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Abstract

Stability of athletic performance is important for practitioners and coaches, since it allows the selection of appropriate training methods and prediction of ages for best results. We performed a longitudinal study of 1694 season-best performances of 242 elite-standard swimmers throughout their careers, from 12 to 18 years of age. Mean stability (descriptive statistics and one-way repeated-measures ANOVA, followed by a Bonferroni *post-hoc* test) and normative stability (Cohen's kappa tracking index and the Pearson correlation coefficient) were determined for seven consecutive seasons. Performance improvements in all events were observed (14.36–18.97%). Bonferroni *post-hoc* tests verified changes in almost all events assessed. Cohen's kappa demonstrated low stability (0.17–0.27) in relative performance. Pearson correlations only became high from 15 to 16 years in the 50-m and 100-m events, and from 16 to 17 years in the 200-m, 400-m, and 1500-m events. Our results show that: (a) swimmers should display a substantial improvement (14–19%) to become elite standard as adults, such as at 18 years; (b) 16 is the age at which the ability to predict adult performance increases markedly.

Keywords: *Longitudinal assessment, elite swimmers, stability, prediction*

Introduction

Stability of athletic performance helps researchers to predict the future success of talented young athletes and coaches to select appropriate training methods. Longitudinal studies are required to do this. In swimming science, few such studies exist but those that have been conducted have: (1) related models of training demand with performance enhancement (Hooper, Mackinnon, & Ginn, 1998; Mujika et al., 1995; Mujika, Padilla, & Pyne, 2002; Termin & Pendergast, 2000; Trinity, Pahnke, Sterkel, & Coyle, 2008); (2) analysed performance variability between competitions, during or between seasons (Costa et al., 2010a, 2010b; Hopkins, Pike, & Nottle, 2010; Issurin, Kaufman, Lustig, & Tenenbaum, 2008; Pyne, Trewin, & Hopkins, 2004; Stewart & Hopkins, 2000); and (3) related performance progression with ranking (Sokolovas, 2006; Trewin, Hopkins, & Pyne, 2004).

It has been suggested that performance assessments based on longitudinal designs are informative, since they allow (Costa et al., 2010b): (1) estimation of the progression and variability of performance during and between seasons; (2) identification of ages at which predictions of swimmers' performance improve; and (3) determination of the probability of swimmers reaching finals or winning medals in important competitions. For example, training intensity has been shown to be the key factor in elite swimmers' performance enhancement from season to season (Mujika et al., 1995; Termin & Pendergast, 2000; Trinity et al., 2008). Improvements of approximately 1% in a competition and within the year were necessary to stay in contention for a medal at the Sydney 2000 Olympic Games (Pyne et al., 2004). The third season of the 2004–2008 Olympic cycle was shown to be the time when performance stability increased strongly for Olympic Games performance (Costa et al., 2010b). However, factors that affect adults are different from those that affect children and can vary during swimmers' careers. For instance, aerobic capacity, maximal-intensity exercise, and skill acquisition are influenced by growth

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and development (Malina, 1994). Hence, there can be wide variation in the age when swimmers approach their maximal individual performance. To the best of our knowledge, there is little information about the prediction of ages for best results. Analysing the overall trends and individual trajectories of swimming performance for a decade, Hopkins et al. (2010) reported that the age for best performance of New Zealand swimmers was 18.9 ± 1.5 years and 18.7 ± 2.5 years for boys and girls, respectively. It is well known that at some point in a swimmer's career, the rate of performance improvement begins to reduce. For national-standard 100-m breaststrokers over seven consecutive seasons, age 16 was a milestone because performance stability increased strongly for adult-age outcomes (Costa et al., 2010a).

There is a lack of information on the stability and variation of freestyle swimming performance during an athlete's formative years, such as from childhood to adulthood. Thus, the purpose of the present study was to track and analyse freestyle performance during elite-standard swimmers' careers, from 12 to 18 years of age. It was hypothesized that there would be low-to-moderate performance stability in the early years, until a point at which the sensitivity of prediction of adult performance improved markedly.

Methods

Participants

Elite-standard Portuguese male swimmers were assessed in the present study. The inclusion criterion was to be among the top 50 Portuguese male swimmers for short-course performances during the 2006–2007 season in any of the freestyle events recognized internationally (i.e. 50-m, 100-m, 200-m, 400-m, 800-m, and 1500-m events). Exclusion criteria were: (1) a swimmer in the Portuguese top 50, but for whom the authors did not have access to season-best performances for some ages; (2) a swimmer from the Portuguese top 50 but had not swum the event at least once per season from 12 to 18 years; (3) a swimmer from the Portuguese top 50 but not at least 18 years old. In total, 242 elite-standard male swimmers were analysed.

Study design

Retrospective analyses of performance of elite-standard male swimmers over seven consecutive seasons were undertaken. Portugal's top 50 list of men in the 2006–2007 season was used to verify inclusion. Performance information was available from an open-access site (www.swimrankings.net). When suitable the Portuguese National Swimming Federation approved collection of the best official results between 12 and 18 years from each swimmer identified in the top 50. A total of 1694 best performances were analysed over the seven consecutive seasons.

Statistical analysis

The normality of the distributions was assessed with the Shapiro-Wilk test, with the null hypothesis that the population was normally distributed. For all events, data presented a normal distribution. Longitudinal assessment was conducted based on two approaches (Kowalski & Schneiderman, 1992): (1) mean stability and (2) normative stability. For mean stability, the mean $\pm$ one standard deviation and quartiles were determined for each chronological age and a given event. The relative frequency of performance variation (i.e. percentage of performance improvement) between consecutive ages and overall career improvement was also reported. Data variation was analysed with repeated-measures analysis of variance (ANOVA) followed by a *post-hoc* Bonferroni test. All assumptions (i.e. independence, normality, and homoscedasticity) to perform the ANOVA analysis were satisfied. Normative stability was investigated via Cohen's kappa (κ) $\pm$ standard deviation, with a confidence interval of 95% as proposed by Costa et al. (2010a, 2010b) and Bragada et al. (2010). Evaluation of κ values was according to Landis and Koch's (1977) suggestion, where stability is excellent if $\kappa \geq 0.75$, moderate if $0.40 \leq \kappa < 0.75$, and low if $\kappa < 0.40$. The Pearson correlation coefficient between paired performances throughout the seven chronological ages was also determined as another normative stability parameter. Here, stability was considered to be high if $r \geq 0.60$, moderate if $0.30 \leq r < 0.60$, and low if $r < 0.30$, as suggested by Malina (2001). These statistical procedures have been used previously in other domains, such as in health (Baumgartner & Roche, 1988; Casey et al., 1994) and physical activity (Glenmark, Hedberg, & Janson, 1994; Pate, Baranowski, Dowda, & Trost, 1996; Telama, Leskinen, & Yang, 1996), for longitudinal data analysis.

Effect sizes were computed based on the eta-squared (η^2) procedure, and values interpreted according to Ferguson (2009): no effect if $0 < \eta^2 \leq 0.04$; a minimum effect if $0.04 < \eta^2 \leq 0.25$; a moderate effect if $0.25 < \eta^2 \leq 0.64$; and a strong effect if $\eta^2 > 0.64$.

Statistical significance was set at $P \leq 0.05$. Thresholds for assigning qualitative terms to chance of a substantial improvement were as follows: < 0.5 %, most unlikely; 0.5–5%, very unlikely; 6–25%, unlikely; 26–75%, possible; 76–95%, likely; 96–99.5%, very likely; and >99.5%, most likely (Hopkins, 2007). All statistical procedures were performed using SPSS software (v.13.0, Apache Software Foundation, Chicago, IL, USA), except κ values that were determined with Longitudinal Data Analysis software (v.3.2, Dallas, USA).

Results

Figure 1 and Table I show a substantial performance improvement during the seven consecutive seasons in all the freestyle events. One-way repeated-measures ANOVA revealed meaningful variations in absolute performance in the 50-m freestyle event ($F_{1,35} = 769.88$; $P < 0.01$, $\eta^2 = 0.77$), 100-m freestyle event ($F_{1,43} = 3326.19$; $P < 0.01$, $\eta^2 = 0.73$), 200-m freestyle event ($F_{1,43} = 16272.81$; $P < 0.01$, $\eta^2 = 0.78$), 400-m freestyle event ($F_{1,44} = 76665.58$; $P < 0.01$, $\eta^2 = 0.75$), 800-m freestyle event ($F_{1,34} = 229702.67$; $P < 0.01$, $\eta^2 = 0.65$), and 1500-m freestyle event ($F_{1,90} = 678366.26$; $P < 0.01$, $\eta^2 = 0.69$). In addition, Bonferroni *post-hoc* tests showed notable differences ($P < 0.01$) between all ages in almost all events assessed. The exceptions were the pair-wise comparison between ages 17 and 18 years in all events and between 16 and 18 years in the 800-m and 1500-m events. The mean overall career improvement was between 14.36% for the 1500-m event and 18.97% for the

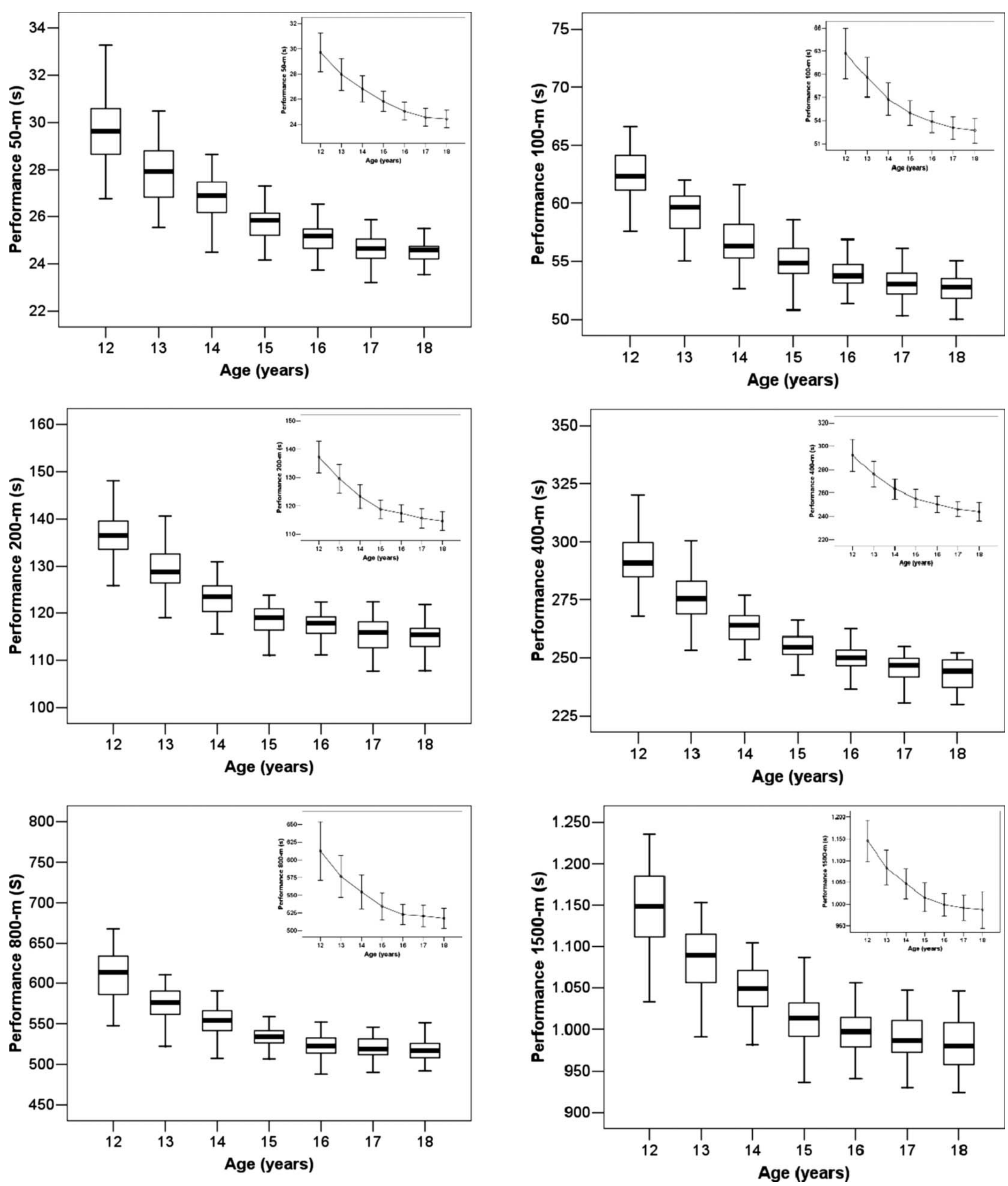

Figure 1. Variations in performance during swimmers' careers, from childhood to adulthood in the freestyle events.

Table I. Changes in performance (%) between chronological ages and for overall career in the time frame analysed.

	Between chronological ages (%)						Overall career (%)
	12–13	13–14	14–15	15–16	16–17	17–18	12–18
50 m	5.85 ± 2.66	4.01 ± 1.91	3.72 ± 2.25	2.97 ± 2.54	1.92 ± 1.91	0.51 ± 1.44	18.97 ± 4.90
100 m	4.89 ± 2.70	4.67 ± 1.96	3.13 ± 1.93	2.02 ± 1.72	1.50 ± 1.64	0.66 ± 1.59	16.86 ± 5.64
200 m	5.54 ± 2.23	4.76 ± 2.79	3.62 ± 2.17	1.19 ± 2.04	1.48 ± 2.63	0.83 ± 1.94	17.43 ± 4.53
400 m	5.47 ± 2.23	4.58 ± 2.38	3.09 ± 1.96	1.85 ± 2.60	1.70 ± 1.99	0.86 ± 2.25	17.54 ± 5.58
800 m	5.74 ± 3.24	3.72 ± 2.49	3.63 ± 2.37	2.08 ± 2.66	0.39 ± 2.20	0.56 ± 2.81	16.13 ± 7.11
1500 m	5.34 ± 2.69	3.35 ± 3.07	2.98 ± 2.57	1.55 ± 2.55	0.75 ± 2.46	0.40 ± 2.96	14.36 ± 5.13

50-m events. The greatest variation was showed to be in the 800-m event (16.13 ± 7.11%). The longer the event distance, the least the overall career improvement.

Table II presents relative performance stability based on the κ values, which express the likelihood of an individual to remain on a given performance trajectory. Stability was rather low for all the freestyle events analysed: 50 m event ($\kappa = 0.22 \pm 0.05$), 100 m ($\kappa = 0.27 \pm 0.05$), 200 m ($\kappa = 0.23 \pm 0.05$), 400 m ($\kappa = 0.17 \pm 0.05$), 800 m ($\kappa = 0.24 \pm 0.05$), and 1500 m ($\kappa = 0.17 \pm 0.05$). Thus, based on overall tracking values from childhood to adulthood, swimmers have a constantly changing performance trajectory. In this sense, a low relative performance stability during their careers should be considered.

Table III presents the correlation coefficients for pair-wise ages. Correlation coefficients were significant in most paired data ($P < 0.01$). From childhood to adulthood, correlations ranged from low ($r \leq 0.30$) to high ($r \geq 0.60$) stability. At younger ages there was lower performance stability when considering its progression to adulthood. However, higher stability in performance times seems to exist when more strict time frames are used. High stability is achieved from 15 to 16 years in the 50-m event ($r = 0.72$) and 100-m event ($r = 0.68$), and from 16 to 17 years in the 200-m event ($r = 0.78$), 400-m event ($r = 0.73$), and 1500-m event ($r = 0.70$). The only exception was in the 800-m event, where only moderate stability and prediction were observed.

Table II. Cohen's kappa and 95% confidence intervals in the freestyle events analysed.

Event	κ	95%CI
50 m	0.22 ± 0.05	0.17–0.27
100 m	0.27 ± 0.05	0.22–0.31
200 m	0.23 ± 0.05	0.18–0.27
400 m	0.17 ± 0.05	0.12 –0.22
800 m	0.24 ± 0.05	0.19–0.29
1500 m	0.17 ± 0.05	0.12–0.22

Discussion

The aim of this study was to track and analyse freestyle performance during elite-standard swimmers' careers, from 12 to 18 years of age. There was substantial performance improvement over the period analysed. Based on tracking values for overall career, relative swimming performance stability was low. Based on more strict time frames, the age of 16 is the chronological point at which the ability to predict adult performance increases markedly.

One-way repeated-measures ANOVA revealed meaningful variations in absolute performance throughout swimmers' careers. Bonferroni *post-hoc* tests confirmed notable improvements in all freestyle events. This same phenomenon has been reported previously in studies describing the individual trajectories (Hopkins et al., 2010) and performance stability (Costa el al., 2010a) of elite young to senior swimmers. Throughout children's formative years, a notable evolution in motor learning skills is observed (Mechsner, Kerzel, Knoblich, & Prinz, 2001). Maturation of the central nervous system enables acquisition of sport-specific tasks and tends to produce better results (Fogassi et al., 2005). The maturation process also results in an annual improvement in strength (Beunen & Malina, 1988) from childhood to adolescence. The greatest rate of increase for males occurs about 12–15 months after the appearance of peak height (Bloomfield, Blanksby, & Ackland, 1990). Available literature suggests that children can improve muscle strength and aerobic fitness through resistance training. Meta-analysis showed that typical gains in muscle strength were approximately 13–30% greater with resistance training than that which is expected from growth and maturation (Falk & Tenenbaum, 1996). In addition, specific aerobic training in swimming effectively increases such capacity above the limits attributed to the age corresponding to the specific period of growth (Baxter-Jones & Helms, 1993). Regarding physical development, multivariate model analysis has identified the anthropometric characteristics of

Table III. Pearson correlation coefficients throughout swimmers' careers in the freestyle events analysed.

50 m	12	13	14	15	16	17	**100 m**	12	13	14	15	16	17
13	0.84**	1					13	0.83**	1				
14	0.75**	0.90**	1				14	0.67**	0.87**	1			
15	0.62**	0.73**	0.81**	1			15	0.34*	0.56**	0.83**	1		
16	0.48**	0.48**	0.58**	0.61**	1		16	0.13	0.36*	0.61**	0.80**	1	
17	0.16	0.25	0.35*	0.33	0.74**	1	17	0.08	0,10	0.33*	0.57**	0.81**	1
18	0.31	0.26	0.32	0.28	0.75**	0.87**	18	−0.62	−0.23	0.16	0.37*	0.68**	0.84**

200 m	12	13	14	15	16	17	**400 m**	12	13	14	15	16	17
13	0.83**	1					13	0.86**	1				
14	0.51**	0.68**	1				14	0.53**	0.78**	1			
15	0.23	0.43**	0.75**	1			15	0.41**	0.57**	0.79**	1		
16	−0.08	0.18	0.47**	0.71**	1		16	−0.02	0.15	0.37*	0.57**	1	
17	−0.10	0.10	0.29	0.56**	0.56**	1	17	−0.08	−0.05	0.15	0.31*	0.72**	1
18	0.10	0.21	0.34*	0.54**	0.48**	0.78**	18	−0.06	−0.04	0.07	0.10	0.53**	0.73**

800 m	12	13	14	15	16	17	**1500 m**	12	13	14	15	16	17
13	0.87**	1					13	0.75**	1				
14	0.61**	0.86**	1				14	0.49**	0.59**	1			
15	0.54**	0.76**	0.80**	1			15	0.34*	0.34*	0.66**	1		
16	0.18	0.43*	0.59**	0.64**	1		16	0.01	0.05	0.43**	0.61**	1	
17	0.06	0.29	0.47**	0.51**	0.68**	1	17	0.04	0.09	0.37*	0.48**	0.62**	1
18	−0.12	−0.03	0.12	0.11	0.45**	0.48**	18	0.20	0.26	0.30	0.44**	0.49**	0.70**

$^{*}P < 0.05$, $^{**}P < 0.01$.

males to be the most suitable variables to predict performance in young swimmers (Saavedra & Escalante, 2010). At least two longitudinal studies reported that improvements in swimming performance during two consecutive seasons were mainly related to increases in physical determinants during growth (Latt, Jurimae, & Haljaste, 2009a). Thus in the future there is a good chance to assess hypothetical covariance between swimming performance and the growth/maturation process throughout athletes' formative development.

For a 95% confidence interval, the κ value (Table II), used to express relative performance stability, was low for all events analysed. Similar data ($\kappa = 0.38 \pm 0.05$) were reported for a 7-year time frame of 12–18 years in the 100-m breaststroke event (Costa et al., 2010a). Intra-individual changes suggested that swimmers were unable to maintain their relative individual positions within a performance trajectory during such a long time frame. Thus, from childhood to adulthood, swimmers have a constantly changing performance trajectory. Most US top 100 swimmers at ages 10–11 years did not become adult elite swimmers (Sokolovas, 2006). Often, early maturing athletes experience more early success than their late maturing peers due to a physical growth advantage rather than enhanced skills or abilities. On a regular basis, those athletes tend to have a higher more stable performance trajectory than later matures. However, at some point in their careers late matures often catch up to, or even exceed early maturers. Besides maturation and growth there are other factors that might impose low stability on a performance trajectory: (1) an acute or a chronic injury (Wolf, Ebinger, Lawler, & Britton, 2009); (2) illness (Hellard et al., 2011); (3) overtraining (Pelayo, Mujika, Sidney, & Chatard, 1996); (4) inappropriate training volume (Sokolovas, 2006); and (5) better support and training conditions. Thus future research should attempt to identify the influence of internal and external training loads on swimming performance from a child to adult/elite swimmer and how they determine an athlete's competitive standard at adult ages.

The correlation coefficients in Table III can be interpreted based on two different points of view: (1) diagonal perspective (e.g. analysing the correlations between chronological ages, one by one) and (2) horizontal perspective (e.g. considering the correlations between each chronological age and 18 years). On a diagonal interpretation, the correlation coefficients tend to be high when considered year by year. When more strict time frames are used, swimming performance stability and prediction increase (Costa et al., 2010b). For two consecutive seasons, high stability and prediction were observed in both young female swimmers (Latt et al., 2009b) and young male swimmers (Latt et al., 2009a) in the 400-m freestyle event.

On a horizontal perspective, the correlations coefficients between performances at 12 and 13 years and those at 16, 17, and 18 years presented a low-to-moderate value. A similar profile was observed from 12 to 18 years for 100-m breaststroke performance (Costa et al., 2010a). Malina (2001) reported that from childhood to adolescence the inter-correlations over a 3-year period are between 0.30 and 0.50 and the trend is to increase after adolescence. Moreover, the identification of talented performers is not possible before the peak growth period occurs (Blanksby, Bloomfield, Elliot, Ackland, & Morton, 1986). Usually the growth spurt is reached around the age of 14 years. Most of the pairwise correlations only became $r \geq 0.60$ at age 16 years. High stability is achieved from 15 to 16 years in the 50-m event and 100-m event, and from 16 to 17 years in the 200-m event, 400-m event, and 1500-m event. Thus it appears that there is no reliability in the prediction of adult performance based on athletes' best performances at earlier ages, such as 12–13 years. However, age 16 can be considered the age at which absolute performance stability increases and, therefore, the ability to predict swimmers' likely adult standard also increases.

When analysing individuals' mean career improvement (Table I), the mean percentage of improvement decreases as those individuals reach adulthood. For each season that passes by, swimmers get closer to their peak personal performance. The best performances are usually achieved during the final stage of an athlete's competitive career (Smith, 2003). For a New Zealand male swimmer, Hopkins et al. (2010) reported that the age for peak performance was 18.9 ± 1.5 years. Platonov (2005) also reported male swimmers' maximal individual performance to be between 18 and 19 years for short-distance specialists (50 m, 100 m, and 200 m) and between 17 and 18 years for long-distance specialists (400 m and 1500 m). For world-class swimmers, it has been reported that age 15–16 the age to achieve the best individual performance in long-distance events (Malina & Bouchard, 1991; Sokolovas, 1998).

A practical implication for practitioners (e.g. swimming coaches) is that early success should be avoided. Coaches must focus on educating swimmers based on growth and maturation cycles. For that purpose, they should help early maturing individuals keep their success in perspective, and ensure later maturing individuals are involved until the age of 16 years. Beginning at age 16, swimmers are close to their best personal performance and the prediction of adult competitive ability increases strongly.

In conclusion, swimmers should display a substantial improvement (14–19%) from childhood to adulthood in all freestyle events to become elite-standard adult swimmers, such as at age 18 years. In addition, coaches should set the age of 16 years as the age at which the ability to predict adult competitive level increases markedly.

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References

Baumgartner, R. N., & Roche, A. F. (1988). Tracking of fat pattern indices in childhood: The Melbourne Growth Study. *Human Biology*, *60*, 549–567.

Baxter-Jones, A. G., & Helms, P. (1993). The development of aerobic power in young athletes. *Journal of Applied Physiology*, *75*, 1160–1167.

Beunen, G., & Malina, M. (1988). Growth and physical performance relative to the timing of the adolescent spurt. In K. B. Pandolf (Ed.), *Exercise and sport sciences reviews* (Vol. 16, pp. 503–540). New York: Macmillan.

Blanksby, B. A., Bloomfield, J., Elliot, B. C., Ackland, T. R., & Morton, A. R. (1986). The anatomical and physiological characteristics of pre-adolescent males and females. *Australian Pediatric Journal*, *22*, 177–180.

Bloomfield, J., Blanksby, B., & Ackland, T. (1990). Morphological and physiological growth of competitive swimmers and non-competitors through adolescence. *Australian Journal of Science and Medicine in Sport*, *22*, 4–12.

Bragada, J. A., Santos, P. J., Maia, J. A., Colaço, P. J., Lopes, V. P., & Barbosa, T. M. (2010). Longitudinal study in 3000m male runners: Relationship between performance and selected physiological parameters. *Journal of Sports Science and Medicine*, *9*, 439–444.

Casey, V. A., Dwayer, J. T., Berkey, C. S., Bailey, S. M., Coleman, K. A., & Valadian, I. (1994). The distribution of body fat from childhood to adulthood in a longitudinal study population. *Annals of Human Biology*, *21*, 39–55.

Costa, M. J., Marinho, D. A., Reis, V. M., Silva, A. J., Bragada, J. A., & Barbosa, T. M. (2010a). Stability and prediction of 100-m breaststroke performance during the elite swimmer's career. In P. L. Kjendlie, R. K. Stallman, & J. Cabri (Eds.), *Proceedings of the XIth International Symposium on Biomechanics and Medicine in Swimming* (pp. 272–273). Oslo: Norwegian School of Sport Science.

Costa, M. J., Marinho, D. A., Reis, V. M., Silva, A. J., Marques, M. C., Bragada, J. A. et al. (2010b). Tracking the performance of world-ranked swimmers. *Journal of Sports Science and Medicine*, *9*, 411–417.

Falk, B., & Tenenbaum, G. (1996). The effectiveness of resistance training in children. *Sports Medicine*, *22*, 176–186.

Ferguson, C. J. (2009). An effect size primer: A guide for clinicians and researchers. *Professional Psychology*, *40*, 532–538.

Fogassi, L., Ferrari, P. F., Gesierich, B., Rozzi, S., Chersi, F., & Rizzolatti, G. (2005). Parietal lobe: From action organization to intention understanding. *Science*, *308*, 662–667.

Glenmark, B., Hedberg, G., & Janson, E. (1994). Prediction of physical activity level in adulthood by physical characteristics, physical performance and physical activity in adolescence: An 11-year follow-up study. *European Journal of Applied Physiology*, *69*, 530–538.

Hellard, P., Guimaraes, F., Avalos, M., Houel, N., Hausswirth, C., & Toussaint, J. F. (2011). Modeling the association between heart rate variability and illness in elite swimmers. *Medicine and Science in Sports and Exercise*, *43*, 1063–1070.

Hooper, S., Mackinnon, L., & Ginn, E. (1998). Effects of three tapering techniques on the performance, forces, and psychometric measures of competitive swimmers. *European Journal of Applied Physiology*, *78*, 258–263.

Hopkins, W. G. (2007). A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a *P* value. *Sportscience*, *11*, 16–20.

Hopkins, W. G., Pike, J. C., & Nottle, C. (2010). Overall trends and individual trajectories of swimming performance in a decade of New Zealand National Championships. In P. L. Kjendlie, R. K. Stallman, & J. Cabri (Eds.), *Proceedings of the XIth International Symposium on Biomechanics and Medicine in Swimming* (p. 72). Oslo: Norwegian School of Sport Science.

Issurin, V., Kaufman, L., Lustig, G., & Tenenbaum, G. (2008). Factors affecting peak performance in the swimming competition of the Athens Olympic Games. *Journal of Sports Medicine and Physical Fitness*, *48*, 1–8.

Kowalski, C. J., & Schneiderman, C. D. (1992). Tracking: Concepts, methods and tools. *International Journal of Anthropology*, *7*, 33–50.

Landis, J., & Koch, G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*, 159–174.

Latt, E., Jurimae, J., & Haljaste, K. T. (2009a). Longitudinal development of physical and performance parameters during biological maturation of young male swimmers. *Perceptual and Motor Skills*, *108*, 297–307.

Latt, E., Jurimae, J., Haljaste, K., Cicchella, A., Purge, P., & Jurimae, T. (2009b). Physical development and swimming performance during biological maturation in young female swimmers. *Collegium Antropologicum*, *33*, 117–122.

Malina, R. M. (1994). Physical growth and biological maturation of young athletes. In J. O. Holloszy (Ed.), *Exercise and sport sciences reviews* (Vol. 22, pp. 389–433). Baltimore, MD: Williams & Wilkins.

Malina, R. M. (2001). Adherence to physical activity from childhood to adulthood: A perspective from tracking studies. *Quest*, *53*, 346–355.

Malina, R. M., & Bouchard, C. (1991). *Growth, maturation and physical activity*. Champaign, IL: Human Kinetics.

Mechsner, F., Kerzel, D., Knoblich, G., & Prinz, W. (2001). Perceptual basis of bimanual coordination. *Nature*, *414*, 69–73.

Mujika, I., Chatard, J. C., Busso, T., Geyssant, A., Barale, F., & Lacoste, L. (1995). Effects of training on performance in competitive swimming. *Canadian Journal of Applied Physiology*, *20*, 395–406.

Mujika, I., Padilla, S., & Pyne, D. (2002). Swimming performance changes during the final 3 weeks of training leading to the Sydney 2000 Olympic Games. *International Journal of Sports Medicine*, *23*, 582–587.

Pate, R. R., Baranowski, T., Dowda, M., & Trost, S. G. (1996). Tracking of physical activity in young children. *Medicine and Science in Sports and Exercise*, *28*, 92–96.

Pelayo, P., Mujika, I., Sidney, M., & Chatard, J. C. (1996). Blood lactate recovery measurements, training, and performance during a 23-week period of competitive swimming. *European Journal of Applied Physiology and Occupational Physiology*, *74*, 107–113.

Platonov, V. (2005). *Sport training for high-level swimmers.* São Paulo: Phorte Editions.

Pyne, D., Trewin, C., & Hopkins, W. (2004). Progression and variability of competitive performance of Olympic swimmers. *Journal of Sports Sciences*, *22*, 613–620.

Saavedra, J. M., & Escalante, Y. (2010). A multivariate analysis of performance in young swimmers. *Pediatric Exercise Science*, *22*, 135–151.

Smith, D. J. (2003). A framework for understanding the training process leading to elite performance. *Sports Medicine*, *33*, 1103–1126.

Sokolovas, G. (1998). Biological maturation of swimmers. In KL Keskinen, PV Komi, AP Hollander (Eds.), *Proceedings of the VIIIth International Symposium on Biomechanics and Medicine in Swimming* (pp. 315–319). Finland.

Sokolovas, G. (2006). Analysis of USA swimming's all-time top 100 times. In J. P. Vilas-Boas, F. Alves, & A. Marques (Eds.), *Proceedings of the Xth International Symposium on Biomechanics and Medicine in Swimming* (pp. 315–317). Porto: University of Porto.

Stewart, A., & Hopkins, W. (2000). Consistency of swimming performance within and between competitions. *Medicine and Science in Sports and Exercise*, *32*, 997–1001.

Telama, R., Leskinen, E., & Yang, X. (1996). Stability of habitual physical activity and sport participation: A longitudinal tracking study. *Scandinavian Journal of Medicine and Science in Sports*, *6*, 371–378.

Termin, B., & Pendergast, D. (2000). Training using the stroke frequency–velocity relationship to combine biomechanical and metabolic paradigms. *Journal of Swimming Research*, *14*, 9–17.

Trewin, C. B., Hopkins, W. G., & Pyne, D. B. (2004). Relationship between world ranking and Olympic performance in swimmers. *Journal of Sports Sciences*, *22*, 339–345.

Trinity, J., Pahnke, M., Sterkel, J., & Coyle, E. (2008). Maximal power and performance during a swim taper. *International Journal of Sports Medicine*, *29*, 500–506.

Wolf, B. R., Ebinger, A. E., Lawler, M. P., & Britton, C. L. (2009). Injury patterns in Division I collegiate swimming. *American Journal of Sports Medicine*, *37*, 2037–2042.