects were asked if it was a pleasurable experience to socialize with others in their car, yielding the following results:

54% "Yes, always"

38% "Yes, on relaxed occasions"

8% "No, never".

These results show that for the vast majority of the subjects, pleasure can be derived from the company of others in the car, thus falling into the category of sociological pleasure.

The subjects were also requested to indicate the persons whose company they appreciated in the car, with the following answers:

77% enjoyed the company of their spouses while driving

69% enjoyed the company of their children while driving

62% enjoyed having their friends while driving

31% enjoyed having their colleagues while driving

(Not all of the 13 subjects were married, or had children living with them and there were two retired persons in the group). By enabling the presence of others in the car (a functionality attribute) sociological pleasure can be derived from using the vehicle (product). This is an example of how pleasurable interaction may be built directly on basic functionality.

The subjects were asked if their car reflected their ideological values, yielding the results presented below:

38% Thought that their car did “not” reflect their ideological values

23% Answered that their car did “somewhat” reflect their ideological values

38% Replied that their car reflected their ideological values “rather a lot”

0% Answered that their car reflected their ideological values “a lot”

One of the subjects that answered that her car reflected her ideological values rather a lot added a comment to the answer, saying that her car was meant to carry her and her spouse and their things and food, in an economic, quick, comfortable and safe manner. The wording of the question and its results support suggesting that identification with the product derives from a match between users’ requirements on the product and its affordances.

The subjects were asked to rank 7 attributes of car seats in order of importance to them. The results are shown below (most important - top of the list).

1. The seat is comfortable
2. The seat has the right adjustment possibilities
3. The seat cover has a soft touch
4. The seat looks good

5. The seat cover is beautiful
6. The seat cover does not need to be washed
7. I look good when I sit in the seat

The combined answers of the 13 subjects have a Kendall coefficient of concordance of 0.83, significant for $p<0.001$. Comfort of the seat ranks highest in the list, followed by the adjustments available (which can be considered an aspect of functionality or usability of the seat). Physiological (tactile) pleasure as well as physiological comfort may be derived from the soft touch of the seat cover, which comes next. The aesthetic qualities of the seat rank in 4th and 5th place, these are necessarily pleasure linked attributes, that may lead to sociological pleasure once others recognize the beauty of the seat. Attribute 6 may be connected to functionality and usability of the seat. Finally the lowest ranking attribute may also be considered an esthetical quality, leading to sociological pleasure.

The results of the questionnaire show the relevance of the four pleasure framework to the specific products considered (cars and car seats). Furthermore, subjects' answers show that pleasure can be derived from the activity of driving and the products that support it. Comfort is seen as one of many possible attributes that contribute to a pleasurable car. Functionality and usability attributes are also present in the results of the questionnaire. These results, and the conclusions of the first part of this section, support revising the model of the hierarchy of user needs (Jordan, 1997) to encompass the aspect of comfort. Figure 3 depicts the suggested adaptations to the model.

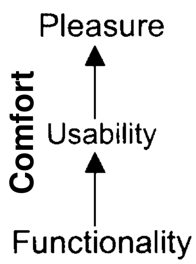

Figure 3: Hierarchy of user needs, adapted from Jordan (1997) to encompass the Human Factor goal of comfort, in its relationship with pleasure, usability and functionality (based on the analysis of the case of car seats).

6. SUSTAINABILITY AND USERS' NEEDS

The goal of Human Factors intervention and its role in product development is considered to be supporting the development of products, which are functional, user-friendly and pleasurable (Jordan, 1997). Although, for many products there is still a long path ahead towards achieving pleasurable interaction, a reflection and argumentation can be made, concerning the importance of the users and developers' role also in attaining environmental sustainability. Environmental planning is encouraged throughout the product life cycle (ISO 14004) and it is generally accepted that moderate and wise use of the planet's resources is a pre-condition to assure a sustainable environment. Besides the need to give users functional, user-friendly and pleasurable products, products could have an appeal embbedded so as to be used in a suitable way, lasting for a long time (conservation) and being well discarded of (in an environmentally friendly way - recycling).

Above the pleasurable level in Jordan's (1997) model of user needs (shown in Figure 1) one should consider the ceiling of sustainability contributing to set designers and users on the right track. That means putting users of products in a perspective that stresses global awareness and what is their role in preserving the environment and assuring a sustainable life style for the coming generations.

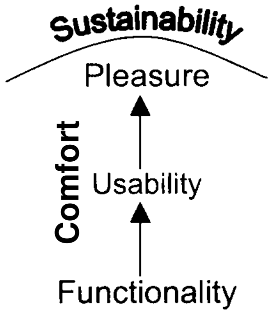

Figure 4: Model of the hierarchy of user needs, adapted from Jordan (1997), considering comfort and limited by sustainability.

The role of human factor specialists in this enterprise is to assure that the emotional responses users attain interacting with products are ones that will be good for us individuals, for society, for humanity and for the planet. The immediate benefit is environmental sustainability. Jordan's (1997) model can thus be further adapted to encompass this sustainability ceiling in the hierarchy of user needs, as shown in Figure 4. Further studies are needed to understand and explore the impact of this limitation on product development and users' interaction with products.

7. CONCLUSION

The exercise of linking comfort and pleasure suggests that comfort fits nicely into being an aspect of pleasure, and that the boundaries between comfort and pleasure in product use are overlapping and specific to the context and situation. It seems that pleasure holds dimensions not included in comfort: performance pleasures, skill pleasures, esthetical pleasures to mention some. The ambition to clarify and define the overlapping and intersection of these two concepts should be pursued as a more strict consideration in the light of a spectrum of empirical cases. Table 1, summarizes the links suggested between comfort and pleasure, while Fig. 2 gives a graphical interpretation of the overlapping boundaries of these concepts and functionality and usability.

Taking as a basis Zhang et al's (1996) suggestion that comfort-discomfort are two interrelated variables, although not a continuum, the authors suggest that different seats (although comfortable) may enable distinctly different pleasurable sitting experiences, since pleasurable can take the form of any or all of the categories considered by Tiger (1992): physiological, psychological, sociological and ideological. One may as well consider the relation between discomfort and displeasure in sitting, although a seat that is pleasurable to look at and to touch may not enable pleasurable sitting.

This study also enables suggesting that part of the usability of the car driver's seat is that it is comfortable. In the same line of thought, seat functionality can be linked to comfort, since basic functionality has an impact on comfort in the seat. Furthermore, basic functionality of the automobile (accommodating other occupants besides the driver) is a pre-condition for sociological pleasure, derived from the company of others in the car.

A suggested hypothesis resulting from the analyses presented herein is that pleasure may either derive from the interaction with a product (given the product's qualities), or it may originate in the activity supported by the product. Other hypotheses were formulated, based on empirical data and the analyses conducted. These included the hypothesis that identification with the product derives from a match between users' requirements and ideological values and the product's affordances.

Finally, this contribution revises Jordan's (1997) hierarchy of user needs, considering the addition of comfort and in the light of environmental sustainability. The result is shown in Fig. 4. Further studies are needed to understand and explore the impact of the limitation of sustainability on the development of pleasurable products and on users' interaction with products.

Implications of the study for industry include the findings that the boundaries between functionality, usability, comfort and pleasure may be indistinct for most products. This urges practitioners to look both at and beyond each of these concepts in order to create good, worthwhile and successful products.

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References

Coelho, D.A. and Dahlman, S., 1999. "Articulation at Shoulder Level - A way to improve car seat comfort?", Technical report - University of Beira Interior, Covilhã, Portugal and Chalmers University of Technology, Göteborg, Sweden, 159 pp.

ISO/DIS 14004, "Environmental Management Systems – General guidelines on principles, systems and supporting techniques", 1995.

ISO/DIS 9241-11, "Ergonomic requirements for office work with visual display terminals (VDTs)"- Part 11: Guidance on Usability.

Jordan, P.W., 1997. "A vision for the future of human factors", in K. Brookhuis et al. (eds.), Proceedings of the HFES Europe Chapter Annual Meeting 1996, (University of Groningen Centre for Environmental and Traffic Psychology), The Netherlands, pp.179-194.

Maldonado, T.,1991, "The idea of comfort", in Design Issues, vol. 8, n.1., pp. 35-43.

Meister, D., 1999. "The history of Human Factors and Ergonomics", Lawrence Erlbaum Associates, Mahwah, New Jersey, USA, 382 pp.

Reynolds, H. M., 1993, "Automotive Seat Design for Seating Comfort", in "Automotive Ergonomics" edited by Peacock, B. and Karkowski, W., Taylor & Francis, London, UK.

Sawaki, Y. and Price, H., 1991, "The Human Technology Project in Japan", Proceedings of the Human Factors Society 35th Annual Meeting - 1991, Santa Monica, California, USA, pp. 1194-1198.

Slater, K., 1985, "Human Comfort", Springfield - lllinois: Thomas Books, USA, pp. 3-11.

Tiger, L.,1992, "The Pursuit of Pleasure." Boston: Little Brown and Company, USA, pp. 52-60.

Zhang, L., Helander, M.G. and Drury, C.G., 1996, "Identifying factors of comfort and discomfort in sitting", Human Factors, 38(3), pp. 377-389.

Article V

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A questionnaire study on basic premises of 'pleasure with products'

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Abstract

This paper reports on a pilot questionnaire study aimed at the empirical validation of 'pleasure with products' theoretical constructs and approaches. Three hypotheses were generated: people actively seek pleasure through their choice of products in their everyday life; people recognize and can discriminate between physiological, psychological, sociological and ideological pleasures with products; and people seek both need pleasures and pleasures of appreciation. 82 Portuguese respondents, sampled from the university community, answered the questionnaire. The results show agreement with the hypotheses, confirming the empirical feasibility of the theoretical constructs and suggesting that these representation formats may be used to communicate pleasure aspects to both users and designers.

1. INTRODUCTION

In many product areas, technical advances and manufacturing processes have reached a level of sophistication that makes any potential competitive advantage, in terms of functionality, reliability and manufacturing costs, marginal. Many manufacturers now see design as one of the few areas in which it is still possible to gain significant advantages over the competitors. Good human factors are, of course, central to achieving excellence in design, and a holistic and positive view of human factors is necessary to understand people's subjective response to products. According to MacDonald (1998), apart from the satisfaction of fulfilling a utilitarian function, an object can give its user pleasure, not only in terms of its ergonomic fit but also through its aesthetic qualities (qualities pertaining to beauty). The issue of pleasure in product design has received growing attention in recent years. As a result, the goal of human factors in product development enlarges from the releif of pain and discomfort and from contributing to the creation of safe and usable products to promoting the pleasures that products can bring to their users (Jordan and MacDonald, 1998). This paper discusses basic premises underlying theoretical constructs on 'pleasure with products' and contributes to the empirical validation and understanding of people's positioning towards this new approach to ergonomical product design. This study has a pilot nature, since, to the best of our knowledge, there were yet no empirical studies with this purpose.

2. PROBLEM DISCUSSION

In this section, definitions of ‘pleasure’ are presented, asides with premises underlying the theory and approaches behind ‘pleasure with products’.

2.1. Pleasure

Although ‘pleasure with products’ has only appeared persistently in ergonomics literature in very recent years, the concept of pleasure has been the object of reflection and study for a longer time. In emphasizing differences between pleasure and pain, Waton (1919) refers to pleasure as “a feeling which we seek to bring into consciousness and retain there” and refers to pain as “a feeling which we seek to get out of consciousness and to keep out” (p. 29). In the *Pleasure and desire* treatise, Gosling (1969) also considers enjoyment (pleasure) as a mode of attention:

> “Enjoyment differs importantly from pain, whereas pain attracts attention to themselves, it is a characteristic of pleasure that attention be attracted to that in which pleasure is taken. (…) If the attention is distracted, their enjoyment is interrupted. What distinguishes pleasure from fear is the form the attention takes. It is say a favorable attention, leading to pursuit rather than avoidance and so on.”

Other authors have taken the task of subdividing pleasure. Lewis (1987) divided pleasures derived from natural entities and artefacts into need pleasures and pleasures of appreciation. Tiger (1992) brought forward a categorization of pleasure, distinguishing among physiological, psychological, sociological and ideological pleasures and claimed that “parts of the brain constantly monitor the comfort of the body and obviously seek to reject pain and seek pleasure.” This view puts pleasure seeking at the core of human motivation and attributes a quality of great importance and high priority to pleasure; hence, the interest of studying pleasure.

2.2. Pleasure with products

Pleasure with products is defined by Jordan (1996) as the emotional and hedonic benefits associated with product use. This author defines the opposite, displeasure in product use, as the emotional and hedonic penalties associated with product use. Our intention is to explore the theoretical structure of ‘pleasure with products’ leading to hypotheses that support empirical testing. In the following discussion, pleasure with products is viewed from three theory based perspectives: in the context of activity, in terms of categories of pleasure with products and in terms of the distinction between need pleasures and pleasures of appreciation. An implicit premise considered is that all products are likely to be relevant for consideration of pleasure requirements. Still, a reflection is made about the categories of products that are likely to be more relevant for consideration of pleasure requirements, from the perspective of everyday use of products. Possible implications of cultural aspects on pleasure with products are also mentioned.

2.2.1. Activities and pleasure with products.

One can distinguish between pleasure with products and pleasure with an activity that is supported by the interaction with a product. In order to illustrate this distinction, a space of pleasure can be imagined, to which both the product as such and the activity give a contribution (Figure 1). This view considers pleasure with products intertwined with activities that may be pleasurably enhanced by product use. The following examples serve the mere purpose of illustration. A pleasurable activity enabled by a supportive product is skiing (enabled by sky equipment). An activity that may be pleasurably enhanced by the characteristics of the product enabling the activity is ironing. The activity of automobile driving can be seen as an example where pleasure is derived from both the enabling product (automobile) and the activity of driving in more balanced contributions (Figure 1).

People's interaction with products in the course of activities may also be considered at different levels, depending on the context and situation of product use. Popper's (1989) theory of objective knowledge presents a pluralistic view of three worlds that can support structuring the context of product use. The three worlds are the world of physical objects or the world of physical states, the mental world or the world of mental states and the world of objective content of thought or the world of ideas. Pleasure with products should be considered in the context of product use, hence the allusion to the activity context. The same product can bring forward different levels of pleasurability, depending on the goals and expectations of the user, the activity that is being performed and the consequences of the interaction.

Tiger's (1992) ideas that emphasize the importance of pleasure seeking for human beings, support the reflections that pleasure plays a very important role in the conduction of human life and that human beings persistently and constantly seek pleasure. Such active seeking of pleasure would justify and validate the pretention that pleasurable products are actually sought by people, and that these are not only justified through manufacturers quest to regain competitive advantage once having achieved a technology ceiling.

This brings us to formulating a working hypothesis on the justification of 'pleasure with products': "people actively seek pleasure by their choice of products in their everyday life". This choice also concerns choosing ways of performing activities, choosing products to use and choosing the context and environment for an activity. What guides this choice is the search for the more pleasurable alternatives.

2.2.2. Categories of pleasure with products.

In his referential book *Designing pleasurable products*, Patrick W. Jordan (2000) structures an important part of his discussion on pleasure with products with the 'four pleasure framework' that had been outlined by Tiger (1992). The framework considers the categories of physio-, psycho-, socio- and ideo- logical pleasure. Physiological pleasure pertains to the sensory organs (e.g. pleasure derived from the tactile properties of a remote control). Sociological pleasure is derived from the relationships with others (e.g. pleasure derived from a cofee machine that enables people gathering around it). Psychological pleasure is considered to originate from cognitive and emotional reactions (e.g. pleasure derived from the accomplishment of a task such as word processing). Finally, ideological pleasure is derived from theoretical entities such as art forms or from the accomplishment or identification of people's values (e.g. pleasure derived from product aesthetics or from using a biodegradable pen by an environmentally conscious individual). Jordan (2000) uses the four pleasure framework as a point of departure to build product benefits specifications that are to be used later in gauging products for pleasurability. We shall test the relevance of the four pleasure framework, a premise of the 'pleasure with products' theory, considering it as another working hypothesis: "people recognize and can discriminate between the four components of pleasure applied to products – physiological, psychological, sociological and ideological".

2.2.3. Need pleasures and pleasures of appreciation.

Need pleasures and pleasures of appreciation are defined by Lewis (1987) as those that can be derived from natural entities and from artefacts. Need pleasures are seen as those that can move a person from a state of discontentment to a state of contentment (e.g. drinking a glass of water to quench the thirst). Pleasures of appreciation accrue because a person finds something pleasurable, no matter what the level of current contentment (e.g. admiring a piece of art work). Jordan (2000) considers this distinction in terms of products as pleasure from the elimination, or absence, of pain versus pleasure derived from the provision of positive, joyful feelings. These notions are used by Jordan (2000) to complement the four pleasure framework in conceiving product benefit specifications. Although not as decisive to Jordan's theoretical construct on 'pleasure with products' as the four pleasure framework, we suggest that this distinction can be linked with the hierarchy of consumer needs (Jordan 2000). We interprete the need pleasures as linked to the lower parts of the hierarchy and the appreciation pleasures as concerning the upper part of the hierarchy. The distinction between need and appreciation pleasures may also be beneficial to distinguish between essential product benefits and those that are non-essential from the person's point of view, but nevertheless add value to the product benefits specification. These added pleasures of appreciation would correspond to pleasures of delight. A third working hypothesis is formulated in order to test the applicability of these constructs: "people seek both need pleasures and pleasures of appreciation".

2.2.4. Scope of products considered most relevant for pleasurability.

An implicit premise considered in this study is that all products are likely to be relevant for consideration of pleasure requirements. However, the scope of this study is limited from the perspective of the scope of activities considered, specifically to those activities pertaining to people's everyday lifes. A reflection on product categories that are likely to be relevant for pleasure in everyday use of products produced the categories listed below. The criterium for inclusion in the listing was covering those product categories that are used repeatedly by people, whether in their private, social or professional environments, and specially those that have an important technological component. The method of derivation consisted of reflection and common sense, and therefore the list is biased towards our own experience.

- Personal products (e.g. music instruments, art tools, sports equipment and wear, makeup, hair-do, perfume, clothes and shoes).
- Consumer products for individual use (portable appliances, e.g. mobile phones, discmans, portable computers, automobiles, pens).
- Consumer products used in the home (general or more focused, e.g. kitchen products, bathroom appliances, or house cleaning products, communication or entertainment products, music hi-fi systems, functional/decorative objects – e.g. lamps and furniture).
- Office and/or home products (telephones, copying machines, computers and software, peripherals, furniture).
- Professional products (hand tools, salesmen brochures and demonstration apparatus, medical technology – e.g. dentist tools or ICU equipment, machinery).
- Artisitc products (posters, paintings, books, music, specifically designed products, e.g. an unusually styled piece of furniture).

There is an obvious dichotomy springing from the list above: products that are very personal in use and collective products. Products may also be classified in terms of the degree of pleasure intention in the design. Pleasure as an intention in the design may be thought relevant to environments (virtual or physical) and experiences, such as public transportation, or internet browsing. Included in the examples given above are products that may be thought as pleasurable in themselves and those that can enable pleasurable activities. The categories considered are also covering Popper's pluralistic view of the three worlds of physical states, mental states and ideas. The 'four pleasure framework' can be connected in its completeness to the product categories enunciated. Trends and fashion can also play a role in the pleasure derived from products, specifically for sociological (from the impact on other people) or ideological (from the fulfillment of people's actualization needs) pleasures. The elimination, or absence of pain, can also be thought as being mediated by many of the products considered in the above listing, as well as the provision of positive, joyful feelings.

2.2.5. Cultural aspects related to pleasure with products.

Pleasure with products, may be influenced by culture, since people's values and experiences play a role in the perception of pleasure. According to Hofstede (1991), culture is "the collective programming of the mind which distinguishes the members of one group or category of people from another". The author distinguishes culture from human nature on the one side, and from an individual's personality on the other. Hofstede presents three levels of uniqueness in human mental programming: a universal level that is inherited which is the 'human nature', a level specific to the group or category and that is learned which is the 'culture', and finally, a level that is specific to the individual and that is both inherited and learned which is the 'personality'. These three levels may be thought to play a part in influencing people's experience with products. This division is also important in planning a study that aims at giving a contribution to finding out what people find pleasurable. People as individuals are unique, and therefore pleasure cannot be entirely distinguished from personal values and taste, or cultural and task setting (Hauge-Nilsen and Flyte forthcoming). Still, interestingly, Hofstede's universal level – 'human nature' – may provide for sufficient commonalities that would enable some understanding of people's positioning in general towards pleasure with products.

2.2.6. Summary of the structure devised.

The theoretical structure explicit in this section considers three perspectives on pleasure with products. The first perspective pertains to the context of product use, or the context of activity, distinguishing between pleasure enabled by an activity and pleasure enabled by the product that supports the activity, and categorizing the worlds of activity (world of physical objects, the mental world and the world of objective content of thought). The second perspective pertains to the categorization of pleasure in terms of the human mediation 'component' that is involved (physiological, psychological, sociological and ideological). Finally, a third perspective considers the impact of pleasure in the person's level of contentment (pleasures of need and pleasures of appreciation).

2.3. Aims

The preceding section reviewed the theoretical construct of 'pleasure with products' yielding a few fundamental premises that were emphasized and formalized as hypotheses. In this section, a set of aims is presented and positioned in relation to the challenges outlined in pioneering works in this field.

The premises underlying ‘pleasure with products’ that were discussed are related to human beings. People are involved in these assertions in terms of their seeking of pleasure and the universality of the categorizations of pleasure. This comes as no surprise since the motivation for this new approach to ergonomical design is looking at people holistically. Meanwhile, this raises the interest of checking, through empirical data, if people actually recognize and agree with these premises. This study is therefore aimed at testing, through general people’s input, the three fundamental hypotheses elicited in the above paragraphs, which are part of the foundations of, and justification for, ‘pleasure with products’; namely:

1. people actively seek pleasure by their choice of products in their everyday life
2. people recognize and can discriminate between the four components of pleasure (Tiger 1992) applied to products – physiological, psychological, sociological and ideological
3. people seek both need pleasures and pleasures of appreciation

Taking a broader perspective, the aims for this study include deducting and testing a structure of concepts that supports the transformation into operative form of ‘pleasure with products’ and allows communicating about pleasure both with users and with designers. The hypotheses are to be tested with input from product users, which also enables pointing out for which products it seems more relevant to consider pleasure requirements. The aims can thus be listed as:

- developing and empirically testing a structure of concepts which allows communicating about pleasure with products both with users and with designers,
- testing hypotheses,
- understanding users and
- finding out to which products are pleasure requirements more relevant.

2.3.1. Challenges.

Collaboration between human factors professionals and designers is needed, according to Fulton (1993), in order to make products and environments that do better than keeping people from getting sick, damaged or irritated, thus enhancing the quality of interaction and experience. Having outlined a ‘pleasure’ based approach to person-centered design, defining pleasure as “the emotional, hedonic and practical benefits associated with products”, Jordan (1998) presents the challenges for human factors that spring from this approach. These are: understanding users and their requirements, linking product properties to pleasure benefits, and developing methods and metrics for the investigation and quantification of pleasure. This study falls into the first challenge, by investigating the empirical fundaments of the types of pleasure that products can bring to their users, based on understanding the role which products plays in people’s lives. It is a pilot study that aims at assessing the viability of the inherent concept structure of ‘pleasure with products’ in terms of its discussion format for both users and designers.

2.3.2. Concluding remarks.

A new approach to product development is now taking form. It concerns agreeability of the interaction people have with products and the pleasure, or emotional benefits, which may accrue for the human beings from that interaction. This study is tendered towards deducting a structure of concepts that is communicable to both users and

designers, and to finding out what people want from products, in terms of understanding to what products is pleasure a more relevant aspect.
The point of view of a sample of Portuguese people concerning agreeability of the interaction with products is sought with this questionnaire study. The questionnaire consists of a general inquiry in terms of products considered, without new products being given to people, but rather discussing pleasure issues in products already used by subjects in their day to day life. This study therefore provides a medium to long term perspective on the pleasurability of everyday products.

3. METHOD

This section elaborates on the design of the questionnaire, presenting the rationale that led to the construction of the questionnaire based on the three hypotheses that were generated. The questionnaire structure and its distribution are also discussed. In general terms, the method that was devised to produce the questionnaire consisted of (see Figure 2):

1. Identifying relevant theoretical approaches.
2. Formulating hypotheses.
3. Breaking down the hypotheses in the scope of the relevant theory.
4. Transforming the pieces resulting from the detailing of the hypotheses into statements.

3.1. Questionnaire structure and distribution

Following the method described in Figure 2, statements were formulated and used in the questionnaire, which was divided into five sections. The first three sections concerned the opinion of the respondent about the statements. Questionnaire respondents judged these statements in terms of agreement / disagreement with them. Their opinion was given in four pre-established alternatives: “I totally agree”, “I agree moderately”, “I disagree moderately” and “I totally disagree”. The language of the questionnaire was Portuguese. A fourth section was devoted to examples requested to respondents on products that gave them pleasure in a way that was reflected in the content of the sentences in the first three sections. A space for comments was available in each of the questionnaire sections. The fifth and concluding section collected demographic data of the respondents (gender, age, level of schooling, level of income).
In order to de-personalize the sentences, in an attempt to allow people to put down their concern of exposing their intimate self, sentences were phrased in terms of ‘people’, instead of ‘you’. Some of the respondents, however, commented on the use of this *persona* as a rule in the questionnaire, in some cases considering that their personal answers did not match their opinion about people in general. In a further attempt to leave people at ease when answering the questionnaire, it was designed so as to be anonimously sent back to the researchers.
The questionnaire was distributed by post mail, to volunteers who manifested their interest in participating. An invitation was initially sent via e-mail (in October 2000) to 150 e-mail addresses in Portugal selected randomly from existing email lists of the Portuguese university community. This was a deliberate attempt to restrict the sample of respondents to the sub-group of academics, although continuing studies should also focus on other groups. Envisaged in this restriction was the choice of targeting a more verbally trained culture subgroup to evaluate the viability of a concepts structure for analyzing and understanding pleasure with products. 82 respondents completed the questionnaire and sent it back to the researchers in a pre-paid postage envelope

supplied with the paper printed questionnaire. Receivership of completed questionnaires was terminated in January 2001.

The respondents were balanced between males (47%) and females (53%), while their age was concentrated in the 26 to 45 years interval (61%), with 21% of the remaining respondents being younger than those and 18% older. 65% of the respondents were university employees, 23% were students and 10% were self-employed. University graduates accounted for 51% of the respondents and another 42% held post-graduations. This profile of demographic characteristics is skewed, on the one hand towards young adults, and on the other towards people with studies at the university level or higher. This distribution of respondents is a result of the sampling procedure that was used.

3.2. Questionnaire design

The three hypotheses to be tested in this study were the points of departure for the design. In the three cases, the rationale followed was to expand the content of the hypotheses and break it down into a number of statements that could be judged by the questionnaire respondents. Links to products are made explicitely in some of the statements. In the process of reaching at the statements, there was an element of choice involved – aspects and examples have been chosen to concretize issues resulting from the breakdown of the hypotheses. These processes are described in the following sub-sections for each of the hypotheses separately. The resulting statements are shown in section 4 (method of analysis and presenting results), in Tables 1, 2 and 3.

3.2.1. Treatment of hypothesis 1.

Hypothesis 1 consisted of "people actively seek pleasure by their choice of products in their everyday life". The breakdown of this hypothesis, leading to the sentences considered in the questionnaire is shown schematically in Figure 3.

Activities and pastimes, objects and artefacts and mental and physical capabilities are the themes into which it is sub-divided. Popper's (1989) pluralistic view of three worlds is used to assure a holistic breakdown, producing a set of encompassing statements. The world of physical objects or states is covered mostly by the physical capabilities (and shape) of the body and by the objects and artefacts. The mental world concerns primarily the mental capabilities and the social aspects involved in activities exemplified as home decoration or everyday use of objects and artefacts. Finally, the world of ideas is reflected mostly in people's creative capacities. Pleasure is associated with the activity in these three worlds, although it may be seen to pertain to the world of mental states as an emotion. The statements reached at are presented in Table 1.

3.2.2. Treatment of hypothesis 2.

Hypothesis 2 consisted of "people recognize and can discriminate between the four components of pleasure applied to products – physiological, psychological, sociological and ideological". The breakdown of this hypothesis, leading to the sentences considered in the questionnaire is shown summarily in Figure 4. Two instances of physiological pleasure were covered in the questionnaire (olfaction and touch). Concerning sociological pleasure, the focus was drawn on products that facilitate social gathering and easily become conversation motives, and on those that pass on the impressions of social or material status. Considered in the questionnaire, as product contributions towards providing psychological pleasure, were: providing the feeling of adequateness to the cognitive demands of the product's use and feeling emotions during product use. Statements representing the category of ideological pleasure included the notion of pleasure attained through contemplation of art forms, pleasure derived from product aesthetics and pleasure derived from the embodiment of people's ideological values in products. The resulting statements can be found in Tables 2-a and 2-b.

3.2.3. Treatment of hypothesis 3.

Hypothesis 3 consisted of "people seek both need pleasures and pleasures of appreciation". This hypothesis was broken down into a generic statement and statements particularized through the use of examples. We considered seats, good physical shape, as well as humoristic qualities of products, as examples for specifically illustrating the hypothesis (Figure 5). The resulting statements are shown in Table 3.

4. METHOD OF ANALYSIS AND PRESENTING RESULTS

Answers to sections 1, 2, 3 and 4 of the questionnaire were analyzed in terms of agreement and disagreement answers and whether the respondent, when requested to do so, gave examples. The categories of 'I totally disagree' and 'I disagree moderately' were combined into one 'disagreement' category in the analysis. A similar condensation was made with the 'I agree totally' and 'I agree moderately' categories into one 'disagreement' category. This condensation was done to enable assessing the statistical significance of the 'agreement' / 'disagreement' imbalance, by the use of the binomial test (Siegel and Castellan 1988). Also, testing the hypotheses seems more effective, given the testing materialized in the expression of opinion about affirmations, in a two case universe of possibilities.

The results showed an overwhelming agreement with the statements that were assessed in the questionnaire. This raised interest in exploring not only the agrees-disagrees dichotomy, but also the level of agreement in comparing the statements. These results are also depicted in the Tables of results (Tables 1, 2-a, 2-b and 3), under the abbreviated headings of 'total agr.' (total agreement) and 'mod. agr.' (moderate agreement).

For the statements which were rated in terms of levels of 'agreement' and for which examples were also requested from the respondents' own lifes, the McNemar change test was computed to test for the significance of the overwhelming direction of change (Siegel and Castellan 1988). The confidence level for both tests was set to 95%. In the following paragraph, an example is given that shows the interest of applying the McNemar change test to the data.

Statement 1.3 consisted of 'People seek activities and pastimes that allow them to express their creative capacities'. The distribution of opinions about this statement, cross-matched with the exemplification done by the respondents is as follows. There were 60 respondents that agreed and exemplified, 2 that disagreed and did not exemplify, while 18 respondents disagreed but exemplified and another 2 respondents agreed but gave no examples (as shown in Table 1). The McNemar change test showed that the significantly predominant direction of change went from disagreement to exemplifying (for those 20 respondents that changed the quality of their answers - whether positive to negative or vice-versa - from the agreement question to the exemplification one).

Tables 1, 2 and 3 show the absolute frequency data for each statement, asides with the associated results of the binomial and McNemar statistical test results (respectively in

the fifth and sixth columns of the Tables). A random sample of the examples provided by respondents is shown for each statement. Table 1 presents the results of the questionnaire concerning the statements that originate from the breakdown of hypothesis 1: “people actively seek pleasure through their choice of products in their everyday life”.
Tables 2-a and 2-b present the results of the questionnaire concerning the statements that originate from the breakdown of hypothesis 2: “people recognize and can discriminate between the four components of pleasure applied to products – physiological, psychological, sociological and ideological”.
Table 3 presents the results of the questionnaire concerning the statements that originate from the breakdown of hypothesis 3: “people seek both need pleasures and pleasures of appreciation”.

5. DISCUSSION

The results show an overwhelming agreement with the statements posed, possibly because pleasure is a strongly loaded word and because the statements are formulated in a positive way. Did we ask people to rate the obvious, pleasure being good? To some extent this question can be answered by comparing the frequencies of total ageement versus moderate agreement for each statement. This comparison shows that some statements are completely accepted by the majority of respondents, but not all of the statements. The result of the statements’ assessment was not even, since validation was stronger for some of the statements. However, interestingly, key parts of all the hypotheses were strongly validated. An overview of the theoretical constructs considered is seen in Figures 3, 4 and 5, where stronger validation of aspects of the breakdown of hypotheses is denoted with asterisks. The sparsity and evenness of the distribution of the more weakly validated aspects does not seem to allow refuting the practicability of the theoretical structure of concepts as a means for communicating about pleasure with products to users and designers. In order to test the robustness of our perspective, one which sees pleasure as a decider of the choices people make among products, it would be worthwhile to consider alternatives to pleasure as deciders of these choices, given that pain, risk, danger, health, performance, usability and comfort have all been satisfied. Value for money and quality are possible alternatives we can consider, but taking a closer look at these concepts, we find overlaps with the structure of pleasure devised in this study. The value of a product to a person is concerned with the level of fulfillment of needs, easiness of use and pleasurability delivered by the product; product quality can be seen very similarly to value. Nonetheless, the economic aspect is detached from pleasure and therefore it seems as a decider of choice, complementing pleasure.
The following sections discuss the results of the questionnaire in connection with the hypotheses that guided the questionnaire design and with the categories of products covered in the respondents’ examples. A final section discusses implications of the questionnaire distribution scope on restricting extrapolation from the results.

5.1. Discussion of results pertaining to hypothesis 1

A vast majority of respondents positively judged the seven statements considered as the breakdown of hypothesis 1 (“people actively seek pleasure through their choice of products in their everyday life”). The same applies to exemplifying for the five statements for which examples were requested. More than half of the total respondents express their total agreement with statements 1.1, 1.4, 1.5 and 1.6, expressing that people seek activities, pastimes objects and artefacts that give them

pleasure, and that they acquire pleasure in decorating their homes and in being in a good physical shape. These results indicate that the majority of respondents accepts hypothesis 1. Given the links to Popper's pluralistic view of three worlds existing in the statements, the applicability of this hypothesis in these contexts is also suggested. This part of the questionnaire results thus indicates that pleasure seeking is done by people through physical objects, mental states and ideas (the latter to a lesser extent, given the weaker validation of 'people's search to express their creative capacities'-statement 1.3).
Having distinguished between pleasure with products and pleasure from activities, we outlined a two-dimensional space of pleasure with products, considering the intertwining of the product and activity dimensions. Examples given by respondents pertaining to statements 1.1 and 1.4 illustrate this symbiosis on pleasure enhanced from the activity and from the enabling product (e.g. playing tennis versus sports gear, or music versus record player).

5.2. Discussion of results pertaining to hypothesis 2

The greater part of respondents positively judged the ten statements considered in the breakdown of hypothesis 2 ("people recognize the four components of pleasure applied to products – physiological, psychological, sociological and ideological"). The same applies to exemplifying in the eleven instances when this was requested in this section of the questionnaire. These results indicate that most respondents accept hypothesis 2. Examples given by respondents included a wide array of products. This indicates that most of the pleasure categories are not recognized only in manufactured, consumer or technological products, but are recognized in many product categories (including food, entertainment, or personal hygiene products). It may therefore not be unwise to intentionally design products that appeal to these kinds of pleasures, since these are already brought up by products and are sought by people. The statements that gave place to a greater number of examples concerning technological products (automobiles, photographic cameras, and the like) were those pertaining to product aesthetics and to material status (statements 2.5a and 2.9). More than half of the respondents totally agreed with statements 2.1, 2.5, 2.7, 2.8 and 2.9, stressing olfactory pleasure (physiological), identification with products and consequent pleasure through the projection of material or cultural status (sociological), pleasure from emotional reactions engendered through product interaction (psychological) and pleasure from art forms and product aesthetics (ideological).

5.3. Discussion of results pertaining to hypothesis 3

A vast majority of respondents positively judged the eight statements resulting from the decomposition of hypothesis 3 ("people seek both need pleasures and pleasures of appreciation"). Most subjects also provided examples for the three instances where these were requested. These results provide empirical evidence in support of Lewis's considerations on need and appreciation pleasures. Moreover, the results demonstrate an empirical foundation on the applicability of this dichotomy to products, through the example of seats. Respondents seem to validate the association of the elimination, or absence of pain with moving from a situation of seat discomfort to a situation of seat comfort. This is inferred from the examples given in respect to statement 3.1 (people can derive pleasure from the elimination, or absence, of pain; random sample of examples given: foot wear, tea kettle, medicines, pills, pain killers, aspirin, medical equipment, mattress, orthopedic mattress, bed, pen, good seats, easy chair, sofa, automobile seat, anatomical design, music). The examples considered by respondents are mostly of a physical pain / relaxation nature. Examples pertaining to a cognitive nature are scarce or not clearly identifiable, despite the fact that most respondents were likely to be computer users.

More than half of the total number of respondents express their total agreement with statements 3.2, 3.3 and 3.4, postulating pleasure from positive feelings (appreciation pleasure), pleasure from comfortable and physically fitting seats (a particular case of need pleasures). In a study of comfort and discomfort, Zhang, Helander and Drury (1996) collected descriptors of comfort for office seats from a large sample of office workers. It was shown that many of the descriptors of comfort found are common to a pleasure dimension (Coelho and Dahlman forthcoming). The statements of this section of the questionnaire pertaining to seats corroborate that comfortably pleasurable seats tender to need pleasures, while aesthetically pleasurable seats tender to appreciation pleasures.

5.4. Categories of products covered by the respondents' examples

The products given as examples by questionnaire respondents illustrate a very broad notion of product. This notion encompasses food, entertainment, appliances, and even medicines, besides technological, or engineering products. Although the introduction to the questionnaire and the examples accompanying some of the statements pointed at consumer, manufactured and technological products, respondents did not limit their answers to this category. This can be understood by the fact that people do not see their lives as segmented and rather tend to have a holistic view on their pleasures. Still, consumer products were included in the examples given by respondents, which safeguards the validation meant for this type of products. As to all the categories of products considered in the initial discussion, the following were brought up in respondents examples: personal, consumer (for individual use), consumer (used in the home), office (and/or home) and artistic. Professional products were not mentioned in the respondents' examples. This absence may be inherent to the characteristics of the subgroup of people answering the questionnaire. For these people, however, professional products may be thought to include computers, or books, which were included in other categories. Consequently, the results do not provide evidence for dismissing the category of professional products as irrelevant for consideration of pleasure requirements.

5.5. Implications of the questionnaire distribution scope on extrapolating from results

The universe where the questionnaire was distributed is particularly confined. Therefore, the extrapolation of the results to a wider population is not straightforward, and would, strictly, have a low validity. Still, these results provide an indication on the pertinence of designing pleasurable products and on the relevance of the underlying concepts outlined in the problem discussion section of this study, contributing to understanding what people want from products. The commonalities among different people's opinions, despite their different values and taste, as observed in the questionnaire results, corroborate Hofstede's 'human nature' level of human mental programming. Although the questionnaire distribution scope was quite restricted, the heterogeneity of the sample (in terms of age, level of studies, or specific knowledge area) was large enough to allow inferring that respondents did not all belong to the same group of 'culture' or even less 'personality'.

6. CONCLUSION

A set of three fundamental premises of the field of knowledge of 'pleasure with products' was empirically tested in this questionnaire study. The results do not refute the practical applicability of these three premises. The study therefore gives a contribution to the empirical validation of the theoretical foundations of pleasure with products. The results also suggest that the structure of concepts devised is suited for communicating about pleasure to users (and hence, to designers too). Given the examples delivered by respondents, the pertinency of pleasure to consumer and other technological product types is also evident. The empirical data gave a contribution towards prooving that people want and seek pleasure from products. Knowledge on converting pleasure requirements on products into engineering design specifications is however still lacking. Product pleasurability metrics are also an area on which further work is needed.

REFERENCES

Coelho, Denis A. and Dahlman, Sven (forthcoming), "Comfort and Pleasure," in Pleasure with the use of products, ed. Patrick W. Jordan and William S. Green, London: Taylor and Francis.

Fulton, Jane (1993), "Physiology and design new human factors," American Center for Design Journal, 7(1).

Gosling, Justin C.B. (1969), Pleasure and Desire – the case for hedonism reviewed, London: Oxford University Press.

Hauge-Nilsen, Anne-Lise and Flyte, Margaret G. (forthcoming), "Understanding attributes that contribute to pleasure in product use," in Pleasure with the use of products, ed. Patrick W. Jordan and William S. Green, London: Taylor and Francis.

Hofstede, Geert (1991), Cultures and Organisations – software of the mind, London: McGraw-Hill.

Jordan, Patrick W. (1996), "Displeasure and how to avoid it," in Contemporary Ergonomics 1996, ed. S. Robertson, London: Taylor & Francis.

——— (1998), "Human Factors for pleasure seekers," Ergonomia, 11, 14-19.

——— and Macdonald, Alastair S. (1998) "Pleasure and Product Semantics," in Contemporary Ergonomics 1998, ed. M.A. Hanson, London: Taylor & Francis, 264-268.

——— (2000), Designing pleasurable products, London: Taylor and Francis.

Lewis, Clives S. (1987), The four loves, Glasgow: Collins.

MacDonald, Alastair S. (1988), "Developing a qualitative sense," in Human Factors in Consumer Products, ed. N. Stanton, London: Taylor & Francis, 175-191.

Popper, Karl R. (1989), "Epistemology without a knowing subject," in Objective Knowledge: An Evolutionary Approach, ed. K. Popper, Oxford: Clarendon Press, 106-152.

Siegel, Sidney, Castellan, N. John (1988), Non-parametric statistics for the behavioral sciences, 2nd ed., New York: Mc-GrawHill.

Tiger, Lionel (1992), The Pursuit of Pleasure, Boston, MA: Little Brown and Company.

Waton, Harry (1919), Pain and pleasure - A philosophy of life, New York: Marx Institute.

Zhang, Lijian, Helander, Martin G. and Drury, Colin G. (1996), "Identifying factors of comfort and discomfort in sitting," Human Factors, 38(3), 377-389.

TABLE 1

QUESTIONNAIRE RESULTS FOR STATEMENTS PERTAINING TO HYPOTHESIS 1

People seek activities and pastimes that give them pleasure							
S1.1	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	82	0	0	significant (agreement)	no change	66	16
no example	0	0	0	significant (exemplification)			
music, cinema, reading, sex, cooking, walking by the sea, travelling, seeing exibitions, playing tennis, eating, comics, studying.							
People seek activities and pastimes that extend their mental and physical capabilities							
S1.2	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	70	11	0	significant (agreement)	significant changes (agreement / exemplification)	12	58
no example	0	1	0	significant (exemplification)	predominant changes (disagrees -> exemplifies)		
research, conferences, walking, swimming, reading, writing, computer games.							
People seek activities and pastimes that allow them to express their creative capacities							
S1.3	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	60	18	0	significant (agreement)	significant changes (agreement / exemplification)	11	51
no example	2	2	0	significant (exemplification)	predominant changes (disagrees -> exemplifies)		
decoration, music, travelling, contemplation of the natural environment.							
People seek and choose objects and artefacts that give them pleasure							
S1.4	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	76	2	0	significant (agreement)	change explained by randomness	46	33
no example	3	1	0	significant (exemplification)			
record player, wristwatch, clothes, pens with differing shapes, daily planner, computer, sports gear, newspapers, television, books.							
People acquire pleasure in decorating their homes with paintings, posters and other objects							
S1.5	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	74	4	0	significant (agreement)	change explained by randomness	49	29
no example	4	0	0	significant (exemplification)			
postcards, posters, furniture, painted walls, books in the bookshelf, CDs in the CD player, carpets, paintings, handicraft.							
People sorround themselves in their day to day life with objects and artefacts that give them pleasure							
S1.6	agrees	disagrees	no answer			total agr.	mod. agr.
	77	5	0	significant (agreement)		39	38
People derive pleasure from being in a good physical shape							
S1.7	agrees	disagrees	no answer			total agr.	mod. agr.
	77	5	0	significant (agreement)		49	28

TABLE 2-a

QUESTIONNAIRE RESULTS FOR STATEMENTS PERTAINING TO HYPOTHESIS 2 (continues)

People derive pleasure from the olfactory properties of some products

S2.1	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	77	3	0	significant (agreement)	change explained by randomness	49	29
no example	1	1	0	significant (exemplification)			

food, cosmetics, clothes, perfume, sea scent, candles, coffee, toasts, incense.

People derive pleasure from the tactual properties of some products

S2.2	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	67	2	0	significant (agreement)	significant changes (agreement / exemplification)	40	37
no example	10	3	0	significant (exemplification)	predominant changes (agrees -> no examples)		

clothes, bed linen, towels, vynil albums, teddy bear, silk, linen, paper.

There are products that bring pleasure to people by being focal points for social gatherings (ex.: coffee machine)

S2.3	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	57	11	0	significant (agreement)	change explained by randomness	33	33
no example	9	5	0	significant (exemplification)			

cushions, sofas, hi-fi sound device, cofee, dinner with friends, wine, the elegance of a wine glass, paintings, adequate lighting.

There are products that provide pleasure by facilitating social interaction by being conversation motives in theirselves (ex.: jewelry)

S2.4	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	53	12	0	significant (agreement)	change explained by randomness	21	44
no example	12	5	0	significant (exemplification)			

radio, television, computers (internet), art (paintings, sculptures, theatre).

There are products with which people have such a relationship that makes them part of their own identity (ex.: wrist watch, swiss knife, pen, clothes)

S2.5	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	62	2	0	significant (agreement)	significant changes (agreement / exemplification)	47	29
no example	14	4	0	significant (exemplification)	predominant changes (agrees -> no examples)		

clothes, sports equipment and objects, newspapers, books, earings, pen, paper, watch, LPs (vinyl), non-leather shoes, spectacles.

Products from which you derive pleasure because these pass on the impression of material status S2.5a

exemplifies	52	
no example	30	significant (exemplification)

Automobile, VW automobile, clothes, house, furniture, watch.

TABLE 2-b

QUESTIONNAIRE RESULTS FOR STATEMENTS PERTAINING TO HYPOTHESIS 2 (continued)

Products from which you derive pleasure because these pass on the impression of cultural status S2.5b

exemplifies	61		
no example	21		significant (exemplification)

paintings, clothes, books, books purchased in the USA, travel, music records (vinyl), music CDs.

People derive pleasure from their feeling of adequateness to the level of cognitive demands of using a particular product (ex.: software for word processing)

S2.6	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	61	3	0	significant (agreement)	significant changes (agreement / exemplification)	34	39
no example	12	6	0	significant (exemplification)	predominant changes (agrees -> no examples)		

software, calculus software, books, literary critique magazines, computer, foreign encyclopedia (English).

People derive pleasure from the emotional reactions engendered through the interaction with certain products (ex.: games)

S2.7	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	64	5	0	significant (agreement)	change explained by randomness	43	34
no example	13	0	0	significant (exemplification)			

bycicles, music records, clothes, TV, books, cinema, theatre, paintings, art, sports equipment (for winsurf, all terrain, tennis).

People derive pleasure from experiencing books, music and art

S2.8	agrees	disagrees	no answer			total agr.	mod. agr.
	79	2	1	significant (agreement)		60	19

People derive pleasure from the aesthetics of some products

S2.9	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	68	3	0	significant (agreement)	change explained by randomness	54	24
no example	10	0	1	significant (exemplification)			

candles, compact photographic camera, CDs, vinyl albums, clothes, foot wear, spectacles, furniture, sofas, automobile, paintings, sculptures, jewelry, pens, hand bags, kitchen appliances, pictures.

People derive pleasure from products that embody their ideological values (ex.: biodegradable materials used in products embody the value of environmental responsibility, electric or hybrid cars)

S2.10	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	53	5	1	significant (agreement)	significant changes (agreement / exemplification)	28	45
no example	20	2	1	significant (exemplification)	predominant changes (agrees -> no examples)		

recycled paper; clothes, footwear, cosmetics and detergents (without material from animals and not tested in animals), biodegradable products, watch, books, paintings, newspapers, energy saving products, environment friendly products.

TABLE 3

QUESTIONNAIRE RESULTS FOR STATEMENTS PERTAINING TO HYPOTHESIS 3

People can derive pleasure from: - the elimination of, or absence of, pain

S3.1	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	53	6	3	significant (agreement)	change explained by randomness	35	34
no example	16	4	0	significant (exemplification)			

foot wear, tea kettle, medicines, pills, pain killers, aspirin, medical equipment, mattress, orthopedic mattress, bed, pen, good seats, easy chair, sofa, automobile seat, anatomical design, music.

People can derive pleasure from: - the provision of positive, joyful feelings

S3.2	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	64	1	1	significant (agreement)	significant changes (agreement / exemplification)	59	20
no example	15	1	0	significant (exemplification)	predominant changes (agrees -> no examples)		

music CDs, vinyl records, books, food, drinks, travel, radio, plants, flowers, sculptures, paintings, colorful vibrant things, windsurf board, all terrain automobile, films.

A basic pleasure of elimination of pain, or absence of pain, associated with seats: - that these be comfortable

S3.3	agrees	disagrees	no answer		total agr.	mod. agr.
	77	3	2	significant (agreement)	47	30

A basic pleasure of elimination of pain, or absence of pain, associated with seats: - that the person sitting should not be physically damaged by the seat

S3.4	agrees	disagrees	no answer		total agr.	mod. agr.
	75	6	1	significant (agreement)	51	24

A seat may provide positive and joyful feelings to people derived from its aesthetics

S3.5	agrees	disagrees	no answer		total agr.	mod. agr.
	69	11	2	significant (agreement)	15	54

Being in a good physical shape gives pleasure to people from: - the elimination, or absence, of pain

S3.6	agrees	disagrees	no answer		total agr.	mod. agr.
	60	20	2	significant (agreement)	24	36

Being in a good physical shape brings pleasure to people from: - the provision of positive, joyful feelings

S3.7	agrees	disagrees	no answer		total agr.	mod. agr.
	76	5	1	significant (agreement)	36	40

People can derive pleasure from the humoristic qualities of a product

S3.8	agrees	disagrees	no answer			total agr.	mod. agr.
exemplifies	56	3	0	significant (agreement)	significant changes (agreement / exemplification)	35	43
no example	22	1	0	significant (exemplification)	predominant changes (agrees -> no examples)		

books, clothes, packagings of some products, games, TV, TV programmes, films, some small artefacts designed by P. Stark (ex.: citrus juicer), representations, sculptures, newspapers.

Figure Captions

FIGURE 1
PLEASURE IN PRODUCT USE AS A TWO-DIMENSIONAL SPACE, ENABLED BY ACTIVITIES AND BY PRODUCTS

FIGURE 2
GENERAL OUTLINE OF THE METHOD USED TO PRODUCE THE QUESTIONNAIRE

FIGURE 3
"PEOPLE ACTIVELY SEEK PLEASURE BY THEIR CHOICE OF PRODUCTS IN THEIR EVERYDAY LIFE" (HYPOTHESIS 1) EXPLODED INTO SOURCES OF PLEASURE THAT ARE LINKED TO THE PLURALISTIC VIEW OF THE THREE WORLDS OF POPPER (1989)

Footnotes to Figure 3:
Dashed arrows in the scheme suggest weaker links.
Aspects marked with asterisks had stronger validation from questionnaire results.

FIGURE 4
BREAKDOWN OF HYPOTHESIS 2 - "PEOPLE RECOGNIZE AND CAN DISCRIMINATE BETWEEN THE FOUR COMPONENTS OF PLEASURE APPLIED TO PRODUCTS – PHYSIOLOGICAL, PSYCHOLOGICAL, SOCIOLOGICAL AND IDEOLOGICAL" - EXPLAINED IN TERMS OF THE CORRESPONDENCE OF PLEASURE CATEGORIES TO MEDIATION ASPECT, PRODUCT CONTRIBUTION AND PRODUCT EXAMPLES GIVEN

Footnote to Figure 4:
Aspects marked with asterisks had stronger validation from questionnaire results.

FIGURE 5
REPRESENTATION OF THE BREAKDOWN OF HYPOTHESIS 3 –" PEOPLE SEEK BOTH NEED PLEASURES AND PLEASURES OF APPRECIATION", INCLUDING THE EXAMPLES CONSIDERED

Footnote to Figure 5:
Aspects marked with asterisks had stronger validation from questionnaire results.

FIGURE 1
PLEASURE IN PRODUCT USE AS A TWO-DIMENSIONAL SPACE, ENABLED BY ACTIVITIES AND BY PRODUCTS

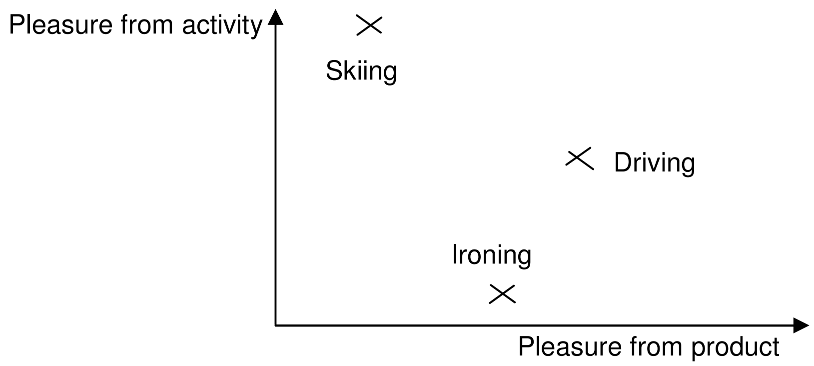

FIGURE 2
GENERAL OUTLINE OF THE METHOD USED TO PRODUCE THE QUESTIONNAIRE

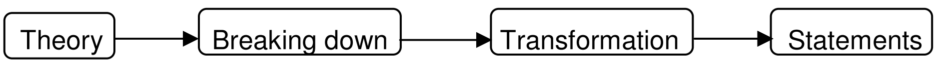

FIGURE 3
"PEOPLE ACTIVELY SEEK PLEASURE BY THEIR CHOICE OF PRODUCTS IN THEIR EVERYDAY LIFE" (HYPOTHESIS 1) EXPLODED INTO SOURCES OF PLEASURE THAT ARE LINKED TO THE PLURALISTIC VIEW OF THE THREE WORLDS OF POPPER (1989)

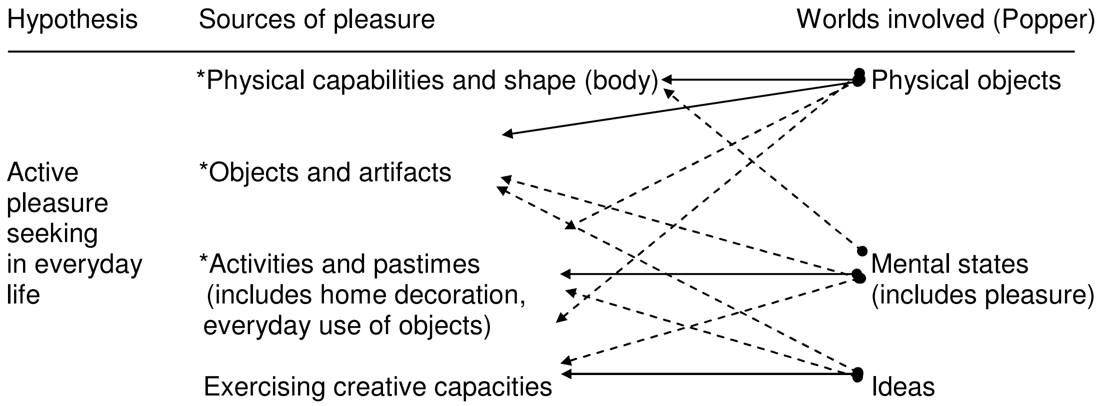

FIGURE 4

BREAKDOWN OF HYPOTHESIS 2 - “PEOPLE RECOGNIZE AND CAN DISCRIMINATE BETWEEN THE FOUR COMPONENTS OF PLEASURE APPLIED TO PRODUCTS – PHYSIOLOGICAL, PSYCHOLOGICAL, SOCIOLOGICAL AND IDEOLOGICAL” - EXPLAINED IN TERMS OF THE CORRESPONDENCE OF PLEASURE CATEGORIES TO MEDIATION ASPECT, PRODUCT CONTRIBUTION AND PRODUCT EXAMPLES GIVEN

Pleasure categories	Mediation through	Product contribution	Examples given
Physiological	sensory organs	*olfactory properties tactual properties	
Sociological	relationships with others	social / conversation focus *part of person’s identity *material status impression *cultural status impression	coffee machine / jewelry wristwatch
Psychological	cognitive reactions emotional reactions	give feeling of adequateness *emotions from interaction	word processor games
Ideological	agreement with subject’s values	*art forms *aesthetics embodiment of values	biodegradable materials

FIGURE 5

REPRESENTATION OF THE BREAKDOWN OF HYPOTHESIS 3 –" PEOPLE SEEK BOTH NEED PLEASURES AND PLEASURES OF APPRECIATION", INCLUDING THE EXAMPLES CONSIDERED

Example	Need pleasures	Pleasures of appreciation
(general)	elimination / absence of pain	*provision of positive, joyful feelings
seats	*comfortable seats *non-damaging seats	seat aesthetics
physical shape	good physical shape	good physical shape
humor in products (products)		humoristic qualities

Article VI

Patterson, E.S., Coelho, D.A., Woods, D.D., Cook, R.I., & Render, M.L. (2000). The Natural History of Technology Change: How Introducing Bar Coding Changes Medication Administration. Paper presented at the Fifth Conference on Naturalistic Decision Making. Tammsvik, Sweden, 26-28 May.

The Natural History of Technology Change: How Introducing Bar Coding Changes Medication Administration

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Abstract

The current interest in improving patient safety and reducing adverse events in health care has led to interest in the use of bar coding to verify medications are correct immediately prior to administration. The result is a natural experiment on the impact of new technology on human performance in a complex setting. Observations at two hospitals in the process of implementing a particular bar coding medication verification system revealed familiar patterns of transformation and adaptation. First, new vulnerabilities in the process of medication administration as a result of missing information about pending and discontinued medication orders were identified. Second, the increase in documentation activities during the high-tempo period of the medication pass encouraged adaptations that bypassed the bar coding system. Third, the automated collection of data about the time a medication was administered artificially raised timely medication administration over other patient care goals. These observations increase our understanding of how the process of medication administration functions and add to the knowledge base of how technology change impacts cognition and collaboration. The findings generate insight into short- and long-term design post-conditions to improve system usefulness and reduce unintended side effects following the introduction of the new technology.

> New technology "alters what is already going on—the everyday practices and concerns of a community of people—and leads to a resettling into new practices." (Flores et al., 1988, p. 154).
>
> "New tools alter the tasks for which they were designed, indeed alter the situations in which the tasks occur and even the conditions that cause people to want to engage in the tasks." (Carroll and Campbell, 1988, p. 4).

1. INTRODUCTION

1.1 Observing Episodes of Technology Change in a Dynamic Field of Practice

It is axiomatic that technology change has far-reaching impacts on the way in which work is conducted in a field of practice (Rasmussen et al., 1994). In opposition to the pervasive myth that a change in medium (e.g., computerized order entry instead of handwritten prescriptions) can be introduced without greatly altering the system, findings from observations of the introduction of new technologies show that little of the former roles, strategies, and paths to failure are preserved across the technology change boundary. In actuality, as a consequence of added or expanded machine roles, practitioners take on new roles and transform their previous roles, the nature of standard practice changes, the expectations for what is normal and what is unexpected changes, and new paths to failure arise (Woods and Tinapple, 1999; Woods and Sarter, in press; Barley and Orr, 1997; Sarter, Woods and Billings, 1997; Woods, Sarter, Graham, and Dekker, 1999; Dekker and Woods, 1999). The reality is patterns of *transformation* and *adaptation*.

This reality has led to the injunction for natural history studies of naturally occurring points of change to better understand the processes of transformation and adaptation (e.g., Cook and Woods, 1996; Dekker and Woods, 1999). The points of change form natural experiments where a change (the new technology) disturbs a system. Observers calibrated to patterns in human-machine performance can watch how the system re-settles into a new equilibrium state in order to learn a great deal about how the system in question works. Natural history studies of points of change serve two purposes. First, these points of change are opportunities to learn how the system actually functions and sometimes mal-functions by observing how practitioners accommodate and adapt to the technology change. The system is examined to see how the technology transforms roles, judgments, coordination and how people adapt to the mix of new capabilities and new complexities. This information helps to reveal organizational, design, and training post-conditions to make the system more useful and reduce unintended side effects from the change.

Second, observing at points of change adds to the knowledge base of how changes impact cognition and collaboration in a way that is generalizable across domains and categories of technologies. This knowledge enables better predictions in advance of future technology changes of the effects of the change, especially side effects such as new complexities and vulnerabilities, and a stimulus to envision alternative design concepts. Armed with this knowledge, we can find higher leverage points for change and develop new concepts for support. If we can better anticipate the reverberations of new technology prior to the process of change, new directions can be pursued when intervention is less difficult and less expensive. Our investigations continue in this vein to begin a natural history of the impact of bar coding on the process of medication administration to serve both these purposes simultaneously.

1.2 Context of Technology Change: Patient Safety, Information Technology, and Stakeholder Beliefs

In health care as in other domains, the expectations for new technologies prior to their implementation are often much more optimistic than is warranted by the research base on the impacts of new technologies on cognition and collaboration. These new technologies are often justified based on their presumed impacts on human performance. For example, it is a common, widespread belief that computerization of the medication order entry process will eliminate errors resulting from illegible physician handwriting. Similarly, a pharmacist anticipating the implementation of bar coding predicted that "The bar coding will eliminate errors [made by nurses]."

As a high-consequence setting with recent public attention given to injuries as a result of patient care, technology change occurs in a highly charged political context of advocacy. Advocacy attempts to generate investments for technological or organizational change. Advocacy is based on beliefs

- about the problems that are important for change to address,
- about the impact of technology on people at work, and
- about how proposed changes will produce differential advantages for various stakeholders.

As such, advocates participate in a social process of change (Kling and Iacono, 1995). Over-simplified models about how poor outcomes occur in health care combined with the widespread belief that substituting machine for human processing eliminates human error create calls for new technologies to guard against human performance problems. One such technology is bar coding used to verify correct medications immediately prior to administration.

As a further complication, health care systems exist in a changing world. The environment, organization, economics, capabilities, technology, and regulatory context all change over time. This backdrop of continuous systemic change ensures that hazards and how they are managed are constantly changing. The general lesson is that as capabilities, tools, organizations and economics change, vulnerabilities to failure change as well -- some decay, new forms appear. The state of safety in any system is always dynamic, and stakeholder beliefs about safety and hazard also change. Progress on safety concerns anticipating how these kinds of changes will create new vulnerabilities and paths to failure even as they provide benefits on other scores.

1.3 Introducing Bar Coding

In a large health care network, bar coding is in the process of being implemented in order to reduce medication mis-administrations by creating an additional verification step that a medication is intended for a patient at a particular time immediately before administration (Bates, 2000). This is performed by scanning a patient's wristband containing the social security number of the patient followed by scanning bar codes on unit dose medications containing the product name and dose information. A database containing information on the ordered medications for particular patients verifies that the medication product and dose are intended to be given in the current time window.

1.4 Points of Observation

Processes of medication administration were observed over a period of several months in two hospitals [DC, EP]. The first hospital, an 80-bed teaching hospital, had implemented the bar coding medication administration system throughout the hospital several weeks prior to the first observation. The second hospital, a 177-bed teaching hospital, was observed prior to the implementation and one week after partial implementation on two wards. The majority of the observations were conducted on telemetry (cardiac) and oncology (cancer) units, although several other units were also observed. Each observation session lasted from one to seven hours and included both day and evening shifts at both hospitals. Additionally, observations of computerized order entry by physicians and order dispensing by in-patient pharmacists were conducted at both hospitals. Complementary interviews were conducted with practitioners, computer support personnel, and health care managers. The introduction remains at an early stage in the second hospital and the shift to such systems has just begun for the network and other health care settings.

In this paper, we describe the process of medication administration, patterns in human-human-machine interaction that helped to guide our observations, and our findings and design recommendations from observed changes associated with the introduction of the bar coding technology. The observed changes reveal unintended side effects from design decisions based on oversimplified models of the nature of practice. The increased understanding gained from these observations is meaningful in that it leads to post-conditions for effective performance with the technology in the short-term and generative ideas for system redesign in the long-term.

2. THE PROCESS OF MEDICATION ADMINISTRATION

In hospitals where medications are electronically ordered by physicians, as opposed to handwritten (but bar coding technology is not in use), the canonical medication administration sequence is:

1) A physician orders medications[22] for a patient by typing in the name of a patient, selecting the generic medication name from a list of available medications tailored to that category of physician, the dose from a list of available doses for that medication, and how often per day the medication is to be given from a list of standardized choices (e.g., BID, TID) in a computerized order entry software system.
2) A pharmacist receives the physician's orders electronically, checks that there are no drug interactions or patient allergies, and dispenses the medications in a medication drawer dedicated to that patient.
3) A nurse electronically receives the orders and writes them on a patient's sheet dedicated to the type of medication administration (e.g., one-time or continuous). The medications are distributed by the nurse during a pre-determined time window, or "medication pass," to the patients under his/her responsibility.[23] The medication passes can theoretically occur every two hours, but the majority of the medications are distributed in the morning at 9 or 10 a.m. The nurse wheels a medication cart to a patient's room, looks up the medications ordered for that medication pass on the

[22] Note that there are deviations across sites and units in the canonical sequence. In some settings, nurses or pharmacists can order medications verbally ordered by physicians. Residents are also able to order medications, but the orders often need to be electronically verified by attending physicians before they become active.

[23] The number of patients assigned to care providers varies widely across units. Intensive Care Units and Pediatric Units commonly have one patient per nurse, whereas oncology units generally vary from 3-7 patients per nurse, and telemetry units vary from 4 to 10. In addition, registered nurses might have "covering" responsibility for an additional set of patients where they administer medications that another nurse, generally an LPN, does not have the training credentials to do.

> handwritten record, takes the medications out of the patient's drawer on the medication cart[24], and administers them. Prior to administration of certain medications, the nurse might need to verify that patient data, such as blood pressure readings, are in a particular range.

There are many points where the canonical medication administration sequence can break down (Allan and Barker, 1990). It is commonly quoted in the medication error literature that there is approximately one medication administration error (MAE) per patient per day, excluding administrations given at the incorrect time (Barker, Pearson, Hepler, 1984). Physicians can forget to order or co-sign medications or to continue expired medications. Similar medications (e.g., Losec and Lasix, Cohen, 1999) can be substituted for each other. There could be translation errors in converting from a brand name of a medication to a generic name (e.g., the generic medication Ritonavir has a brand name Norvir® and could be confused with the brand name Retrovir®, which is a brand of zidovudine). Medications could be administered to the wrong patient. The medications could be administered at an incorrect dose, particularly intravenous (IV) medications that are administered by a pump or medications that need to be manipulated, such as cut in half. The correct medication could be given in the wrong form (e.g., sustained release rather than immediate release) or by the wrong route (IV push rather than IV piggyback). The medications could fail to be administered if they are not dispensed to the nurse, put in the wrong medication drawer, or if the medication administration is forgotten. Medications could be given twice if they were not documented as given prior to a shift change. Finally, medications might be administered too late or too early to be effective at maintaining a level amount in the bloodstream.

The observed bar coding medication administration system is intended to reduce the frequency of these types of breakdowns. The bar coding system is designed to verify that the drug, dosage, route, and time of administration are correct for the appropriate patient immediately before a nurse distributes the medication. The system is advertised to be a:

> "…point-of-care solution for validating the administration of medications. Automation of the medication administration process will reduce inaccurate medication administration and increase the efficiency of documentation. As each medication is scanned by a bar code reader, the software will validate that the medication is ordered, timely, and in the correct dose, as well as electronically document the medication as Given." (p. 1, Implementation and Training Guide).

With the bar coding technology, the designers' expectation is that the canonical sequence of medication administration will remain mostly unchanged. Physicians should experience no change in the process of electronically ordering medications. Pharmacists should dispense the medications as before, except that they would add a bar code to the individual medications. In addition to verifying and signing off on the medications, they would have an additional step of entering the order into the bar coding medication administration software. The nurses should distribute medications

[24] At all sites, narcotic medications were stored separately in order to more tightly restrict access. The protocols for accessing medications not available in the medication cart varied across sites. At several sites, medications not in the medication drawer were available in an automated distribution system on the ward rather than delivered by pharmacy.

as before, except that they would have an additional step of scanning the wristband of the patient and the medication packets before administering them. The scanning equipment and software would be attached to the standard medication cart (Figure 2).

Another assumption of the designers of the new system is that, rather than using a handwritten record for determining what medications to distribute, the nurses would use the system to display the medications. At the appropriate time, the nurse would scan a patient's wristband and obtain information electronically about the prescribed doses, routes, and times for that patient's medications (Figure 3). Each medication would then be scanned in order to verify that the medication, dose, route, and time are correct immediately before administration to the patient. If the system detects no discrepancies, the medication would be documented as given at the time when the nurse scanned it (who would have logged in earlier). For several of the medications, some additional information would be typed in for documentation purposes, such as the number of puffs given for inhalants, before scanning and administering the next medication for the patient.

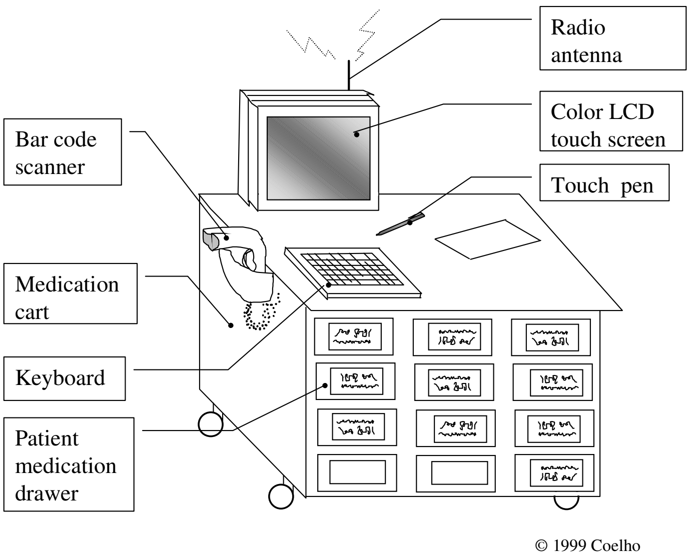

Figure 2. Medication cart with bar coding system

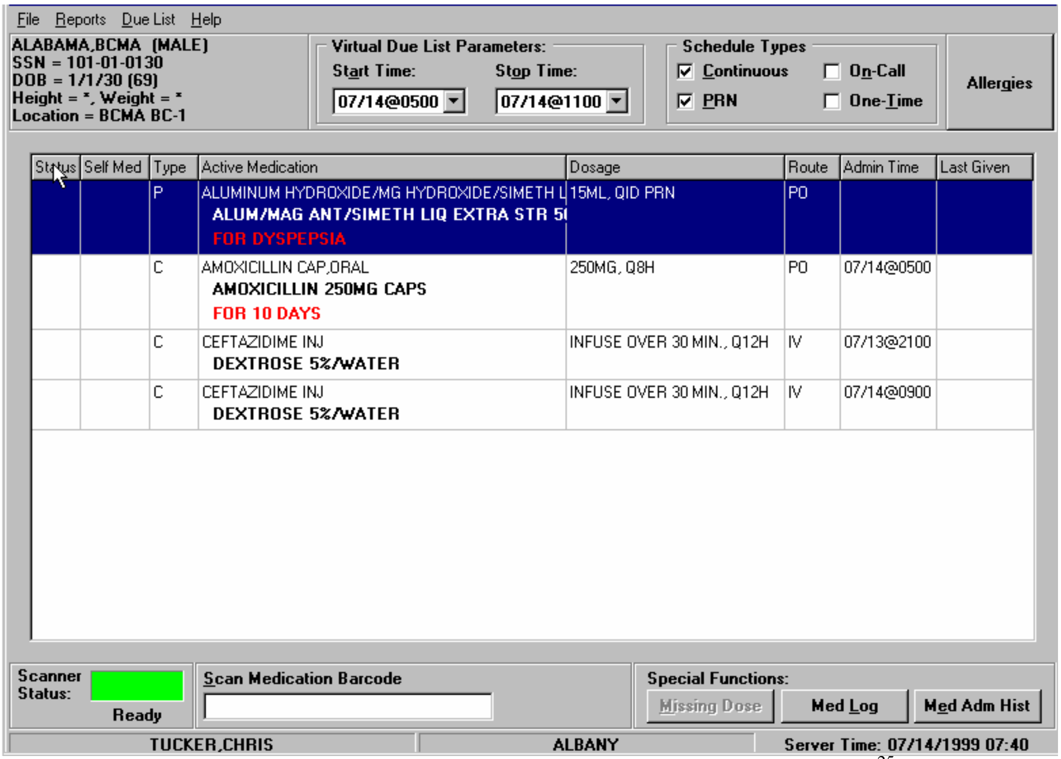

Figure 3. Software interface after scanning a (fictitious) patient's bar coded wristband[25]

[25] This is a ***fictitious*** patient record used for training by the CIO National Training and Education Office (1999) for the bar coding medication administration software that was studied.

3. GUIDING OBSERVATIONS WITH KNOWLEDGE OF PATTERNS

In natural history studies of technology change, it is generally recognized that observers need to be open to discovery about patterns of transformation and adaptation. The methodological challenge is to recognize unexpected patterns without getting lost in the details of the setting or technological system. It is difficult to recognize patterns without some pre-conceptions of what might yield insight, and we believe that it is impossible to avoid all pre-conceptions prior to observation. The need is to develop conceptual looking glasses that prepare the observer to recognize surprising patterns as departures from anticipated patterns. The latter can be derived by analyzing how the setting in question instantiates aspects of the research base. These possible patterns calibrate the observer to the specific design issues with the particular technology in the particular setting.

From previous research, we identified patterns (Woods et al., 1994, chapter 5) that were useful in guiding our observations. Bar coding technology and its associated software in medication administration can be characterized as instantiating the following elements:

- automated verification
- automated documentation
- interface to a supervisory control process
- system that changes the distribution of mental and physical workload
- system that redistributes the costs and benefits of goal conflicts
- trigger for task and system tailoring, new roles, new failure modes, side effects

3.1 Automated verification

Automated verification is a form of critiquing. Critiquing is a cooperative architecture between the human and machine where the human conducts their activities in a way that is observable to the machine that flags unexpected activities (Fischer et al., 1991). The usefulness of this type of system depends on the level of effort needed to make activities observable to a machine agent, the amount of deviation from a standard sequence that is typical in a nature of practice, and how the software responds to a detected discrepancy between intended and observed actions. Generally, critiquing systems that weakly commit to the machine intelligence, such as by providing warning dialogs but not prohibiting access to information or restricting the ability to conduct certain actions, are more effective in improving human-machine performance.

3.2 Automated documentation

Automated documentation is often coupled with automated verification because, in order to make human activities observable to machine processing, the information is translated into an electronic format. The electronic format is then easy to manipulate, store, and share. It is difficult to maintain correspondence between the machine's view and the actual situation with automated documentation because: 1) some information is easier to automatically capture than others, 2) maintaining the machine's view requires effort when updates occur, and 3) the machine is not able to correctly recognize all of the pertinent elements.

Automated documentation therefore also can change the data available to reviewers after-the-fact who would assign credit or, particularly, blame for outcomes among those involved. The after-the-fact review is a social and psychological process of causal attribution (Woods et al., 1994, chapter 6; Cook, Woods and Miller, 1998). The trail of crumbs left by data capture in the technology provides a partial picture of the processes leading up to an outcome. The partial picture can play into biases in the causal attribution process affecting organization's reactions to failure. For example, the partial picture available after-the-fact may make it easier to blame "sharp end" practitioners for poor outcomes.

3.3 Interface to a supervisory control process

What is observable (feedback) about the supervisory control process in question often changes (Sarter et al., 1997) with the introduction of new technology. Tracking what aspects of the state of the process are visible and what aspects are hidden or opaque is critical for anticipating problems in situation assessment, problems in coordinating and synchronizing activities, and limits on the ability to detect and recover from unintended and undesirable states. Poorly designed computer systems hide interesting events and changes and the activities of other agents (Clark and Brennan, 1991).

3.4 System that changes the distribution of mental and physical workload

New automation frequently produces changes in mental and physical workload distribution, points of possible workload bottlenecks, and workload management strategies (as opposed to the naïve view that automation always reduces all forms of mental workload for all participants). Thus, there are expected to be changes in the distribution of workload over time following the introduction of new technology, especially at peak workload periods or in escalating situations (Woods and Patterson, in press).

3.5 System that redistributes the costs and benefits of goal conflicts

Multiple interacting goals pervade practice. Yet the conflicts and dilemmas multiple goals produce rarely are part of developers and advocates idealized views of practice. New demands that result from the new systems, and the organizational changes they serve as carriers for, can sharpen the conflicts. For example, additional workload generated by introduction of new systems will have to be accommodated relative to the ongoing production pressures, while also serving (at least apparently) other purposes the new systems are to support (e.g., safety). Observing how introducing new artifacts creates or sharpens dilemmas and double binds will help us to predict unintended effects of technology change.

3.6 Trigger for task and system tailoring, new roles, new failure modes, side effects

Practitioners are active adaptive agents in the change process. They adapt their behavior (task tailoring) and the artifacts in their world (system tailoring) to meet their goals given the constraints, demands and pressures of practice (Woods et al., 1994; Cook and Woods, 1996). Again, repeated patterns abstracted from past studies can stimulate where and how to look at new episodes of change. Practitioners adapt to workload bottlenecks; at a coarse grain through: shifting workload in time, shedding perceived lower priority tasks or activities, doing all scheduled tasks but less thoroughly, and recruiting more resources (Huey and Wickens, 1993). At a finer grain, practitioners will adapt through system or task tailoring. Practitioners may try to tailor the technology to preserve old way of doing things. They will try to work around complexities or bottlenecks, for example, by scanning en mass rather than at point of delivery. They will try to find ways to use the system as a resource, for example, by developing ways to “trick” it. They may “escape” under some conditions when pressures to perform in the world overwhelm the complexities of doing the tasks through the system. They will develop buffers to enable coping with complicating factors and the inherent variability of the world, for example, they could develop ‘private stocks’ of drugs and supplies with later replacement via the bar coded objects.

The viability of practitioners’ adaptations is not always immediately clear to practitioners. People engage in a rapid development cycle of trying something, failing, trying something else, succeeding in the short run but producing undesired side effects, changing again, and so on. The adaptations are local, constrained by outside forces (e.g. resources, brittleness of the technology itself) and the speed with which people can test new approaches. Eventually, early, more heterogeneous adaptations coalesce into a routinized pattern tuned to the specific context of that individual work setting.

Tracing and anticipating the complexities introduced and practitioners’ adaptive workarounds as side effects of technology change is important because it helps reveal how the change can create new paths to failure. Success in technology development depends on identifying these side effects as kinds of post-conditions on change – supporting the new roles and judgments and mitigating possible new failure modes in the design of the human-machine systems and larger socio-technical system.

3.7 What will change with bar code scanning?

Armed with these general patterns in cognition and collaboration following the introduction of new technology, we can also make more pointed predictions about where to observe during an episode of change based on the specific characteristics of the new technology. Most narrowly, bar coding technology is a change in the form of data entry. Information is scanned in electronic form rather than typed or handwritten. Nevertheless, bar coding technology and the associated verification software is expected to have much broader-reaching impacts beyond reducing the time to enter data:

1. The format of the scanned data lends itself to software programs designed to match the similarity of one set of data with another. Given that medication and patient data is available in electronic form, one can develop software to check the match between medication requirements (timing, dose, drug, route) and particular patients. This ability enables the verification function of the bar coding technology.
2. The system represents a change in media for documented information: data about when a particular medication was administered by a particular person is electronically captured in a standardized format that lends itself to aggregated data analysis and expanded access to the data.

3. The input system associated with the bar code technology has the ability to automatically capture data such as the time and who is logged into a computer system, which previously was handwritten by the practitioners.
4. The information about what medications to administer is maintained through the software rather than on handwritten forms. With this change, strategies such as flagging pages by physically manipulating them to stick out from a notebook are no longer able to take the same form. In addition, the information set available can be different depending on design decisions about how much historical, non-medication, and pending information is displayed.
5. Multi-user access to the information is changed. Previously, multiple people could read and write on the medication administration records at multiple times. With the bar coding technology, it is a design decision about how many people can access the software and particular patients' data concurrently.
6. The bar coding technology increases coupling between parts of the system. When the bar coding technology is not working, information is no longer available that used to be available because of the previous diversity of information sources.
7. The bar coding technology can facilitate communication among various practitioners. In order to enable the verification function of the technology, both the intended and administered medications must be in electronic form. Software programs can then be written to route this information or provide access to this information remotely.
8. Software associated with the bar coding technology can easily be created that restricts the ability of the practitioner to perform certain actions. The designer has the flexibility to constrain the practitioner in ways that are strongly or weakly committed to the software. For example, the system could strongly commit to the system by restricting access to information to users without particular credentials, outside time windows, or if pre-requisites are not met such as typing in a user name and password. Alternatively, the system could weakly commit to the system by allowing access to the information but providing critiques when deviations from expectations are identified.

Thus, the shift to bar coding technology represents possible changes along multiple dimensions, each with many degrees of freedom. Generalizability of patterns resulting from the introduction of bar coding technology, just as with any other technology (e.g., computerized order entry systems, automated medication dispensing devices), need to be conditioned on how the technology is characterized along multiple interrelated dimensions. Additionally, these dimensions can be exploited to improve the system design in the face of unintended side effects and increased vulnerabilities in ways that are more generative than accept/reject recommendations (Woods, 1996).

4. OBSERVED CHANGES IN PATTERNS OF ACTIVITY

Using the knowledge about patterns following the introduction of new technology as a guide for where to focus the observations as well as reactions during interviews from stakeholders to the bar coding technology, the data was iteratively collected and analyzed. Based on our investigations, several patterns emerged that indicated unanticipated side effects from the introduction of the observed bar coding technology and associated software. These side effects provided insight into gaps between the designers' implicit models of performance and the actual nature of practice: 1) First, there was a lack of information in the bar coding software about discontinued and pending medication orders, which increased the risk of missing the administration of intended medications not in the active order list. 2) Second, the system design increased documentation activities during the high-tempo medication pass. Practitioners were observed to employ strategies that bypassed aspects of the bar coding system in order to reduce workload during the high-tempo period. 3) Finally, the timestamping documentation in the software created the perception among the nurses that timely medication administration was artificially raised as a priority over other patient care goals.

4.1 A New Path to Failure: Missing Pending and Discontinued Medication Orders

> "Safety systems pose a special problem in design. Oftentimes the design feature added to ensure safety eliminates one danger only to create a secondary one." (Norman, 1988, p. 206)

Bar coding technology in medication administration is generally justified as improving system safety by adding a verification or "double-check" layer of defense against medication mis-administrations. The vision is that mistakes occurring earlier in the process can be caught immediately before the irrevocable action of administering the medication to the patient, verifying that that specific medication is intended to be given at that time to that patient. The predicted outcome from introducing this technology is that wrong patient, wrong dose, wrong medication, wrong route, and wrong time medication errors will be reduced (cf. Allan and Barker, 1990, medication error taxonomy). In addition, "missed dose" errors should decrease because the nurse will have an interface displaying all of the medications to be administered at that time, which will serve a reminding function. It is not generally expected that bar coding will increase particular types or create new forms of medication errors.

In contrast to these expectations, new vulnerabilities in the medication administration process were observed following the introduction of the bar coding system. In general, the verification function of the system relied heavily on the assumption that the information in the database was accurate. In actual practice, however, the accuracy of the data was always uncertain (Figure 4).

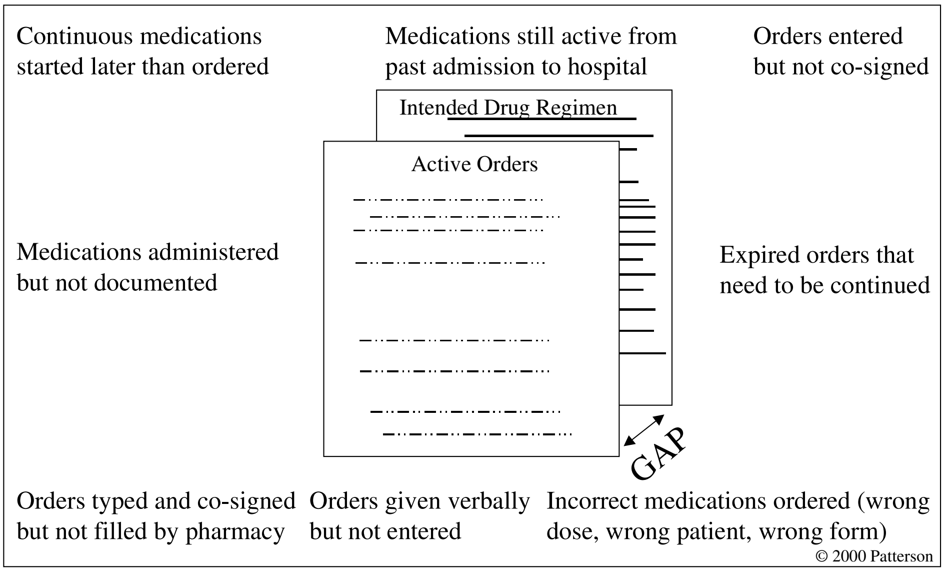

Figure 4. Observed gaps between intended drug regimens and bar coding system information

For example, a potent chemotherapy medication was ordered to be administered 11 a.m. Nevertheless, the nurse was unable to administer the medication at 11 a.m. because an IV site was not available. When a site became available, she was unable to access the patient record in the bar coding system because it was in use by another person. (Note that there was no way to identify or communicate with the other person accessing the record with this particular system.) Because she had previously verified with multiple physicians that the chemotherapy medication was intended to be administered, the labeled medication was available from pharmacy, and the medication was already late, the medication was administered at 2:45 p.m. Thirty minutes later, the nurse was successful in accessing the patient record in the bar coding system, but the medication was not in the list of medications to be administered. After spending ten minutes browsing through all of the medications in the patient record, the nurse called pharmacy. It was discovered that IV medications are automatically removed from the current medication list several hours after the intended administration time. A new order was then entered by the pharmacy so that the medication could be documented as administered.

The most frequently observed gap between the intended drug regimen and the list of medication orders in the bar coding system was missing medications due to being held up at earlier verification steps. A design decision in the bar coding software was made to only allow access to current orders that have been electronically entered, co-signed, and filled by pharmacy. As a result of this decision, when questions arose as to whether or not to administer a medication not in the active order list, the nurses were observed to access other information sources, including the computerized order entry system, the pharmacist, and the physician. Accessing other information sources required a significant investment of resource and was sometimes delayed or dropped under time pressure. In addition, it was judged to be overly resource intensive to verify every medication for every patient, and therefore a side effect of the particular design of this system was the potential for increased missed medications, particularly when there was no reason for the nurse to anticipate that a medication was missing from the order list.

Although many of these contributions to gaps between the intended drug regimen and active orders were observed prior to the introduction of the bar coding system, the lack of information about discontinued, expired, and pending orders, in combination with the loss of medication order history that was available with the paper records, increased uncertainty about missing medications. Our observations lead directly to a design recommendation to provide a larger view of the patient care process to the nurses, such as by providing historical information on medication orders, views of the status of medications that are not fully verified, information about when and why medications were discontinued, and predictive displays of future medication administrations plans. These expanded visualizations would better support nurses in anticipating that intended medications might be missing from the medication orders. When displaying the information about the status of medications, we suggest that the system interface use unique marks to distinguish between medications that have never been ordered for a particular patient, medications that have been discontinued, and medications that have expired. In addition, the system could facilitate communications with other practitioners during these scenarios such as by providing a communication link to the pharmacist, physician, or previous shift's nurse to question the status of a particular medication.

4.2 Strategies to Reduce Workload During the Medication Pass

Although the main objective of introducing the bar coding system was to reduce medication mis-administrations, an additional benefit of the system was claimed to be improved efficiency of documentation. Although the physical act of bar scanning was often more efficient than handwriting or typing information[26], the design of the bar coding system required that the medication be scanned during administration. This design decision required that the documentation activity be conducted during the high-tempo period of the "medication pass." This design characteristic works against the commonly observed tactic in event-driven, high-consequence domains such as aviation to free up mental and physical resources during high-tempo periods by shifting other tasks such as documentation to low-tempo periods. Most likely in response to this shift in distribution of workload, strategies were observed that decreased workload during the medication pass, such as scanning all medications for a patient prior to administering them and delaying documenting refused medications until a later time (Table 1).

There were undesirable side effects from some of these strategies. With some of these strategies, the users bypassed the bar coding system, eliminating many of the verification benefits of the system. In addition, when delayed documentation activities were dropped, the system's view of the situation became incorrect, partial, or distorted. Efforts to minimize documentation burdens, such as dropping requirements

[26] Note, however, that situations were observed when the bar codes were not read by the scanner for technical difficulties, the wristband was not available or was not on the patient's wrist, the wristband could not be scanned because the scanning equipment could not enter the room of an isolation patient, and the increased documentation requirements such as typing in the number of teaspoons administered made the process less efficient. In addition, there is no "undo" command, so when there was a need to change the documented information, the practitioner was required to enter an alternate interface to edit a text file. Finally, there are documentation requirements for "held" medications that did not exist with the paper system.

for information to be typed in, would make it easier to use the bar coding technology during high-tempo periods. In addition, features that would make it easier to update information in the database such as "undoing" refused medications or batches of medications would improve the accuracy of documented information.

Observed Strategy	Hospital 2 Oncology 1 Week Post-BCS	Hospital 1 Telemetry 7 Weeks Post-BCS
Typing in wristband information	x	x
Scanning wristband on table next to patient		x
Scanning medications similar to administered ones	x	x
Typing in medication information after administration	x	x
Documenting self-administration medications as given	x	x
Scanning medications to be given at a later time		x
Scanning opened medication packets after administration	x	
Scanning all medications at once for a patient	x	x
Documenting refused medications at a later time	x	x
Administering verbally ordered medications not in system	x	
Documenting administration sites before site decision (e.g., left, right side)	x	x
Documenting medication effectiveness at a later time	x	

Table 1. Observed strategies to delay or minimize workload during administration

4.3 Raising Timely Medication Administration Over Other Patient Care Goals

In interviews with users of the bar coding system, the dominant reaction was that the system artificially raised the priority of timely medication administration over other safety and production goals. As one nurse explained: "I became a nurse to help patients, not to be a pharmacist's assistant at Walgreen's." Although the stated primary goal of the system was to reduce medication mis-administrations, the nurses felt that the greatest impact was on when the medications were distributed. For example, at the first hospital the medication administration passes for the entire hospital were moved back by one hour. This shift in time gave the nurses more time to prepare for the main medication pass in the morning after their arrival on shift and generally greater flexibility in when medications could be distributed. At the second hospital, the nurses requested to move the medication time windows in the software back by half an hour, but this was not possible with the current version of the software as it only allowed hour increments. The proposed change in administration time was desired so that the nurses could have enough time to receive the shift change update and do preliminary assessments of their patients before distributing the morning medications.

Although the medication administration times prior to and after the introduction of the bar coding system were theoretically identical, and administrations farther than a certain increment were required to be documented both before and after the system was introduced, the bar coding software was viewed to much more rigidly enforce those procedures. With the particular software design, medications that were more than a hard-coded number of minutes before or after the intended administration time (generally 30 or 60 minutes) were flagged in red and required a typed reason for the deviation. These "wrong time errors" could then be much more easily summarized and analyzed than with the paper-based system.

Additionally, although requests for immediate action from patients were delayed both before and after the implementation of the bar coding system during medication passes, verbal justifications for delays based on being a few minutes away from the end of a time window were only observed after the implementation of the system. At the first hospital in the telemetry unit several weeks after implementation, a senior nurse was training a junior nurse on the system. Near the end of the time window for the medication pass, they were asked to get a glass of water, obtain pain relief medication (multiple requests were made by the patient through multiple practitioners during the medication pass), and clean a urinal. To each of these requests, they responded that they would come back later, verbally and physically displaying a high sensitivity to the fact that "we only got a few minutes left." In contrast, a nurse on an oncology ward at the second hospital prior to the implementation of the bar coding system immediately obtained pain medication when requested by patients.

As converging evidence, plots of the time when the medications were administered before and after the implementation of the bar coding system appear to provide converging evidence that there was a change in the pattern of administration activities (compare Figures 5 and 6).

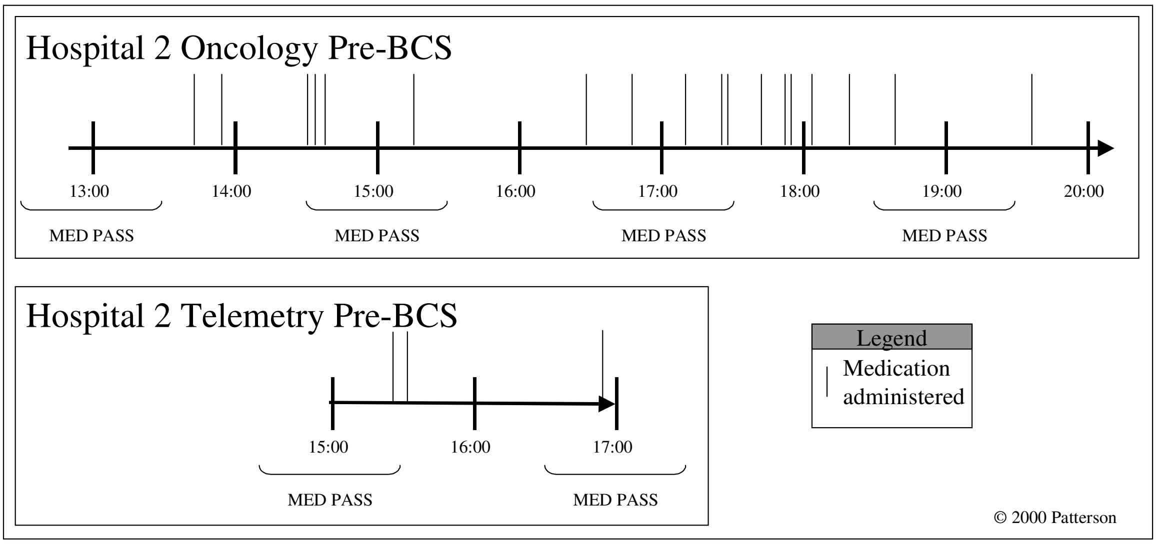

Figure 5. Medication administrations before bar coding system

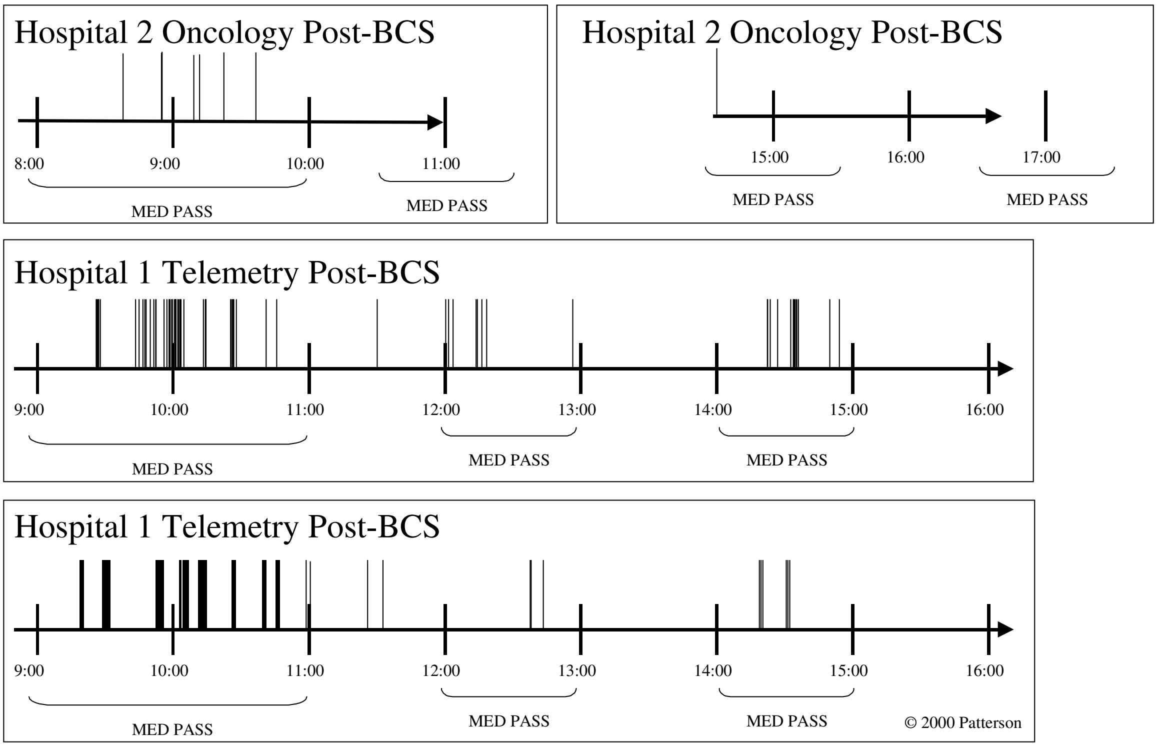

Figure 6. Medication administrations after bar coding system

It could be argued that this change in pattern of medication administration meets the intended goal of the bar coding system by reducing "wrong time" medication errors. The question to be answered is what activities are delayed in order to deliver the medications within the scheduled time window. In Figure 7, the interruptions that a nurse dealt with during bi-hourly medication administrations on an oncology ward prior to the introduction of the bar coding system are displayed. Although some interruptions were arguably much less important than medication administration activities, some were not. For example, the nurse took twenty minutes to better restrain a patient who was at risk of falling. Also note that the observed nurse was highly experienced, took no personal breaks during these seven hours, and verbally reported that she was working as quickly as she judged to be safe. She commented that with the bar coding system that was anticipated to arrive in several weeks, she would have a difficult time defending why several medications were administered outside the time window although she felt that she had appropriately traded off the various risks and goals during the shift. In short, she was concerned that the documentation would provide a distorted view of her activities and level of competence during that time.

The ability to efficiently track timing seems to shift practitioners' criteria and possibly create a tendency to sacrifice other goals when they compete with providing medications within the computer's window. However, the timestamp data on when the medications were distributed are not vital to the core goals of the bar coding system.

There are many degrees of design freedom that could in principle be used to reduce the unintended side effect of artificially raising the emphasis on timely medication administration. Within the current system framework, there are short-term changes that could be made such as enlarging the hard-coded limits on the time windows for the medication passes, or removing the time windows altogether. Similarly, the timestamped data could be protected, either by periodically deleting it or by restricting access to local personnel such as the floor nurse manager. More long-term suggestions might include interface visualizations that better represent the proximity to dangerous boundaries associated with particular medication administration times. For example, certain medications are much more important to deliver on time in order to maintain a particular level in the bloodstream, whereas others could be missed completely with little to no effect.

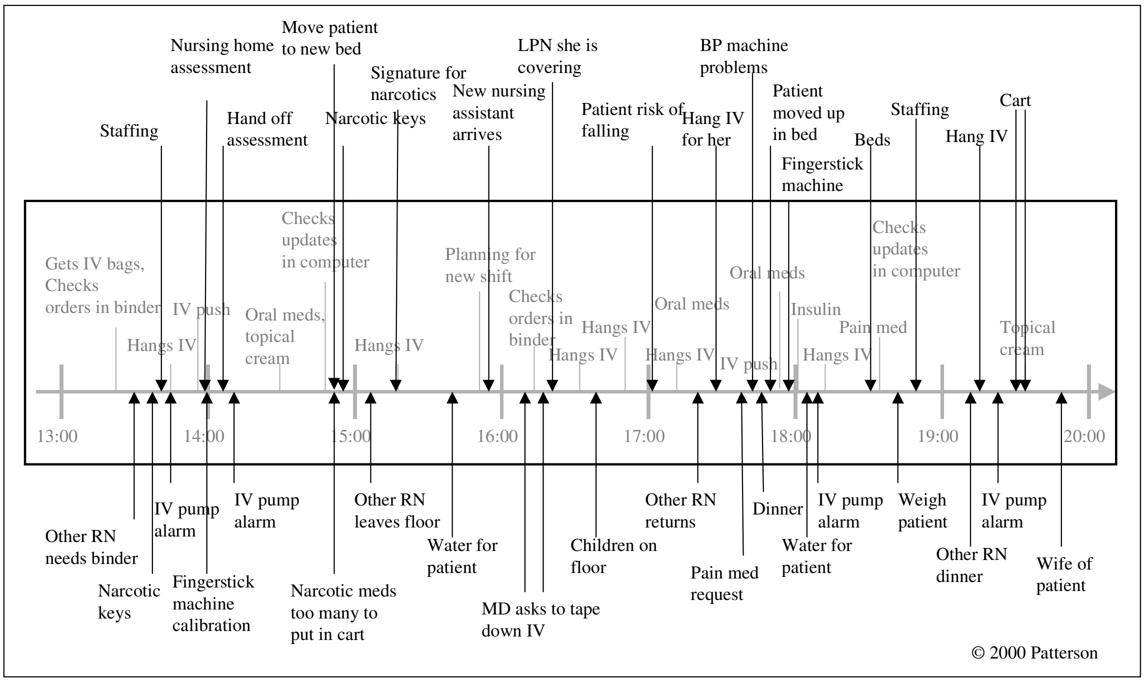

Figure 7. Interruptions during medication administration

5. DISCUSSION

We observed unintended reverberations on patterns of activity, partly because the particular bar coding technology system was based on idealized, oversimplified models of the nature of practice. First, we observed that the bar coding software did not provide information about medication orders that did not have the status of being fully verified by appropriate personnel. With the prior system, nurses were able to view information about pending and discontinued medication orders. When medications were anticipated to be intended for distribution but were not available because they were held up at prior verification steps or had been automatically discontinued without the physician being aware of it, the nurses were observed to question whether the medication was desired to be administered. As a result of this change, it is highly predictable that medications that are intended for administration but are not available in the active order list in the software will not be administered, creating new paths to a "missed dose" outcome. Visualizations that provide a larger view of the patient care process to the nurses, such as by providing historical information on medication orders, views of the status of medications that are not fully verified, information about when and why medications were discontinued, and predictive displays of future medication administrations plans would better support nurses in anticipating that intended medications might be missing from the medication orders. In addition, the system could facilitate communications with other practitioners during these scenarios such as by providing a communication link to the pharmacist, physician, or previous shift's nurse to question the status of a particular medication.

Second, the system design changed the workload distribution by adding documentation activities during the high-tempo medication pass. It is a frequent pattern in dynamic, event-driven domains for practitioners to shift documentation activities to low-tempo periods in order to free up resources to deal with unanticipated events during high-tempo periods. When nurses were observed to follow this pattern, they were forced to circumvent the bar coding system in various ways. For example, they scanned medications prior to administering them. Unintended side effects from this and similar strategies included that defenses against last-minute medication or patient substitutions were eroded and that the information in the database deviated from the actual situation. For example, the time that the medication was administered was incorrect and changes that occurred after scanning such as refused medications were not always changed in the database. Organizational and design changes to minimize documentation burdens would make it easier to use the bar coding technology during high-tempo periods. In addition, features that would make it easier to update information in the database such as "undoing" refused medications or batches of medications would improve the accuracy of documented information.

Finally, the automated collection of data about the time a medication was administered created a perception among the nurses that timely medication administration was artificially raised in priority over other patient care goals. Because the timestamp data was electronically captured in a format that could easily be summarized and analyzed, the feature was viewed as enabling a new form of monitoring of their activities. In addition, the data that was captured by the system was observed to be partial and distorted, leaving out information such as responding to a patient at risk of falling. Because the timestamp data on when the medications were distributed are not vital to the core goals of the bar coding system, there are many degrees of design freedom that could in principle be used to reduce the unintended side effect of artificially raising the emphasis on timely medication administration. Within the current system framework, there are short-term changes that could be made such as enlarging the hard-coded limits on the time windows for the medication passes, or removing the time windows altogether. Similarly, the timestamped data could be protected, either by periodically deleting it or by restricting access to local personnel such as the floor nurse manager. More long-term suggestions might include interface visualizations that better represent the proximity to dangerous boundaries associated with particular medication administration times.

Ideally, these types of natural history studies would become a standard activity during the introduction of any new technology in complex human-machine settings in order to improve the system's usefulness and reduce undesired side effects. The methodology is actually quite simple in principle. Episodes of technology change are identified and observed without otherwise intervening in the system. Note, however, that in our experience, the insight that is gained through observations is heavily dependent on the observer. The patterns that are recognized during the observations rely heavily on the observer's depth of knowledge of patterns in distributed cognition and collaboration and prior experience with observational data collection and analysis. Prior knowledge of potential patterns are not predictions to be verified or disproved, such in a hypothesis testing experiment, yet they still serve an important role in providing the observer with "conceptual looking glasses" in order to abstract from the details of the particular setting (Sarter and Woods, 1993). Training an observer to achieve this ability to "see" patterns appears to be more involved than describing the set of patterns that are likely to occur and motivating the observer to look for them. An additional methodological challenge is to make the leap from the analytic insight to generating alternative design concepts and post-conditions to reduce unintended side effects. Although this ability appears to be trainable based on our experience, it might be difficult to learn without an apprenticeship term, as there is a large creative component that needs to be matured through hands-on design activities.

In order to go beyond an academic exercise, investigations such as these need to yield changes in an actual field of practice (Hughes, Randall, and Shapiro, 1992). Generic timing issues experienced in any design endeavor complicate the ability to intervene in the design process. Because the observations are conducted during the implementation of the technology, there is often a desire to immediately act upon design suggestions. Nevertheless, the intense production pressures experienced during implementation necessitate that only tightly constrained changes can be immediately implemented. To have a broader impact, the design concepts need to be converted into a format that will influence the next generation design of the technology. In order to be integrated in early enough in the design cycle, the concepts need to be ready before the next design cycle has begun. Therefore, investments need to be made in advance of project resource allocations and at a level that is generalizable beyond a specific product implementation since important aspects are likely to change from one generation to another.

In addition to investments aimed at improving the next generation design of new technologies for a specific domain, longer-term investments will eventually yield greater returns. Currently, our ability to predict impacts of new technologies prior to their introduction are limited by our understanding of how technologies impact cognition and collaboration in a field of practice. Results from natural experiments such as these need to feed back into a research base on how the dimensions of the technology impact cognition and collaboration. For example, we know that there are dimensions of technologies, such as how strongly or weakly they commit to brittle machine intelligence, which have predictable impacts on joint human-machine performance. Further identification and modeling of these dimensions will allow us to make purchase recommendations and design changes prior to implementation that will improve the technology's usefulness and reduce unintended side effects when changes are much less expensive and risky to make. Thus, one linchpin of future success is the ability to proactively anticipate and assess the impacts of technology change in order to forestall new paths to failure before they have the opportunity to occur.

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7. REFERENCES

Allan, E.L., and Barker, K.N. (1990). Fundamentals of medication error research. *American Journal of Hospital Pharmacy*, 47(3): 555-571.

Bates, D.W. (2000). Using information technology to reduce rates of medication errors in hospitals. *BMJ*, 320: 788-791.

Barker, K.N., Pearson, R.E., Hepler, C.D. et al. (1984). Effect of an automated bedside dispensing machine on medication errors. *Am J Hosp Pharm*. 41:1352-8.

Barley, S.R., and Orr, J.E. (Eds.) (1997). *Between craft and science: Technical work in U.S. settings.* New York: Cornell University Press.

Borel, J.M. and Rascati, K.L. (1995). Effect of an automated, nursing unit-based drug-dispensing device on medication errors. *Am J Health-Syst Pharm 52*: 1875-9.

Clark, H., & Brennan, S. (1991). Grounding in Communication. In L. Resnick, J. Levine, and S. Teasley (Eds.), *Socially Shared Cognition.* Washington, DC: American Psychological Association.

Cohen, M.R. (Ed.) (1999). *Medication errors: Causes, Prevention, and Risk Management*. Boston, MA: Jones and Bartlett Publishers.

Cook, R.I., Woods, D.D., and Howie, M.B. (1990). The natural history of introducing new information technology into a high-risk environment. In *Proceedings of the 36th annual Meeting of the Human Factors Society*.

Cook, R.I., and Woods, D.D. (1996). Adapting to new technology in the operating room. *Human Factors*, 38(4), 593-613.

Cook R. Woods D. Miller C. (1998) A Tale of Two Stories: Contrasting Views on Patient Safety. National Patient Safety Foundation, Chicago IL, 1998.

Cook, R.I., Render, M.L., & Woods, D.D. (2000). Gaps in the continuity of care and progress on patient safety. *BMJ*, 320: 791-794.

Dekker, S.W.A. and Woods, D.D. (in press). To Intervene or Not to Intervene: The Dilemma of Management by Exception. *Cognition, Technology and Work.*

Dekker, S.W.A. and Woods, D.D. (1999). Extracting Data from the Future: Assessment and Certification of Envisioned Systems. In S. Dekker and E. Hollnagel (Eds.), *Coping with Computers in the Cockpit*, Ashgate, 7-27.

Fischer, G. Lemke, A. C., Mastaglio, T. and Morch, A. I. (1991). The role of critiquing in cooperative problem solving. *ACM Transactions on Information Systems*, 9, No. 3, April 1991, 123-151.

Flores, F., Graves, M., Hartfield, B. and Winograd, T. (1988). Computer systems and the design of organizational interaction. *ACM Transactions on Office Information Systems,* 6, 153-172.

Huey, B.M., & Wickens, C.D. (1993). *Workload transition: implications for individual and team performance*. Washington, D.C.: National Academy Press.

Hughes, J.A., Randall, D., & Shapiro, D. (1992). Faltering from ethnography to design. In *Proceedings of Computer-Supported Cooperative Work.*
Hutchins, E. (1995). *Cognition in the Wild*. Cambridge, MA: MIT Press.
Kling, R. and Iacono, C S. (1995). Computerization movements and the mobilization of support for computerization. In S. Leigh Star (ed.), *Ecologies of Knowledge: Work and Politics in Science and Technology*, State University of New York Press, Albany NY.
Norman, D. A. (1988). *The design of everyday things*. New York: Doubleday.
Patterson, E.S., Woods, D.D., Sarter, N.B., & Watts-Perotti, J. (1998). Patterns in cooperative cognition. *COOP '98, Third International Conference on the Design of Cooperative Systems*. Cannes, France, 26-29 May.
Rasmussen, J., Pejtersen, A., & Goldstein, L. (1994). *Cognitive Systems Engineering*. New York: John Wiley & Sons, Inc.
Sarter, N., & Woods, D. D. (1993). Evaluating the impact of new technology on human-machine cooperation. In J. A. Wise, V. D. Hopkin, & P. Stager (Eds.), *Verification and validation of complex systems: Human factors issues.* New York, NY: Springer-Verlag.
Sarter, N. B., Woods, D. D., and Billings, C. E. (1997). Automation Surprises. In G. Salvendy (Ed.) *Handbook of Human Factors/Ergonomics* (Second Edition) John Wiley & Sons, Inc.:New York.
Schwarz, H.O., and Brodowy, B.A. Implementation and evaluation of an automated dispensing system. *Am J Health-Syst Pharm*. 1995; 52:823-8.
Woods, D.D., & Patterson, E.S. (2000). How unexpected events produce an escalation of cognitive and coordinative demands. P.A. Hancock and P.A. Desmond (Eds.). *Stress Workload and Fatigue*. Lawrence Erlbaum, Hillsdale, NJ.
Woods, D.D. & Cook, R.I. (2000). Nine Steps to Move Forward on Patient Safety. Prepared for the National Patient Safety Center and the VA Midwest Center for Inquiry on Patient Safety.
Woods, D.D. , Johannesen, L., Cook, R.I. & Sarter, N. (1994). *Behind Human Error: Cognitive Systems, Computers and Hindsight*. Crew Systems Ergonomic Information and Analysis Center, WPAFB, Dayton OH.
Woods, D.D. (1993). Process tracing methods for the study of cognition outside of the experimental psychology laboratory. In G. Klein, J. Orasanu, & R. Calderwood (Eds.), *Decision Making in Action: Models and Methods.* Norwood, NJ: Ablex Publishing Corporation.
D.D. Woods and D. Tinapple. W^3: Watching Human Factors Watch People at Work. Presidential Address, 43rd Annual Meeting of the Human Factors and Ergonomics Society, September 28, 1999. Multimedia Production at http://csel.eng.ohio-state.edu/hf99/
Woods, D.D. and Sarter, N. (in press). Learning from Automation Surprises and Going Sour Accidents. In N. Sarter and R. Amalberti (Eds.), *Cognitive Engineering in the Aviation Domain*, Erlbaum, Hillsdale NJ.
Woods, D. D., Sarter, N., Graham, J. and Dekker, S. Predicting How Technological Change May Create Human Error. Institute for Ergonomics/Cognitive Systems Engineering Laboratory Report, ERGO-CSEL 99-TR-02, The Ohio State University, Columbus OH, March, 1999.