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Title: Confirming the value of adolescent swimming performance models

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Abstract

Purpose: To evaluate the efficacy of existing performance models to assess the progression of male and female adolescent swimmers through a quantitative and qualitative mixed-methods approach. ***Methods:*** Fourteen published models were tested using retrospective data from an independent sample of Dutch junior national-level swimmers from when they were between 12 and 18 years of age (n=13). The degree of association by Pearson's correlations were compared between the calculated differences from the models and quadratic functions derived from the Dutch junior national qualifying times. Swimmers were grouped based on their differences from the models and compared with their swimming histories that were extracted from questionnaires and follow-up interviews. ***Results:*** Correlations of the deviations from both the models and quadratic functions derived from the Dutch qualifying times were all significant except for the 100 m breaststroke and butterfly and the 200 m freestyle female events *(p<0.05)*. Additionally, the 100 m freestyle and backstroke for males and 200 m freestyle male and female events were almost directly proportional. In general deviations from the models were accounted for by the swimmers' training histories. Higher levels of retrospective motivation appeared to be synonymous with higher-level career performance. ***Conclusion:*** This mixed-methods approach helped to confirm the validity of the models that were found to be applicable to adolescent swimmers at all levels, allowing coaches to track performance and set goals. The value of the models in being able to account for the expected performance gains during adolescence allows for peripheral factors that could affect performance to be quantified.

Keywords: target-setting, longitudinal, Mixed Linear Model, sub-elite, quadratic functions

Introduction

Advancements in measurement instruments, quantifiable performance indicators, [1,2] the availability of large public datasets and statistical tools [3-5] have precipitated the development of performance modelling in team and non-cgs (centimeter, grams and seconds) sports. [1,2] The expansion in the number of sport performance models therefore raises the question about their validity and practical value. Swimming is a sport at the forefront in the development of performance models, potentially because of the ease with which individual performances can be quantified. [6]

To date, most swimming performance models have focused on predicting future performance and talent identification using methods including neural models and networks, [4,7,8] repeated-measure ANOVAs [9] and mixed linear modelling. [10-12] Predictive models of performance are commonly assessed using cross or external validation. [4,7,13] However, to date there have been equivocal outcomes with some researchers reporting high levels of accuracy, [4,7] and others [13] suggesting that secondary factors, in addition to age and performance, would have been required to correctly predict 2012 Olympic champions.

Currently most sport performance models have mainly utilized data from elite-level athletes. Although intuitive to rely on this data to identify future talent, it is known that many of the super-elite, (defined as international representation and medal-winning) athletes were not selected through traditional talent identification programs. [14] Typically, the pathway to elite performance is known to be non-linear, with early selection not a requirement of future success, provided the athlete was involved in deliberate practice. [15,16] Researchers investigating talent identification acknowledge the need for a better understanding of numerous predictors, e.g. the idiosyncrasies of biological variability, the environment and these interactions, before talent identification tools are effective. [5,14] However, a consequence of the complex mathematical basis of the models is the obscurity in participants and coaches understanding the output. Since

super-elite athletes can arise from the adolescent sub-elite population, Dormehl et al. [11] & Dormehl et al. [12] pursued a novel approach to performance modelling. The focus was not on predicting future talent or performance but instead to provide coaches and swimmers with an intuitive, simple goal-setting and performance-tracking tool.

Therefore, the aim of this study was to evaluate the efficacy of the Junior Swim Performance models [11,12] (subsequently referred to as the JSP models), whilst employing a quantitative and qualitative mixed-methodological approach with an independent sample of national-level adolescent swimmers. The first sub-aim was to verify the suitability of the underlying dataset of sub-elite swimmers from which the JSP models were derived. This was achieved through a quantitative comparison with equivalent quadratic functions derived from another dataset, the Dutch junior national qualifying times in The Netherlands, [17] known as Dutch limits (DL). Additionally, the JSP models were considered in relation to the Allen et al. [10] models, since their models were developed using similar statistical methods in the same sport. The second sub-aim was to evaluate the applicability of the JSP models as target-setting and performance-tracking tools. This was implemented by means of a qualitative evaluation into the possible causes for deviations from the modelled progression in performance as predicted by the JSP models.

Methods

Participant information

The inclusion criteria were that all identified swimmers had to have qualified to participate in one or more of the Dutch Junior National Championships (DJNC) since 2003 and had swum competively for at least 5 years. Following discussions with the head swimming coaches at regional talent centers in The Netherlands, these criteria identified a total of 14 potential participants (7 females and 7 males) for inclusion in the study. Of the 14 potential

athletes one declined to participate due to illness. The study was approved by the institutional ethics committee and conformed to the recommendations of the Declaration of Helsinki. All potential participants were sent an email with a cover letter and an information sheet detailing the purpose of the project. Participants were informed that their identities would be kept confidential and given the option to withdraw at any time. Swimmers who agreed to participate and who returned written consent or assent and parental consent (in cases where the participants were under 18 years), were sent an online questionnaire to complete and invited to attend a follow-up interview. Therefore, a total of 13 club swimmers (7 females and 6 males) ranging in age from 17 to 24 years (18.69 ± 2.12 years, mean ± SD) agreed to participate in the study. Two of the 13 swimmers had represented their country at junior international level.

Data collection

Swimming histories

A retrospective questionnaire designed to elicit information on participants' swimming history during childhood and adolescence was utilized. The questionnaire was compiled in line with the proposed methods of Côté, Ericsson, Law [18], since it relied on the accurate recollection of past events and experiences over many years. The questionnaire was first piloted and translated into Dutch using a translation-back-translation process. [19]

The questionnaire, which was completed on-line, was split into three sections and designed to be completed within 20 to 30 minutes. The first section enquired about defining moments in the swimmers' careers including: when they started swimming, in which stroke, when they participated in their first swimming competition and when they qualified for the DJNC. The second section required a chronological account of their progression in swimming from 12 to 18 years, or to their current age for those participants who were younger than 18 years old. The section covered topics including which club(s) swimmers belonged to, the total

number of swim-specific and land training hours completed per week, average mileage covered per week and the swimmers' main competitive strokes and distances. Swimmers were required to provide a response to each item for every season from age 12 years, up to their current season or to a maximum of 18 years. The final section of the questionnaire recorded information regarding potential factors that influenced (positively or negatively) the swimmers' participation in the sport. The topics investigated included: injury history, long-term breaks from training and competition (3 or more months), levels of motivation and focus, the age at which swimmers believed they stopped growing in height and finally whether they experienced any desire to cease competing in the sport.

Reliability of the information collected in the questionnaires was obtained using a test-retest approach in the form of a follow-up interview that was designed to triangulate the information provided as part of the original questionnaire. [18] Quantifiable information provided by the participants was independently verified by their current coach and against Swimrankings [20] and any potential discrepancies were highlighted prior to interview. In addition to cross checking discordant information, the interviews also aimed to identify which factors swimmers perceived to be influential to their performance and required swimmers to recall the highlights of their competitive careers. Additionally, participants were asked to rank their enjoyment and motivation on a 10-point scale by sketching a plot for each factor from when they were 12 years of age, up to their current season or to a maximum of 18 years of age. Because enjoyment and motivation are known to be difficult to recall and quantify, [18] participants were allowed to review their plots at any point during the interview. The individual interviews followed a semi-structured format and were conducted in the first language of the participant (Dutch or English) by the same bilingual independent interviewer who had prior experience of qualitative research methods. Interviews were conducted within 3 weeks of completing the questionnaire and took between 30 and 60 minutes. An audio recording of each interview was made and the majority

were conducted at the club at which the swimmers trained, prior to or following one of their training sessions. Two participants were interviewed over the telephone due to their involvement in residential national training programs.

Performance times

Season's best (short course) performance times, achieved between the ages of 12 and 18 years, for the 13 participants were downloaded from SwimRankings (www.swimrankings.net). Additionally, using a similar approach to illustrate the fit of previously published models, [10] the seasons' best performance data of the Olympic medalists, Ryan Lochte and Katie Ledecky were downloaded from the USA Swimming website (www.usaswimming.org).

The swimmers' performances were compared with the models of sub-elite adolescent swimmers derived by Dormehl et al. [11] and Dormehl et al. [12]. Additionally, the swimmers' times were compared against quadratic functions derived from the DL for 12 to 18 year olds for the 2016 season that were obtained from the Koninklijke Nederlandse Zwembond [17]. In the Netherlands, there are no qualifying times for the 50 m freestyle event and females are only eligible to compete in the DJNC between the ages of 12 and 16 years whereas boys are only eligible between the ages of 13 and 18 years.

Data analysis:

Performance times

The quadratic functions, in the form $y = ax^2 + bx + c$, where y = percent change in performance time and $x + 12$ = age in years, for the DL [17] were derived for each sex and event separately using a second order polynomial regression analysis.

Gradients of improvement for consecutive pairs of swimmers' seasons' best performances were calculated separately for each event as (Eq. 1),

$$\textit{gradient of improvement }_{swimmer} = \frac{I_{n+1}-I_n}{age_{n+1}-age_n} \qquad\qquad \text{Eq. 1}$$

where "*I*" is the percentage improvement in performance from the baseline age of 12 years, '*age*' is the swimmers' age at the time of achieving the seasons' best time measured in years and "*n*" represents the season number.

Where a swimmer failed to post a season's best time for two or more consecutive years, no gradient was calculated for that period of time. *Gradients of improvement* $_{JSP}$ and *gradients of improvement* $_{DL}$ were calculated using the JSP models and the DL quadratic functions (Table 1) respectively using the corresponding values from each equation over the same $age_{n+1} - age_n$ range as was used in the calculation of *gradient of improvement* $_{swimmer}$ above (Eq.1). Since it is easier to interpret deviations from a straight line than a curve, percent relative difference from the model was calculated for each event and sex separately (Eq. 2):

$$\frac{\textit{gradient of improvement }_{JSP} - \textit{gradient of improvement }_{swimmer}}{\textit{gradient of improvement }_{JSP}} \times 100. \qquad \text{Eq. 2}$$

Percent relative improvements from the DL quadratic functions were calculated in the same way. For each event a simple linear regression was derived from plotting the relative improvements from the JSP models against the corresponding relative improvements from the DL quadratic functions. Pearson's correlation coefficients squared were also determined. All analyses were conducted using SPSS version 22.

Swimming histories

The swimming histories of all participants were assigned to one of three distinct groups, namely "descenders", "variable" or "ascenders". The groupings were based on compliance to two criteria of their percent relative improvement in their two main events each season from the JSP models. The criteria used for assigning swimmers to their respective groups included: (1) the overall gradient in the percent relative improvement across all seasons (i.e. negative =

descenders; positive = ascenders; fluctuating = variable); and (2) the number of occasions the percent relative improvement traversed the model line (i.e. once = ascenders/descenders; twice = variable).

The quantitative data from the questionnaires from each group was summed and calculated as a percentage of the number of swimmers for each item in each group. The timing of attainment of estimated adult height was estimated as 15 to 16 years (females) and 18 to 19 years (males) of age, where mean growth slows to less than 1 cm per year according to the growth curves of Roelants, Hauspie, Hoppenbrouwers [21]. The mean and standard deviations for the enjoyment and motivation scores, and the corresponding percent relative improvement for each group were also calculated.

Results

Quadratic functions from the DLs

In order for direct comparisons to be made, non-linear regressions using data from the DLs, with the same *x* and *y*-axes as those of the JSP models, were derived. The DL functions are shown in Table 1.

Quantitative comparison between the JSP models and the DL quadratic functions

As illustrated in Figure 1, all the DL quadratic functions would generally require a swimmer with the same baseline time to improve at a higher rate than the JSP models. The incremental improvement between seasons, relative to the equivalent modelled improvement, rather than their proximity to the modelled lines, confirm that both Katie Ledecky and Ryan Lochte progressed at rates more similar to those of the JSP models than the DL quadratic functions (Figure 1).

For every event, the percent relative improvement of the Dutch swimmers from each JSP model were compared directly with their corresponding percent relative improvement from

the DL quadratic functions using Pearson's correlations (Table 2). The linear regressions for four events (100 m freestyle males, 200 m freestyle males and females, 100 m backstroke males) were almost directly proportional, i.e., $y=x$. The gradients for the linear relationships for every event were more shallow than $y=x$. Since all the relationships also had negative y-intercepts, there is a small window where a swimmer who slightly outperformed the JSP models would underperform the DL quadratic functions (bottom left zone in Figure 2). Most notable was that this group of swimmers were all young (less than 13.5 years of age in the 100 m freestyle, Figure 2). This indicates that the JSP models are less constraining on younger swimmers than the DL quadratic functions. Interestingly, the small number of swimmers who fell above $y=x$ thresholds were always at the older end of the age range and this in turn, suggests that the JSP models are more constraining than the DL quadratic functions for older adolescents.

The lowest coefficients of determination were found in the 200 m freestyle and 100 m butterfly and breaststroke events for females (Table 2). The threshold age of peak performance for the DL quadratic functions for these events occurred before the cut-off age of 16 years, however the JSP models peaked later. This means that after the threshold age of these quadratic functions an anomalous negative improvement in a swimmer's performance would be predicted while the JSP models still predicted positive improvement.

Qualitative analysis of the performance deviations of the JSP models

The data was normalized by calculating the differences in the relative improvement of the Dutch swimmers off their predicted improvement from the JSP models, effectively flattening the JSP models to the x-axis. Assigning the swimmers to one of three groups ('descenders', 'variable' or 'ascenders'), based on their deviations from the x-axis allowed general patterns to be revealed (Figure 3). Although some of the 'ascenders' displayed

variability from their predicted progression, unlike the 'variable' group, the inconsistencies in their performances remained above the predicted improvement determined from the JSP models. Motivation and enjoyment tended to follow the same trend as the deviations from their predicted performances for 'descenders', however in the 'variable' and 'ascenders' groups, motivation appeared to remain high following dips in their improvement relative to the JSP modelled line. Decreases in enjoyment tended to precede dips in their improvement relative to the JSP modelled line for the 'variable' group, but remained consistently high and stable for swimmers in the 'ascenders' group (Figure 3).

One of the most noticeable patterns in the swimming histories of the Dutch swimmers were that the 'ascenders' tended to increase the volume of their training and become more focused and motivated later in their careers compared with 'descenders' (Table 3). There were no obvious patterns in the club or coach switching, stroke or distance switching or breaks in training for any group, but case histories did align with deviations from the predicted models for those individual swimmers.

Discussion

The purpose of validating pre-existing performance models for adolescent swimmers was accomplished in this study. A current shortcoming in the development of models is that few are empirically evaluated. [4,7] The models of Dormehl et al. [11] & Dormehl et al. [12] therefore utilized an innovative model-evaluation procedure using a quantitative and qualitative mixed-methodology. The outcomes of this study included the advancement in the appraisal of model development, as well as highlighting a broader applicability of the JSP models in being able to quantify performance gains in adolescent swimmers of all standards.

In an effort to consider the placement and shape of the trajectories of the JSP models, they could be analyzed alongside other similar trajectories that also show the progression of

swimming performance with age. In this study, the Allen et al. [10] models and DL quadratic functions were selected for this purpose. The *y*-axis reference for all swimmers' performance times in the Allen et al. [10] models have the same stationary endpoint, i.e., the 2012 Olympic gold medal times, whereas the *y*-axis references for both the JSP models and the DL quadratic functions were determined from a swimmer's unique baseline time. Since it was not feasible to re-plot the Allen et al. [10] models using the same *y*-axis reference, a direct comparison with their models is not possible. However, the same two international swimmers used in exemplar plots by Allen et al. [10] are shown in Figure 1. The different approaches to the *y*-axis reference highlights a difference in purpose of the Allen compared with the JSP models. Models that use a dynamic *y*-axis reference enable customized starting points for all adolescent swimmers of any standard from elite level (Figure 1) to novice. Young, inexperienced swimmers would fall far from the fixed points of the Allen et al. [10] models to be considered for selection, but these models [10] do identify a window of peak performance in elite-level swimmers upon reaching adulthood.

The DL are derived from a system known as the MSS (Multi-year selection system) that is based on the annual top 16 performances at the preceding years European Championships. [22] The qualifying times are therefore based on a large sample of international elite level swimmers and revised and published annually for use as thresholds for national competition selection criteria in The Netherlands. However, the unconventional, but creative use of the 2016 DL data as quadratic functions, plotted using the same axes as the JSP models, has provided a direct comparison of two datasets; a sub-elite sample (JSP models) and a junior-elite level sample (DL). From the comparisons made using the same independent Dutch swimmers (Table 2, Figure 2) it would appear that the DL quadratic functions, like many TID programs, promote the identification of talent at a younger age (i.e. they tend to favor early maturers) and hence risk de-selecting swimmers who may yet develop later on, a well-known

concern among talent selectors. [13,23,24] In contrast, the JSP models plot the progression of mean expected performance improvement and these trajectories seem not to preclude late developers. There were however four events, namely the 100 m freestyle and backstroke for males, as well as the 200 m freestyle for males and females, where the JSP models and the DL quadratic functions were almost in total agreement. Nevertheless, the JSP models are not intended to be used as team selection tools, since the large population of swimmers that would be included would be unrealistic and thus beyond the means of most regional talent centers. [25] Interestingly, Dormehl et al. [12] commented that cross-validation identified the 100 m freestyle (female) model had the poorest fit, but this event showed a fairly linear relationship against the DL functions (Figure 2, Table 2).

An important and novel addition to this study was the use of qualitative data to evaluate the JSP models as performance-tracking tools by exploring the deviations of the Dutch swimmers' performances from their predicted progressions. Importantly, the JSP models correctly identified the swimmers who ultimately became junior elite-level swimmers as those consistently outperforming their predicted performance progression (Figure 3). Furthermore, the models also identified swimmers who only qualified to compete nationally at a young age, as those who progressively fell further below their predicted performance (Figure 3). Additionally, deviations observed for this sample were explained by, and appear to be associated with, historical swimming-related events uncovered in the questionnaires and follow-up interviews (Figure 3, Table 3). Although the addition of these factors as further predictors to the JSP mixed-linear models could be considered, this would defeat their purpose as broad, interpretable goal-setting tools devoid of the multiple confounding variables.

It has also been reported that swimmers maintain their motivation to train and compete by regularly surpassing their personal best times [26] and that effort remains a precursor to success. [27] A similar phenomenon was confirmed for all the Dutch swimmers but it was evident

that a previous above-average season only temporarily sustained motivation during a below-average season (Figure 3).

Practical applications

The JSP models have been verified as an objective tool to track the performance of adolescent swimmers, where performance gains due to external factors can be quantified beyond those predicted to occur during adolescence. Additionally, their accessibility to junior swimmers at all levels allows coaches to set realistic goals, as well as identify early and late maturers. Since each event is modelled separately, it would also be possible to identify in which strokes swimmers are making the most progress and could thus aid in the process of stroke and distance specialization. However, caution is required in using these models for talent identification, since it is not only a swimmer's progression in comparison with the model, but also their absolute baseline performance time that need consideration.

Conclusions

In this study, a novel application of both qualitative and quantitative methods was used to validate the JSP models, thus confirming their validity and applicability. It is anticipated that, through further application of these models in a broad range of settings, more supporting evidence will be discovered.

These models are as applicable to junior elite-level athletes as they are to non-elite swimmers. It is reassuring that with the use of flexible baseline performance times, the expected progression in performance of all adolescents of both sexes and in all strokes, is measurable. With the possibility to exclude the expected gains in performance during adolescence, the peripheral factors that will always affect performance can be further quantified.

Acknowledgements

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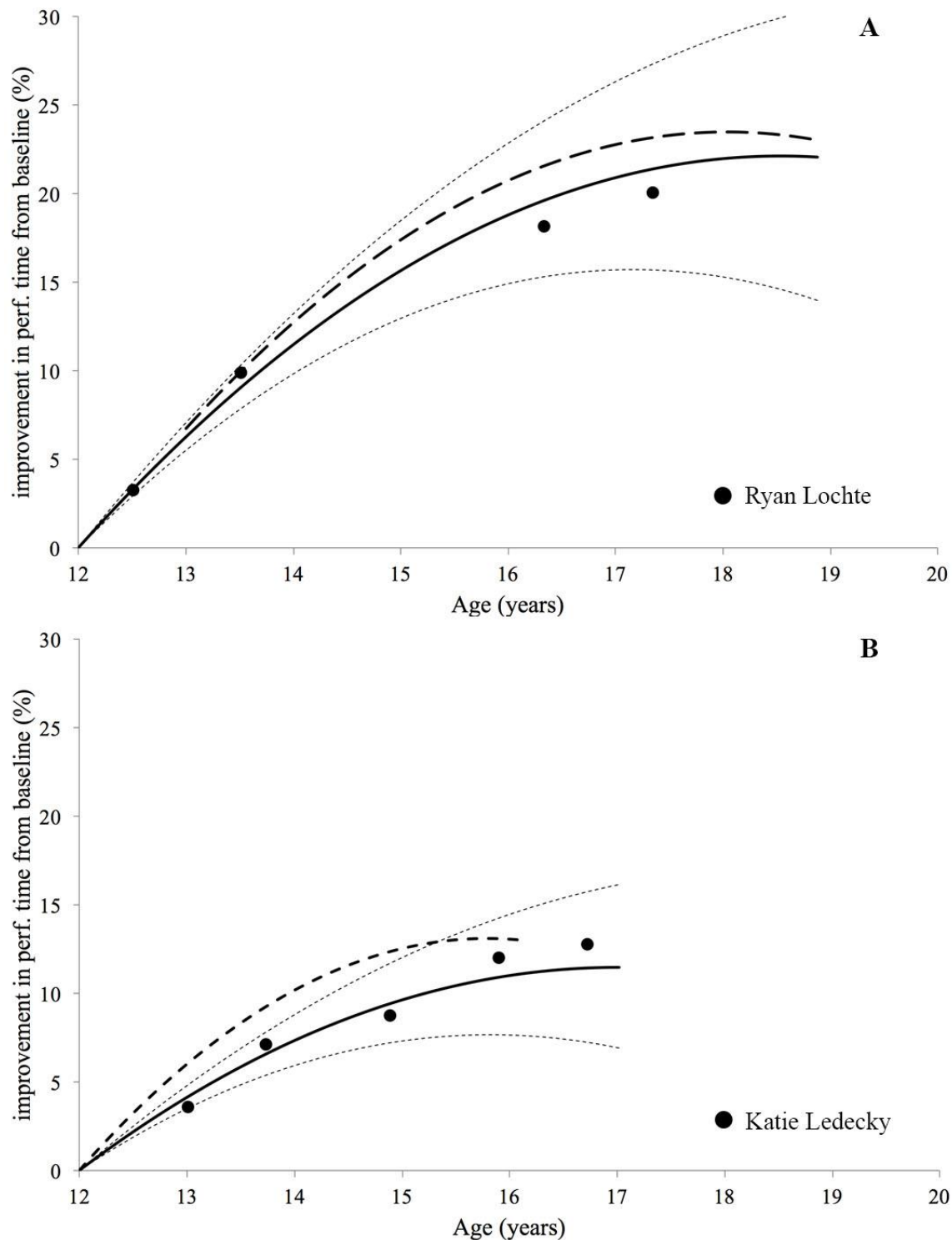
Figure 1: Quadratic functions of the progression of performance in the 200m freestyle event modelled from a baseline of 12 years of adolescent male (A) and female (B) swimmers. The dashed lines represent the DL quadratic functions and the solid lines and dotted lines represent the mixed linear model functions and standard errors, replotted from Dormehl, Robertson, Williams 11 & Dormehl, Robertson, Williams 12 respectively.
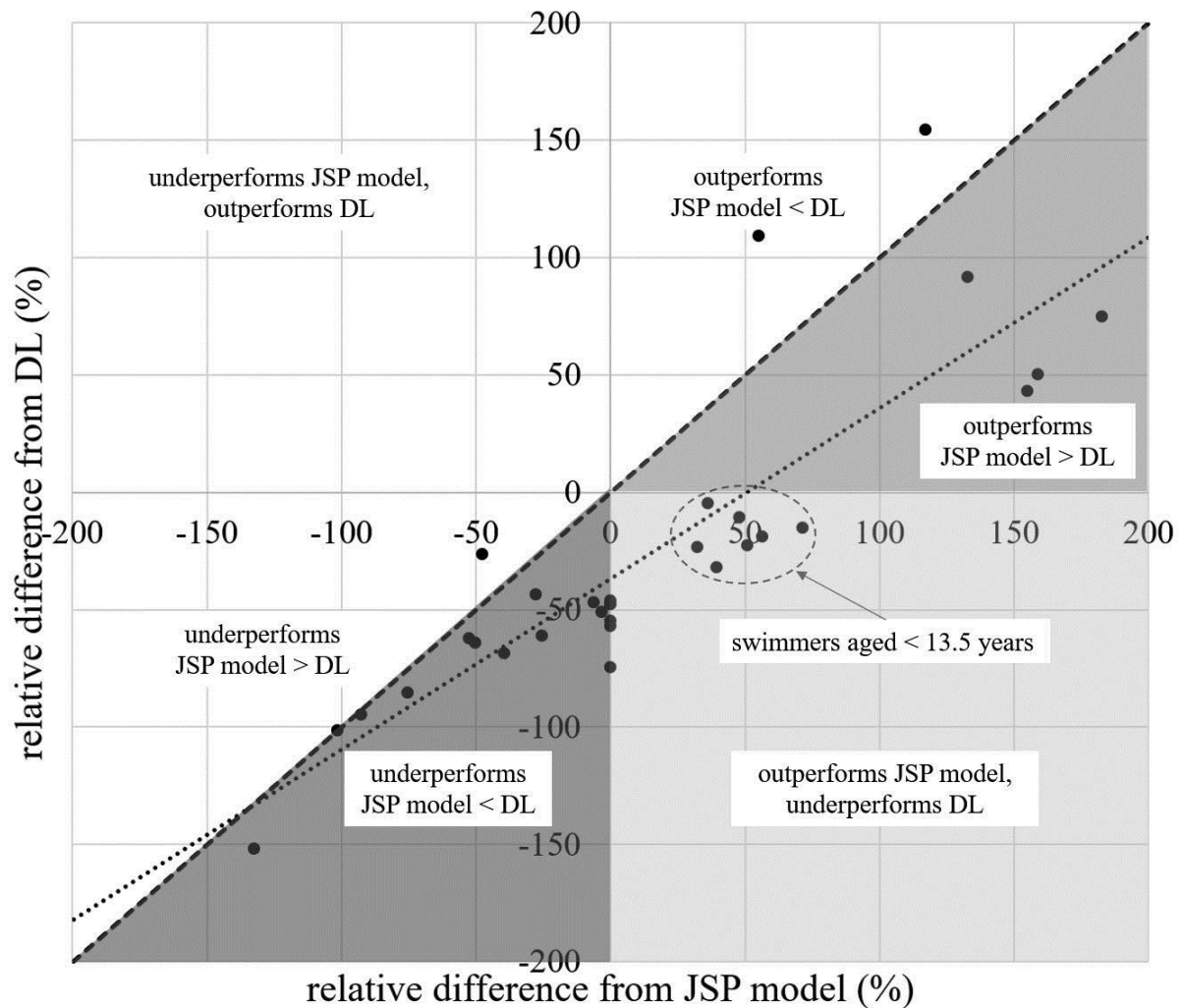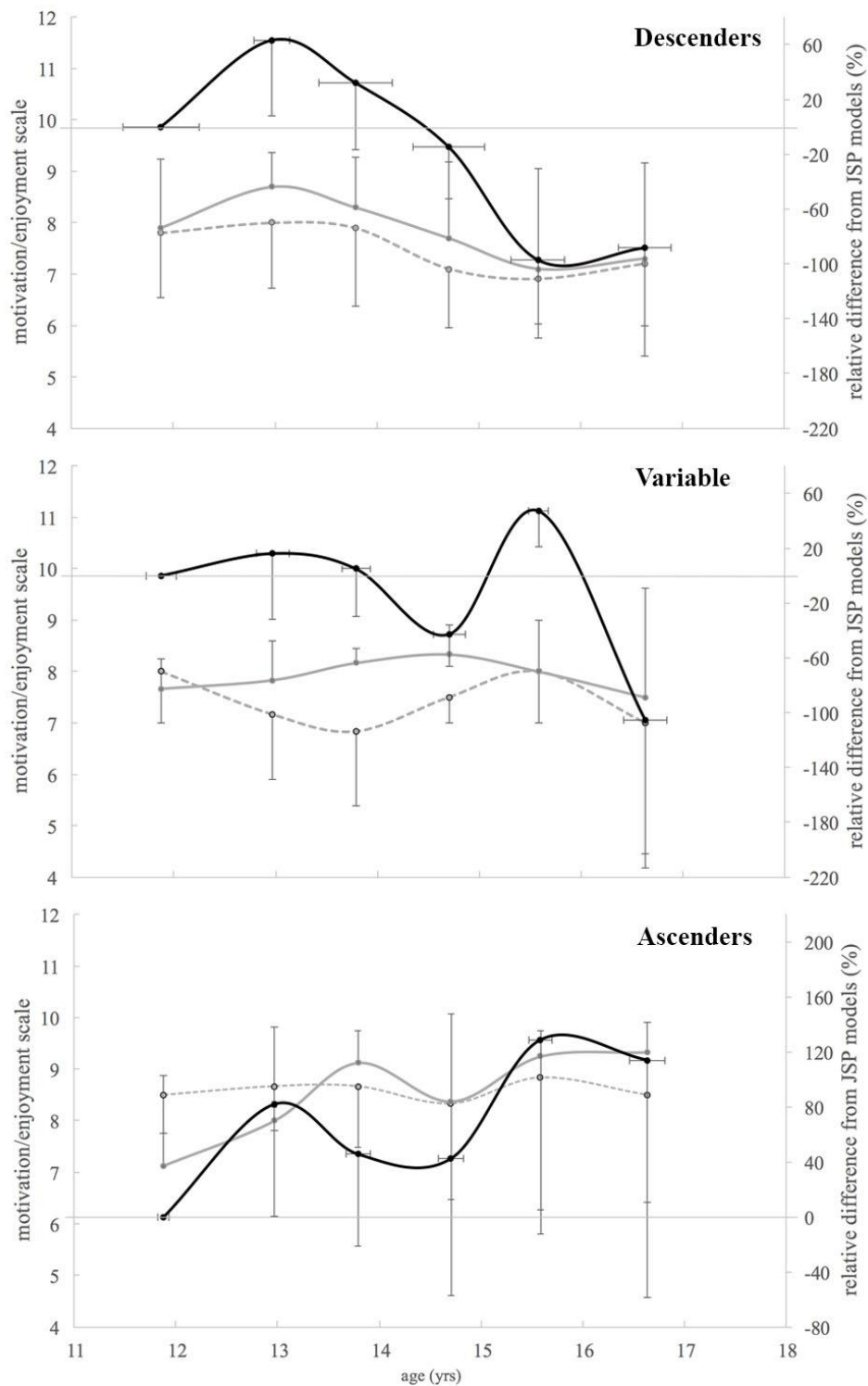
Figure 2: Comparison of the percent relative improvement of female Dutch swimmers from the JSP model compared with their percent relative improvement from the DLs for the 100m freestyle event. The dashed line represents y − x and the dotted line represents the linear regression for Dutch swimmers (Table 2).

Figure 3: The progression in mean percent relative improvement from the JSP models (solid black line), enjoyment (dashed grey line) and motivation (solid grey line) of Dutch swimmers between the ages of 12 and 18 years, grouped as 'descenders', 'variable' and 'ascenders' respectively. The flattened JSP modelled lines* are shown at y=0. Error bars show 1SD (descenders: n = 5; Variable: n = 4; Ascenders: n = 4).

Table 1: Summary of the quadratic functions derived from the DLs.

Event	Sex	Quadratic (a)	Linear (b)	Intercept (c)	r^2
100 m freestyle	M	-0.70 (0.06)	25.20 (1.71)	-201.32 (12.70)	1.00
200 m freestyle	M	-0.66 (0.08)	23.78 (2.31)	-191.00 (17.20)	1.00
100 m backstroke	M	-0.71 (0.06)	25.19 (1.90)	-200.52 (14.08)	1.00
100 m breaststroke	M	-0.65 (0.07)	23.87 (2.25)	-193.30 (16.74)	1.00
100 m butterfly	M	-0.95 (0.15)	33.46 (4.50)	-266.12 (33.44)	0.99
200 m individual medley	M	-0.69 (0.09)	24.89 (2.56)	-200.06 (19.08)	1.00
100 m freestyle	F	-0.92 (0.10)	28.97 (2.88)	-215.63 (20.15)	1.00
200 m freestyle	F	-0.92 (0.10)	28.92 (2.85)	-215.13 (19.94)	1.00
100 m backstroke	F	-1.08 (0.13)	33.56 (3.77)	-247.89 (26.38)	1.00
100 m breaststroke	F	-1.00 (0.17)	31.10 (4.73)	-229.86 (33.08)	0.99
100 m butterfly	F	-1.26 (0.08)	39.19 (2.34)	-289.62 (16.32)	1.00
200 m individual medley	F	-1.06 (0.09)	33.08 (2.44)	-245.08 (17.08)	1.00

Note: The correlations were all significant at $p < 0.05$; standard error in parentheses.

Table 2: Summary of the linear regressions of the Dutch swimmers' relative improvement from the JSP model compared with their corresponding relative improvement from the DL quadratic functions.

Event	Sex	Gradient (m)	Intercept (c)	r^2
100 m freestyle	M	0.97 (0.03)	-2.94 (1.97)	0.96
200 m freestyle	M	0.89 (0.05)	-10.60 (2.47)	0.92
100 m backstroke	M	0.92 (0.03)	-12.59 (2.07)	0.97
100 m breaststroke	M	0.83 (0.02)	-16.10 (1.26)	0.99
100 m butterfly	M	0.73 (0.05)	-20.51 (3.44)	0.90
200 m individual medley	M	0.78 (0.03)	-16.64 (1.99)	0.96
100 m freestyle	F	0.73 (0.08)	-36.87 (6.11)	0.73
200 m freestyle	F	0.93 (0.13)	-6.56 (12.27)	0.61
100 m backstroke	F	0.61 (0.06)	-46.20 (4.17)	0.82
100 m breaststroke	F	0.56 (0.12)	-38.34 (9.22)	0.49
100 m butterfly	F	0.51 (0.12)	-71.96 (7.50)	0.54
200 m individual medley	F	0.65 (0.06)	-32.77 (4.39)	0.81

Note: The correlations were all significant at $p < 0.05$; standard error in parentheses.

Table 3: Group differences in potential factors affecting swimming performance.

Factors		'descenders' (n=5)	'variable' (n=4)	'ascenders' (n=4)
swim-specific training (hours per week)	increased		75	100
	peak	80	25	
	stable	20		
land training (hours per week)	increased		50	100
	peak	60	50	
	stable	40		
long-term breaks in training	early	20	12.5	50
	mid		12.5	50
	late	20	25	
	none	60	50	
changes in club or coach	early	20	12.5	50
	mid	20		25
	late		12.5	25
	none	60	75	
most focussed in swimming	early	20	25	
	mid	80	25	
	late		50	100
most motivated in swimming	early		25	
	mid	60	50	
	late	40	25	100
timing of attainment of estimated adult height*	early	40	50	50
	average	60		25
	late		50	25
changes in main stroke/s	early			
	mid		37.5	75
	late	20	37.5	
	none	80	50	25
changes in main or second distance/s	early		58.3	
	mid	20	8.3	
	late		8.3	
	none	80	25	100

* - classification according to the growth curves of Roelants, Hauspie, Hoppenbrouwers [21], where 15- 16 years (females) and 17-18 years (males) is considered 'average'.

Note: All values calculated as percentages. Factors were classified as increased (overall increased from 12 – 18 years), peak (increased and then decreased from 12 – 18 years), stable (no more than 1 hour / week difference from 12 – 18 years); early (between 12 - 14 years), mid (between 14 – 16 years) and late (between 16 – 18 years).