



UNIVERSIDADE DA BEIRA INTERIOR

Engenharias

Is there any correlation between voice and human ovulation?

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Dissertação para obtenção do Grau de Mestre em
Bioengenharia
(2º Ciclo de Estudos)

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Covilhã, Outubro 2018

“

- You can be looking forever and find nothing.
- Turning over rocks and finding nothing is a progress.

“

I origins
(Movie - 2014)

- **Acknowledgement**

These are the first words you will read in this Dissertation, but they were the last and most difficult ones to be written. It took me a while to find the rights words, I was always getting that filling that is not as good and honest as I wanted... But now the clock is ticking, and I do not want to live this page in blank, so I just opened up my heart for you to now, that this is not “just” a Dissertation, a Project, or a study, this was a huge part of my development as a person.

Taking the first step and decide to do a Master Degree was a difficult choice, I did not think I was ready and a lot of times I thought that it would be useless, I was in a bad place at that time, but then I found people around me that helped me to see the bigger picture, and I decided to dedicate two more years of my life to study, and now I do not regret it.

It was not always easy, but I have learned a lot and I deliver this Dissertation with a heart full of joy and a filling of one more mission accomplished, and for that, I want to thank everyone that supported me. The Professors Nuno Pombo, Nuno Garcia and Doctor Kristina Drusany Staric who believed in my capabilities and were always available to help me in everything I needed, I also want to thank Professor Pedro Dinis who let me develop this project which was his proposal. To my Colleagues Virginie Felizardo, Ivan Pires and Joel Caetano who helped me and taught me a lot on the development of the mobile application and on the analysis of the data collected for this dissertation, I really am grateful for your help and friendship during this year.

At least but never less important I would like to thank my Family for all the efforts they have done to give me the possibility to have a Master Degree, and all their comfort and incentive words to help me through this two years, a special thank to my Husband I really appreciate all your patience and support throughout this journey, thank you for never leave my side and

always believe in me, even when I did not. Without you all I could not have done it.

Thank you all for everything, I will be forever Grateful.

The author would also like to acknowledge the contribution of the COST Actions IC1303 - AAPELE - Architectures, Algorithms and Protocols for Enhanced Living Environments, and CA16226 SHELD-ON Indoor living space improvement: Smart Habitat for the Elderly

- **Resumo**

Esta dissertação descreve os problemas dos métodos atuais utilizados para a deteção da ovulação, bem como revê artigos científicos que apoiam a correlação entre voz e ovulação.

Para a abordagem deste estudo foi necessário desenvolver uma aplicação para recolha de dados de áudio (voz). Esta aplicação móvel foi disponibilizada de forma a que mulheres pudessem fazer registos uma frase pré-definida, diariamente, por um período de dois meses.

Após a recolha, os dados foram tratados e analisados para se averiguar se existe alguma correlação entre variação de voz e a ovulação. Se os resultados obtidos confirmarem a autenticidade dos dados publicados, será possível o desenvolvimento de uma aplicação com base nessas informações num projeto futuro.

- **Palavras-Chave**

Ciclo Menstrual, Ovulação, Voz, Infertilidade, Gravidez

- **Resumo Alargado**

Introdução

Esta secção apresenta o resumo alargado da dissertação intitulada “Existe alguma correlação entre a voz e a ovulação?” (Is there any correlation between human voice and human ovulation?)

Este resumo alargado tem a seguinte organização: em primeiro lugar, apresentam-se a descrição do problema e o principal objetivo da dissertação. Seguidamente é feita uma breve descrição do trabalho desenvolvido bem como os principais resultados. Por último são descritas as conclusões deste trabalho e propostas para trabalho futuro. Neste resumo as referências não estão numeradas sequencialmente a fim de manter a coerência da numeração com o texto em inglês.

Descrição do Problema e Objetivos da Dissertação

A deteção da ovulação é um problema comum à maioria das mulheres, independentemente da sua idade fértil, e é importante para o planeamento de uma gravidez ou para a sua prevenção. Os métodos atualmente em uso não são simples nem higiénicos.

O desenvolvimento das tecnologias de informação estimulou o desenvolvimento de aplicações que vão desde o planeamento da rotina diária, nutrição à prática de desporto, entre muitas outras.

A principal motivação para a realização deste projeto é fornecer mais informação, resultados e dados fiáveis afim de ser possível o desenvolvimento de uma futura aplicação móvel, que utilize esta

informação. Tendo isto em consideração, o maior objetivo para este projeto é a deteção de algum tipo de correlação entre voz e ovulação.

Foram analisados vários estudos onde verificamos que vários aspetos poderiam ser abordados com uma metodologia diferente, já que a voz pode mudar de acordo com múltiplos parâmetros [2], [3].

Várias mulheres mostraram-se interessadas neste projeto e nas perspetivas futuras para que ele poderá contribuir e foi claro que os profissionais de fertilidade têm interesse na contribuição deste projeto para a deteção da ovulação. Este trabalho fornece as seguintes contribuições:

1. Estabelece o estado da arte, estudos nesta matéria até aos dias atuais.
2. Desenvolveu uma aplicação móvel (app) para recolha de dados para análise.
3. Fornece um ensaio clínico, realizado em Portugal e na Eslovénia, consistindo na recolha de dados para posterior análise e conclusões finais.

Estado da Arte

Neste capítulo, apresentamos uma breve introdução sobre o ciclo menstrual, a voz e as alterações da mesma, para que possamos ver quais as mudanças que podem estar relacionadas com a ovulação.

Em relação ao cálculo do período de ovulação de uma mulher, ou a identificação do mesmo período, existem alguns métodos atualmente disponíveis no mercado. Alguns dos mais utilizados são: medição de temperatura, o teste de ovulação digital e a calculadora de período fértil, que serão discutidos e explicados mais adiante neste capítulo.

Para esta secção foi escrito e submetido um artigo de revisão sistemática que pode ser encontrado no final desta dissertação.

Diferentes estudos já abordam este tema, mas apenas alguns estudaram diretamente a relação entre a voz e a ovulação. Os poucos que abordaram esta questão não obtiveram resultados coerentes, o que demonstra que há necessidade de efetuar mais estudos com diferentes abordagens e métodos. Com base nesta breve conclusão foi tomada a decisão de prosseguir com este estudo, utilizando uma abordagem diferente para identificar um método viável.

Desenvolvimento

Em resumo, neste capítulo apresentamos o desenvolvimento do projeto, onde descrevemos todas as fases do mesmo, desde o planeamento, materiais e métodos, o desenvolvimento da aplicação e análise dos dados obtidos.

Primeiro, é necessário criar uma aplicação móvel para recolher dados de áudio e armazená-los. Será então desenvolvido um método para análise dos mesmos e poderemos comparar os resultados com os previamente obtidos nos estudos analisados no capítulo anterior, para finalmente poderemos verificar se existe uma correlação entre voz e ovulação e explorar futuras possibilidades.

Para este projeto é necessário registar um conjunto de gravações da mesma frase para manter a consistência entre as amostras, optamos por pedir á participante para contar de 1 a 10, todos os dias, por exemplo, pela manhã, para que possamos comparar as mudanças de frequência de cada participante. Com a comparação diária destes registos, pudemos identificar variações específicas como a frequência máxima, mínima e média, mas para este estudo utilizamos apenas as variações da Frequência Fundamental(F0). Os valores obtidos devem indicar se a participante está no período de ovulação.

Os dados foram guardados no telemóvel num arquivo de texto (txt) que foi enviado para a base de dados Firebase de onde foram posteriormente extraídos para análise. No total, obtivemos 25 participantes, mas apenas 14 registaram o mínimo de 30 gravações, o valor necessário para uma análise viável. No total, obtivemos 827 gravações, informações solicitadas e algumas informações adicionais, como valores do índice de massa corporal (IMC), número de registos e data final, que podem ser consultados na Tabela 7.

A fim de obter o máximo de informação possível dessas gravações, testámos diferentes análises possíveis.

A primeira abordagem foi a limpeza dos dados e escolhemos o Matlab para os analisar, para isso, precisámos de converter todos os arquivos txt em arquivos excel para que pudessem ser abertos e processados no Matlab.

No Matlab, explorámos alguns filtros para estabelecer quais poderiam ser mais eficazes para o que estávamos a tentar identificar. Em todos os casos, uma FFT (Fast Fourier Transform) estava presente.

Depois de testar muitas possibilidades, chegámos a um código onde definimos a escala e o intervalo para analisar este código. Pode ser consultado no final desta dissertação, na secção dos anexos.

Após termos todas as nossas estimativas de período fértil para cada participante, os valores de F0 e a variação da frequência dos dias de menstruação e ovulação foram calculados em relação aos dias restantes do mês, os resultados podem ser vistos na Tabela 8.

Conclusões e Proposta de trabalho Futuro

Após uma análise de resultados, foi descoberto mais do que esperávamos e levantaram-se mais questões do que as iniciais. Apesar do facto deste

projeto não ter estabelecido alterações vocais relacionadas com tabaco, álcool, IMC ou exercício físico, levou-nos a questionar as diferenças de eficácia de cada pílula anticoncepcional. Os resultados para algumas das participantes foram os esperados, o que nos leva a crer que de facto poderá haver uma correlação entre a voz e a ovulação, mas, no entanto as nossas dúvidas surgem, quando participantes que tomam a pílula apresentam valores fora do normal. Após uma análise, a questão da eficácia de algumas pilulas foi levantada.

Quanto à questão título “Existe alguma correlação entre voz e ovulação humana?” Podemos concluir que algumas mudanças na frequência fundamental durante o ciclo menstrual podem ser vistas e correlacionadas com as fases do ciclo.

Mais investigações serão necessárias para concluir esta hipótese, mas conseguimos ver no futuro a possibilidade de desenvolver uma aplicação móvel que possa fazer esta análise, identificar a ovulação e, eventualmente, informar a utilizadora se ela está a tomar uma pílula adequada ao seu organismo. Sendo assim, o desenvolvimento deste projeto mostrou que, sim, voz e ovulação podem ser relacionadas.

- **Abstract**

This dissertation describes the problems of the current methods of ovulation detection and reviews scientific papers that support the connection between voice and ovulation. For this study's approach it was necessary to develop an initial application to collect audio data. This mobile application has been distributed to women (test participants) so that they would record a predefined phrase, daily, during the ovulation cycle for a period of two months.

After the collection, the data, will be treated and analyzed to establish if there is indeed any correlation between voice variation and ovulation. If the results obtained confirm the authenticity of the published data, it will be possible to develop an application based on this information in a future project. If the authenticity of the published data does not occur, a more in-depth study and analysis of the data must be done in order to establish any relation between the voice variation and ovulation cycle.

- **Key Words**

Menstrual Cycle, Ovulation, Voice, Infertility, Pregnancy

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- **Abbreviations and Acronyms**

FSH	Follicle Stimulating Hormone
LH	Luteinizing Hormone
BMI	Body Mass Index
dB	Decibel
ENT	Ear, nose and throat
F0	Fundamental Frequency
FFT	Fast Fourier Transform
IQR	Interquartile Range
HNR	Harmonics to noise ratio
Hz	Hertz
SD	Standard Deviations
SFF	Speaking Fundamental Frequency
SLT	Speech Language therapist
ST	Semi-Tones
VTL	Vocal Tract Length

1. Introduction

This first chapter, expose the major goal of this project, what was my motivation to choose the theme and the contribution that this project development will give to society and future developments. Also, in this you can see the chapter's organization of the full dissertation.

1.1. Objective

The main objective of this project is to detect a correlation between voice and ovulation.

1.2. Motivation

Information technology development has spurred the development of applications that range from daily routine planning, nutrition to sports, among many others.

The detection of ovulation is a problem common to most women, regardless of their fertile age. Ovulation detection is important to plan a pregnancy or to prevent it. The methods currently in use are neither simple not hygienic.

I was offered the analysis of a study that came to interesting results, in which it was shown that voice and ovulation are connected [1]. I found in some of the precursor studies I consulted that there were some aspects that should be approached with a different methodology, as voice can change according to multiple parameters [2],[3],[4].

I find this subject particularly interesting and, thinking ahead, it is my opinion that the development of an application that detects the ovulation using the voice would be interesting women and economically viable.

My motivation to carry out this investigation is to provide technology developers with credible results and data to assist them in creating a mobile application.

1.3. Contribution

The market and target audience study has clearly shown that Fertility professionals have interest in this project's contribution to ovulation detection. It is expected that this work provides the following parameters:

1. Establishes the state of the art studies in this subject to the present day.
2. A mobile application (app) was developed to collect data for analysis. This app as guided the participants during the clinical trial.
3. Provides a clinical trial, carried out in Portugal and Slovenia, consisting of data collection for further analysis and final conclusions.

1.4. Organization

The present dissertation is organized by chapters that show the project development process sequence. The motivations, objectives and contributions have been shown in this first chapter. The following chapters are organized as follows:

- **Chapter 2 - State of Art:** In this chapter all parameters relevant to the development of this project are discussed. Initially we address the main factor that is the ovulation cycle, as well as the current methods to detect the ovulation. We will also explain the voice and the voice variation. Next, we have elaborated a study on existing applications and an analysis of articles that correlate ovulation and voice change.
- **Chapter 3 - Implementation:** This chapter describes all the steps taken to carry out this project, its planning, the materials and methods used, as well as the target audience and the development of the first application to collect the necessary data.
- **Chapter 4 - Results:** In this chapter the data collected will be treated and analyzed in order to obtain clear and quite objective results.
- **Chapter 5 - Conclusion and Future Developments:** The last chapter deals with the conclusions obtained and possible developments, improvements and analyzes to be carried out.

2. State of Art

In this chapter we present a brief introduction about ovulation in order to better understand its cycle and functionality. We also address the other key parameter of this project, the voice and their changes, so that we can see which changes may be related to ovulation.

Regarding the calculation of the ovulation period of a woman, or the identification of the same period, there are some methods currently available in the market. Some of the most used are: temperature measurement, the digital ovulation test and fertile period calculator, which will be discussed and explained later in this chapter.

2.1. Ovulation

To better define the menstrual cycle, we must divide it into two phases of similar duration (approximately 15 days each). The first is the preovulatory phase, also called the proliferative phase; the second is the post-ovulatory phase, also called the secretory phase, as we can see in Figure 1 [5]. Women usually perceives these phases by their own characteristic sensations [6].

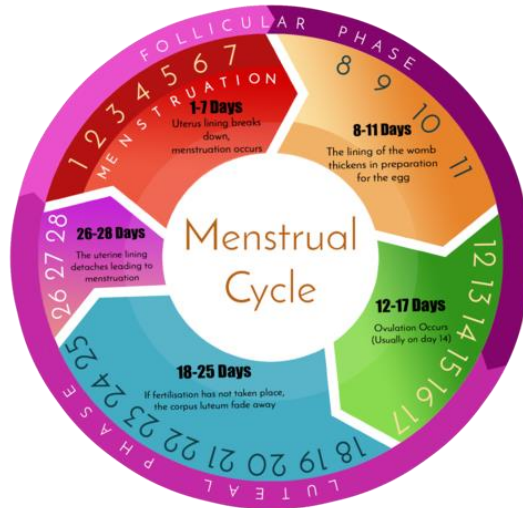


Figure 1 - Menstrual Cycle and Follicular Development (Adapted from [4]).

Ovulation is one phase of the menstrual cycle, the stage in which the egg is released by the ovary and reaches the fallopian tubes to follow the uterus and become fertilized. In this stage, there is the release of two hormones produced by the pituitary: Follicle Stimulating Hormone (FSH) and Luteinizing Hormone (LH). FSH allows the egg to develop in the ovary and LH acts on the ovary follicle so that it reaches its maximum development and releases the mature egg [7]. Together with the release of the egg, the ovarian follicle becomes a corpus luteum, a temporary endocrine structure characteristic of women, which produces progesterone to prepare for possible fertilization. If no fertilization occurs, this corpus luteum and egg will be expelled in the form of menstruation [8].

2.2. Current methods of ovulation detection

Ovulation is a phase of the cycle that involves several hormones and so there are some secondary signs and symptoms, such as increased secretions, body temperature, sexual desire, appetite, and emotional fragility are present and are usually signs that the fertile period of a woman is being initiated [8]. This section addresses the changes detected

throughout the menstrual cycle and the most commonly used methods of ovulation detection.

2.2.1. Counting the days of the month

Studies have concluded that by counting the days after the onset of menstruation there would be a high probability that the dates obtained are in fact in the period of ovulation [9], for these studies were often use hormonal tests to verify the accuracy of the data. Tests with progesterone were made and it was concluded that after an interval of 10 to 14 days after the onset of menstruation the person was in the fertile period, and it was also seen that this data could vary according to the person [10].

Currently, there are already mobile applications that do this work for us. Type in the start date and end of the last menstruation and the application calculates the days of possible ovulation, Figure 2 [11].



Figure 2 - Ovulation Calendar (Adapted from [10])

2.2.2. Observation of temperature, mucus, and cervix

As in the counting of days, there are also applications that record the data, entered daily, for temperature measurement. These data are analysed and the application gives you the most likely days of ovulation through statistical analysis, throughout the month, depending on the increase in body temperature, Figure 3. An example of an application that uses the temperature measurement as a basis is the Natural Cycles [12].

As in all applications that use statistics, there is a margin of error because several factors can affect the results, in case of a temperature variation due, for example, to a fever. situation increases the body temperature and induce a false positive ovulation.

Studies have shown the increase in temperature can identify the fertile and ovulation period of a woman, it was considered that the increase of the basal body temperature during the luteal phase of the normal cycle of the ovary is caused by the progesterone produced by the corpus luteum [13].

As we can easily confirm by the analysis of the following image (Figure 3 [14]), we see that there is an increase in temperature in ovulation and that this temperature increases and stabilizes over time, while there is the formation of the *corpus luteum* until its expulsion in the form of menstruation, in the image we can also observe that with the increase in temperature there is also a large increase of progesterone over time, and that this also reduces when the corpus luteum disappears.

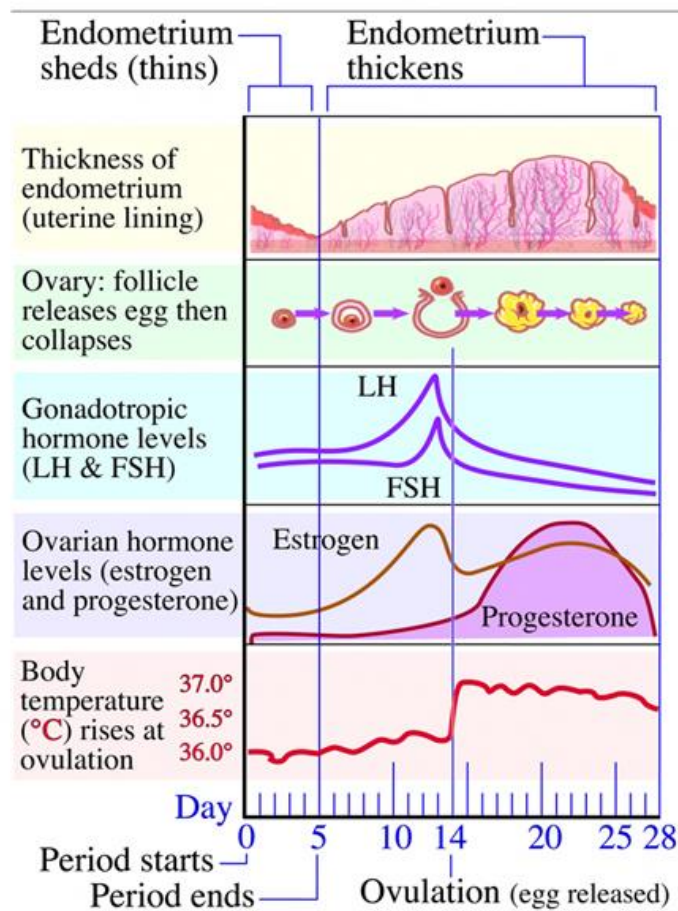


Figure 3 - Cycle characteristics (Adapted from [13]).

Released fluids are also one of the very important parameters for the detection of ovulation and diseases. For the detection of ovulation what is important to note is the elasticity of the mucus expelled by the organism.

Some physicians believe that ovulation occurs before the lowest point in the temperature cycle, while others believe that ovulation occurs at low or after thermal change [15].

Studies were done, where they saw the variation of the elasticity of the cervical mucus throughout the month and measured the temperatures, and drawing the graphs concluded that the elasticity of the mucous membranes is higher in the fertile period Table 1 [16].

Table 1 - Cervical mucus changes in the menstrual cycle (Adapted from [15]).

Fertile Period	Infertile Period
Thin, profuse, clear	Thick, scant, turbid
Easy to aspirate	Difficult to aspirate
Spinnability or Fibrosity (Thread formation) 10 to 20 cm	Spinnability or Fibrosity (Thread formation) 0 to 1 cm
Sperm survival optimal Good motility Numerous spermatozoa	Sperm survival poor Poor motility 0 to few spermatozoa
Pus cells normally absent	Pus cells usually present

They performed artificial insemination tests and concluded that the results were positive. However, they concluded that the greater the elasticity and quantity of mucosa, the less its viscosity, and therefore the greater the fluidity of the spermatozoa to the egg, thus being more conducive to fertilization Figure 4 [16].

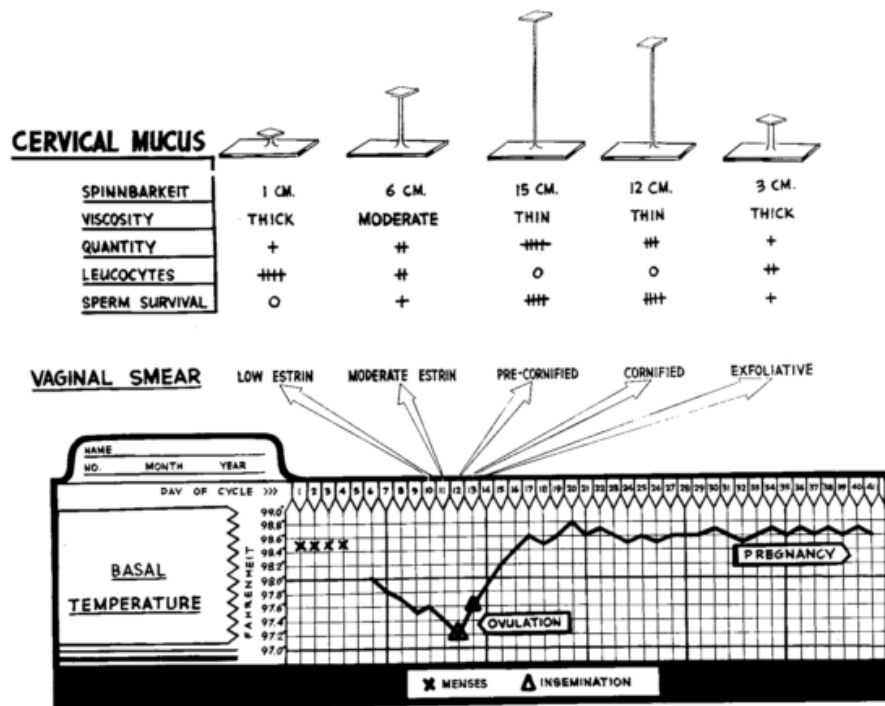


Figure 4 - Time of optimal fertility (Adapted from [15]).

Histologic changes in the endometrium during the menstrual cycle have been well characterized for more than 30 years. The first (follicular) half of the menstrual cycle is characterized by rapid endometrial growth that is primarily stimulated by estrogen. During the second half of the menstrual cycle (luteal), stimulated by estrogen and progesterone, growth in thickness occurs in a slower process until the time of menstruation, when all but a thin basal layer of the endometrium are excreted by the body [17]. There is the growth of the endometrium in the case of fertilization occurring, this accommodating the fertilized egg. We did see the evolution of the endometrium along the cycle on Figure 3.

2.2.3. Hormonal Tests

Currently, there is also the digital ovulation test, for example, the Clearblue Digital Ovulation test [18] which helps to maximize the chances of getting pregnant naturally by identifying the 2 most fertile days of each cycle by measuring changes in the level of the main fertility hormone - LH. In Figure 3 presented the variation of the temperature over time, compared to the variations of the LH during the menstrual cycle.

2.3. The voice and its changes

Voice changes often occur with several minor illnesses. Most of us experienced having a hoarse voice or even losing our voice entirely, usually when we have a throat infection or abuse our voice. But sometimes a change in voice can be a sign of a more serious problem. The sounds we make when we speak or sing are produced in the larynx, sometimes called the voice box, a structure located in the throat between the back of the tongue and the trachea. The larynx is surrounded by a cartilage structure that is noted as Adam's apple in the throat, Figure 5 [19].

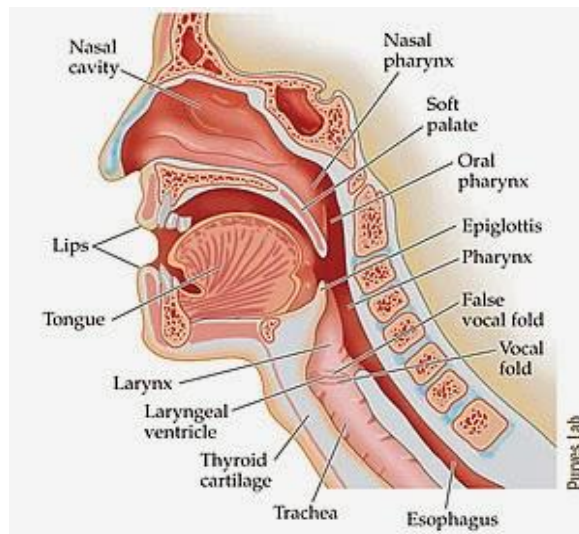


Figure 5 - Vocal System (Adapted from [18]).

Every breath of air that goes to and from the lungs passes through the larynx. The space inside the larynx is called the glottis and this is where the voice is produced. Two bands of elastic tissue - the vocal cords - are attached to the wall of the glottis by tiny muscles. The air that passes through the small space between the vocal cords makes them vibrate and produces a sound [20]. Changes in the shape of this gap, by the ability of a person to move their vocal cords, will produce changes in the sound produced. The shape of a person's throat, nose and mouth determines the sound quality, which is why we all have different voices.

The causes of voice changes include the following [21]:

- Inflammation of the larynx - laryngitis: Many minor infections can cause temporary inflammation and swelling of the cords, known as laryngitis, producing a hoarse voice. Extending the voice can also cause hoarseness for a few days. This can become a chronic problem for people who: have allergies, are exposed to smoke, with reflux problems (gastroesophageal reflux disease), drinking too much alcohol, or excessive use of voice (singers, teachers).

- Growth of Vocal Strings - These may be harmless cysts or polyps, or cancerous growths.
- Hormonal changes - That is why teenagers' voices "break" around puberty and some pregnant women perceive a deeper voice. A lack of thyroid hormone sometimes causes swelling of the vocal cords and a hoarse voice.
- Damage to the nerves of the larynx - Can interfere with the movement of vocal cords and affect speech.

During certain times of life, the female voice production may change, such as in early puberty, pregnancy, menstrual cycle, and menopause. Naturally occurring vocal fold swelling may result in hoarseness, reduced range of intensity, and loss of phonation stability. Vocal tone is typically more affected by hormonal imbalances. Virilization is the abnormal secretion of androgenic hormones in women. The vocal effects are low amplitude, hoarseness and occasionally vocal breaks [22].

2.3.1. Parameters to analyse voice

The parameters used to analyse voice are:

- F_0 - Fundamental Frequency - measured more frequently in Hertz (Hz), is the term used to refer to the physical parameter resulting from the vibration of the vocal chords per unit of time in sustained vocal behavior or in chained speech. It reflects the efficiency of the phonatory system, laryngeal biomechanics and its interaction with aerodynamics [23]. The acoustic correlate of the perceived pitch is sexually dimorphic due to differential vocal fold development during puberty [1].
- F_0SD - Standard deviation of the fundamental frequency

- F_{0min} - Minimum values of fundamental frequency
- F_{0max} - Maximum values of fundamental frequency
- **HNR** - Harmonics to noise ratio (HNR); a harmonicity object represents the degree of acoustic periodicity called as HNR, and it is expressed in decibels (dB). It is used as a measure for quality of the voice [24] [25].
- **SD** - Standard deviation as seen in [23].
- **DF** - is the averaged distance between adjacent resonating frequencies (formants) and is also sexually dimorphic [1].
- **Shimmer** - Amplitude perturbation defined as the average absolute difference between the amplitudes of consecutive periods, divided by the average amplitude as seen in Figure 6 [24][26].
- **Jitter** - Frequency perturbation defined as the Cycle to Cycle variation of fundamental frequency, that is the average absolute difference between consecutive periods is called as jitter as seen in Figure 6 [24][26].

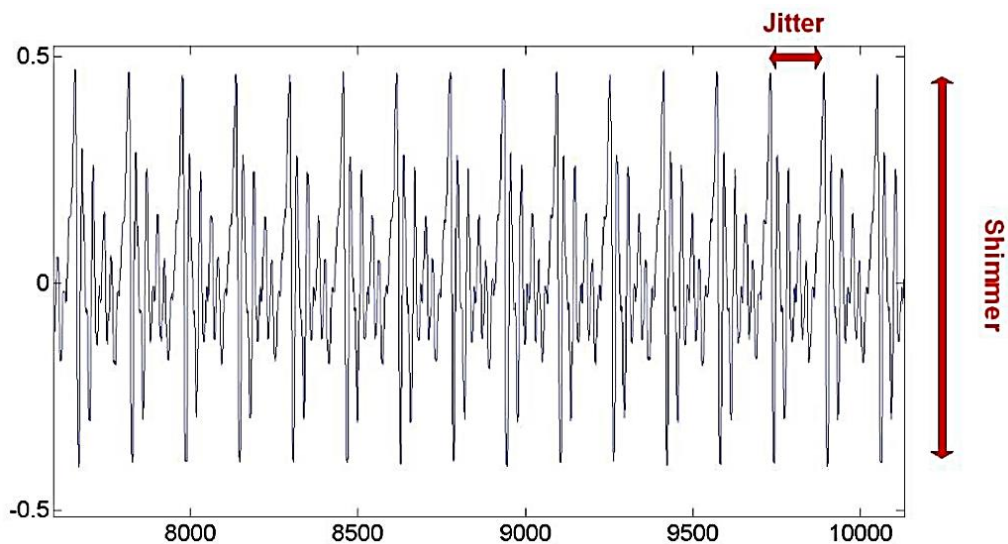


Figure 6 - Jitter and Shimmer perturbation measures in a speech signal (Adapted from [23][25]).

In Table 2 we can see the normative parameters for sound signals emission for children, women and men [27].

Table 2 - Normative parameters for sound signals emission (Adapted from [26]).

	Children	Women	Men
F ₀ (Hz)	206 - 281	177 - 244	100 - 137
Jitter (%)	0.909 - 5.158	<1	<1
Shimmer (%)	0.393 - 1.013	<3	<3
HNR (dB)	-	>7	>7

The voice fundamental frequency (F₀) is one of the most used parameters for its analysis. This F₀ value can change from men to women and some studies even analysed it on different countries with different languages. There is a substantial amount of data on the frequency of the voice fundamental (F₀) in the speech of speakers who differ in age and sex.

Published data of F₀ in speech show its range of variation, often expressed in terms of two Standard Deviations (SD) of the F₀-distribution, which is approximately the same for men and women if expressed in semitones, but the observed SD varies substantially in different investigations. Most of the differences can be attributed to these factors: SD is increased in tone languages and it varies with the type of discourse. The study performed in German reached 129 and 238 for F₀ values and 2.3 and 1.9 for SD values for Men and women respectively. In French the values reached was 115 and 226 for F₀ and 1.9 and 2.5 for SD values for Men and women respectively. In Chinese the values reached was 108 and 184 for F₀ and 4.1 and 3.8 for SD values for Men and women respectively. In English the values reached was 127 and 186 for F₀ and 3.8 and 5.4 for SD values for Men and women respectively [28]. With the results obtain in the previous study we can clearly see that the language can also influence the main F₀ and SD values

for each country. In the next table we can see the values obtained in studies for Portuguese population.

For Portuguese population, we can see the average values of F0 for women and men for different semitones and while speaking, Table 3 and Figure 7 [29], instantly we can conclude that Portuguese women have a higher F0 mean value than man, which is common even in other languages.

Table 3 - Ranges of F0 mean values for Portuguese Adults (Adapted from [28]).

Sex	Women	Men
Age	18-52	17-49
Vowel [a]	199-215Hz	111-125Hz
Vowel [i]	206-262Hz	122-175Hz
Vowel [u]	205-253Hz	123-129Hz
Reading	180-242Hz	106-129Hz
Conversation	187-210Hz	109-123Hz

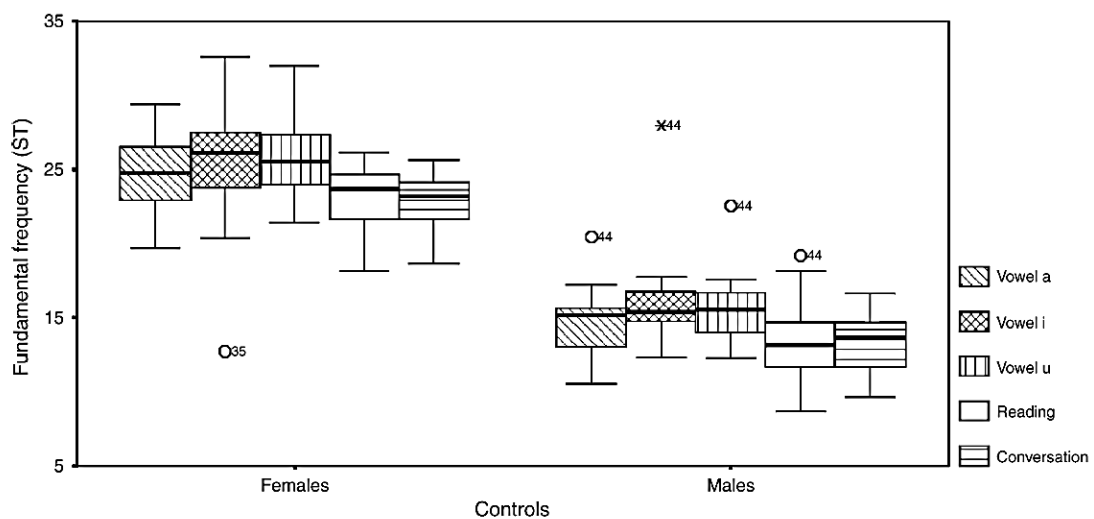


Figure 7 - F0 distribution (in semitones) for Portuguese normal people (Adapted from [28]).

Also, the age was analysed for the Portuguese population, as we can see in Table 4 [29], the results are very interesting and agree with the results obtained at others articles. For men, the decrease of F0 is remarkable during puberty and quips a successive deceleration until about 35 years of age, and then it begins to rise again, around 55 years of age. For women, F0 is stationary up to the age of menopause, when it decreases to reach a minimum that is about 15 Hz lower around 70 years of age. The physiological changes responsible for this can be understood as an effect of the increased testosterone-oestrogen ratio [28]. A similar lowering of F0 can be induced by the habit of smoking which we will referred ahead [30]. An increase in muscular tonus caused by emotional factors can also lead to an increase in F0min.

Table 4 - F0 means and standard deviations for normal speakers according to age (Adapted from [28]).

Sex	Women		Men	
Age	19-40	41-67	19-40	41-67
Vowel [a]	212.5 ± 6.6	210.2 ± 10.1	121.0 ± 6.2	102.1 ± 8.9
Vowel [i]	225.5 ± 5.5	216.5 ± 13.6	135.4 ± 13.1	108.1 ± 9.2
Vowel [u]	230.1 ± 6.5	222.6 ± 5.4	128.2 ± 6.7	110.0 ± 9.9
Reading	196.9 ± 3.8	177.5 ± 5.4	116.1 ± 5.9	93.2 ± 7.0
Conversation	189.9 ± 4.2	180.7 ± 5.0	112.7 ± 4.4	100.4 ± 4.3

Although no extensive and comparative studies exist, as far as we know, there is some evidence of culture and language related differences in pitch as we already have seen in the beginning of this sub-chapter, is different languages justify the different F0 around the world, is it possible that even with the same language but different accent justify it too? This issue was studied in Portugal, since we have very different accents depending on the localization. For this investigation they only selected subjects with 'normal' voice and all the subjects were diagnosed by an Ear, nose and

throat (ENT) specialist with nasolaryngostroboscopy and by a Speech Language therapist (SLT) through perceptive auditory assessment, they selected Lisbon and Funchal hospitals to record in a sound-treated cubicle using similar equipment and only oral reading recordings were analysed[31].

The results seem to support the supposition that the Speaking Fundamental Frequency (SFF) average and Semi-Tones (ST) during oral reading for Portuguese females is within the limits of the published data which is between 178 and 224 Hz (or 41,3 and 45,3 ST respectively). The mean for females from Lisbon was 199,4 Hz (or 43,3 ST) and for females from Funchal was 198,4 Hz (or 43,2 ST) [31] at Figure 8 and Figure 9 we can clearly see this slight differences but they do not seem significant.

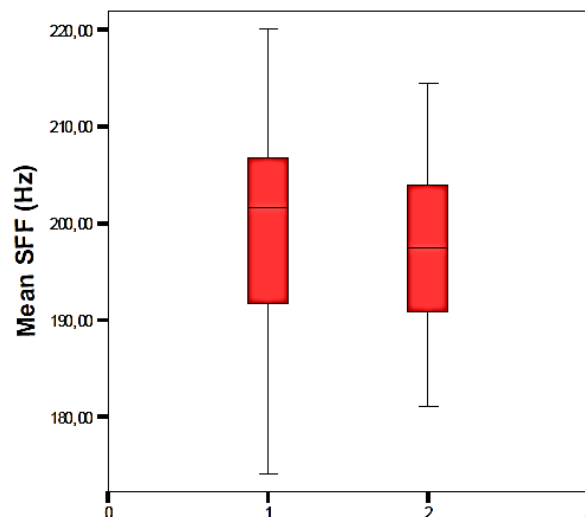


Figure 8 - Mean SFF distribution for Lisbon (1) and Funchal (2) (Adapted from [30]).

The pitch means the difference between Lisbon (43,3 ST) and Funchal (43,2) data is 0,1 ST. Obviously, this small difference is not statistically significance ($U=107,5$, $z=-0,773$, $p>0,05$). Figure 9 illustrates the distribution of all subjects' mean SFF. Note that almost all females' mean pitch is lower than 44 ST [31].

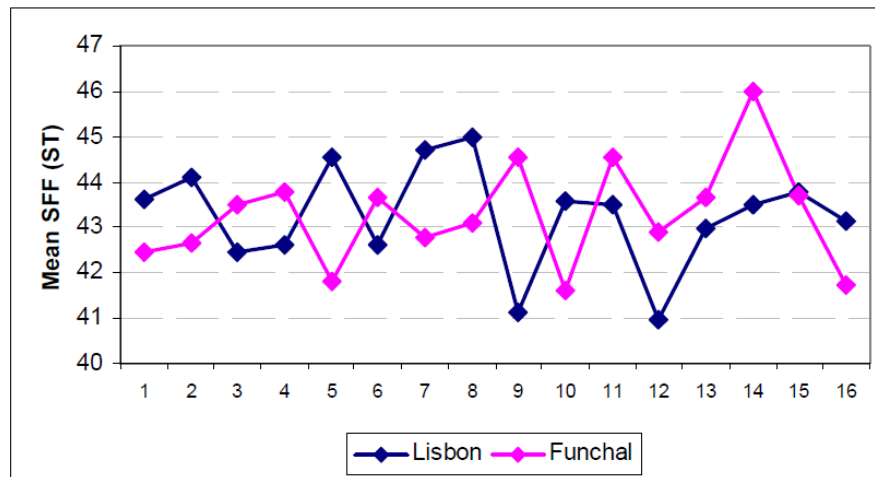


Figure 9 - Distribution of the mean SFF measures across subjects (Adapted from [30]).

2.3.2. How Body Mass Index (BMI), Smoking and Alcohol habits influence voice parameters

As we could see in the previous chapter there are different causes for vocal frequency change. The hypothesis that smoking habits, alcohol and BMI could influence these changes had already been confirmed by previous studies that we consulted.

In relation to age, the influence of that parameter in voice change as we could see on table 4. As far as smoking habits are concerned, there are some studies that have reached some interesting conclusions.

A study about vocal quality in theater actors analysed this parameter and concluded that the actors that did not smoke, had better voice performance than the ones who smoke [32].

Smoking is a general health risk. Studies have demonstrated the association between smoking and changes in the larynx, and saw that it frequently leads to voice disorders, laryngeal pathologies as well as changes in voice characteristics.

Statistically significant increases for physical and total scores of the Voice Handicap Index were found in the smokers group ($P < 0.05$). Significant differences were observed for the acoustic parameters between smoker and nonsmoker groups, Table 5 [30].

Some studies also show that there are significant changes in voice when we start smoking. Others even compare these changes to men values and see the more frequent symptoms for each gender [2].

Age and smoking influence voice frequency, but body mass is another important parameter for this analysis.

Table 5 - Comparison of acoustic parameters between female smokers and non-smokers (sustained of/a/) (Adapted from [29])

	Smokers Meidan (IQR)	Nonsmokers Median (IQR)	<i>p</i> Level
Habitual F0 (Hz)	205.97 (201.75-215.05)	227.22 (210.02-243.26)	0.000*
Mean F0 (Hz)	205.92 (201.81-215.54)	228.48 (210.22-228.48)	0.156
% Shimmer	0.68 (0.18-0.21)	0.50 (0.23-0.77)	0.003*
% Jitter	0.21 (0.18-0.24)	0.20 (0.15-0.23)	0.000*
HNR (dB)	24.65 (21.87-25.92)	24.94 (22.53-27.03)	0.164
Intensity (dB)	62.54 (58.00-66.00)	60.00 (57.00-66.00)	0.421
*Significant an $P < 0.05$			
Abbreviations: F0 Fundamental Frequency; HNR Harmonic-to-noise-ratio; IQR Interquartile Range			

Voice parameters can reflect sex-specific body morphology in men and women [3]. Studies of several mammalian species confirm that formant frequencies (vocal tract resonances) predict height and weight better than does fundamental frequency (F0, perceived as pitch) in same-sex adults due to differential anatomical constraints. There is some evidence that information about body shape, not only height and weight, may be present in the human voice. The principal mechanism linking voice to body shape is probably hormonal.

Among women, waist-to-hip ratio and the body mass index are robust predictors of fecundity and correlate with ratings of women's physical

attractiveness. Women with lower waist-to-hip ratios are also rated as having more attractive voices [33], and listeners are able to gauge women's waist-to hip ratios from their voices alone [34]. Among men, chest-to-hip ratio and height positively predict physical attractiveness and reproductive success. Like body size, body shape influences mate preferences across a range of human cultures and is likely to be important for both mate selection and intersexual competition. Various Vocal Tract Length (VTL) estimate predicted women's waist-to-hip ratios and hip circumferences significantly better than men's, but shimmer, jitter and maximum F0 predicted men's hip circumferences better than women's [3]. Reaching these results it was a really important discovery, this information could help identify body characteristics through voice which could possibly be used to have a more complete description of a criminal, when we have a voice record to analyse, for example.

We already saw that lots of factors influence the voice, we will now consider the last parameter that we took into account for this dissertation, wich was BMI. In the next image, we have the results of a study that analysed and compared three groups of people, one with the low BMI, normal BMI and other with high BMI values, which means underweight, normal and overweight people respectively [35].

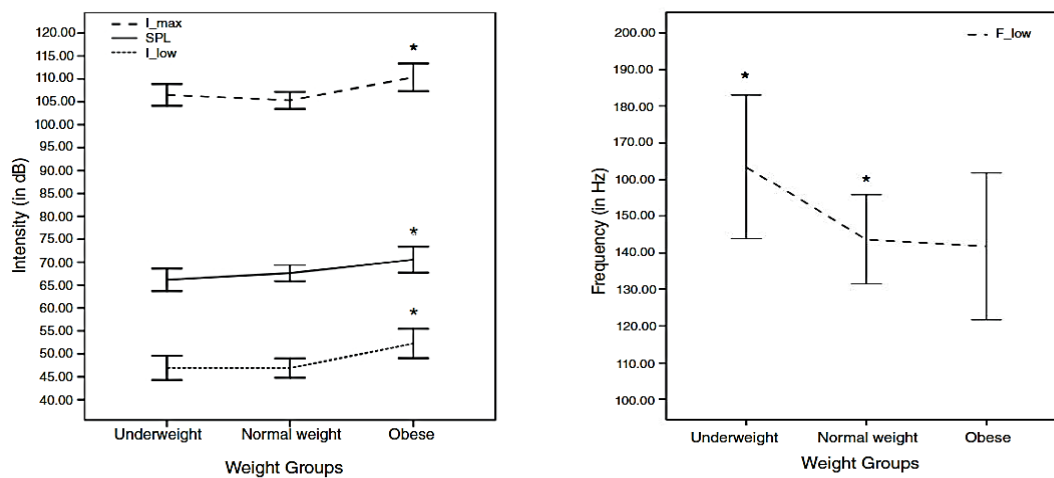


Figure 10 - Vocal differences for each BMI groups (Adapted from [34]).

2.4. Ovulations and voice correlation (Appendix I - Systematic Review)

For this section a Systematic review article was written and submitted, it can be found as an Appendix chapter at the end of the dissertation.

A brief introduction of what is covered in the review article, and a simple analysis of the results found on the correlation between ovulation and human voice will be provided for now.

As we have seen in this chapter, lots of variables can cause voice changes. One of the tested parameters, was the uttering of vowels and complete sentences and these were the results: Figure 11 [36],[23] as we can see there are substantial differences: Based on these studies, about the correlation between voice and ovulation, it is clear why full sentences registration and analysis was preferred over vowel utterance.

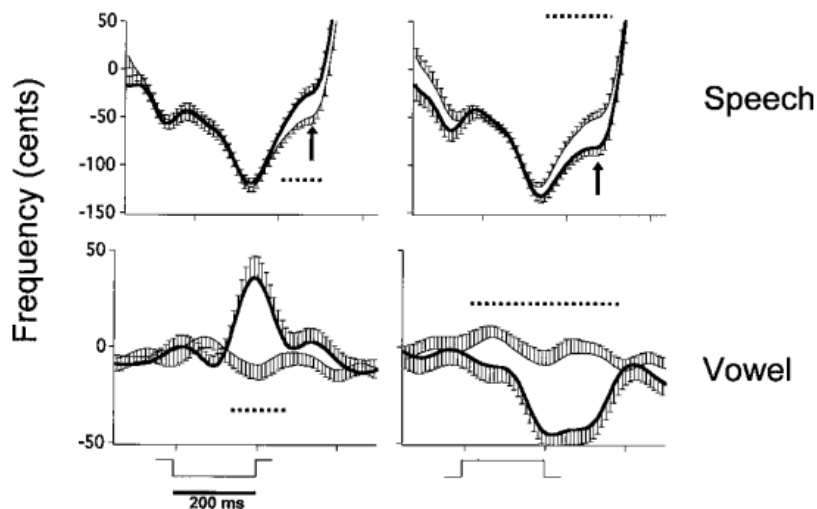


Figure 11 - F0 in speech and vowels (Adapted from [35]).

Most Studies came to the same results and conclude that there is a huge probability that voice is indeed correlated to ovulation, not only that, but it was also possible to spot differences between women that were using

contraceptives and the ones, that were in their normal cycle. Several parameters were analysed for this matter.

As we can see in Figure 12 [37], women’s attractiveness increases in the fertile window and it can be noticed in voice frequency. So, with this information, we can assume that we can identify the ovulation period by analysing the voice frequency.

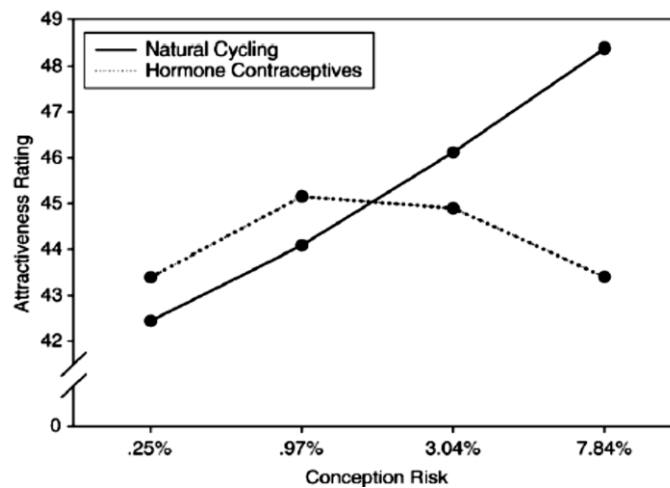


Figure 12 - Average voice attractiveness rating as a function of conception risk in natural cycling women and those taking hormonal contraceptives (Adapted from [36]).

Several studies specifically correlate ovulation and human voice. In Figure 13 [1] we can see the results of one of these studies which the ovulation phase was confirmed using LH indicators and values. The results were very interesting, as we can see there in a visible increase of the pitch with the proximity of the ovulation date.

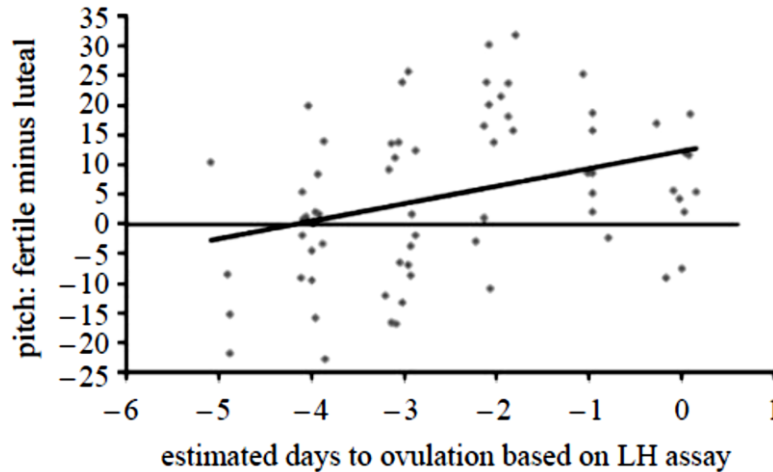


Figure 13 - Correlation of high versus low-fertility differences in voice pitch and proximity to ovulation in the high fertility recording section (Adapted from [1]).

Different studies address this theme, only a few covers this issue directly and the ones that do leave a lot of questions, and use different methods. Because of this we still cannot establish this correlation. Further studies must be done, with different approaches, and methods.

On the Article attached at the end of the dissertation the different studies done so far are mentioned, along with their results.

Based on this information the decision to go ahead with this study was made, using a different approach to identify a viable method.

3. Implementation

In this chapter the development of the project is presented, and all phases of the project are described, from planning, materials and methods, target public for the development of the applications and analysis of the data obtained.

3.1. Project Development Planning

First, it is necessary to create an application to collect audio data and store it in an appropriate format such as e.g. in text format, then develop a method to analyze the data collected so that later we can compare the results of the analysis previously done, finally to verify if there is a correlation between voice and ovulation and explore future research possibilities.

3.2. Materials and Methods

For this project it is necessary to collect recordings of the same phrase as to keep consistency across samples, we chose to ask the participant to count from 1 to 10, every day for example in the morning so that we can compare the frequency changes of each participant. With the daily comparison of these records, we were able to identify specific variations such as the maximum, minimum and average frequency, but for this study, we only used the F0 variations. The values obtained should indicate if the participant is in the Ovulation period.

In order to collect the necessary data without extra costs, we decided to develop an Android application, so in this case, we only need to use a mobile phone, since a microphone is necessary, to record the data.

3.3. Target Audience

Currently, as we have seen in the previous chapter, there are several methods to identify if a woman is in the ovulation period, from temperature, mucous membranes among others. After the contact with some women and with experts from fertilization clinics, we noticed the discomfort that these traditional methods cause. Taking this into account, and after studying other works that compared the frequency of participants' voice, we decided to develop this application to collect data and make an analyse of it, in order to evaluate if there is a possibility to develop a mobile application to give this result to the participants without the uncomfortable traditional methods. The idea was strongly supported by women, if this can be developed in the future we will be able to eliminate the discomfort of traditional methods.

3.4. Mobile Application (App)

The app to collect audio data will only need a microphone, considering that nowadays all mobile phones have this functionality, the app will be used by it, just download our app and it is ready to work.

The app for data collection was developed for later analysis, done in Java, in Androidstudio®. For this mobile app we developed an app for the female audience with some daily questions, to compare the results. Below are some screens shots of the app, Figure 14.

Chapter 3 - Implementation

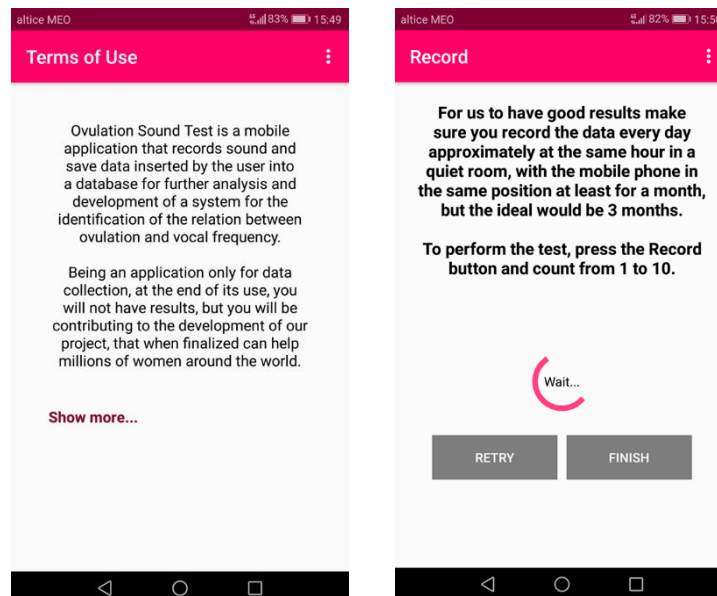
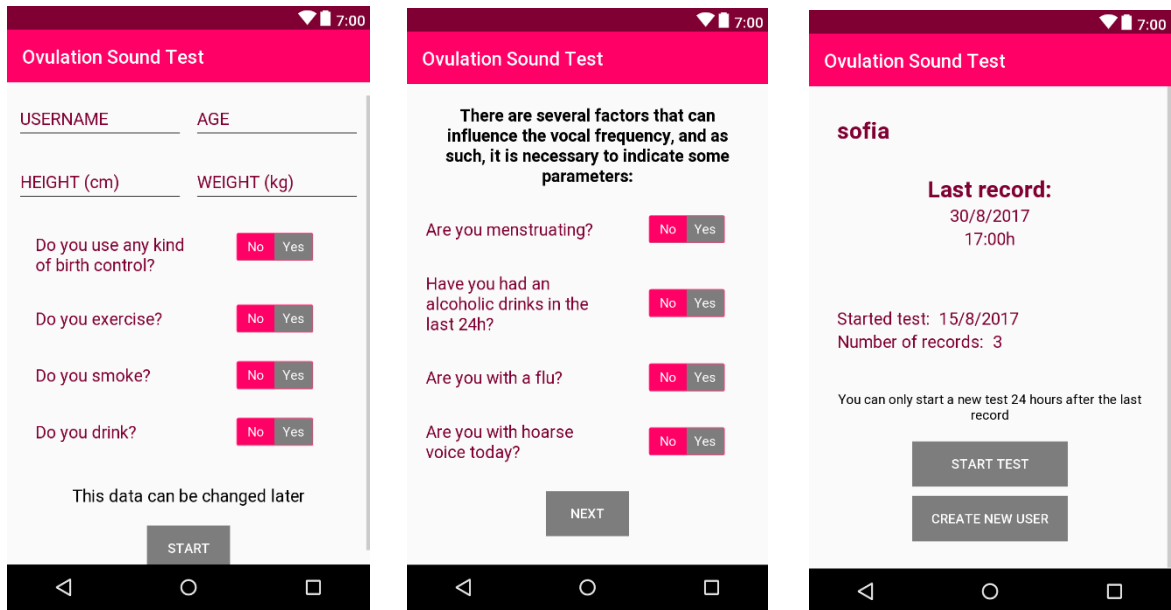


Figure 14 - Mobile application Print Screens

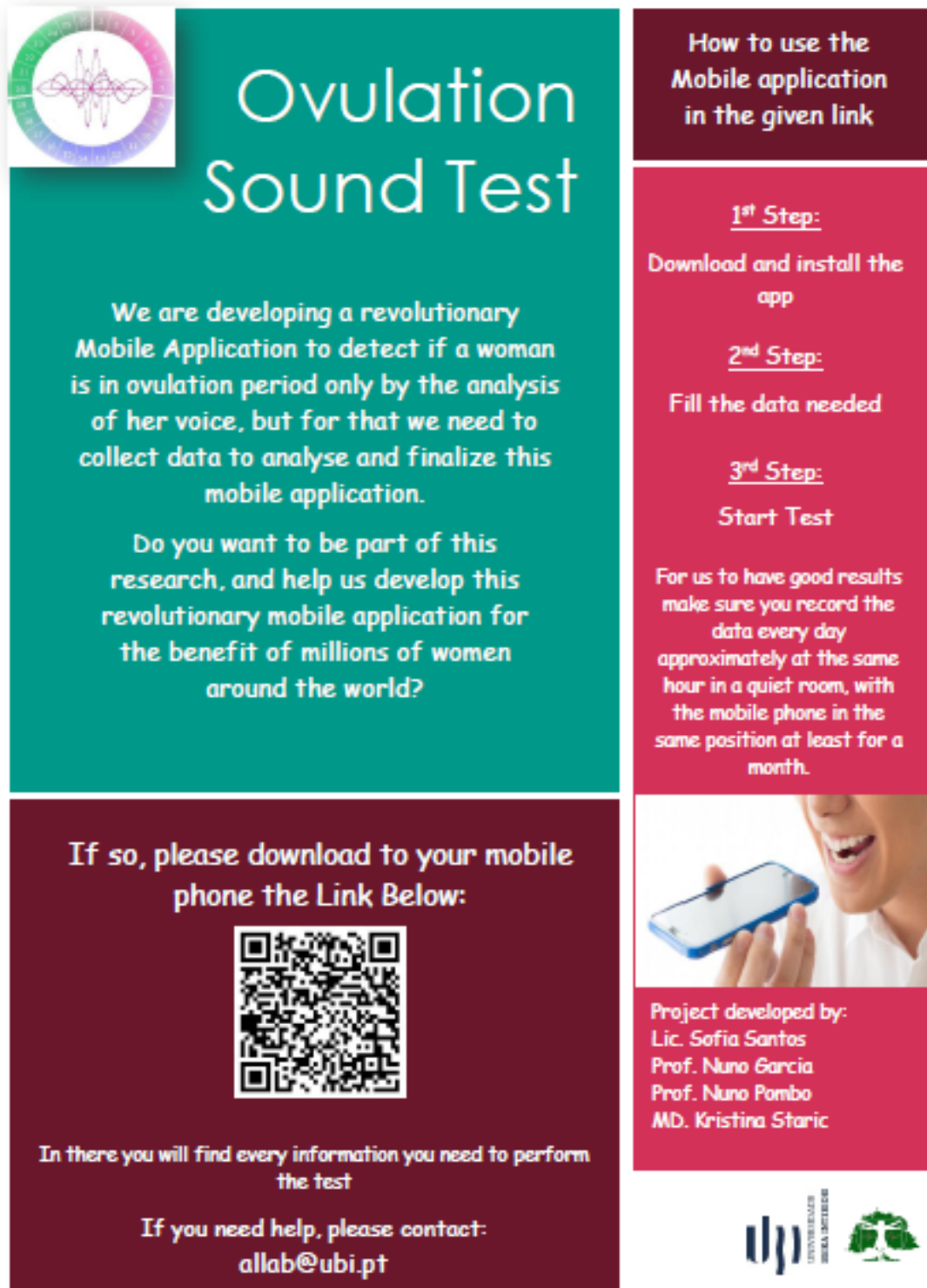
3.5. Data Collected

In the data collection phase, with a partnership with Dr. Kristina Drusany Staric from Slovenia, an app was made available to students from the University of Ljubljana and to patients also from Slovenia. In Portugal a collaboration of students from the University of Beira Interior was requested, and flyers were posted, to gather volunteers within the female population, for the development of the project.

To facilitate the dissemination of the mobile app a QR Code was added in order to be more accessible. On the flyers, we can also see a short description of the project, how to use the mobile app and an incentive text appealing for women contribution on this project, Figure 15.

The preliminary study was conducted between January 2018 and April 2018, in which participants performed daily registrations with some indications like, trying to record at the same hour, in a quiet place, and with the mobile phone in the same position in order to obtain good data to analyse.

The data were saved on the mobile phone in a text file (txt) which was sent to Firebase database via an internet connection. In this database, I received all the txt files for each recording Figure 16.



The flyer is divided into several sections. At the top left is a circular logo with a colorful border and a soundwave in the center. The main title 'Ovulation Sound Test' is in large white font on a teal background. Below the title is a paragraph explaining the development of a mobile app to detect ovulation through voice analysis. A second paragraph asks if the user wants to be part of the research. To the right, a dark red box contains the heading 'How to use the Mobile application in the given link' and three numbered steps: 1st Step (Download and install the app), 2nd Step (Fill the data needed), and 3rd Step (Start Test). Below the steps is a paragraph of instructions for recording data. At the bottom left, a dark red box contains the text 'If so, please download to your mobile phone the Link Below:' followed by a QR code and the email 'allab@ubi.pt'. At the bottom right, a pink box features a photo of a smiling woman holding a smartphone and lists the project developers: Lic. Sofia Santos, Prof. Nuno Garcia, Prof. Nuno Pombo, and MD. Kristina Staric. Logos for UBI and a tree are at the bottom right.

Ovulation Sound Test

We are developing a revolutionary Mobile Application to detect if a woman is in ovulation period only by the analysis of her voice, but for that we need to collect data to analyse and finalize this mobile application.

Do you want to be part of this research, and help us develop this revolutionary mobile application for the benefit of millions of women around the world?

How to use the Mobile application in the given link


1st Step:
Download and install the app

2nd Step:
Fill the data needed

3rd Step:
Start Test

For us to have good results make sure you record the data every day approximately at the same hour in a quiet room, with the mobile phone in the same position at least for a month.

If so, please download to your mobile phone the Link Below:



In there you will find every information you need to perform the test

If you need help, please contact:
allab@ubi.pt

Project developed by:
Lic. Sofia Santos
Prof. Nuno Garcia
Prof. Nuno Pombo
MD. Kristina Staric





Figure 15 - Ovulation Sound Test Flyer

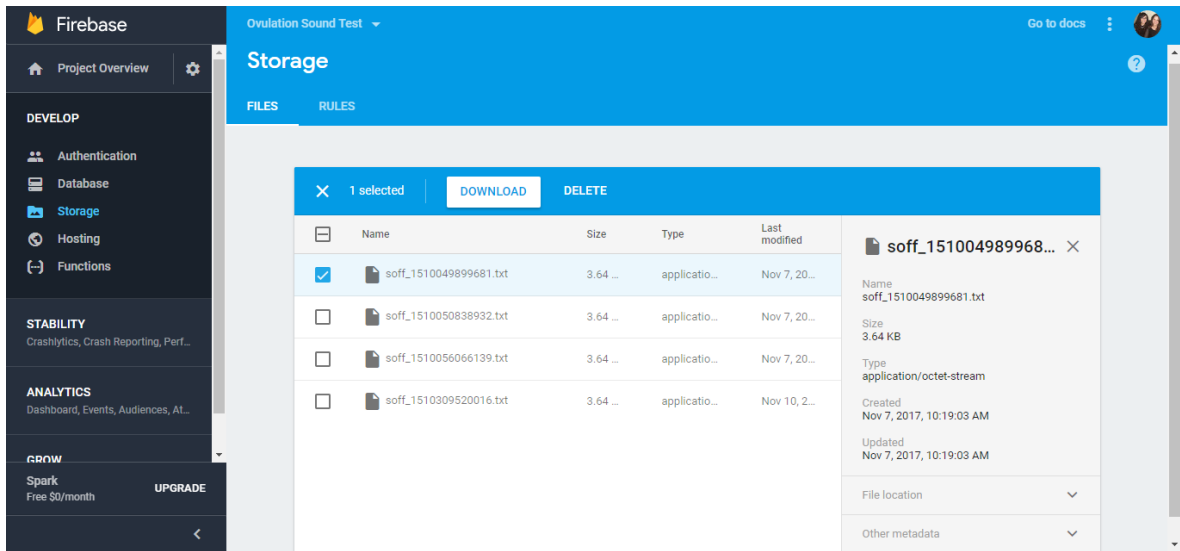


Figure 16 - Firebase Data collection

On the next flow chart from Figure 17, we have a resume of the steps made for the data collection process.

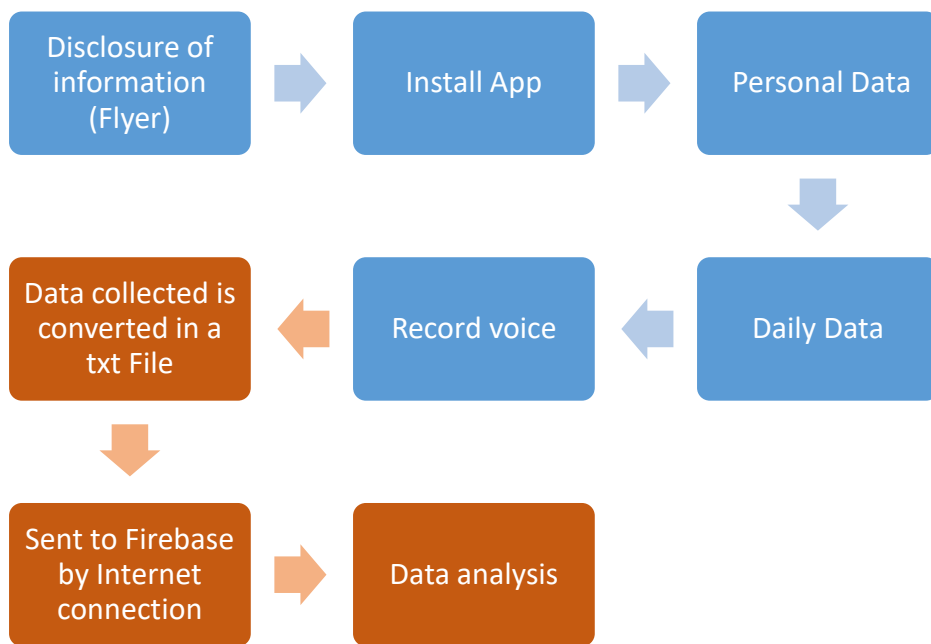


Figure 17 - Data Collection Flow Chart

In total, we got 25 participants, but only 14 recorded the minimum of 30 recordings, the amount needed for a good analysis. Nevertheless 4 participants, that recorded more than 10 times, were accepted (data single out in yellow letters). The other 7 Participants were excluded due to the lack of recording (data single out in in red letters). In total we collected 827 recordings. In the following table we can see the respective information asked each of them, and some additional information such as BMI values, number of recordings and finished date, Table 7.

BMI Is calculated with the values of height and weight of each participant, using the formula: $BMI = \text{weight (kg)} \div \text{height}^2 \text{ (m}^2\text{)}$; the value obtained classify you as an underweight person, values under 18.5 (Yellow background), Normal Weight person, values between 18.5 and 24.9 (Blue background), Overweight person, values between 25 and 30 (Orange background) and obese person, values above 30 (Red background) [38].

Table 6 - Data Collected

Participant	Initial Date	Age	Weight (kg)	Height (cm)	BMI	Contraceptive	Exercise	Smoke Daily	Drink Daily	N° of Records	Finish Date
P1	2018/01/20	24	65	165	23.9	NO	NO	NO	NO	1	-----
P2	2018/01/07	21	90	167	32.3	NO	YES	NO	NO	67	2018/03/15
P3	2018/01/09	25	70	165	25.7	NO	YES	NO	NO	3	-----
P4	2018/01/09	22	90	163	33.9	NO	NO	NO	NO	43	2018/03/16
P5	2018/01/09	22	95	172	32.1	NO	NO	NO	NO	54	2018/03/15
P6	2018/02/04	26	58	171	19.8	NO	YES	NO	NO	13	2018/03/04
P7	2018/03/16	34	70	168	24.8	YES	YES	NO	NO	29	2018/04/29
P8	2018/01/08	20	57	169	20	YES	YES	NO	NO	60	2018/03/15
P9	2018/01/07	22	53	146	24.9	YES	NO	YES	NO	21	2018/02/17
P10	2018/01/10	23	57	158	22.8	YES	NO	NO	NO	58	2018/03/15
P11	2018/01/09	27	51	160	19.9	YES	YES	YES	NO	44	2018/03/15
P12	2018/02/05	30	65	167	23.3	NO	NO	NO	NO	1	-----
P13	2018/03/18	24	93	168	33	NO	NO	YES	NO	1	-----
P14	2018/01/07	25	73	163	27.5	YES	YES	NO	NO	54	2018/03/15
P15	2018/01/07	31	67	163	25.2	NO	YES	NO	NO	50	2018/03/12
P16	2018/03/16	42	95	158	38.1	NO	NO	NO	NO	1	-----
P17	2018/01/08	24	57	162	21.7	YES	NO	YES	NO	20	2018/03/25
P18	2018/01/09	35	57	162	21.7	NO	NO	NO	NO	63	2018/03/15
P19	2018/03/15	27	58	169	20.3	NO	YES	NO	NO	10	-----
P20	2018/01/14	24	48	168	17	NO	YES	NO	NO	32	2018/03/15
P21	2018/01/09	25	65	160	25.4	YES	NO	NO	NO	47	2018/03/15
P22	2018/02/05	43	64	171	22.2	YES	YES	YES	NO	2	-----
P23	2018/01/07	24	58	162	22.1	NO	YES	NO	NO	58	2018/03/15
P24	2018/01/09	22	61	164	22.7	YES	YES	NO	NO	38	2018/03/15
P25	2018/01/08	24	52	162	19.8	YES	NO	NO	NO	57	2018/03/15

3.6. Data Processing and Analysis

In order to get as much information as possible out of those recordings, we tested different possible analyses.

The first approach was to clear the data, because the data is an audio recording converted into a txt file in a mobile phone, and this process could create some bugs in the txt file. After clearing all the txt files and analysing the possibilities to compile the data, it was found that the place was the Matlab, For this, we need to convert all the txt files into excel files so that they could be opened and processed in Matlab.

In the process at the Matlab, we explored some filters to establish which ones could be more effective to what we were looking for. In all cases, a Fast Fourier Transform (FFT) was present. A FFT is an algorithm that samples a signal over a period of time (or space) and divides it into its frequency components. These components are single sinusoidal oscillations at distinct frequencies each with their own amplitude and phase, Figure 18 [39].

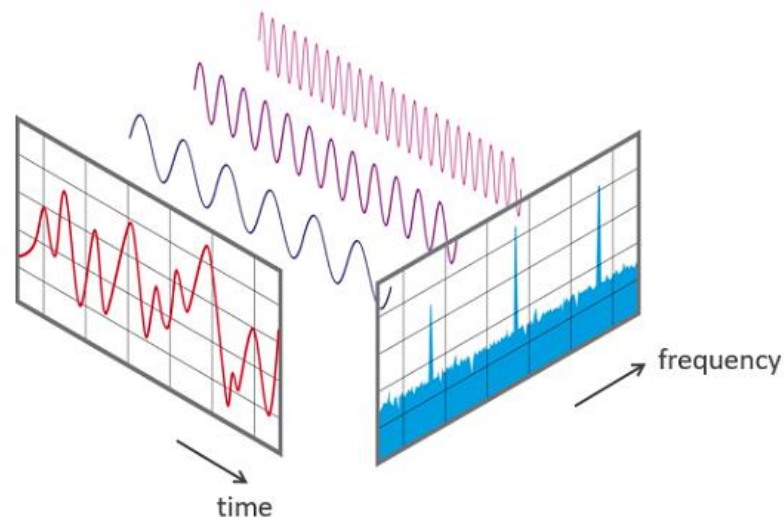


Figure 18 - View of a signal in the time and frequency domain (Adapted from [38]).

After testing a lot of possibilities, we reached this code where we defined the scale and range to analyse (code is in Appendices)

First, we had to import the Excel file we had already cleared and adjusted to be able to import to Matlab.

Explaining the code, the data was imported separating all text from all numerics, after that we establish the vector length to be able to know the from where to where we want to analyse the data. We saw that the numeric part of the data collection started at line number 14 so we indicated that we wanted to select everything from 14 till the end of the file.

The frequency of sampling and the period calculation was needed, in order for us to be able to select the interval of frequencies we wanted. Regarding audio signal we choose to delete every frequency above 128Hz and below -128Hz, because we verified that the sensor has no resolution. After that, the frequency vector was calculated (FFT) and a low-pass filter was added with a cut-off frequency of 400 Hz in order to select fundamental frequencies. As we saw in the previous chapter, vocal frequencies change for different reasons, so we considered the Portuguese female fundamental frequency approached in a study we have already mentioned. We select the fundamental frequencies above or equal to 140Hz or less or equal than 300Hz because as we seen in the previous chapter, the Portuguese female F0 are always between those values. At the end, the F0 estimated is displayed on the screen. Once we achieved this major goal and reached a solution we had to run every file through this code to get the values for each day.

The results were recorded on an Excel File for a better analysis. Since the days that the participants had their menstruation are known, we were able to count the days till the fertile window (10 to 14 days, as we saw in chapter 2), this method was used to establish the need to use other ways to detect the ovulation beside this one. After having all our estimate fertile window for each participant, the F0 values and the variation of the frequency of menstruation and ovulation days were calculated in relation

to the remaining days of the month, the results can be seen on the next chapter in Table 8.

On the next flow chart (Figure 19) we have e resume of the steps made for the Data Processing and Analysis.

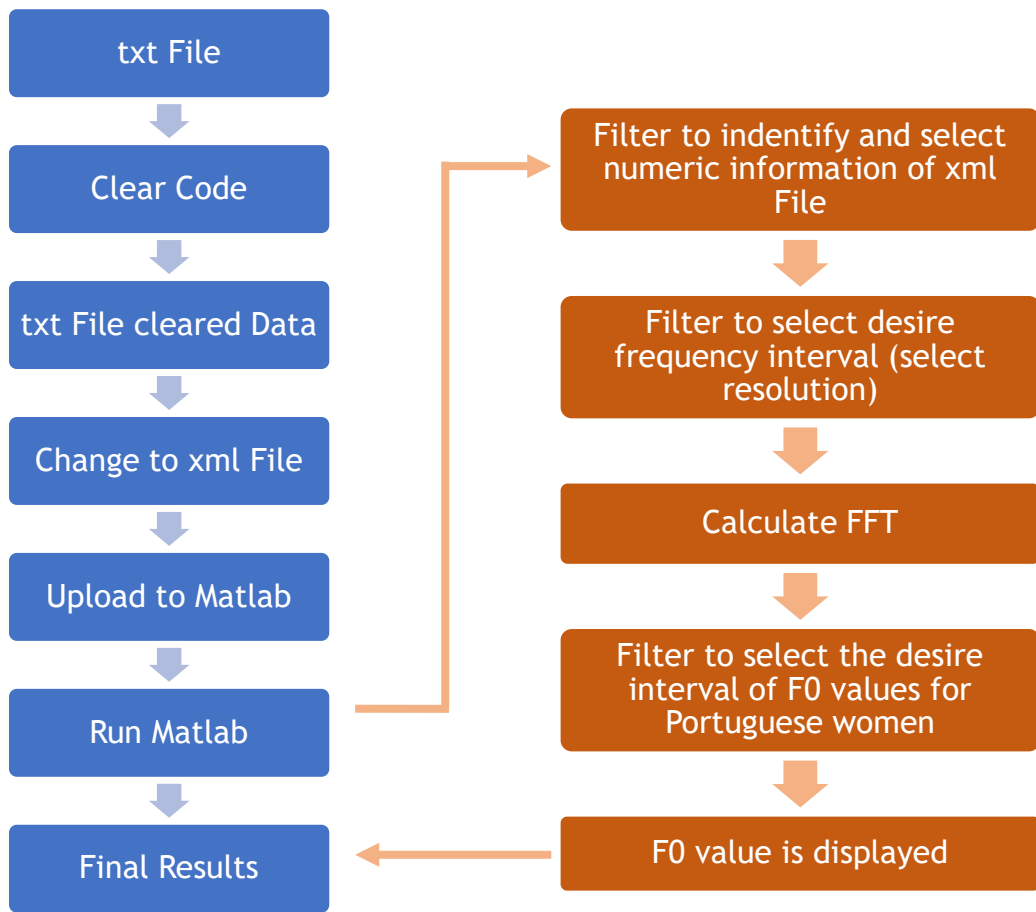


Figure 19 - Data Processing and Analysis Flow Chart.

4. Results and Discussion

With the analysis described above we reached very interesting results registered in the table below, along with the parameters that seemed relevant that were asked to the participants at the onset of the project. Starting the analysis, we felt the need to ask the participants if their cycle were regular, if they have any hormonal or reproductive ailments that could influence the menstrual cycle, they were also questioned about the kind of contraceptive pill they were taking.

When we analyzed all data collection, we did not find changes in the parameters that could be related to the answers on everyday questions, as we had the average values of the expected ovulation phase values, menstruation period and the neutral period and just after that we calculated the differences between them. So a change in one day, in this case, was minimal since we are doing average values of that respective period.

By analyzing the data collected we could see that some values met our expectations while others did not which raised some speculation that is still not answered. The values that raised these questions are marked on the following table and discussed below.

Table 7 - Results Obtained

(VFM - Variation of the frequency of menstruation days in relation to the remaining days (except days of ovulation); VFO - Variation of the frequency of Ovulation days in relation to the remaining days (except Menstruation days); VFOM - Variation in the frequency of Ovulation days in relation to Menstruation days)

Participant	Notes	Contraceptive	Type	Regular	Menstruation FO	Ovulation FO	Nothing FO	VFM	VFO	VFOM
P2	IMC 32.3	No	--	No	199.34	215.91	195.82	1.79%	10.26%	8.31%
P4	IMC 33.9	No	--	No	171.36	206.47	182.86	-6.29%	12.91%	20.48%
P5	IMC 32.1	No	--	Yes	176.51	212.28	201.36	-12.34%	5.42%	20.26%
P6	Exercise	No	No Info	No Info	154.3	236.13	183.55	-23.37%	17.27%	33.78%
P7	IMC 24.8, Exercise	Yes	No Info	No info	213.242	192.424	190.32	12.04%	1.1%	-9.76%
P8	Exercise	Yes	Mercilon (Pill)	Yes	202.43	202.64	184.32	9,82%	9,94%	0.10%
P9	Smoke	Yes	Estinette (Pill)	Yes	184.32	192.25	166.73	10.55%	15.31%	4.30%
P10	--	Yes	Diane (Pill)	Yes	205.98	205.195	190.16	8,32%	7.31%	-0,38%
P11	Exercise, Smoke	Yes	Ring	Yes	179.96	193.15	188.69	-4.63%	2.36%	7.32%
P14	IMC 27.5, Exercise	Yes	Minigest (Pill)	Yes	186.51	215.97	192.15	-2.94%	12.39%	15.79%
P15	IMC 25.2, Exercise	No	--	No	203.895	192.08	214.27	-4.84%	-10.25%	-5.79%
P17	Smoke	Yes	No Info	No Info	217.84	196.05	224.95	-3.16%	-12.85%	-10%
P18	--	No	--	No	217.13	177.55	197.68	9.84%	-10.18%	-18.23%
P20	IMC 17, Exercise	No	--	Yes	195.75	161.76	187.04	4.67%	-13.52%	-17.36%
P21	IMC 25.4	Yes	Minigest (Pill)	Yes	181.32	187.81	177.73	2.02%	5.67%	3.58%
P23	Exercise	No	--	No	199.14	208.31	187.99	5.93%	10.8%	4.6%
P24	Exercise	Yes	Evra (Transdermal)	No	178.74	197.01	175	2.14%	12.58%	10.22%
P25	--	Yes	Minigest (Pill)	Yes	217.06	159.80	182.99	18.61%	-12.67	-26.38%

Pink background - Values are according to previous studies

- The pink background on their VFOM value indicate that the results on these cells are as expected.
- For the participants that were taking contraceptive pills de VFOM values are close to zero, which means that the frequency variation between ovulation phase and menstruation phase is minimal. That, indicates the lack of ovulation, as we have seen in the previous chapters by analyzing previous studies.
- For the Participants that were not taking any kind of contraceptive the VFOM values were very high, indicating a big variation of F0 values from menstruation phase to ovulation phase, this can mean that these participants are ovulating in the expected window.

Yellow background - Values for women that use other contraceptives than the pill.

- Although the VFOM values were expected to be closer to zero, since these participants were taking oral contraceptives, this does not happen.
- Is it possible that the transdermal and vaginal ring are less effective? if so, this could justify these results that showing that the participant is likely ovulating.
- As the participants are taking a pill it should regulate their menstrual cycle. So if they ovulate, it should happen in the expected period.

Green background - VFOM values were much higher than expected, even higher than those in yellow background.

- Two of the tree participants taking the *Minigest* contraceptive have plausible ovulation values.
- Once again the question arises; is it possible that this contraceptive is less effective than others or the hormone concentration not

enough to block the ovulation for these two participants? If that is the case these results, make sense!

Blue background - The blue marks show the women that do not use any kind of contraceptive and had low values on VFOM.

- By the value obtained in VFOM, the participants can be classified as not regular and not ovulating.
- If the participant does not use contraceptives and has a regular cycle, it should be possible to notice the variation between the ovulation and menstruation, so high VFOM values were expected.
- For these singled out participants the values were low, which can mean different things, either they did not ovulate on the expected date (10 to 14 days after the first day of menstruation), or they did not ovulate at all. Some of the participants are known to have irregular cycles or short ones.

5. Conclusions and Future Development

The correlation study of voice and ovulation is not new. In fact, several authors ([1],[25],[37],[4]) have published results showing that no consensus about fundamental frequency change between the ovulation and menstruation period.

After discussing some results, more than we expected was discovered and raised further questions than the initial ones. Despite the fact that this project did not establish voice changes related to smoking and alcohol habits, IMC or physical exercise, it leads to questioning the differences in effectiveness of each contraceptive pill.

The results for some participants that were taking contraceptive pills showing VFOM values are close to zero, we can conclude that there is a lack of ovulation. Other results for some participants that were not taking any kind of contraceptive the VFOM values were very high, this can mean that these participants are ovulating in the expected window.

We also had some results concerning participants that were taking contraceptive pills and had high VFOM values, which made us question about the effectiveness of some contraceptive pill. Some participants with none regular cycle and not taking any kind of contraceptive pill had low VFOM values, which mean that they either had the ovulation period outside of the expected window or did not had it at all.

Regarding the title question “Is there any correlation between voice and human ovulation?” we can conclude that some change in fundamental frequency during the menstrual cycle can be seen and correlated to which phase.

Further investigation will be needed to work on this hypothesis but it is clear that it is possible, in the future, to develop a mobile app that can make this analysis, identify the ovulation and, eventually, inform the participant if she is taking a pill that really blocks their ovulation, because when women start taking contraceptive pills, most times, no exams are done to establish which is the best pill for that specific person, so it is a process of trial and error. This is not enough, because each pill has a different hormone concentration, and the pill that a participant is taking may not have the necessary concentration to effectively and totally block the ovulation.

This being so, development of this project has shown that, yes, voice and ovulation can be related, and the development of an app in the future could be used not only to detect ovulation, but to identify if we are taking the right contraceptive pill. With this result, in the future, more studies are needed to verify the contraceptive effectiveness so that women are not taking unnecessary hormone concentrations.

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Appendices

Article

Is there any correlation between voice and human ovulation? A systematic review

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Abstract

Introduction: Knowing the time of ovulation can help to improve fertility rates rates and unwanted pregnancy prevention. Studies suggest that there is a correlation between pitch of voice and ovulation in women, being able to use that information would be a very simple and hygienic way to detect ovulation.

Objective: The goal is to review the literature on the correlation of voice characteristics and ovulation, discussing the best practices and recommendations for future studies and developments in this field.

Methods: An extensive search for methodological papers on the correlation between voice and ovulation was performed. This procedure was

supplemented by scientific papers that correlate ovulation to other parameters of women behavior during the ovulation cycle. In addition, a detailed analysis of the methods developed, and the conclusions reached in the studies that specifically focus on the correlation between human voice and ovulation were performed.

Results: In a screening of the literature 814 papers were found. Of these, only 4 focused on the correlation between voice changes and ovulation. Those 4 papers were meticulously analyzed, 12 were added for a deeper understanding on the influence of ovulation in a woman's behavior, and 6 were researched to allow a thorough understanding of the analysis of voice parameters and its changes during the life of an individual.

Discussion: There are only a few studies related to this field and more studies are needed to develop a method that uses this information in order to help women identifying their ovulation and fertile window. Nevertheless, participants are often skeptic about this discovery, so more studies must be made to confirm this relation between voice changes and ovulation, and to devise a method that can be both simple and hygienic that would constitute a breakthrough in fertility efforts.

Conclusions: Research shows that new cost reducing methods can be implemented to help a woman find her fertile time window. Although more expensive methods that rely on hormone detection are more exact, it is commonly enough to provide an approximate estimative on the fertile windows and research suggests that this can be done by the analysis of several parameters that can be found in the voice of the individual.

Keywords: Ovulation, fertile window, voice, fertility, menstrual cycle.

1. Introduction

An understanding of human sexuality is very important for the evolutionary analysis of life history, behaviour and social organization. In the last two decades, the interest in researching women's behaviour during the menstrual cycle has increased [1].

The menstrual cycle is regulated by cyclic variations in ovarian hormones. The ovarian cycle is divided into two phases, the first (follicular phase) begins with the menstrual period and ends just prior to ovulation. The second (luteal phase) is the time from ovulation to the onset of menses. The principal hormones that regulate the menstrual cycle are oestrogen and progesterone. Oestrogen reaches its highest level just before ovulation and menstruation, the progesterone level is increased after ovulation and, like oestrogen, reaches its highest level just before menstruation. The oestrogen concentration reaches its apex on the 21st day of the menstrual cycle in the typical 28-day cycle [2].

Recent research studies documented a variety of ovulatory cues in humans that indicate visual and olfactory parameters might provide subtle clues that show if women are at the fertile phase of the cycle, which are potentially detected by men, although mostly in a subconscious way. In relation to visual cues, soft tissue asymmetry is lowest around the time of ovulation [3], while female facial attractiveness significantly increases during the fertile phase of the cycle [4][5].

In addition, research claims that women dress more attractively and provocatively [6] during their fertile period and that they are more likely to spend more money on beauty products [7][8][9]. In relation to olfactory cues, there are a number of studies that have found that men are more attracted to the scents of women during their fertile period than out of it [10][11][12]. For example, female lap dancers receive significantly higher tips during the fertile phase of their cycle, compared with the luteal phase

[13], suggesting that a combination of factors including scent, appearance and possibly movement patterns may change in relation to cycle phase [6].

Moreover, the physiological effect of the menstrual cycle is liable to infer changes on the individual across the menstrual cycle as sex hormone receptors were found in other tissues [14]. Researchers are not only studying olfactory and visual changes during the cycle but also explore changes in women's voice. In fact, the human voice provides information about individual characteristics such as body size, age, health status and emotional state [15]. In line with this findings, studies have shown evidence that female voice changes across the menstrual cycle suggesting that it plays an important role in mate selection [16][17].

The larynx is one of the organs that is influenced by hormones. Voice alterations are well known during sexual maturation, and disorders that occur in some endocrine diseases of the hypophysis, thyroid gland, adrenal glands, testicles and ovaries. Other studies claim that these disorders can also be seen during menstruation, pregnancy and menopause. In some opera performer's contracts, they allow the performer to refrain from singing during the premenstrual period, because voice complaints are usually not psychogenic or anxiety-induced [18][19].

The vocal fold mucosa contains specific receptors for sex hormones, therefore, sex hormones, such as oestrogen and progesterone, have a great impact on voice affecting female vocal fold histology and laryngeal function. Laryngeal changes in females are evident throughout life starting at puberty, fluctuating systemically during the reproductive years with the menstrual cycle and changing again with decline of hormonal activity at menopause. Menstruation, pregnancy, and menopause affect variations in female vocal production and they all coincide with marked hormonal changes [17][20]. So, if the hormones in the menstrual cycle change, the voice will have cyclic changes as well.

During the peak of oestrogen, the laryngeal mucous membrane becomes thicker and increases mucus excretion, and in the luteal phase, the mucous membrane dries out and thickens [21]. These changes change the quality of the voice and should cause the female voice to be more attractive at the time of fertility to facilitate the likelihood of sexual intercourse. This voice change that occurs during premenstrual period is part of the set of adverse symptoms reported by women during the menstrual cycle known as Premenstrual syndrome (PMS). It begins at 1-2 weeks before the onset of menstruation and subside with its onset. One third of women has described it as a set of characteristics including loss of vocal power, decreased vocal range and flexibility, vocal fatigue, loss of harmonics, and reduction of overall quality [11] [12]. This is an effect of ovarian hormonal concentration variations.

The detection of the fertile days is usually done from measuring basal body temperature (BBT), urinary stick system for Luteinizing Hormone (LH) surge, and serum progesterone measurements in the midluteal phase of by transvaginal ultrasound [22]. The measurements of BBT and urine tests can be purchased and done by the patient alone, but they are time consuming and the second one may also become unpractical and expensive if it is done for several cycles. Yet, the detection of fertile days from the analysis of voice is a non-invasive technique that could help women that want to conceive. A mobile app that performs this test could lower the number of visits at the doctors' consult and lower the costs of fertility diagnostic procedures.

The studies that support the correlation between the ovulation and the uniform characteristics of the voice are promising. It is relevant not only to determine and measure this correlation but also to determine disruptive technology-based solutions that may improve the knowledge and awareness on the ovulation cycle.

In this paper, a systematic review of the articles that specifically address uniform characteristics of the voice and ovulation correlation is provided, analysing and comparing their methods and results, to clearly establish the correlation between ovulation and voice. The goal of this research is to study the matter further and to find a practical use to these findings. The development of a mobile app, for example, with this information, where a woman can find out if she is ovulating or not, only by the analysis of her voice, would be an advance in the tactics used to detect ovulation, with the potential of helping millions of women around the world.

2.Methods

2.1. Research questions

The primary research questions of this review were (RQ1) What is already known about ovulation period identification by voice? (RQ2) How can we improve and make a good use of the identification of ovulation period by the analysis of voice records?

2.2. Inclusion criteria

The studies that were included in this review met the following criteria: (1) presented a relation between ovulation and voice change, (2) included data about the recording process, (3) were written in English. In this study, the participants had to be women that were not taking contraceptive pills and were ovulating normally.

2.3. Search strategy

To determine the state-of-art related to ovulation and voice relation, a research was conducted on the following databases: ACM Digital Library, Biology Letters, IEEE, NCBI-PMC.PubMed, Science Direct and Web of Science. Only the studies published from the year 2006 until October 6th, 2017 and met the inclusion criteria that were established for this study.

2.4. Extraction of study characteristics

The following data were extracted from the studies and tabulated (see Table 1): year of publication, population, devices, settings, database and the outcomes as presented in Table 2.

3.Results

The records identified through database searching counted 814 results. After duplicate removal 799 results remained, out of 764 titles and abstracts that were then screened to test eligibility, 50 full-text papers were eligible for inclusion. Thus, the full-text evaluation of these papers resulted in the exclusion of 46 records that did not match the defined criteria. Many of the excluded papers reported studies about other correlations to ovulation but not specifically voice. The selection procedure was based on the PRISMA statement which flowchart is presented in Figure 1.

Appendices

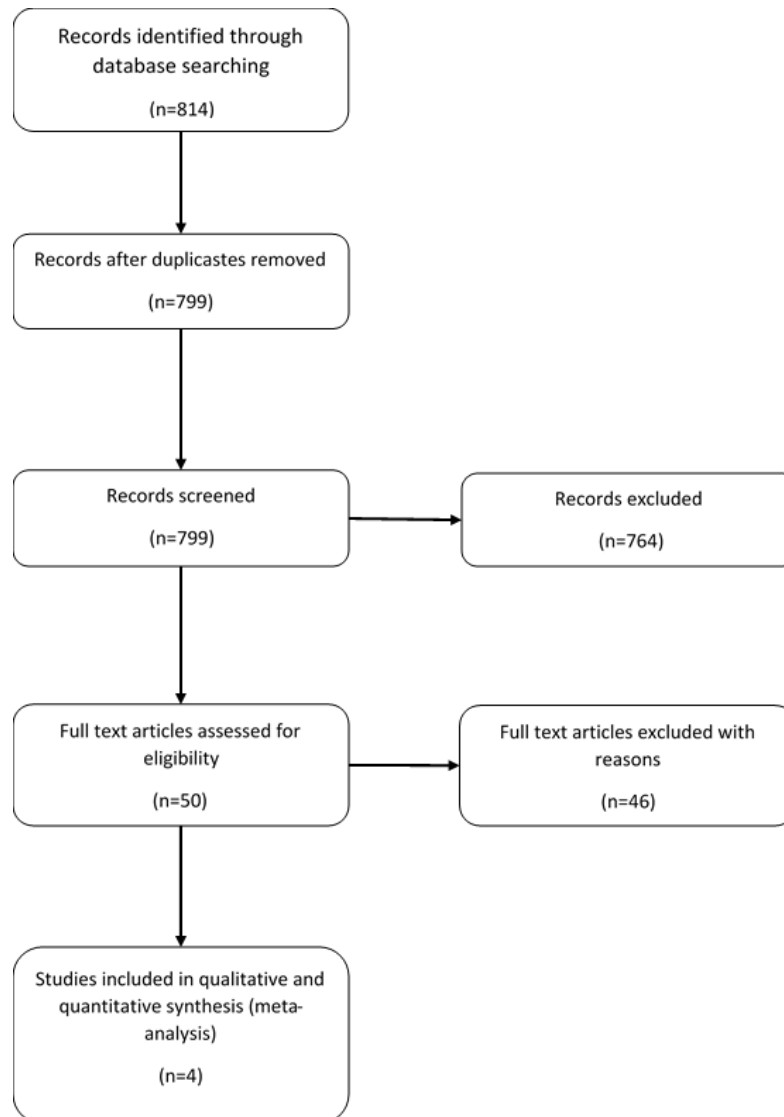


Figure 1 - Study workflow.

As shown below (in Table 1), all the included studies represent around 250 participants, but as we can see in the table, one of four studies published included in this review were published in 2017 and another one in 2011, while the other two studies were published in 2008. All of the included studies were classified as a descriptive study design.

Table 1 - Included Studies.

Author	Year of Publication	Population	Purpose of the study	Devices	Settings
Biology Letters					
Bryant [23]	2008	114 women	The authors proposed an analysis of vocal tracks in ovulation period	Digital recorder with a cardioid condenser microphone	Laboratory
Science Direct					
Pipitone [24]	2008	51 women	The authors investigated attractiveness ratings of female voices collected at different points of the menstrual cycle, to see if there are a correlation between those parameters.	Altec Lansing AHS515 headset, microphone, computer	Laboratory
Web of Science					
Fischer [25]	2011	33 women	The authors developed this study to gain further insights into the mechanisms underlying this variation in perceived attractiveness and the relationship between vocal quality and the timing of ovulation.	Desktop	Laboratory
NCBI - PMC/PubMed					
Banai [1]	2017	44 women	the purpose of this study was to investigate changes in sexually dimorphic vocal characteristics and quality of women's voices in different phases of the cycle and to compare these with users of monophasic hormonal contraception.	Not mentioned	Laboratory

Table 2 - Studies outcomes.

Author	Outcomes
Biology Letters	
Bryant (23)	The authors proposed an analysis of vocal tracks in ovulation period, they collected vocal samples from 69 normally ovulating women. In these samples they measured fundamental frequency, formant dispersion, jitter, shimmer, harmonics to- noise ratio and speech rate. Statistical analyses were run using SPSS-PC 15.0 generalized linear model repeated measures. women closer to ovulation within the fertile window showed greater differences between their high- and low-fertility vocal pitch.
Science Direct	
Pipitone [24]	The authors investigated ratings of female voice attractiveness as a function of menstrual cycle phase. They recorded women´s voices at four different times during their menstrual cycle. The samples were categorized from low to high conception risk based on menstrual cycle phase and empirical pregnancy data. Results showed a significant increase in voice attractiveness ratings as the risk of conception increased across the menstrual cycle in naturally cycling women. There was no effect for women using hormonal contraceptives.
Web of Science	
Fischer [25]	The authors combined hormone measurements and acoustic analyses, to characterize voice changes on a day-to-day basis throughout the menstrual cycle. Voice characteristics were measured from free speech as well as sustained vowels. In addition, they asked men to rate vocal attractiveness from selected samples. The free speech samples revealed marginally significant variation in F_0 with an increase prior to and a distinct drop during ovulation.
NCBI - PMC/PubMed	
Banai [1]	The authors wanted to analyse the vocal padrones in different phases of menstrual cycle, Voice recordings were obtained in the menstrual, late follicular and luteal phases. Natural cycle phases were identified by reverse counting method, with LH surge confirmation using LH test kits. Voice samples were analysed using <i>Praat</i> software. Results showed that voices of naturally cycling women had higher minimum pitch in the late follicular phase compared with the other phases, and the voice intensity was at its lowest in the luteal phase. In contrast, there were no voice changes across the cycle in hormonal contraceptive users.

By analysing all studies it could be seen that each of them used the same methodologic approach: they started by analysing the volunteers and asked them to answer to a survey about their smoking and drinking habits, age, height, weight, career (e.g., a singer), training or voice lessons, ovulatory cycle, birth control methods and health conditions that could affect the voice.

The volunteers were then divided into two groups, depending on the phase of menstrual cycle they were in. All studies collected data from women in birth control to compare the results. Each study used a method to detect and confirm the ovulation phase in the volunteers, the tests used were, luteinizing hormone test [1][23], urine analysis [25], and counting the days since the date of the last menstruation [24]. For the recording phase, in all of the studies, volunteers had pre-defined sentences they choose to record, or a composed phrase and a simple vowel to compare. The tests, for all studies, were made in a controlled environment, in a silent room, a high fidelity microphone, and doing rehearsals for recording. In all the cases, the data collected were analysed using software, in order to have quick results and easy reproduction of graphics for analysis.

Authors in [1] claim that it is possible to analyse the differences on the voice parameters in the low and high fertility phases, as there are significant changes: at the higher fertility phase, the frequencies rise when comparing to the low fertility phase.

The parameters analysed were:

- F0 - Fundamental Frequency - measured more frequently in Hertz (Hz), is the term used to refer to the physical parameter resulting from the vibration of the vocal chords per unit of time in sustained vocal behavior or in chained speech. It reflects the efficiency of the phonatory system, laryngeal biomechanics and its interaction with aerodynamics [26]. The

acoustic correlate of the perceived pitch is sexually dimorphic due to differential vocal fold development during puberty [23].

- F0SD - Standard deviation of the fundamental frequency
- F0min - Minimum values of fundamental frequency
- F0max - Maximum values of fundamental frequency
- HNR - Harmonics to noise ratio; a harmonicity object represents the degree of acoustic periodicity called as HNR, and it is expressed in decibels (dB). It is used as a measure for quality of the voice [27].
- SD - Standard deviation [26].
- DF - is the averaged distance between adjacent resonating frequencies (formants) and is also sexually dimorphic [23].
- Shimmer - Amplitude perturbation defined as the average absolute difference between the amplitudes of consecutive periods, divided by the average amplitude [27][28].
- Jitter - Frequency perturbation defined as the Cycle to Cycle variation of fundamental frequency, that is the average absolute difference between consecutive periods is called as jitter [27][28].

In Table 3 we can see the normative parameters for sound signals emission for children, women and men [29].

Table 3 - Normative parameters for sound signals emission. (adapted from [29]).

	Children	Women	Men
F ₀ (Hz)	206 - 281	177 - 244	100 - 137
Jitter (%)	0.909 - 5.158	<1	<1
Shimmer (%)	0.393 - 1.013	<3	<3
HNR (dB)	-	>7	>7

These studies also show that there are good results when women say a complex sentence, but the same does not happen when vowels are recorded. So with this information it can be concluded that vowels are not a good speech reference for this kind of analysis, and that for further studies, the choice of what is recorded by the volunteers is very important [24],[30].

After analysing the data collected, all the researched papers reach the same conclusions, that when speaking a sentence, women's vocal pitch was higher in the high fertility phase as compared to low fertility phase voice pitch, these differences being more pronounced on the 2 days preceding ovulation, when the probability to conceive is the highest [1][24]. On the study of voice attractiveness researchers concluded that vocal attractiveness was only found for females who were naturally cycling and there were no menstrual cycle effects on voice attractiveness ratings for those taking hormonal contraceptives, [23].

4. Discussion

Previous studies have shown that there are changes in women's behaviour and physical appearance in the non-fertile and fertile phases of the menstrual cycle. It is assumed that these changes are regulated by fluctuations in sex hormone levels across the cycle, as receptors for sex hormones have been found on the vocal folds, therefore suggesting a link between hormone levels and vocal fold function, which in turn will likely cause changes in voice production [1].

The analysis and comparison of these studies show some aspects that can be improved. It appears that the use hormone and urine tests to confirm the ovulation can be replaced by voice tests, that although not being able to provide immediate results and being less precise, are easily deployable and can be implemented in a non-intrusive manner. Having the right

information, the woman just needs to count the days approximately for the ovulation after the last menstruation. With that information, the woman's fertile window can be found and the change in vocal peak assessed in those days. Nevertheless, this approach needs to be tested and validated in a real field trial.

However, attempts to identify changes in voice production across the menstrual cycle have produced mixed results, that can be explained by different materials and programs used or different conditions of recording. But overall, they confirm earlier findings that say that women's voice exhibit with a higher and more variable fundamental frequency just prior to ovulation.

5. Conclusions and future directions

This systematic literature review has synthesized and summarized the studies that analysed the correlation between voice and ovulation. Four studies were examined and the main findings are summarized below:

- (RQ1) What is already known about ovulation detection by voice?

The previous studies have already found that there are changes in voice during fertile time window, in these for studies they all reach the same conclusions, that these changes are only visible when women spoke a sentence and not just a monotone. They all concluded that voice frequency gets higher near the ovulation phase.

- (RQ2) How can we improve and make a good use of the detection of ovulation by voice records?

The analysis of these articles leads to the conclusion that there is a need to further study this phenomenon to confirm these observations, and to analyse the costs of such test. There is a possibility to use these findings on

a mobile application that can be made available through the applications stores, allowing fertility information to be easily accessible to a wider population.

Acknowledgments

This work was supported by FCT project PEst- OE/EEI/L A0008/2013 (Este trabalho foi suportado pelo projecto FCT PEst-OE/EEI/LA0008/2013).

The authors would also like to acknowledge the contribution of the COST Actions IC1303 - AAPELE - Architectures, Algorithms and Protocols for Enhanced Living Environments, and CA16226 SHELD-ON Indoor living space improvement: Smart Habitat for the Elderly.

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Matlab Code

```
“  
data=importdata('FileP1.xlsx');  
a=length(data.data);  
data= data.data(14:a,1);  
Fs=48000; %Hz  
T=1/48000;  
data(data>129) = 128;  
data(data<-128)=-128;  
  
ydft = fft(data);  
freq = Fs*(0:(length(data)/2))/length(data);  
ydft = ydft(1:length(data)/2+1);  
[b0,a0] = butter(2,400/(Fs/2));  
ydft = filter(b0,a0,ydft);  
  
ynew1=ydft(freq>=140 & freq<=300);  
fnew1 = freq(freq>=140 & freq<=300);  
[maxval,idx] = max(abs(ynew1));  
fprintf( 'Complex cepstrum F0 estimate is %3.2f Hz.\n',fnew1(idx))  
“
```