A longitudinal modelling approach for the progression of sub-elite youth swimming performance

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University

Signature: …………………………………………………………

Abstract

Formal long-term athlete development programmes emerged at the turn of the century and, despite some fierce criticisms, have evolved significantly since their inception. The first generation of athletes to grow up with these systems are now coming of age. The purpose of this thesis was to track a population of adolescent school-level swimmers between the ages of 12 and 18 years over an 8-year period so as to assess their performance progression as they matured under these athlete development programmes.

The first study aimed to track the performances of the sub-elite athletes at an annual international school championship and to compare their progression with those of both junior elite and elite-level swimmers. In addition to narrowing the gender gap, the records of the sub-elite swimmers have continued to improve. In contrast, both of these factors remained relatively stable for junior elite and elite-level swimmers over the same period.

Swimming affords athletes the possibility of within-sport specialisation. This almost unique aspect of swimming led to the two investigations of the second study. Firstly, the paired stroke combinations preferred by swimmers were determined using Cohen's Kappa tests in a cross-sectional design. Secondly, the stability in the event selection of each swimmer during their adolescent years was explored longitudinally. Both males (33.9±5.8%) and females (36.9±6.5%) preferred to swim the 50 and 100 m freestyle events together over any other paired stroke combination. The majority of swimmers preferred to specialise in specific stroke techniques over distance specialisms with breaststroke being the only stroke in which swimmers of both sexes chose to specialise early. Most notable was that females specialised earlier than males.

Studies three (males, n = 446) and four (females, n = 514) utilised mixed linear modelling to determine the quadratic functions of the performance progressions of adolescent swimmers (between the ages of 12 and 19 y) in seven individual competition events. Males progressed at more than twice the rate of females (3.5 and 1.7% per year, respectively) in all strokes over this age range. This was likely due to the fact that females reach puberty before males. Thresholds of peak performance occurred between the ages of 18.5±0.1 y (50 m freestyle and the 200 m individual medley) and 19.8±0.1 y (100 m butterfly) for males, but between the wider range of 16.8±0.2 y (200 m individual medley) and

20.6±0.1 y (100 m butterfly) for females. Using an independent sample of Dutch Junior national swimmers (n = 13), the fifth and final study aimed to evaluate the efficacy of the models developed in studies three and four as both target setting and talent identification tools. This was achieved through a mixed-methods approach where quantitative and qualitative data confirmed the applicability of the models for adolescent swimmers of any skill level.

This thesis demonstrates that sub-elite swimmers have probably benefitted from first generation athlete development models. Longitudinal modelling of their data provides a valuable platform from which all adolescent swimmers can be compared and used to inform the next generation of bespoke swimming-specific youth development programmes.

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List of abbreviations

ASA	Amateur Swimming Association
ADSP	Athlete Development Support Pathway
BA	Biological Age
BMI	Body Mass Index
CA	Chronological Age
CGS	Centimetres Grams Seconds
DCMS	Department for Culture, Media and Sport
DJNC	Dutch Junior National Championships
DL	Dutch Limits
DMGT	Differentiated Model of Giftedness and Talent
DMSP	Developmental Model of Sports Participation
EMTD	Expanded Model of Talent Development
FINA	Federation Internationale De Natation
FMS	Fundamental Movement Skills
IM	Individual Medley
JSP	Junior Swimming Performance
KNZB	Koninklijke Nederlandse Zwembond
LC	Long Course
LTAD	Long Term Athlete Development
MLM	Mixed Linear Model
NGB	National Governing Body
PHV	Peak Height Velocity
RAE	Relative Age Effect
SA	Skeletal Age
SC	Short Course
SI	Stroke Index
SL	Stroke Length
SMART	Specific Measurable Agreed Realistic Time-based
SMTD	Standard Model of Talent Development
SR	Stroke Rate
SSS	Sport Specific Skills
TD	Talent Development
TI	Talent Identification
TID	Talent Identification and Development
v	Velocity
VO_2	Volume of Oxygen
VO_{2max}	Maximum Volume of Oxygen uptake
WHO	World Health Organisation
YPDM	Youth Physical Development Model

Chapter 1

1 Introduction

One of the founding sports in the modern Olympic Games, swimming has been reported to be amongst the most popular physical activities to participate in throughout the majority of European countries (Scheeder et al., 2011). It also enjoys amongst the highest participation rates from the population aged 14 years and older in England and as such enjoys some sizeable government funding (Amateur Swimming Association, 2015; Sport England, 2016a); see section 2.1 for further details. A recent review in The Netherlands touted swimming as one of the few truly lifelong sports as it is often started at a very young age and is enjoyed by many beyond retirement age (van der Werff & Breedveld, 2013). Some parents introduce their children to swimming as babies with initial lessons focusing on basic water competencies, starting from the age of 6 months. In the Netherlands, children are advised to attend formal structured swimming lessons from the age of 4 years onwards (Nationaal Platform Zwembaden | NRZ, 2016) however in the UK, swimming is a compulsory part of the National Curriculum where it is recommended to be taught from the age of 5 years (Department for Education, 2013). Swimming is also listed as one of the fundamental skills under physical literacy as part of the Long Term Athlete Development programme (Balyi, Way, Higgs, Norris, & Cardinal, 2014). Like most sports, swimming can be undertaken both recreationally and of course in competition. It not only spans different ages, but also different levels, from novice all the way through to super-elite level competitors and at the 2012 London Olympic Games, three of top 10 most popular athletes searched on the social web, were swimmers (The Guardian, 2012). This was likely due to the highly-anticipated rivalry between two of the sport's most well-known super-elite athletes, namely Ryan Lochte and Michael Phelps.

Defining the standard or skill level of athletes has proven difficult, as highlighted by Swann, Moran, and Piggott (2015). They identified eight different definitions for elite-level athletes in the literature and summarised that the classification of "elite" depends on, amongst other things, the highest level of competition achieved, world ranking, and experience of the athlete, as well as how competitive a country is in the sport, and even the sport itself. Most recently, Rees et al. (2016) proposed a scale of performance level from non-elite (below national level) through to super-elite (Gold medallists at Olympic Games or World Championships). Below elite level, terms such as sub-elite (Balyi et al., 2014;

Coutinho, Mesquita, & Fonseca, 2016; Johnson, Tenenbaum, Edmonds, & Castillo, 2008; Macnamara, Moreau, & Hambrick, 2016), semi-elite (Burgess & Naughton, 2010; Swann et al., 2015) and amateur (Ford, Ward, Hodges, & Williams, 2009; Gonaus & Mueller, 2012; Robertson, Burnett, & Gupta, 2014) have been coined. Unfortunately, there is even less consensus on definitions for these terms with some authors using them interchangeably and others making various distinctions between them. Perhaps the most prudent way to consider the different standards and levels is through a continuum (Figure 1.1). For the purpose of this thesis, the term "sub-elite" will be used to describe all swimmers who are yet to represent their country in at least the semi-finals (top 16) of a FINA-sanctioned international competition.

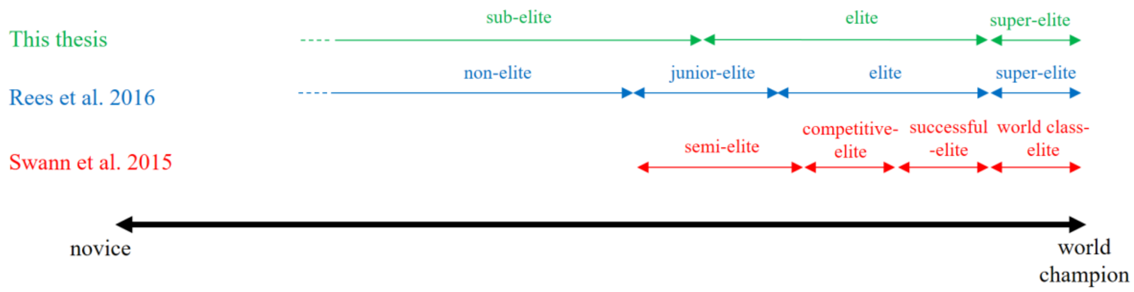


Figure 1.1 A schematic of a skill-level continuum showing some differences in terminology between authors.

Given the popularity and status of swimming within high-level events such as the Olympic Games, the pathway from novice through to the super-elite level has become the focus of much research over the years but the vast majority of the literature has focussed on the elite-level end of the spectrum.

With the Olympic motto, "Faster - Higher - Stronger" promoting the idea of continued improvement and progression, the exponential growth in sport science over the years has undoubtedly helped many sports advance, not least of all swimming. From the seven gold medal haul of the likes of Mark Spits at the 1972 Olympic Games to the unprecedented 23 gold medals won by Michael Phelps over five Olympic Games between 2000 and 2016, sport science has been at the forefront of development in the sport.

The unparalleled medal tally of these Olympians raises an unusual aspect of swimming as a single sport. Although a few other sports such as track and field athletics and cycling also include specialisms within the sport, the range of distances and strokes within swimming is unique. Despite this, much of the existing literature has either only focussed on freestyle or combined multiple strokes and/or distances together. Re-classified recently as an early specialisation sport (Balyi et al., 2014), athletes taking up swimming are known to invest large amounts of their time, engaging in many hours of deliberate practice (Light, Harvey, & Memmert, 2013) in an effort to develop the necessary range of stroke competencies in order to compete even before reaching adolescence.

Swimming is a truly multidisciplinary activity that requires expertise in almost all facets of sport science including, physiology, psychology, biomechanics, nutrition and performance analysis. Being a chronometric sport, it also generates vast amounts of data, much of which is recorded and preserved following all competitions. This treasure trove of data has provided researchers with the means to investigate the pathway that led yesterday's champions to glory in an effort to plot the path of future champions. While both a prudent and profitable approach, it is not without its shortcomings, as the path to success at the highest level rarely has the same origin or environmental influences. Many talent identification (TI) programmes have been cross-sectional in nature, relying on one-off outstanding performances by youth, often in adolescence, where chronological and biological ages (CA and BA respectively) do not run parallel (Rees et al., 2016). These systems continue to reward early maturers who display adult-like qualities in outperforming their less mature competition, who often drop out of the sport long before their real potential is ever realised.

While the value of longitudinal data has long been known, previous studies have focussed on retrospectively tracking the performance of only the very best athletes (Allen, Vandenbogaerde, & Hopkins, 2014; Pyne, Trewin, & Hopkins, 2004), in the hope that they will be able to model a perfect "railway track" from novice to expert and hopefully super-elite performance. While this approach has merit, it relies on young athletes fitting a specific profile at exactly the right moment to be detected, selected and developed, in the hope that a single one-off performance may be recognised.

The true value of longitudinal data from adolescents is however that it affords researchers the opportunity to establish developmental norms by not just focussing on the super-elite pathways, but also by considering the sub-elite range from where tomorrow's champions are likely to emerge. A top-down approach to TI and talent development (TD) has provided insights into the performance pathway for some of today's elite athletes, albeit a very narrow and historical pathway. Longitudinal data has yet to provide a bottom-up option to TI in any sport, including swimming. Such an approach affords the ability to consider the many alternative pathways to the elite level. It is intended that the collection and analysis of data from athletes in the sub-elite range may help to map performance norms and also provide some information on the mean expected progression of performance through the adolescent years. This approach could provide sport scientists and coaches with the tools to track the performance of their athletes, set realistic goals and identify individuals who are outperforming the expected norms consistently over time.

The rationale for this thesis has been to focus on sub-elite adolescent swimmers to offer a new approach to TI and within-sport specialisation. To date, the progression of sub-elite swimmers has not been characterised, either in terms of their specialisation or in their progression in performance gains. Together these aspects will provide a platform to understand the mean progression of athlete development and as a consequence the possibility to identify adolescent swimmers who do not follow this trajectory. This could enable coaches to refine their TI procedures and provide swimmers with bespoke guidance with regards to setting SMART goals. It could also help to provide direction about when and in which strokes and distances swimmers should focus and eventually specialise.

Chapter 2

2 Literature review

2.1 Introduction

Sport, a multibillion pound industry, fulfils one or two needs for adults and children alike: health and wellbeing through participation (Fraser-Thomas, Côté, & Deakin, 2005; Mountjoy, 2011), and the desire to be the best through competition (Bailey et al., 2010). To date, it is mainly only elite-level adult athletes who have traditionally attracted the attention of National Governing Bodies (NGBs), sport scientists and the public, although there is a growing awareness that it is at the youth level where the greatest future impact is possible (Capranica & Millard-Stafford, 2011). It is likely that the relative abundance of adult studies is due to the homogeneity of the sample, for which a simple cross-sectional approach is sufficient. The dynamic, nonlinear nature of physical growth and maturation coupled with psychological and emotional development through childhood (Armstrong, Welsman, Williams, & Kirby, 2000; Beunen & Malina, 1988; Tanner, 1989) makes research on children very challenging. One of the most important considerations involves the ethics of working with children for the purpose of predicting their potential futures. This is especially applicable at an age when their cognitive ability to understand the consequences of their choices and eventual actions is often limited (Wylleman & Reints, 2010).

Just over a decade ago, the first models for athlete development were proposed, with programmes designed specifically for children as they mature (Balyi, 2001; Côté & Hay, 2002). Since then, a focus on youth development in sport has gained momentum. It has required the collective efforts of all the major participants of children in sport: NGBs, coaches and parents (Pankhurst & Collins, 2013). Many governments have implemented these youth sports models, however there has been a lag in the co-ordination of all aspects of a child-centred approach. In many instances youngsters continue to drop out of sports clubs as a result of exposure to overly competitive programmes (Barreiros, Côté, & Fonseca, 2014; De Knop & De Martelaer, 2001). Many of these programmes are poorly designed, with little attention paid to the significance of birth date (Musch & Grondin, 2001), gender (Sherar, Esliger, Baxter-Jones, & Tremblay, 2007) and the grouping of multiple age categories (Baxter-Jones, 1995; Kojima, Jamison, & Stager, 2012). It is the responsibility of sport scientists and NGBs to ensure that any advancement in the understanding of youth development in every sport is clearly communicated to all stakeholders involved in a practical and applicable manner (Martindale & Nash, 2012).

Coaches play an important role in creating an environment that fosters a child's psychological and social development (Côté & Fraser-Thomas, 2007) as well as the child's intrinsic motivation to participate and remain involved in sport (Deci & Ryan, 1985). Unfortunately many coaches lack pedagogic awareness and coaching education initiatives often fail to sufficiently address the unique psychosocial needs of young athletes (Pankhurst & Collins, 2013). Parents also play a significant role in supporting their children through their development years by providing opportunities to choose and participate formally in activities (Bloom, 1985) but their role tends to diminish with maturity (Côté, 1999). Additionally, many TI systems (see section 2.4) fail to adopt a multidimensional approach (Reilly, Williams, Nevill, & Franks, 2000; Simonton, 1999) and commonly aim to identify adult qualities in children in the hope that they will translate into potential future world class performers (Vaeyens, Lenoir, Williams, & Philippaerts, 2008).

Swimming, a sport in which individual performance is easily quantifiable, provides a useful model in which the effectiveness of the current status of youth athlete development can be evaluated. Swimming also enjoys worldwide acceptance both in terms of elite competition (it is one of the founding Modern Olympic sports) and health and wellbeing (Maglischo, 2003). Despite the very specific facility requirements, participation in swimming is considerable at all ages, and it enjoys sizeable funding from many governments (Amateur Swimming Association, 2015; Sport England, 2013). The most recent data from the Sport England "Active People Survey" reports that 6.23% of 14 to 25 year olds and 5.61% of adults over the age of 26 years in the UK participate in swimming at least once a week (Sport England, 2016a). Although it is the most popular sport for adults, it is only the third most popular sport for youth, behind football and athletics.

2.2 Considerations of athletic development through childhood

Children become and remain involved in sport either to achieve excellence or for personal wellbeing, including making friends, fitting in socially, improving self-esteem and even enjoyment (Bailey 2010). Athletic development has been an area of considerable interest since the early work of Riordan (1977) and Bompa (1995) who explored training methods designed specifically for children, in contrast to the methods used for adults. Following this work, numerous researchers have proposed frameworks for athlete development (Abbott & Collins, 2004; Bailey & Morley, 2006; Wormhoudt, Teunissen, & Savelsbergh, 2013). These models of athlete development include:

- LTAD - Long-Term Athlete Development model (Balyi, 2001)
- DMSP - Development Model of Sport Participation (Côté & Fraser-Thomas, 2007)
- YPDM - Youth Physical Development Model (Lloyd & Oliver, 2012).

2.2.1 An outline of the Long-Term Athlete Development Model (LTAD)

Following his observations of the Canadian Men's Alpine Ski team over an eight-year period, Balyi (1991) proposed a double quadrennial periodised training programme. In Balyi's opinion, high level athletes who had completed years of preparation needed to focus on organised sport-specific and high-intensity training to bring about further adaptation and improvement. In generating an eight-year long-range plan, he introduced phrases like "Training to Train" and "Training to Compete", which would later form the basis of the LTAD model (Table 2.1). While his initial focus was specifically on long-term periodised training plans, he had in fact started to consider the long-term development of athletes.

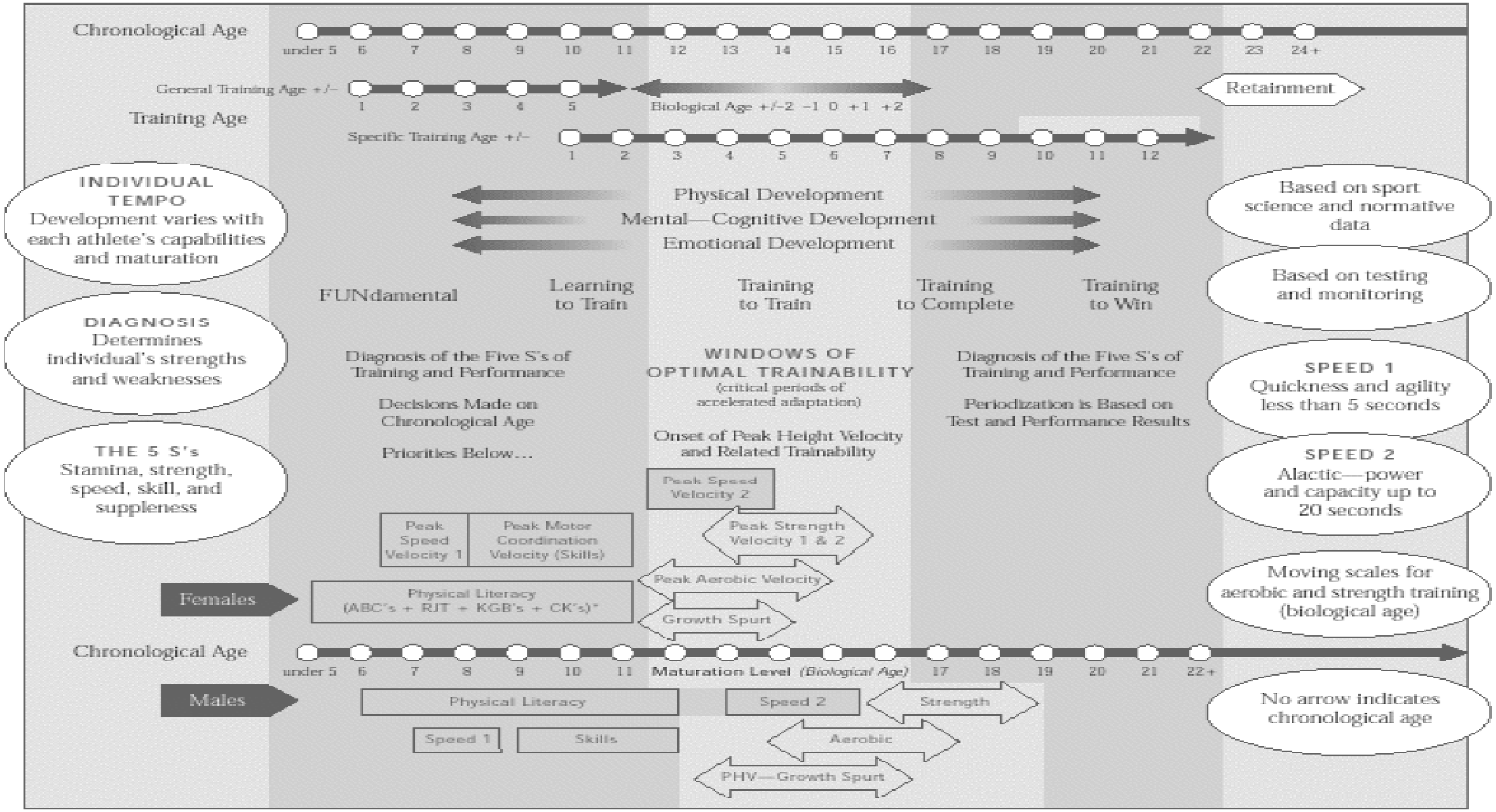
Balyi (2001) proposed that sports could be classified into early specialisation sports, for example gymnastics and diving, or late specialisation sports, being most other sports (Table 2.1). He promoted his LTAD model as a generic model to be developed more specifically by individual sporting codes to meet the individual or sport-specific needs of their athletes. The fact that adult programmes were superimposed on young athletes (Balyi, 2001; Burgess & Naughton, 2010) and that male programmes were used to train females (Balyi, 2001), highlighted the lack of an individualised/specialised approach to the development of talent. This was affirmed by Norris and Smith (2002, cited in Ford et al., 2011) who believed the effectiveness of any training programme relies on the concept of individualisation.

Table 2.1 The evolution of the stages and age ranges of long-term athlete development for early and late specialisation sports

2001 (Balyi)				2004 (Balyi & Hamilton)			2008 (Higgs, Balyi & Way)			2014 (Balyi et al.)		
Stages of Early Specialisation Sports	**Stages of Late Specialisation Sports**	**Ages (y)**		**Stages of Late Specialisation Sports**	**Ages (y)**		**Stages of Late Specialisation Sports**	**Ages (y)**		**Stages of Late Specialisation Sports**	**Ages (y)**	
		M	F		M	F		M	F		M	F
							Active Start	0-6		Active Start	0-6	
	FUNdamental	6-10		FUNdamental	6-9	6-8	FUNdamental	6-9	6-8	FUNdamental	6-9	6-8
				Learning to Train	9-12	8-11	Learning to Train	9-12	8-11	Learn to Train	9-12	8-11
	Training to Train	10-14	10-13	Training to Train	12-16	11-15	Training to Train	12-16	11-15	Train to Train	12-16	11-15
Training to Train							Learning to Compete	16-20	15-19	Train to Compete	16-23	15-21
Training to Compete	Training to Compete	14-18	13-17	Training to Compete	16-18	15-17	Training to Compete	20-23	19-23	Train to Win	19±	18±
Training to Win	Training to Win	18+	17+	Training to Win	18+	17+	Training to Win	23+	23+	Active for life	Enter at any age	
Retirement/Retraining	Retirement/Retraining	-	-	Retirement/ Retraining	-	-						

Information sourced from (Balyi, 2001; Balyi & Hamilton, 2004b; Balyi et al., 2014; Higgs, Balyi, & Way, 2008)

Balyi (2001) suggested that children between the ages of 9 and 12 years have a critical period of motor skill development where they acquire fundamental movement skills, including running, throwing, jumping, hopping and bounding. The aforementioned age ranges for this critical period which did not correspond with the stages in the 2001 model, were revised by 2004 (Table 2.1). To refine the relevance of the age classes, Balyi and Hamilton (2004b) proposed Peak Height Velocity (PHV) as a means of determining the BA of athletes from the ages of 12 and 14 years, for girls and boys respectively (Figure 2.1). Furthermore, the 2004 model included a distinction between fundamental motor skills (FUNdamental stage) and fundamental sports skills (in an extra stage: Learning to Train). Deli, Bakle, and Zachopoulou (2006) found that children as young as 5 years benefited from structured practice and their learning of motor skills progressed more than children who were left to learn through "free play" (widely accepted to be self-motivated and unstructured activities that were completed without any form of instruction), a view supported by Vandorpe et al. (2012). The 2008 version of LTAD incorporated this idea in another earlier stage (Active Start). Whitehead (2001) described fundamental movement skills, establishing the term "physical literacy". Later versions of the LTAD model incorporated this terminology, where "physical literacy" spans "Active Start" to "Learning to Train" (Balyi et al., 2014; Higgs et al., 2008).



*ABC's = Agility Balance Coordination Speed + RJT = Run Jump Throw + KGB's = Kinesthesia Gliding Bouyance Striking with objec + CK's = Catching Kicking Striking with body

Figure 2.1 Overview of Long-term Athlete Development (Balyi & Hamilton, 2004), pp. 7.

2.2.2 An outline of the Development Model of Sport Participation (DMSP)

The DMSP model of Côté and Fraser-Thomas (2007) based on the experimental work of Côté (1999) emphasises the psychological component of athlete development. The framework proposes three main outcomes namely, recreational participation through sampling, elite performance through a variety of sports and elite performance through early specialisation in a single sport (Figure 2.2). The pathway to the first two outcomes starts with a sampling phase (ages 6 – 12 years). In the case of recreational participation, the sampling phase is followed by the recreational phase (ages 13-17 years).

Athletes who attain an elite performance level through participation in multiple sports, progress through a specialising phase (ages 13-15 years) and an investment phase (ages 16-17 years). During the sampling phase athletes are predominantly engaged in a wide variety of "deliberate play" activities, which according to Côté and Hay (2002), are intrinsically motivating activities that are based on sports or games where the rules have been modified to make them more enjoyable e.g. street football. This is followed by a phase of specialisation that is characterised by a reduction in the variety of activities with the volume of "deliberate play" being matched by the same volume of "deliberate practice". Ericsson, Krampe, and Tesch-Römer (1993) defined "deliberate practice" as highly structured activities that required considerable effort, designed to achieve optimal levels of improvement. During these specialising years, there is a reduction in the number of sports in which the athlete participates, with the emergence of a preferred sport. Extensive "deliberate practice" is the focus of the investment phase, which is the final stage in the pathway to elite performance.

An alternative pathway to elite performance as shown in Figure 2.2, is achieved through the focus on a single sport. This approach involves only one phase of early specialisation and investment where "deliberate practice" is favoured over "deliberate play" (Côté & Fraser-Thomas, 2007).

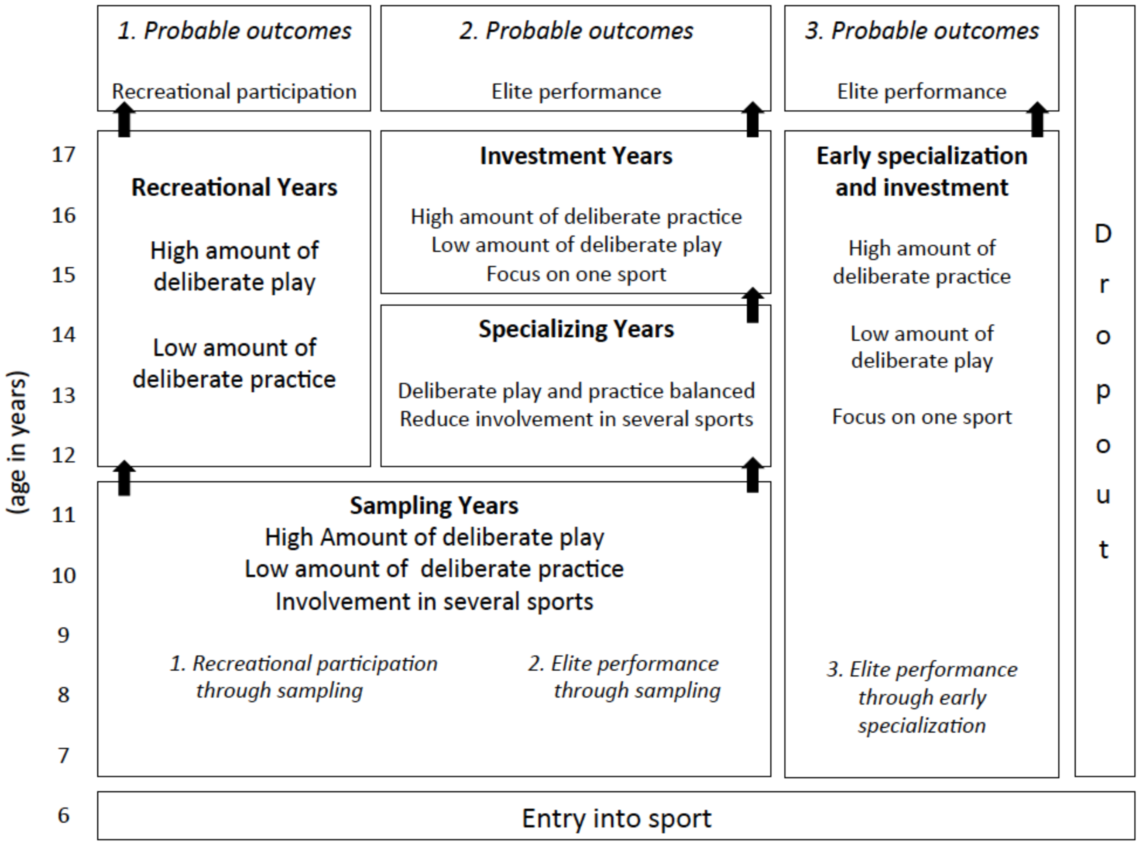


Figure 2.2 The Development Model of Sport Participation. Information sourced from Côté and Fraser-Thomas (2007), pp. 288.

2.2.3 An outline of the Youth Physical Development Model (YPDM)

The most recent model of athlete development was proposed by Lloyd and Oliver (2012). They emphasise the physical qualities of fundamental movement skills, sports-specific skills, agility, speed, power, strength, hypertrophy and endurance and metabolic conditioning, with a progression in relative importance with chronological age (CA) (Figures 2.3 and 2.4). The training structure develops from being unstructured in early childhood through to very highly structured in adulthood. These authors acknowledge the difference in individual needs between sexes with regards to the timing and tempo of maturation.

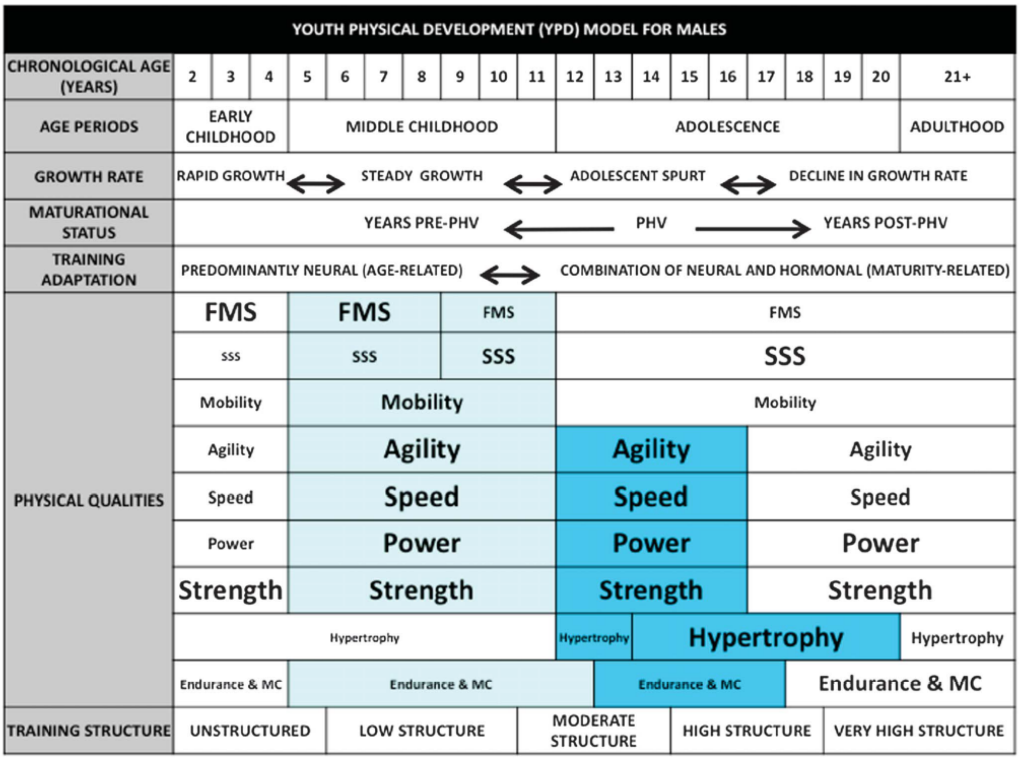


Figure 2.3 The YPD model for males. Font size refers to importance; light blue boxes refer to pre-adolescent periods of adaptation, dark blue boxes refer to adolescent periods of adaptation. FMS = fundamental movement skills; MC = metabolic conditioning; PHV = peak height velocity; SSS = sport-specific skills; YPD = youth physical development. Information sourced from Lloyd and Oliver (2012), pp. 63.

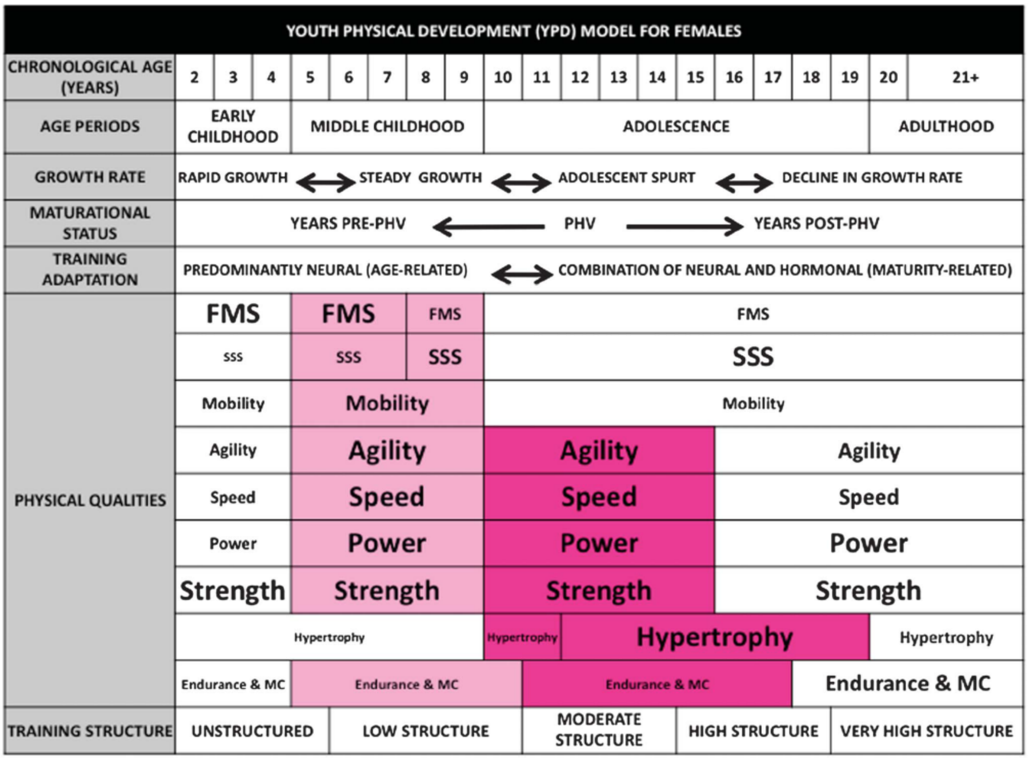


Figure 2.4 The YPD model for females. Font size refers to importance; light pink boxes refer to pre-adolescent periods of adaptation, dark pink boxes refer to adolescent periods of adaptation. FMS = fundamental movement skills; MC = metabolic conditioning; PHV = peak height velocity; SSS = sport-specific skills; YPD = youth physical development. Information sourced from Lloyd and Oliver (2012) pp. 64.

2.2.4 Evaluation of the LTAD model

Since the LTAD model has evolved and been refined (Balyi et al., 2014), it makes it very challenging to validate and assess objectively. The first documented version of Balyi's LTAD model emerged in 2001. Balyi (2001) stressed that the production of elite-level athletes requires a long-term structured commitment to their training and development, not merely the pursuit of success in the short term. To support his claim that it took 8 to 12 years for talented athletes to reach elite-level performance, he cited Ericsson et al. (1993), among others. A focal point of Ericsson's study included the work of Simon and Chase (1973, cited in Ericsson et al., 1993) and their "10-year rule", the length of time it took to become a grandmaster chess player. Ericsson et al. (1993) and Helsen, Hodges, Van Winckel, and Starkes (2000) both verified that a minimum of 10 000 hours of work, which was equated to 10 years of deliberate practice, was required to reach an expert level of performance in music and soccer respectively. Similar findings were confirmed in a comprehensive review of American Olympic athletes who competed between 1984 and 1998, where an average of 12 to 13 years was suggested to be required to develop Olympic level talent (Gibbons, Hill, McConnell, Forster, & Moore, 2002). Ericsson et al. (1993) also commented that, in most cases, the path to becoming an expert performer started in childhood. Balyi recognised not only the period of time it would take to develop high-level performers, but also that the process would need to begin at an early age. This standpoint, forming the basis of his model, had seemingly been accepted (Bailey et al., 2010) but the finer details of what, how, where and when to develop/train has been at the centre of many criticisms of LTAD.

Balyi's (2001) implication that fundamental motor skills could not be recaptured at a later stage, if they were not properly developed within critical periods (windows of opportunity), has been very controversial. Although Viru et al. (1999) found these "windows of opportunity" to be plausible at certain points in maturation, most commonly associated with growth spurts, they emphasised that further research was required. Conflicting research (Polman, Walsh, Bloomfield, & Nesti, 2004) has indicated that fundamental movement skills are trainable in adulthood. Balyi's stance that children who did not successfully train and develop within these "windows" would permanently limit their development is still debated (Bailey et al., 2010; Ford et al., 2011). Furthermore, Bailey et al. (2010) felt that the physiological bias in Balyi's LTAD model was to the detriment of psychological and environmental components, although the recent LTAD 2.0 has made attempts to address these factors that were clearly overlooked in the original models (Balyi et al., 2014). Ford et al. (2011) thoroughly investigated the development of physiological components of fitness such as aerobic and anaerobic capacity, strength, speed and power within these "windows of opportunity". The majority of their results remain inconclusive, with further research being advised to establish whether these "windows of opportunity" do exist with regards to fundamental movement and sport-specific skills, and whether their development in earlier years could manifest in later stages of development. Recent research by Macnamara et al. (2016) has refuted claims that higher skilled performers start deliberate practice at an earlier age than lower skilled performers. These authors point to the important contribution that psychological domains, such as cognitive ability, behaviour, genetics and personality contribute to the attainment of expert performance, creating even more doubt about the existence of the aforementioned "windows of opportunity".

Bailey et al. (2010) insinuated that Balyi and Hamilton (2004) were inadvertently advocating the early identification of talented athletes despite the findings of Bloom (1985), that less than 10% of elite-level athletes had reached a performance level by the age of 12 years and Sokolovas (2006) who found that approximately 50% of the top 100 USA ranked swimmers at age17 to 18 years, had never ranked in the top 100 in younger age-groups. However, in making a distinction between early (mainly individual sports) and late specialisation sports (all team sports), Balyi (2001) and Balyi and Hamilton (2004) suggested that specialisation (the learning of sport-specific skills) before age ten, for late specialisation sports was not recommended, a view supported by Jess and Collins (2003). The early specialisation model was however criticised by Wiersma (2000), who believed that the lack of diversification at an early age, limited the physical and social development of young athletes, as it potentially limited their overall motor skill development. This potentially restricted their chances of successfully taking up alternate activities and could ultimately lead to early specialisation athletes dropping out, usually due to burnout.

Balyi (2001) and Balyi and Hamilton (2004), also recognised the pressures of competition and stressed the negative aspect of overemphasising competition at a young age. In addition to training, they proposed that children understood the value of training (Learning to Train and Training to Train) before being prepared for competition (Training to Compete). This view was supported by Martindale, Collins, and Daubney (2005) who warned that, while early specialisation in sports tended to produce successful age-group performers, it appeared to have a limited effect for long-term development. The research of Sokolovas (2006) on the top 100 USA ranked age-group swimmers provided some strong evidence of this lack of long-term development. Lang and Light (2010) pointed out that despite these recommendations and findings, the Amateur Swimming Association (ASA), the UK's national governing body for swimming, seemingly contradicted the prescribed model by lowering the minimum age for national competitions to ten and eleven years for girls and boys respectively.

The original versions of LTAD were also criticised for seemingly not having a multi-dimensional approach to athlete development, focussing only on physical attributes. Malina et al. (2005) illustrated that even though physical and biological talents usually determine team selection, these attributes are often poor predictors of skill (Abbott & Collins, 2002; Bailey et al., 2010). In a study on elite and semi-elite soccer players, Reilly et al. (2000) found that these athletes differed in cognitive aspects like ego orientation and anticipation skill, physical attributes like body shape, physiological attributes like aerobic power, as well as skill-related aspects like agility.

Further research on soccer has shown how, within an age group, the older boys were often selected over younger players because of their greater physical development (Helsen, Van Winckel, & Williams, 2005). In a study on young elite British athletes (n = 453, aged 8-16y) swimmers and tennis players were reported to be born in the first half of the selection year (Baxter-Jones, 1995). This relative age effect (RAE) inadvertently came about as sports were arranged into age groups (ironically a system designed to equalise competition). RAE has the greatest impact during adolescence and can have detrimental consequences for late developing athletes in systems that do try to identify talent early. Perhaps the inconsistency among NGB's to agree consistent age bandings for swimming has meant that longitudinal datasets are largely incompatible. This makes them difficult to compare and thus this important aspect has received only minimal attention with regards to swimming to date (Baxter-Jones, 1995; Kojima et al., 2012; Kojima & Stager, 2010).

2.2.5 Evaluation of the alternatives to the LTAD model

As with LTAD, DMSP has been through several revisions (Côté, 1999; Côté & Fraser-Thomas, 2007, 2011), most of which have been published in obscure locations, possibly to avoid the scrutiny of academic peer review. While the DMSP does focus on the psychological (motivational) aspects of development and participation, a limitation of the original LTAD models (Bailey et al., 2010), it neglects the physical development of children. DMSP classified each developmental stage by fixed CAs (Figure 2.2), an approach criticised by Ford et al. (2011) for failing to recognise the differential in the timing and tempo of biological maturation of children. Biological development may affect the natural selection of activities that an individual chooses to either sample or focus on as a result of their perceived physical advantages (in the case of early maturers) or disadvantages (in the case of late maturers). DMSP also does not discern between genders in terms of psychological development, but some empirical retrospective evidence to support the sampling approach to sports participation was provided independently by Bridge and Toms (2013). Despite the relationship between the number of sports participated in from the age of 11 to 15 years and the standard of competition reached at ages 16 to 18 years being highly significant ($p < 0.001$, n = 1006), the participants in this study were expected to rely on their ability to recall their experiences from many years prior. One other small (n = 32) independent study has also found that early engagement and sampling were factors leading to the attainment of elite status in football (Ford & Williams, 2012). Nevertheless, these seem to be some of the only aspects of the DMSP that have been investigated to date. It would appear that the DMSP is loosely based on the traditional Western education systems, whereby students are encouraged to start their primary education with a broad mix of subjects followed by a more selective approach in the later years of their secondary education. This process eventually culminates in a chosen specialism for their tertiary education.

Although not promoted as such, the YPD model appears to be little more than an evolution of the original LTAD model. Its focus is primarily on physical development and, much like the original LTAD models, is built on principles that cater for gender differences and an individualised approach to training, but in the case of the YPD model there is a strong emphasis on strength development in line with the author’s interests. Lloyd and Oliver (2012) claim that their model circumnavigates the window of opportunity limitation, for which LTAD is commonly criticised (Bailey et al., 2010; Ford et al., 2011), but unlike DMSP, YPDM gives any psychological aspects of development only a cursory mention. While YPDM appears to be well researched, based on the considerable volume of literature cited, it is yet to be empirically tested against other models.

Possibly the most damning criticism facing all of these models is that they have all attempted to approach childhood athletic development from a narrow perspective, focussing on either the physical (original versions of LTAD and YPDM) or psychological (DMSP) aspects, but never both together. Bailey et al. (2010) argued that any attempt to view human development from a mono-disciplinary approach was bound to be flawed as there are multiple dynamic factors that affect sports participation. They proposed a multidimensional approach was required where biological, psychological and social factors were all considered together in what they referred to as a biopsychosocial approach, although this is yet to be tested. While none of the models have professed to cover all aspects of human development, this is unfortunately how they have been interpreted (Bailey et al., 2010). It is likely that, as a direct result of these criticisms, LTAD has evolved into in LTAD 2.0. This was recently released by Canadian Sport for Life featuring a more holistic approach to talent identification and development (TID), covering physical, cognitive and emotional aspects of development (Balyi et al., 2014). However, to the best of the author’s knowledge, LTAD 2.0 is yet to be evaluated.

2.2.6 The implementation of LTAD in the UK

Due to the absence of any significant implementation or current endorsement of the YPDM and the limited implementation of DMSP, LTAD remains the most practical and applied model, despite the lack of scientific validity (Bailey et al., 2010; Ford et al., 2011; Lloyd & Oliver, 2012; Martindale et al., 2005). The UK Government's "Game Plan" document (DCMS/Stategy Unit, 2002) highlighted the importance of international sporting success in generating a sense of national pride, and suggested that the improved profile of sport increased interest in participation, particularly in the youth. Game Plan also explained the importance of identifying talent from an early age and endorsed the work of Dr Istvan Balyi and the LTAD model (Balyi, 2001). Consequently it was adopted by 19 sports in the UK, including badminton (Badminton England, 2005), cricket (England and Wales Cricket Board, 2005), hockey (England Hockey, 2005) and swimming (Grange & Gordon, 2004). It is interesting to note that "Game Plan" has recently been superseded by "Sporting Future: A new strategy for an active nation" (HM Government, 2015), where no formal reference has been made to athletic development programmes. However, the document does state that there is no reason to change the "systems" that have contributed to Olympic and Paralympic success.

LTAD may not have been perfect but it did bring some uniform structure to the previously independent programmes of NGBs. Possibly criticisms of it have brought many NGBs and sports together to try to create a framework on which coaches can build. Even critics of the LTAD model concede that it has some positive aspects, i.e. it provides a guideline to co-ordinate ages and training principles for young athletes (Bailey et al., 2010). Following its implementation in the UK, results have been mixed and even where it has been adopted and seemingly successfully implemented, such as in the case of British Swimming, teething problems remain. Most faults appeared to lie with ASA's interpretation of the model, where coaches became overly focussed on training volumes, rather than with LTAD itself (Lang & Light, 2010). LTAD was not the only system that has contributed to success however and other sports, such as rowing (British Rowing, 2009) and cycling (British Cycling, 2009), who adopted whole sport plans involving Sport England's "Grow, Sustain, Excel" initiative (Sport England, 2008), also saw noticeable improvement in their results at Olympic level (International Olympic Committee, 2013c). Many authors see LTAD as an ideology rather than a precise scientific model (Bailey et al., 2010; Ford et al., 2011; Martindale et al., 2005). Despite their efforts to counter many claims of LTAD and their assertion that it is based on unsubstantiated science, they all concur that further research is required. However, Ford et al. (2011) point out that there are issues with assessing paediatric exercise science, not least of all, ethics. It would appear that the ASA do however still value the LTAD framework. Their newest programme, known as the Athlete Development Support Pathway (ADSP) that is due for release later in 2016, is expected to be heavily based on the revised LTAD 2.0 (Freeman, 2016).

Despite LTAD starting as a development model for potential elite athletes that focused on early specialisation, it has evolved, and appears now to be a model based on increasing participation at all levels, possibly creating a path for lifetime involvement in sport (Norris, 2010). This is potentially the most important factor that the Department for Culture Media and Sport (DCMS), in its report to the Government in the UK, was interested in when it endorsed the LTAD model (Balyi, 2001). Although not specifically stated as an outcome of LTAD, it would appear that the DCMS valued the peripheral benefits in terms of reducing long-term costs of health care, improving facilities, creating jobs and reducing crime through building national pride and creating opportunities for positive active lifelong involvement in sports (Johnston, Harwood, & Minniti, 2012). These values also feature prominently in the new “Sporting Future” policy (HM Government, 2015).

2.3 Considerations of maturation and development through childhood

All models of athlete development through childhood and any implementation thereof rely on a detailed understanding of the maturation process. It is well documented that sporting success relies not only on the innate abilities with which athletes are born (nature), but also in combination with environmental factors (nurture) (Baxter-Jones, 1995; Malina, 1994a). These factors could include highly structured and specific training through adolescence and a supportive and stable socio-economic environment (Figueiredo, Goncalves, Coelho e Silva, & Malina, 2009; Malina et al., 2013; Seabra, Mendonca, Thomis, Malina, & Maia, 2011; Vaeyens et al., 2008), and have been differently emphasised in the athlete development models of LTAD, DMSP and YPDM outlined above.

It is reported that maturation can vary both in terms of tempo and timing (Beunen & Malina, 1988; Malina, 1994a). The timing of the onset of maturation has been found to affect sport selection, where early-maturing athletes tend to be favoured for strength and power based activities (Helsen et al., 2005; Kojima et al., 2012) in contrast to later maturing athletes who are favoured for activities where light weight and flexibility are important (Malina et al., 2013). Similarly, birth dates appear to impact selection, where athletes born closer to the start of seasons tend to be selected ahead of their younger and less developed peers (Dudink, 1994; Gil, Ruiz, Irazusta, Gil, & Irazusta, 2007; Kojima et al., 2012; Malina et al., 2000). Consequently Baxter-Jones (1995) enquired as to whether youth competition should be grouped by age and went on to question whether young people should be competing at all.

The existence of sufficient rigorous data on some aspects of athletic development in children has been valuable in influencing the creation of training programmes for young athletes. For example, following confirmation of the relationship between peak VO_2, the highest rate that oxygen is consumed during exercise, and training (Armstrong, Tomkinson, & Ekelund, 2011), the International Olympic Committee compiled agreed recommendations for the training of young athletes (Mountjoy, Armstrong, & Bizzini, 2008). This emphasises the value of a detailed understanding of the factors that affect childhood development that include physical, physiological, psychological and social factors. The American Academy of Pediatrics (2000) has also emphasised the need to consider these factors in their recommendations for intensive training in youth.

2.3.1 The effects of physical and physiological factors

The World Health Organization (WHO) published new data to profile the standard changes in height, weight and body mass index (BMIs) of healthy children as they mature (de Onis et al., 2007) to supersede the older growth standards (Tanner, Whitehouse, & Takaishi, 1966). It is known that the growth profile of children has changed during the last century (Tanner, 1989), with children not only growing into larger adults, but also maturing earlier, due mostly to changes in global nutrition. Current selection criteria for different sports often rely heavily on specific physical characteristics (Abbott, Button, Pepping, & Collins, 2005; le Gall, Carling, Williams, & Reilly, 2010) and the use of growth profiles of male (Baxter-Jones, Helms, Maffulli, Bainespreece, & Preece, 1995) and female (Erlandson, Sherar, Mirwald, Maffulli, & Baxter-Jones, 2008) athletes from a variety of sports have illustrated these differences. In an effort to improve selection procedures, Baxter-Jones et al. (1995) and Erlandson et al. (2008) attempted to create the optimal physical profiles for both team (soccer) and individual sports (swimming, gymnastics and tennis). This was however, in part, disputed by Gonaus and Mueller (2012), who suggested that a unique optimal physical profile of a team sport player could not exist owing to the different positions within a team.

The pace of physical development in the transition from childhood (2 to12 years) through adolescence (12 to 18 years) to adulthood varies greatly. This led Beunen and Malina (1988) to correlate physical and motor performance with peak height velocity (PHV) using data from a longitudinal growth study involving young Belgian boys. Although PHV, as a term, was not used until the 1930’s, the concept of expressing somatic growth relative to age has been used for over a century (Natale & Rajagopalan, 2014). The variation in the timing and tempo of maturation continues to be an unresolved complication in youth sport selection. Despite these differences, the most commonly accepted system to balance competition for sports is to categorise children into chronologically-determined age groups. Many sports adopt multi-age classifications, a system that has come under fierce criticism for failing to provide fair competition, due to the differences in biological maturity of athletes who are grouped by CA (Kojima et al., 2012). Alternatives are generally impractical, but BA and skeletal age (SA) have been considered. PHV has also been used as a measure to estimate the maturational status or BA of competitors and SA has been used as a means to verify CA. It has however shown to be unreliable, particularly in the case of early and late maturers, with the range of SAs in a CA group exceeding 4 years (Malina, 2011).

Van Praagh and Dore (2002) identified that between the ages of 8 and 18 years, the body mass of males and females increases by approximately 160% and 145% respectively. This dramatic change is a consequence of age; however, there is a significant confounding effect with gender and these two variables cannot be considered in isolation. According to Ankarberg-Lindgren and Norjavaara (2004), puberty begins at approximately 8 to10 years for females and 10 to 12 years of age for males and brings about large changes to the endocrine systems. While various hormones including insulin-like growth factor 1 (IGF-1), thyroid and growth hormone are known to affect muscle growth during puberty, testosterone is believed to have the greatest influence and works synergistically with other growth factors (Van Praagh & Dore, 2002). Van Praagh and Dore (2002) also reported that both genders experienced a linear increase in muscle force between the ages of 5 and 15 years, but thereafter only males experienced large gains in strength until their late teens. They noted substantial differences in the increase of testosterone between sexes between early and late puberty and suggested that early-maturing children could expect to have greater muscle mass and strength than late-maturing children. However, Beunen and Thomis (2000) noted that the strength advantage of early matures all but disappeared by adulthood, with late matures often having the advantage as adults. Additionally, both Abbott and Collins (2002) and Till, Cobley, O'Hara, Chapman, and Cooke (2013) suggested that, in anthropometric terms, later maturers could expect to catch-up to their earlier maturing peers.

Muscle cross-sectional area, often related to absolute strength, was found by Van Praagh and Dore (2002) to be smaller in children than adults. Development in strength could also be explained by changes in the muscle fibres of adolescents as they mature. Muscle fibre type is considered to be genetically determined, however a reduction in type I fibres was found in males between the ages of 10 and 35 years (Jansson, 1996, cited in Van Praagh and Dore, 2002). Hypertrophy of type II muscle fibres after puberty (particularly in males) is thought to be due to increased testosterone secretion (Glenmark, Hedberg, & Jansson, 1992). Glenmark, Hedberg, Kaijser, and Jansson (1994) suggested that females were more dependent on training (specifically strength and speed training) in order to develop strength after puberty. For males, 13 years is a pivotal age for strength development and it is likely to occur following the attainment of PHV. Adolescent males gain explosive strength and muscular endurance (Beunen & Thomis, 2000), experience significant increases in peak torque forces (Degache, Richard, Edouard, Oullion, & Calmels, 2010) and have higher power outputs than females (Mikulic & Markovic, 2011).

Armstrong and Welsman (2000) highlighted the difference in the development of peak VO_2 between genders. Males experience an increase in peak VO_2 from childhood through adolescence to early adulthood, whereas peak VO_2 in females plateaus in adolescence. Differences in cardiac stroke volume were cited as a potential cause for this variance. Costill et al. (1985) reported peak VO_2 to be one of the best performance predictors for swimming (r = 0.80, for trained swimmers), and Armstrong and Welsman (2000) considered this a suitable measure of aerobic fitness in children aged 8 to18 years. That said, peak VO_2 does not provide a direct measurement of performance.

2.3.2 Effect of psychological and social factors

Despite the difficulties of collecting data on the physiological development of adolescents, it presents less of a challenge than the collection of data on their psychological development. Whilst children's interest in sport changes with maturation (Malina, 2007), little appears to be known about how, why and when they change. However, A. M. Williams and Reilly (2000) believed psychological skills such as motivation, cooperation, coping and attention to be essential to success in sport. Additionally, the social aspects of sport are also accepted to be an important contributing factor mediating the choice of children to both participate and remain involved in sport (Cope, Bailey, & Pearce, 2013; Light et al., 2013).

As with physical and physiological characteristics it has been intimated that social and behavioural changes are more closely related to biological, rather than CA (Nicholls, Polman, Morley, & Taylor, 2009; Sherar, Cumming, Eisenmann, Baxter-Jones, & Malina, 2010). This is predominantly due to the timing of the onset of puberty, since this has been hypothesised to affect behaviour in adolescents. The difficulties in the quantitative measurement of psychological factors with biological maturity have resulted in very little evidence of its relevance. However, as adolescents mature they have been reported to remain in sport for social, fun and health reasons over competition (Wold & Kannas, 1993) and drop out as they develop other interests (Figueiredo et al., 2009; Malina, 2007). It is thought that specialisation (Côté, 2004; Wiersma, 2000) and competition (Balyi & Hamilton, 2004b) can have detrimental psychological impacts if encouraged in children who are too young. This was supported by Wylleman and Reints (2010) who proposed that children potentially became frustrated and disinterested in sport when they were unsure of their roles and the demands placed on them in a competitive environment. They asserted that a child's understanding of role clarity and their responsibility in relation to the competitive environment only became fully developed by the age of 8 to 10 years. These relatively anecdotal comments with no substantial data, might identify a critical age or maturation status, and bring into question the rigidly-prescribed ages for the progression from deliberate play to deliberate practice in the DMSP of Côté (1999).

That children should not merely be considered as small adults (Balyi & Hamilton, 2004b; Maffulli & Helms, 1988) is as relevant to physical factors as it is to psychological and social factors. Thus the focus on intrinsically-motivated play activities in younger children is important to developing their self-determined motivation (Côté, Baker, & Abernethy, 2003). In one of very few quantitative studies, 11 to 12 years of age was proposed to be a critical point after which motivation in physical activity declined (Warburton & Spray, 2009). While not specifically related to any particular sport, the WHO has reported that as many as two thirds of children, aged 11 to 15 years, are not participating in the recommended levels of activity (Seabra et al., 2011). Even more ominously, only 19.7% of adolescents aged 13 to 15 years were reported by The Lancet to be participating in an hour of physical activity per day (Hallal et al., 2012). This emphasises the importance of understanding why children join in and maintain their involvement in sports.

2.4 Talent Identification and Development

In the continual pursuit of excellence in sport, TI and TD are two key areas of interest to NGBs, researchers, coaches and athletes (Pankhurst & Collins, 2013; Syed, 2010; Vaeyens et al., 2008). According to Abbott and Collins (2004) the effective identification and development of talent is imperative to maximising the limited resources available to athletes, if athletes are to realise their potential and remain involved in sport for the long term. Despite this view, Abbott and Collins (2004) concede that experts are seemingly unable to agree on what talent is and how reliably it can be measured. Burgess and Naughton (2010) defined talent as the rate at which an individual is able to acquire new skills. This aligns with the opinion of Gagné (2010) that gifts have a strong biological basis and that talents are the manifestation of gifts whereby athletes reach their full potential, through practice (Pankhurst & Collins, 2013). A. M. Williams and Reilly (2000) referred to TI as the process whereby current performers are recognised as having the potential, in sport-specific criteria, to become future elite athletes and the provision of a suitable, opportunity-rich, learning environment as TD.

There are a multitude of definitions for elite athletes (Swann et al., 2015) and consequently Rees et al. (2016) have recently distinguished between elite (senior international level) and super-elite (Gold medallists at Olympics or World Championships) athletes. The considerable volume of current publications and reviews on TID, despite the lack of a substantial body of evidence, suggests that this has become an emerging field of research. Many researchers have acknowledged that talent is dynamic and difficult to identify (Bailey & Morley, 2006; Martindale et al., 2005). This possibly also offers some justification as to why NGBs continue to base their selection policies on static one-off performances (Bailey & Morley, 2006; Côté & Hay, 2002), rather than on the potential individuals have to achieve at a higher level (Abbott & Collins, 2002; Bailey & Collins, 2013)

The purpose of TID is to develop successful adult athletes but it is known that predicting future talent in young children is seldom reliable (Abbott & Collins, 2004; Martindale et al., 2005). Furthermore there is anecdotal evidence illustrating that there are different routes to elite status (Côté & Hay, 2002) and there is also a risk of missing potentially talented young athletes if they are not involved in a specific sport during a TI session (Bailey & Morley, 2006). As a consequence some academics propose that, if future talent is to be successfully identified in children, NGBs should aim to avoid summative cross-sectional assessments and rather focus on creating environments conducive to longitudinal formative assessments (Bailey & Morley, 2006; Bloom, 1985). However, a key consideration for NGB's in conducting longitudinal assessments is to ensure the continued participation and interests of athletes to remain in their sports. This is particularly important because skill acquisition is non-linear and athletes should thus be considered as complex dynamic systems (Phillips, Davids, Renshaw, & Portus, 2010).

Numerous efforts have been made to construct TID models (Abbott & Collins, 2002; Bailey & Collins, 2013; Bailey & Morley, 2006; Gagne, 1985; Simonton, 1999; Vaeyens et al., 2006) but many of these have been criticised for the lack of practical application (Burgess & Naughton, 2010; Phillips et al., 2010). Simonton (1999) highlighted that talent changes over time, a factor he included in his generic model by ensuring that it was dynamic in nature. This factor, also evident in the model of Vaeyens et al. (2006), has been commended (Phillips et al., 2010). Although Simonton's (1999) model is theoretical, his formula allows for the inclusion of numerous weighted components, something that Hoare and Warr (2000) suggested were crucial to TI modelling. This is another aspect that has perhaps ensured the longevity of Simonton's (1999) model in this field. Valuable aspects of the model by Vaeyens et al. (2006) are that it is multidimensional and it does not de-select young children with potential. Furthermore, many models also appear to assume the linear progression of talented athletes from the period where they are first identified to eventual representation at elite level.

One of the most well-known models of TD, the Differentiated Model of Giftedness and Talent (DMGT) was originally proposed by Gagne (1985). Figure 2.5 illustrates the most recent evolution of his model known as the "Expanded Model of Talent Development" (EMTD), where he has distinguished between natural abilities and interests. Nevertheless, the essence of the concept remains unchanged. Gagné (2010) acknowledged that there are many unknowns with respect to the ideal environment for TD, but three catalysts (intrapersonal, environmental and chance) are likely to influence the process. Vaeyens et al. (2008) commended van Rossum and Gagné (2005) for highlighting the dynamic nature and multidimensional aspects that can influence talent in sport. However, the seeming lack of substantial evidence since then to understand how these factors interact means that such models remain largely untested within the sporting context.

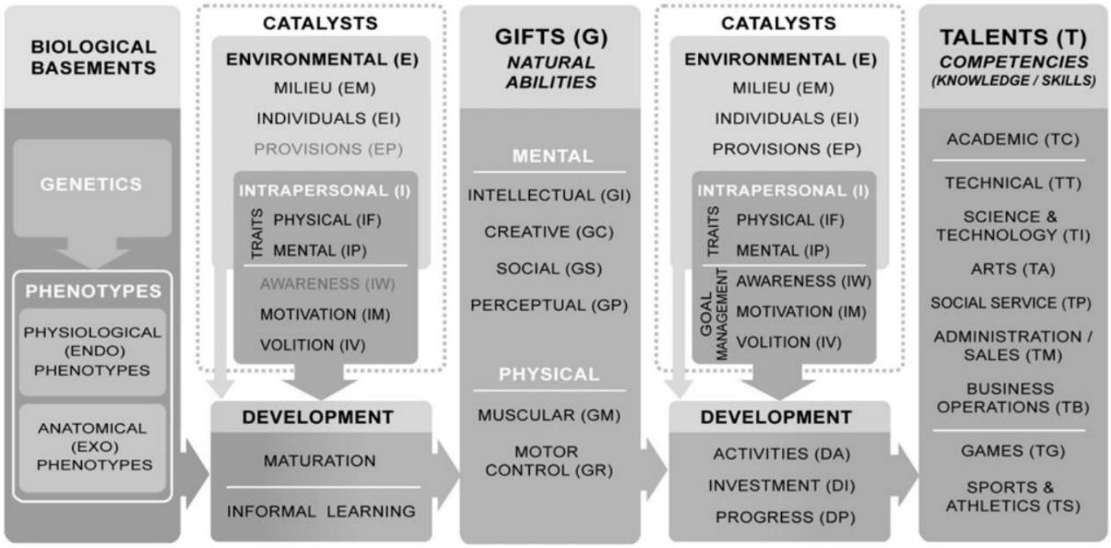


Figure 2.5 Gagné (2013)'s Expanded Model of Talent Development (EMTD), pp. 15.

A recent paper by Gulbin, Weissensteiner, Oldenziel, and Gagné (2013) has highlighted how rarely (<7%) Australian athletes progressed in a linear fashion through the various levels of representative sport, finding instead that as much as 83.6% of these athletes experienced a variable non-linear route into elite-level sport. Their work sheds light on how many athletes experience periods of progression, regression and even leave one sport to take up another, as was the case for athletes like Helen Glover (K. Williams, 2013) and Lizzy Yarnold (Bedi, 2014).

Recently, Bailey and Collins (2013) summarised what they felt were the most widely practised policies in selection, progression and exclusion of talent in a pyramid (Figure 2.6) termed the “Standard Model of Talent Development” (SMTD). They highlighted that it was often almost impossible for those athletes who were de-selected from a programme to re-enter it and that the policies of many sporting bodies remained biased towards athletes who specialised in their chosen sport early (Collins et al., 2011). Bailey and Collins (2013) argued that these circumstances created an illusion whereby successful athletes from TID programmes had arisen because of their selection, ignoring the invisible pool of potentially talented athletes that were never considered. This argument is of particular relevance in sports such as swimming where there is a lack of consensus as to whether it is an early or late specialisation sport (Balyi et al., 2014; Lang & Light, 2010; Sokolovas, 2006).

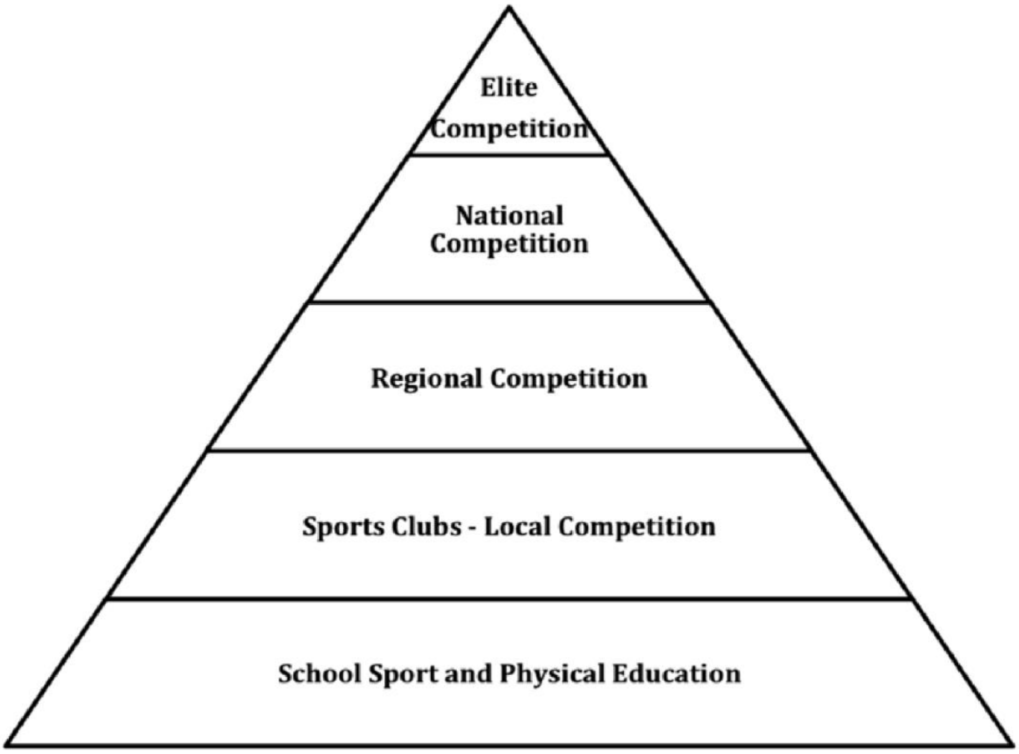


Figure 2.6 The pyramid model of Sports Development (Bailey & Collins, 2013), pp. 249.

2.4.1 Evaluation of Talent Identification

Although the aim of TI is to select promising pre-pubertal athletes and TD endeavours to support their progression to elite level (Pankhurst & Collins, 2013), these two processes should be considered together due to the evolutionary nature of talent (Abbott & Collins, 2004).

Practitioners involved in TI have been criticised for oversimplifying the process and their opinions are often given inflated status, whilst lacking supporting evidence (Pankhurst & Collins, 2013). Additionally, researchers have also been guilty of ignoring the validity and reliability of their TI testing procedures, as evidenced by the lack of repeatability of their results (Abbott & Collins, 2004).

This is possibly because many of the current TI practices rely on mono-disciplinary tests (Abbott et al., 2005), numerical scores and static variables, that are known to be unstable and non-linear (Bailey & Morley, 2006), with the common assumption that these measures will somehow predict future success. Multiple reasons have been identified as contributors to the poor predictive validity of common TI practices:

- Many tests fail to accurately represent the competition setting, often relying on generic physical assessments or closed skill tests that do not correlate well with the demands that athletes will face in a realistic competitive environment (Araújo, Davids, & Passos, 2007; Vaeyens et al., 2008).
- Well-rehearsed sport specific skills that have been gained through practice, often flatter to deceive as they coax potential selectors into believing that young, often pre-pubescent, athletes have talent. This is due to the speed at which their skills appear to have been acquired (Abbott & Collins, 2002; Abernethy & Wood, 2001; A. M. Williams & Hodges, 2005).
- Despite the unstable nature of anthropometric and physical characteristics (Abbott et al., 2005; Vaeyens et al., 2008), numerous NGBs continue to favour them as measures of potential talent (Lidor, Côté, & Hackfort, 2009), whilst ignoring other relevant parameters (Abbott & Collins, 2002).
- The use of anthropometric measures are complicated by the fact that athletes are often assessed based on their CA rather than their BA (Reilly et al., 2000).
- The RAE, a well-reported phenomenon (Baxter-Jones, 1995; Musch & Grondin, 2001), has not been given due consideration in a number of TI assessments. Although the birth date effect was reported to be unimportant in a TI study on football (Carling, le Gall, Reilly, & Williams, 2009), it is often the case that at junior level, the older athletes within an age class do have a temporary advantage that has been mistaken as talent (Burgess & Naughton, 2010).
- TI is often based on cross-sectional studies (Abbott & Collins, 2004) even though many of the physical components being assessed are

likely to change or may not be as important at the elite level (Lidor et al., 2009). As a result Helsen et al. (2000), Helsen et al. (2005) and Vaeyens et al. (2006) all advocate a longitudinal approach to TI, rather than rewarding instant success.

- There has also been a drive to pinpoint a single gene that would characterise the perfect athlete (Baker & Horton, 2004). Notwithstanding the ethical implications thereof, this flawed view ignores the contribution of the environment in the nature versus nurture argument (Scott et al., 2005).
- Many TI practices have been criticised for underestimating or negating the effect of psychosocial factors that influence the path to elite-level performance including, access to facilities (Bloom, 1985) and the role of parents (Bloom, 1985; Côté, 1999; Martindale et al., 2005).
- The intrinsic motivation of young pre-teen athletes to participate and compete in a particular sport is often overlooked. Young athletes who are intrinsically motivated and committed to high levels of training are more likely to remain involved in the sport in the long term (Hany, 1996). Collins and MacNamara (2011) criticised a review by Phillips et al. (2010) for failing to consider the importance of such psycho-behavioural constructs.

While the primary purpose of TI is to target individuals with the potential to become elite performers, Abbott and Collins (2004) stressed the importance of psychological factors in maintaining success at the highest level, something that Martindale et al. (2005) referred to as staying power. These factors included motivation and commitment to training in order to deal with the increased demands (both intrinsic and extrinsic) placed on athletes and the ability to maintain their focus amidst the many distractions associated with elite-level performance. However, as Pankhurst and Collins (2013) point out, psychological factors are difficult to assess.

The consequences of poor TI processes result in many late developing athletes with potential being de-selected, often leading to dropout (Collins et al., 2011), as the processes often result in exclusivity rather than inclusivity (Burgess & Naughton, 2010). TI systems that rely solely on competition results at a young age often place additional stresses on athletes, as the pressure and expectation to perform from coaches, parents and even NGBs becomes overwhelming (Martindale et al., 2005; Simonton, 1999). Those athletes that do achieve early success, usually through early maturation, are often given an artificially inflated status that may affect their further education and well-being in the long run (Fraser-Thomas, Côté, & Deakin, 2008; Wall & Côté, 2007; Wiersma, 2000). Through choosing to specialise early, they commit to a pathway that often only leads to transient success and/or dropout (Bompa & Haff, 2009). This led Moesch, Elbe, Hauge, and Wikman (2011) to propose that effort, rather than results, be rewarded and that practitioners place less emphasis on competition in the early stages of athlete development.

One of the outcomes of TI is that it inevitably leads to athletes choosing to specialise early in a sport in which they are believed to show potential. This is often due to the fact that successful performance is prioritised over unrealised potential in the long term (Martindale et al., 2005). The practice of early TI persists even in late specialisation sports where it is unnecessary and often ineffective (Vaeyens, Güllich, Warr, & Philippaerts, 2009). The well-publicised success of Helen Glover in the 2012 UK Olympic rowing team, after her response to an advertisement as part of the "Sporting Giants" campaign that was posted by the UK talent team (K. Williams, 2013), holds promise for promoting later identification of talent and late sport specialisation as a viable approach. This campaign has now been superseded by "#DiscoverYour Gold" where it has been extended to include more late specialisation sports (UK Sport, 2016).

In conclusion, a multidimensional approach to both TI and TD would be most efficient and effective, with consideration for both performance and environment (Abbott & Collins, 2004; Rees et al., 2016). Bailey and Morley (2006) pointed out that interested athletes are self-selected but talented ones are not. There is agreement among many of the academics that more longitudinal evidence is needed rather than the current reliance on anecdotal reports (Bailey & Morley, 2006; Burgess & Naughton, 2010; Phillips et al., 2010). However, Abbott and Collins (2004) criticised the tendency of many researchers to focus on the theoretical rather than the applied approach that practitioners are more likely to accept.

2.5 Long-term observational studies

Studies in sport science are commonly either observational or experimental in approach. Experimental studies are generally cross-sectional in design whereas many observational studies are often longitudinal (Thomas, Nelson, & Silverman, 2011). The choice of approach depends predominantly on the purpose of the study, with many researchers preferring the experimental approach because of the shorter time-scale (Vaeyens et al., 2008) and the opportunity to define and control potential variables (Hellard et al., 2005). As a consequence, considerably fewer long-term studies have been undertaken to date, but examples include Allen et al. (2014); Costa, Marinho, Bragada, Silva, and Barbosa (2011) and Costa, Marinho, Reis, Silva, Marques, et al. (2010) in swimming, Philippaerts et al. (2006) in soccer, Elferink-Gemser, Visscher, Lemmink, and Mulder (2007) in field-hockey and Matthys et al. (2013) in handball.

While the terms longitudinal and tracking studies are often used interchangeably to describe long-term observational studies, for the purpose of this review, they will be considered separately. The key distinguishing feature used to discern longitudinal studies is that they follow a single population of the same individuals over a period of time. Tracking studies, on the other hand, track the progression of events that occur over time without the restriction of measuring the same athletes. Table 2.2 and Table 2.3 summarise tracking and longitudinal studies conducted in swimming to date.

Table 2.2 Summary of tracking studies conducted on swimming

Author (date)	Purpose	Skill level	Sex	Statistical methods for performance progression analysis	Number of years over which data was sourced
Chatterjee and Laudato (1996)	Comparative analysis of world record times for men and women in swimming, running and skating	Elite	Male and Female	Regression analyses	70
Heazlewood (2006)	Evaluation of the power of mathematical models to predict future performance.	Elite	Male and Female	Regression analyses	4
Thibault et al. (2010)	Tracking of the evolution of the gender gap	Elite	Male and Female	Regression analyses	111
Stanula et al. (2012)	Prediction of the development of freestyle swimming performance	Elite	Male and Female	Regression analyses	112
O'Connor and Vozenilek (2011)	Analysis of the effect of equipment on swimming performance times	Elite	Male and Female	None	20
Saavedra, Escalante, Garcia-Hermoso, Arellano, and Navarro (2012)	Comparison of pacing strategies in the 200 and 400 m Individual Medley.	Elite	Male and Female	None	12
Wolfrum, Knechtle, Rüst, Rosemann, and Lepers (2013)	Investigate the effects of course length on freestyle swimming speed for men and women at national and international level as well as changes in freestyle swimming speed between 2000 and 2012.	Elite/Sub-Elite	Male and Female	Regression analyses	12
Wolfrum, Rüst, Rosemann, Lepers, and Knechtle (2014)	Investigate potential changes in breaststroke swimming performance across years in national and international athletes and compare potential changes in freestyle swimming performance.	Elite/Sub-Elite	Male and Female	Regression analyses	17
König et al. (2014)	Investigate the age of finalists (top 8) of Olympic Games and World Championships for all race distances and strokes between 1992 and 2013.	Elite	Male and Female	Regression analyses	21
Knechtle et al. (2016)	Investigate the age of winners of Olympic Games and World Championships for all race distances and strokes between 1992 and 2013.	Elite	Male and Female	Neural Network and non-linear regression	21

Table 2.3 Summary of longitudinal studies conducted on swimming

Author (date)	Purpose	Skill level	Sex (age in y±SD)	Duration of study (No. of times measured)	Sample size (sex)	Statistical methods for performance progression analysis	Main findings
Baxter-Jones, Goldstein, and Helms (1993)*	Model aerobic power in pre-mid and post pubertal youth from a range of sports (including swimming)	Intensively trained	M and F (8-16#)	3 y (3)	At start: 453 (F=222,M=231) By completion: 271 (F=126,M=145)	Repeated-measures ANOVA	Aerobic power related to physical growth and in males to pubertal development. Different sports showed different patterns of aerobic power with age, dependent on training.
Baxter-Jones et al. (1995)	To determine whether physical and physiological characteristics of athletes were the results of training during adolescence.	Intensively training, as expected national level in future	M and F (9-16#)	3 y (3)	453 (F=222, M=231)	None within sport, ANOVA's between sports	Swimmers and tennis players had advanced sexual maturation compared with gymnasts. No evidence that training affected maturation.
Mujika et al. (1995)	To determine the relationship between components of training and variations in performance across a season.	Elite	Not reported	2 y (3-performance 8-training)	18 (F=8, M=10)	Regression analyses	Training intensity, rather than training volume or frequency, key to performance improvement in swimming.

Stewart and Hopkins (2000)	Determine the consistency of performance for swimmers within and between competitions	National	M (15.1±1.3 to 17.9±2.7) F (14.8±1.3 to 15.8±1.9)	20 days (2)	Junior champs (F=162, M=149) Open Champs (F=104, M=117)	Mixed linear modelling	Swimmers are stroke specialists, not distance specialists.
Edelmann-Nusser, Hohmann, and Henneberg (2002)	Demonstrate that adaptive behaviour of an elite female swimmer could be modelled using non-linear mathematical method of artificial neural networks.	Elite	F (Not reported)	2.8 y (19)	2	Neural Network	The neural models were very accurate in predicting the female 200 m backstroke performance time at the 2000 Olympic Games.
Avalos, Hellard, and Chatard (2003)	Model relationship between training and performance using a pre-existing linear mixed model.	Elite	M and F (22±3)	3 y (24 – training, 8 wks before to each annual performance, 3-performances)	13 (F=6, M=7)	Mixed linear modelling	Described a multi-annual model for training of swimmers to improve performance.
Trewin, Hopkins, and Pyne (2004)	Analyse variability in performance of Olympic swimmers. Measure progression of swimmers between world ranking and Olympic performance Estimate magnitude of performance improvement required to improve chances of winning a medal	Elite	M and F (ages not reported)	Approx. 9 months (2)	407 (F=183, M=224)	Mixed linear modelling	Improvements of 0.6% are necessary for top ranked swimmers to increase their chances of medalling.
Pyne et al. (2004)	Competitive performance progression in the lead up to the Olympic games	Elite	M and F (15-33[#])	12 months (3 separate competitions)	51 (F=26, M=25)	Mixed linear modelling	Improvements of 1.0 to 1.4% in performance time required by elite swimmers in pre-Olympic year to increase chances of medalling.

Hellard et al. (2005)	Effect of intensity and volume of training on long and short term performance.	Elite	M and F (19.3±2.3)	4 y (8-16, 2-4 per y, training 4, 1 per season, competition)	7 (F=4, M=3)	Regression analyses	Low intensity training should comprise 40 to 50% of training volume in the taper phase.
Sokolovas (2006)	Comparison of top 100 swimming times of US swimmers at different ages.	Sub-Elite and Elite	M and F (ages not reported)	5 y (Unknown)	1000 (F=500, M=500)	None	Approx. 10% of U10 swimmers were still ranked in the top 100 at the age of 17 to 18. Elite-level females change events until 13 to 14 years of age. Elite-level males change events until 15 to 16 years of age.
Anderson, Hopkins, Roberts, and Pyne (2008)	Evaluate the relationship between fitness test measures and competition performance	Elite	M and F (ages not reported)	3.6 y (7)	40 (F=16, M=24)	Mixed linear modelling	The combination of fitness and technique are important in order to improve performance
Lätt et al. (2009a)	Assessment of physical, physiological and biomechanical development in male swimmers.	Trained (2-3 y)	M (13±1.8)	2 y (3)	29	Regression analyses	Improvement in swimming, mainly related to increases in height and arm span, as well as sport specific VO_2
Lätt et al. (2009b)	Physical, physiological and biomechanical maturation in female swimmers.	Trained (3.7± 1.8 y)	F (12.7±2.2)	2 y (3)	26	Regression analyses	Improvement in swimming, mainly related to biomechanical factors in young female swimmers. v, SI, SR, SL
Costa, Marinho, Reis, Silva, Marques, et al. (2010)	Analysis of the stability of world ranked male swimmers performance times over 5 years	Elite	M (ages not reported)	5 y (4)	477	Repeated-measures ANOVA	World-ranked swimmers' performances improved markedly between the 2003 and 2008 seasons in freestyle.

Costa et al. (2011)	Analysis of the progression of performance of adolescent swimmers careers who later became elite	Sub-Elite	M (12-18#)	6 y (6)	242	Repeated-measures ANOVA	By 18 years of age, male swimmers need to improve by 14-19% in order to achieve elite level. 16 years of age is the point at which it becomes possible to predict adult performance
Maszczyk et al. (2012)	Test and compare whether regression models or artificial neural networks predicted sport results more precisely.	Trained Sub-Elite (4 y)	M (12±0.5)	1 y (Not Reported)	189	Neural network and non-linear regression	Neural models determined to be potentially superior to regression models. They offer better optimisation potential in predicting results; could be used for athlete recruitment and selection processes.
Costa, Bragada, Mejias, et al. (2013)	Training effects on energetics and performance in swimming	National	M (21.0±3.3)	1 y (3)	9	Non-parametric repeated-measures ANOVA	Energetic variables in elite swimmers do not adapt following several months of swimming training.
Morais, Marques, Marinho, Silva, and Barbosa (2014)	Model latent growth curve of performance and biomechanics over a season	Junior National	M (12.33±0.65) F (11.15±0.55)	38 weeks (4)	30 (F=16, M=14)	Regression analyses	High inter and intra-subject variability in performance growth. Gender had significant effect at baseline and during performance growth
Allen et al. (2014)	Produce estimates of age-related progression that can serve as benchmarks for talent development.	Elite	M and F (ages not reported)	Multiple y (Multiple)	683	Mixed linear modelling	Men achieve peak performance later than women. Peak performance occurred at later ages for shorter distances in both sexes. Men and women have similar duration of peak performance (2.5±1.5 years).

no SD reported, * No Performance data

2.5.1 Tracking studies

Tracking studies tend to be retrospective. As a consequence they often include a considerable volume of historical data, with the studies of Stanula et al. (2012), using data from all the freestyle swimming events at the Olympic games between 1896 and 2008, and Thibault et al. (2010), using data from four Olympic disciplines, including athletics, swimming, speed skating, track cycling and weightlifting, spanning more than 100 years. Recent research by König et al. (2014) and Knechtle et al. (2016) have investigated the age of finalists and of champions respectively in all strokes at the Olympic Games and World Championships between 1993 and 2013. The rationale for undertaking tracking studies (Table 2.2) could include one or more of the following:

- to quantify long-term changes in performance,
- to construct and/or evaluate models,
- to predict future performance,
- to identify correlations between regulatory and technological advancements and performance, and
- assist in optimising coaching practices.

The description of the long-term improvement in performance that highlight differences between genders was a purpose of one of the first tracking studies that reviewed a few cyclical sports, including swimming (Chatterjee & Laudato, 1996). Quantifying the progression of performance has been a dominant theme of many subsequent studies (Knechtle et al., 2016; König et al., 2014; Stanula et al., 2012; Thibault et al., 2010).

One of the advantages of large datasets, a characteristic of tracking studies (Table 2.2), is to provide the opportunity to develop statistical models of performance (Chatterjee & Laudato, 1996) or to identity which pre-existing models best fit the empirical data (Heazlewood, 2006). Another main reason for modelling past performance, is to predict future performance, another key use of tracking studies (Stanula et al., 2012).

Another purpose of some tracking studies has been to attribute reasons for unexpected changes in performance. Examples include unparalleled improvement in performances in woman compared with men, the effects of doping (Thibault et al., 2010), changes to swimming regulations (e.g. turns, starts, pool depth) and swimsuit design (O'Connor & Vozenilek, 2011). Other tracking studies have focused on the applied value to coaches such as identifying selection criteria (Heazlewood, 2006) and evaluating successful pacing strategies (Saavedra et al., 2012).

2.5.1.1 Evaluation of tracking studies

Tracking studies enable scientists to consider the development or stability of performance over time as a result of the long-term effects of physical development, new training methods and advances in technology that would not be possible in a cross-sectional setting (Costa, Marinho, Reis, Silva, Marques, et al., 2010). However, while the correlations of varying factors can be described through the use of tracking data, the actual cause and effect of these variations remain largely unknown.

Studies in which the data are sourced after the event, by their nature, have restricted methodology where many preferable variables may not have been recorded or controlled, as would be the case in a cross-sectional study (Hellard et al., 2005). As a consequence, the conclusions drawn from tracking studies can be limited, questionable or even contradictory (Liu, Paul, & Fu, 2012). The design of the O'Connor and Vozenilek (2011) tracking study in which the authors used a comparable “control” sport, namely track athletics, was a practical novel solution as a means to compare trends and suggest potential reasons for deviations from the expected trend.

In addition, tracking studies can suffer from incomplete or biased data sets where, for example Chatterjee and Laudato (1996) noted that there were significantly more data available for male athletes than females, as a result of males having a longer history of competition. While it has been the goal of researchers to derive predictive models of performance based on the tracking of past performances, regular changes and updates to the rules of sports like swimming, make accurate modelling more challenging (Stanula et al., 2012).

There have been a number of approaches to predictive modelling using, amongst others, physiological, mathematical or probability strategies, none of which yet effectively predict future performances (Liu et al., 2012). These authors suggest that until all factors which influence human performance are accounted for, modelling is unlikely to produce accurate estimations. However, besides being extremely difficult to achieve, the practicality of the application of such a model to coaches and athletes is highly questionable. While models of best fit, which are based on statistical computations, have proven to be effective for short-distance events, Stanula et al. (2012) highlighted their difficulty in predicting the outcome of longer distance events, where unaccounted variables are likely have a greater effect. Vaeyens et al. (2008) proposed that models should be based on factual parameters, rather than computational data collected from historical performances, for the purposes of TI.

2.5.2 Longitudinal studies

Similar to tracking studies, longitudinal studies can be retrospective, however they also allow researchers an opportunity to follow a planned test-retest scenario, but without the intervention approach of experimental studies. Perhaps the most notable difference in comparison with tracking studies is that they are used to observe potential changes in the same population of athletes over a considerably shorter period of time. Table 2.3 summarises the rationale for undertaking longitudinal studies that include:

- predicting the age at which athletic performance improves the most,
- estimating the progression and variability of athletes' performances within and between competitions,
- predicting which athletes are likely to become finalists and medallists at major competitions,
- testing and refining training models using real data to optimise future performance and
- assisting coaches with the setting of realistic goals and to devise training programmes that are individually tailored to specific needs of their athletes.

Trying to separate the performance gains that are made by athletes due to training as opposed to natural growth and development has been one of the most important debates. Malina (1994a) highlighted the need for longitudinal studies to better understand how and when athletes' performances progressed in terms of physical development and training. Numerous studies have therefore considered how changes in physical, physiological and biomechanical parameters affect performance throughout puberty (Baxter-Jones et al., 1993; Lätt et al., 2009a, 2009b). One of the purposes of these studies is to help coaches gain perspective on the success of early-maturing athletes and enable them to provide appropriate career advice (Costa et al., 2011). Longitudinal studies such as that of Sokolovas (2006) enable the performance of individual age-group swimmers to be tracked as they have progressed through their careers. They have offered an insight into how relatively few of the early-maturing athletes who dominated their age group championships developed into adult elite athletes.

The majority of longitudinal studies in swimming have focused on elite athletes (Table 2.3). These studies have allowed the evolution and consistency of individual performances to be analysed (Allen et al., 2014; Anderson et al., 2008; Costa, Bragada, Mejias, et al., 2013; Stewart & Hopkins, 2000; Trewin et al., 2004). This has enabled the variability of performance between and within competitions throughout a season with a variety of rationales, including the assessment of the discrepancies between world rankings and performance in major international competitions (Trewin et al., 2004) and the evaluation of the effects of training on the performance of individual swimmers (Anderson et al., 2008). Studies such as these allow practitioners to predict the potential finalists and eventual medallists at these championships and determine realistic individual performance goals (Allen et al., 2014; Allen, Vandenbogaerde, Pyne, & Hopkins, 2015; Avalos et al., 2003; Pyne et al., 2004).

Another function of longitudinal studies is in the testing of existing models with time-based data collected for this purpose (Avalos et al., 2003; Hellard et al., 2005). Physiological models (Banister, Calvert, Savage, & Bach, 1975) and neural pathway theoretical models (Edelmann-Nusser et al., 2002; Maszczyk et al., 2012; A. J. Silva et al., 2007) have been constructed using cross-sectional studies. These physiological models have limited value in predicting future performance without the refinement possible from longitudinal data (Hellard et al., 2005).

2.5.2.1 Evaluation of longitudinal studies

The sheer number and magnitude of disadvantages associated with longitudinal studies is a leading factor as to why so few are ever initiated. Compared with an experimental or cross-sectional approach to research, the most obvious deterrent to undertaking longitudinal studies is that they tend to take a considerable amount of time. Currently these studies generally follow one of three approaches: between seasons, within season and across adolescent development. Although within season studies have been as short as 20 days (Stewart & Hopkins, 2000), between season and adolescent studies are considerably longer. Researchers are often limited by the number of seasons they can record for a study, because the length of each season usually spans an entire year. Consequently, most between season studies have thus far not exceeded three years (Table 2.3). This can reduce the rigour that trends can be determined and if conducted using an adolescent sample, would not sufficiently span the process of maturation. Furthermore, long-term studies potentially require significant funding which may be difficult to justify and could be subject to withdrawal (Baxter-Jones et al., 1995).

Longitudinal studies often suffer from a high participant dropout rate. This means there is a need to build sufficient capacity into the initial study design because of the risk that small final sample sizes would have on reliability. Reasons for participants pulling out of study typically include illness, injury, overtraining and lack of support (Baxter-Jones et al., 1995; Costa et al., 2011).

Although longitudinal observational studies generally have good external validity, this is at the expense of internal validity where there is often considerable variability between participants and a bias in those that eventually complete the study. Furthermore, this variability can limit the ability to discern subtle trends above any background noise (Costa, Bragada, Mejias, et al., 2013). Unlike cross-sectional studies where there would usually be a prescribed schedule, Hellard et al. (2005) suggested that the lack thereof, as well as an absence of random sampling in observational studies, reduces the validity of the results. Anderson et al. (2008) highlighted the difficulty in including a comparable control group of athletes for longitudinal studies because of their focus on striving towards attaining sporting success. This factor further exacerbates the validity of this type of study. Additionally, Costa, Bragada, Mejias, et al. (2013) noted that researchers were often forced to work with “convenient” samples within the population, as coaches and athletes were often focussed on their own independent preparation and training. The authors went on to highlight the need for improved data collection procedures that minimised the disruption to the training and performance of the participants.

Observing the development of adolescent athletes can only be achieved through a longitudinal approach however there are many confounding variables that affect their performance. Much of the improvement in the performance of pubertal swimmers can be attributed to physical development and growth (Baxter-Jones et al., 1993; Lätt et al., 2009a, 2009b) and despite early maturers often outperforming their later maturing counterparts, the late maturers often catch up and surpass their early-peaking peers (Costa et al., 2011). Consequently, these authors suggest that is very difficult to predict future success before the age of 16 years. The studies by Baxter-Jones (1995); Costa et al. (2011); Lätt et al. (2009a, 2009b) are among the few longitudinal studies that have considered the development of non-elite swimmers through adolescence (Table 2.3). Although they have provided some useful insights, none have delivered the level of detail now possible through mixed-linear modelling.

Despite the many disadvantages, longitudinal studies facilitate the measurement of changes in an individual athlete’s performances over time, answering questions not possible using experimental designs (Malina, 1994a). Many authors agree that the advantage of longitudinal data in predicting future success and identifying talent outweighs the costs involved (Costa et al., 2011; Vaeyens et al., 2008). The ability to effectively evaluate training and thereby design personalised programmes is another advantage that may only be possible using this approach (Costa, Bragada, Mejias, et al., 2013). Similar to tracking studies, longitudinal studies are also of value in refining predictive performance models (Avalos et al., 2003).

2.5.3 *Evaluation of the statistical approaches used in long-term studies*

There are numerous statistical methodological approaches that have been used by researchers to investigate athletic performance from both tracking and longitudinal studies (see Tables 2.2 and 2.3). Of the few long-term observational studies that aimed to describe athletic performance progression, the most commonly used methodologies included:

- Regression analyses
- Repeated-measures analysis of variance (ANOVA)
- Neural networking
- Mixed-linear modelling.

2.5.3.1 *Regression analyses*

As one of the first methods chosen to analyse the progression of athlete performance data, regression analyses have also been the most widely used in long-term observational studies on swimming. There are numerous approaches to regression analyses where some are appropriate for longitudinal, repeated-measures data (see Table 2.3) and others for tracking, independent data (Table 2.2). In swimming, some regression analyses have been linear (Heazlewood, 2006; Lätt et al., 2009a, 2009b), but most performance data are non-linear and hence polynomial regressions from second order up to 17th order (Wolfrum et al., 2014) have been most frequently used.

The most common concern with regression analyses is the goodness of fit. Numerous approaches have been developed to improve fit including the addition of variables (Goldstein, 1986) and increasing the order of the polynomial regression (Wolfrum et al., 2014). Recently this has led to some arguments that overfitting has given too much emphasis to confounding variables such as the 4 yearly patterns in performance prevalent in Olympic cycles (Pyne et al., 2004; Stanula et al., 2012) and temporary performance gains as a result of advancements in swim suit design (O'Connor & Vozenilek, 2011). Reducing the length of time over which regressions are performed, can overcome problems with poor fit, but this in itself is a limitation (Edelmann-Nusser et al., 2002; Maszczyk et al., 2012).

2.5.3.2 Repeated-measures analysis of variance (ANOVA)

To date, two main research groups have made use of repeated-measures ANOVA's to analyse the progression of swimming performance from longitudinal datasets (Baxter-Jones et al., 1993; Baxter-Jones et al., 1995; Costa, Bragada, Mejias, et al., 2013; Costa et al., 2011; Costa, Marinho, Reis, Silva, Marques, et al., 2010). Although this approach can measure the stability or change in performance over time, it is not possible to quantify the rate of this change. However, it is the constraints and assumptions that underlie this statistical procedure that restrict its applicability. For example, violations of sphericity in the progression of performance data are common (Hopkins, 2003), the time intervals between repeated measures must be fixed and performers without complete datasets cannot be included in the analysis (Hoffman, 2015).

2.5.3.3 Neural Networks

With the advancement of computational power, statistical software and access to vast datasets, this methodological approach is gaining in popularity for both cross-sectional (A. J. Silva et al., 2007; Wilk et al., 2015) and long-term observational studies (Tables 2.2 and 2.3). Currently it is common to use these large datasets to pre-programme the system so that it can be used to predict future performances. In this context neural networking is more accurate at predicting performance than regression analyses (Edelmann-Nusser et al., 2002; Maszczyk et al., 2012).

Despite the promise of this approach, it is not without its drawbacks. Firstly, the requirement of large datasets is often beyond that of a single athlete to produce. Hence, additional athletes that are similar in almost every way (e.g. level and training load) are required in order to pre-train the system (Edelmann-Nusser et al., 2002). Secondly, the creation of such networks is hugely complex and can therefore be very time consuming and also the outputs are often less accessible to athletes and coaches (Lees, 2002).

2.5.3.4 Mixed-linear modelling (MLM)

Like neural networks, MLM's have been gaining in popularity in swimming (Table 2.3) and other sports including track and field (Hollings, Hopkins, & Hume, 2014), triathlon (Malcata, Hopkins, & Pearson, 2014) and cycling (Paton & Hopkins, 2006). Although not a traditional longitudinal study, MLM's have also recently been used to interpret the pacing strategies of male (Lipinska, Allen, & Hopkins, 2016b) and female (Lipinska, Allen, & Hopkins, 2016a) long-distance swimmers. These two studies show an almost unique application of MLM's in swimming where the laps, rather than repeated performances, were used as repeated measures.

Similar to repeated measure ANOVA's, MLM's also require repeated measures data and thus this statistical procedure is not relevant to tracking studies. Nevertheless, MLM's are an attractive option in the analysis of longitudinal datasets that violate the constraints of repeated-measures ANOVA's (Table 2.3). In addition to their flexibility in the use of incomplete datasets and variable time intervals, they have another advantage over repeated-measures ANOVA's. Their greater statistical power allows for rates of progression to be quantified (Hoffman, 2015). Unlike linear regression analyses, where confounding variables can prove to be problematic and predictive powers have been questionable, thus far, MLM regression analyses have proved to be superior (Allen, Vandenbogaerde, Pyne, et al., 2015).

Even though MLM's negate almost all of the constraints of the other three statistical procedures, MLM's are however not without their own issues. They still require fairly large parametric datasets, but not on the same scale as neural networks (Hoffman, 2015). Similar to neural networks, the computational procedures are also complex, however the outputs from MLM's tend to be more comprehendible for coaches and athletes (Allen et al., 2014).

2.6 Considerations for swimming through childhood

Swimming, like running, skating and rowing, is a cyclic sport meaning that the athlete's goal is to cover the race distance in the shortest possible time. This factor means that regular individual performance measures are possible, making swimming an ideal sport for longitudinal and/or tracking studies. Excluding the marathon (10 km) that is an open water event, modern Olympic swimming events are swum in long course (LC) pools and cover distances from 50 m to 1500 m for males and 50 m to 800 m for females (International Olympic Committee, 2013b). The World Cup and World Junior Swimming Championships (females 15-17 y and males 16-18 y, Figure 9.2) are competed over the same distances as the Olympics for males and females respectively (Fédération Internationale de Natation, 2013a). Surprisingly, the only FINA international competition contested in a 25 m pool, the Short Course (SC) World Championships, is held for adults only, covering the same events as all the other competitions.

There are four recognised swimming strokes, two long-axis (front crawl and backstroke) and two short-axis strokes (breaststroke and butterfly) with all races also comprising starts, turns and finishes (Maglischo, 2003). Breaststroke is the oldest stroke, from which both butterfly, the youngest stroke, and backstroke evolved (Maglischo, 2003). Front crawl appears to be the most widely researched and most popular stroke in swimming, being the fastest (Kennedy, Brown, Chengalur, & Nelson, 1990) and the most efficient (Barbosa et al., 2006) of the four strokes. It is often the stroke of choice in the freestyle event, where swimmers are permitted to swim any style, except in medley events (either individual or relay) where they may swim any style excluding backstroke, breaststroke or butterfly (Federation Internationale De Natation, 2008).

There are four main parameters of a swimming performance that are commonly measured, namely velocity (v), stroke rate (SR), stroke length (SL) and stroke index (SI). Originally v was synonymous with performance time over the total race distance (East, 1970). However, it was soon realised that the inclusion of starts and turns meant that v changed dramatically over the course of the race (Craig & Pendergast, 1979), and it is now standard to measure v as the time taken between two set points in the mid-section of the pool. It is reported that *v* decreases as race distance increases (Arellano, Brown, Cappaert, & Nelson, 1994). SR, also referred to as stroke frequency by some authors (Barbosa, Costa, et al., 2010; Grimston & Hay, 1986; Pelayo, Wille, Sidney, Berthoin, & Lavoie, 1997), was first defined by East (1970) as the number of strokes per second. SL, the distance covered in one arm cycle (East, 1970), is calculated as, SL = *v*/SR. SI, the product of SL and *v* (Costill et al., 1985), has become favoured as a measure of swimming technical efficiency (Jürimäe et al., 2007; Lätt et al., 2010).

2.6.1 Athlete development in swimming

Based on the increasing pressure for nations to develop talent, in an effort to win medals on the global stage, many sporting NGBs have redirected their attention to increasing youth participation and performance levels in all sports, including swimming (Barreiros et al., 2014; De Knop & De Martelaer, 2001; Light et al., 2013). In the UK, the ASA is one of many NGBs to have fully adopted LTAD (Grange & Gordon, 2004) and continues to endorse and promote it (Amateur Swimming Association, 2010; Freeman, 2016). They have however been criticised for promoting performance over participation (Johnston et al., 2012; Lang & Light, 2010).

The improvement in performance of British swimmers between the Sydney (2000) and the Beijing (2008) Olympic Games does however provide a significant argument in support of LTAD. From winning no medals at the Sydney Olympic Games in 2000, prior to LTAD, British swimmers went on to win two bronze medals by the 2004 Athens Games and, by Beijing (2008), had won a total of six medals, comprising two gold, two silver and two bronze (International Olympic Committee, 2013c). Despite the relatively disappointing performance of British swimmers at the London 2012 Olympics where only three medals were won, the official performance debrief (British Swimming & The ASA, 2013a) did not identify long-term athlete development as a potential cause for the poor results. In general, the report suggested that the programmes in place were appropriate but that there were potential issues with competition planning and time trials, as well as psychological issues related to social inhibition and media distraction.

Lang and Light (2010) highlighted concerns of elite and novice coaches of "The Swimmer Pathway", an interpretation of LTAD, and its effect on swimming technique and the motivation of swimmers. In pursuit of meeting the prescribed mileage for training, many elite coaches felt that novice coaches were ignoring or severely restricting the amount of technical development, emphasising too much volume of training. This could lead to overuse injuries, burnout and ultimately to swimmers dropping out (Salguero, Gonzalez-Boto, Tuero, & Marquez, 2003). The major criticism of "The Swimmers Pathway" is that it marginalised late starters to the sport or athletes who did not commit to recommended training loads. This highlighted the problem with a generic model of LTAD being interpreted by the ASA to create "The Swimmer Pathway" and in turn, the individual coach's interpretation of prescribed frequencies and volumes of training, that seemed to be based on the unsubstantiated views of Sweetenham (1999). However subsequent peer-reviewed research (Faude et al., 2008; Laursen & Jenkins, 2002) has found that endurance athletes were able to improve their sport-specific performance using high-intensity interval training rather than the high "breakpoint volume" prescribed for swimmers by the Amateur Swimming Association (2003) from the "Training to Train" phase upwards. In addition, Arellano (2010) categorically disagreed with the seemingly widespread use of excessive training volumes by ASA swimming coaches as a means to develop stroke technique in young swimmers, citing the low retention rate of top age group swimmers in long term elite programmes, as a consequence.

A further criticism of the ASA was that "The Swimmer Pathway" appeared to be contradicted by their competition entry requirements (Lang & Light, 2010). In an attempt to discourage coaches from focussing their training on the development of power for sprint performances in young athletes (10 – 11 year olds), the ASA originally dropped 50 m events for the youngest category of age group swimmers and opened up the 800 m and 1 500 m to them. The ASA have now adjusted the minimum age for all events and make no mention of distances (Amateur Swimming Association, 2016). This suggests that the original decision was possibly short-sighted, as it meant that the youngest age-group swimmers would have been required to complete significant endurance training, despite "The Swimmers Pathway" advocating that the training for swimmers in the "Swim Skill" phase focus on technical development (Amateur Swimming Association, 2003). Nevertheless, both strategies were discordant with the recommendations of Balyi and Hamilton (2004b) that children of this age should not compete at all. It is however interesting to note that LTAD 2.0 now advocates structured competition in the FUNdamentals stage of their development framework, 6 to 9 and 6 to 8 years for males and females respectively (Balyi et al., 2014).

The DMSP model of Côté and Hay (2002) has been considered with respect to the approaches of a number of swimming clubs in Australia, France and Germany (Light et al., 2013). These authors question the rigidity of the model with respect to the timing of the transition between the sampling and specialisation phases in light of the large number of hours of swimming training (deliberate practice) undertaken by 9 to 12 year olds precluding their participation in other sports at this young age. Nevertheless, they do note the positive emphasis placed by the coaches and the community on fun and acknowledge the importance of balancing challenge with success. Young swimmers are often encouraged to measure their progression against their own personal best times, rather than merely the placing they achieve when they compete. Improvements during puberty are often easily achieved due to the effects of the natural physical maturational process. This tends to provide a sense of progression and achievement that serves to motivate swimmers to remain in the sport and continue working towards improving their performance.

2.6.2 Swimming-specific considerations during athlete development

As with all sports, there are a number of sport-specific considerations that are important in swimming. In section 2.3, the physical, physiological, social and psychological developmental changes that occur through childhood were discussed. The timing and pace of these changes are of relevance to the preparation of swimmers for successful performance and participation.

Recent analyses of Olympic and World Championship swimming events spanning the modern Olympic era by Costa, Marinho, Reis, Silva, Marques, et al. (2010); Thibault et al. (2010) and Stanula et al. (2012) confirm that performance times continue to improve. However, despite development in training, O'Connor and Vozenilek (2011) suggested that technical advances in swimwear may have been a major contributor to the unexpectedly high number of world records during the 2008 and 2009 period. Subsequently a new ruling has banned this and other similar technical swimwear advancements to maintain equality (Federation Internationale De Natation, 2011).

2.6.2.1 Research setting: competition vs. training environment

Many researchers have investigated the performance of elite-level swimmers in competition. Their work predominantly included comparative studies until the 2000 Sydney Olympics. Since then, focus appears to have turned towards the performance of sub-elite and international-level adolescents (Jürimäe et al., 2007; Kjendlie, Haljand, Fjørtoft, & Stallman, 2006; Lätt et al., 2010). All studies undertaken in competition provide external validity because of the accompanying elements such as the pressure of high expectations and elevated levels of motivation and arousal (Crocker & Graham, 1995; Nicholls et al., 2009). Nevertheless, similar studies conducted in the training setting, determining stroking characteristics comparing adults with children (Kjendlie, Stallman, & Stray-Gundersen, 2004) and untrained school children with anthropometrics (Pelayo et al., 1997), have shown similar trends to those in competition.

Unfortunately, the scope of studies in competition is limited. Outside of the competition setting more parameters can be controlled, physiological data can be collected and in-pool devices can be used. Such studies have enabled a greater understanding of the biomechanics (Chollet, Chalies, & Chatard, 2000; Seifert, Chollet, & Bardy, 2004; Toussaint, Hollander, v. d. Berg, & Vorontsov, 2000) and energetics (Barbosa, Fernandes, Keskinen, & Vilas-Boas, 2008; Kjendlie, Ingjer, Madsen, Stallman, & Stray-Gundersen, 2004; Ratel & Poujade, 2009) of swimming. Furthermore studies have also been undertaken to evaluate training per se (Arellano, Lopez-Contreras, & Sanchez-Molina, 2003; Keskinen & Komi, 1993), as well as to determine the effect of training interventions (Alberty et al., 2008; Aspenes & Karlsen, 2012; Wakayoshi, D'Acquisto, Cappaert, & Troup, 1995).

Interestingly, two studies on adolescents attempted to combine the developing knowledge of those parameters that can only be measured outside of competition with performance in competition. Barbosa, Costa, et al. (2010) reported that SI was not a useful predictor of performance in young males (mean age 12.53±0.6 y, n = 38). However, in a more extensive study, Saavedra, Escalante, and Rodriguez (2010) found that numerous anthropometric measures, as well as level of training and technique were important predictors of performance for the male subjects in their study (mean age 13.6±0.6 y, n = 66). Although Moesch et al. (2011) suggested that athletes competing in sports measured by time, like swimming, would benefit from later specialisation and less training at earlier ages, a recent study by Light et al. (2013) found that club swimmers drawn from France (n = 76), Germany (n = 20) and Australia (n = 33) with a mean age of 10.39±1.07 years, were in fact not averse to early specialisation and competition from an early age, given the right setting.

2.6.2.2 Variables influencing swimming performance

The biomechanical aspects of swimming performance are affected by, amongst other things, anthropometrical and physiological differences as well as performance level, experience and technique (Barbosa, Bragada, et al., 2010).

It is well known that there are physical and physiological differences between genders, where the gender gap in elite swimming has been stable at 8.9% since 1979 (Thibault et al., 2010). Andrei Vorontsov, the former head coach of the Russian Olympic Swimming Team, undertook a few physical and physiological studies on trained young swimmers (Vorontsov & Binevsky, 2002; Vorontsov, Binevsky, Filonov, & Korobova, 2002; Vorontsov, Dyrco, Binevsky, Solomatin, & Sidorov, 2002). Although there was considerable reliance on his findings in the production of the “The Swimmer Pathway”, his work has not been peer-reviewed, nor has it been cited by any recognised researchers in this field. Since then, Wells, Schneiderman-Walker, and Plyley (2006) undertook a broad study to describe many of these features for high-level adolescent swimmers, including cardiovascular function, respiratory function, absolute maximal aerobic power in addition to muscular strength and power. The greater stroke-specific power of males compared with females is a key gender difference that has been demonstrated by many authors (Sharp, Troup, & Costill, 1982; Toussaint et al., 2000; Wells et al., 2006). The greater power of males is likely to be a main contributor to the longer SL and thus higher *v* of males recorded by Pelayo, Sidney, Kherif, Chollet, and Tourny (1996) and Seifert, Chollet, and Chatard (2007). However, measurements of power and allometric scaling might elucidate further detail as to the nature of the differences in SL and *v*. Even though Pelayo et al. (1997) reported significantly higher SI values for post-pubescent males than females, Saavedra et al. (2010) suggested that SI was a better performance predictor for females. To compensate for their apparent lack of strength, Seifert, Chollet, et al. (2007) suggested that females increased their SR and adjusted their motor organisation by switching to a superposition coordination as defined by Chollet et al. (2000).

Muscularity or lean body mass was found by Klika and Thorland (1994) to be a significant contributor to sprint swimming performance in both pre-pubescent and post-pubescent males. In particular, they found leg-kick force and peak VO_2 to be important discriminators among these swimmers. They emphasised the importance of the leg-kick in maintaining higher horizontal velocity and the correct body position in the water.

Pacing strategies in swimming are becoming an area of increased interest at the elite level (Chatard, Girold, Cossor, & Mason, 2001; Foster, Schrager, Snyder, & Thompson, 1994; Lipinska et al., 2016a, 2016b). A 12-year longitudinal study on the pacing strategies of elite-level individual medley swimming events has been conducted by Saavedra et al. (2012). They found that men tended to adopt a positive pacing strategy; starting events faster than they finished them. In contrast, women chose a negative pacing strategy. Based on these findings gender-specific training was recommended. In young sub-elite athletes, fatigue seems to play a major role in their pacing strategies (Kjendlie et al., 2006; Lambrick, Rowlands, Rowland, & Eston, 2013). There are fewer studies on the pacing strategies used by adolescent swimmers (Dormehl & Osborough, 2015; Kjendlie et al., 2006). Kjendlie et al. (2006) were able to distinguish medallists by their strategy to increase their SR towards the end of a race from the other finalists who decreased their SR in the latter half of 100 m freestyle events. This observation suggests that in addition to strength, the cognitive ability of young swimmers to plan and execute effective pacing strategies are areas that should be developed.

2.6.2.3 Age Groups

Following the 2nd FINA World Youth Swimming Championships Kojima and Stager (2010) demonstrated that older swimmers in each multi-age group (ages 14–17 y for females, ages 15–18 y for males) represented a disproportionately high number of qualifying participants and finalists in all events. Additionally, it was identified that it was common practice for swimming federations to combine more than two CA groups into a single competition group, a practice that is highly controversial (Kojima, Jamison, & Stager, 2012; Saavedra et al., 2010).

There appears to be few differences between genders before puberty however from age 12 years onwards, the performance gap in swimming appears to increase (Kojima et al., 2012). The same authors identified distinct differences in the size and strength within multi-age groups, due to a considerable difference in maturity status. Interestingly, Kojima et al. (2012) proposed that since females mature physically earlier than males, they are better equipped to compete fairly with older females after reaching the age of 15 years, whereas males can only start competing fairly with older males after the age of 17 years.

2.6.3 Talent identification and development in swimming

Despite the body of evidence against the use of cross-sectional performance-based selection criteria (outlined in section 2.4), many swimming NGBs around the world continue to use qualifying times as the basis of their detection mechanism for talent (Australian Sports Commission, 2013; British Swimming & The ASA, 2013b; Koninklijke Nederlandse Zwembond, 2012; Vlaamse Zwemfederatie vzw, 2013). In addition to performance times, some practitioners continue to place substantial emphasis on the anthropometric characteristics of potential elite swimmers (Harati, Azizimasouleh, Dana, & Mirzaianshanjani, 2011; Mevaloo & Shahpar, 2008) with only cursory attention given to other contributing factors such as sociological and psychological characteristics. In a rare multivariate-analysis on young Spanish national swimmers (aged 11-13 years), Saavedra et al. (2010) found anthropometric variables, followed by specific fitness, technical domains, chronological age and aerobic and speed endurance to be the strongest correlates of swimming performance. Furthermore, compared with control groups, geneticists have found a correlation between elite sprint swimmers and the angiotensin-1-converting enzyme (ACE) gene (Woods et al., 2001), despite Scott et al. (2005) having found no link between genetics and long distance running performance in Kenyan endurance athletes. Scott et al. (2005) did however suggest that there was a strong environmental influence.

Following the relatively poor performance of Australian swimmers at the London 2012 Olympic Games, a review by the Australian Sports Commission (2013) commented that the current selection criteria was limited, as it was only targeting youth who had chosen to specialise early, despite swimming being considered by many as a late specialisation sport (Moesch et al., 2011). Interestingly, of those athletes who were selected for early TD programmes, swimmers seemed to be best suited to adjusting to the demands of high intensity training programmes alongside their academic pursuits (Wylleman & Reints, 2010) possibly due to their early exposure to a high frequency of long, intense training sessions.

2.7 Summary

Since the turn of the century, athlete development programmes have been widely adopted by NGB's the world over (Amateur Swimming Association, 2003; Department: Sport and Recreation South Africa, 2015; Koninklijke Nederlandse Zwembond, 2015a; Raleigh, 2011; Swimming Natation Canada, 2008). Scientists agree that while there was merit in the original approaches to athlete development, they continue to require constant evolution (Balyi et al., 2014; Côté & Fraser-Thomas, 2007). For example, it is agreed that athlete development programmes need to be refined as our understanding of all the variables affecting the process of growth and maturation in all domains (physical, psychological, emotional and social) improves (Bailey et al., 2010; Côté & Hancock, 2016). Additionally, there is consensus that the rate of maturation is variable both between and within the sexes (Beunen & Malina, 1988; Malina, 1994b; WHO Multicentre Growth Reference Study Group, 2006). However, an area of contention is the age at which athletes should be targeted for progression through the different stages of development (Bailey et al., 2010; Ford et al., 2011; Macnamara et al., 2016; Wiersma, 2000).

While athlete development systems have evolved, there is a lack of consensus on which model stands out as the best. There is evidence to suggest that athlete development programmes have had a positive influence on elite-level performances (British Swimming & The ASA, 2013a; Rees et al., 2016), but as yet, little attention appears to have focussed on the impact of these programmes on the sub-elite athlete. The greater volume of research on elite-level performances is likely due to the fact that data was historically only collected for this calibre of performer. Recent exponential improvements in both technology and data-collection procedures, plus the public's insatiable desire to be informed, has led to a massive increase in the generation of data on numerous sporting activities for all levels and ages of athlete (Sports-Tek Software, 2016; Swimrankings, 2016; USA Swimming, 2016).

Ideally, athlete and TD programmes would be synonymous, where athletes of all levels would benefit. However, there is an acceptance that, since athlete funding is limited (Martindale et al., 2005), TI programmes are necessary.

There is however agreement that the reliance of current TI programmes on cross-sectional approaches is flawed (Abbott & Collins, 2004). They tend to be biased and lack external validity (Bailey & Collins, 2013; Vaeyens et al., 2008), since many take place outside of competition. There is also a lack of agreement on the premise of early and late specialisation (Baker, 2003; Macnamara et al., 2016). Consequently, there is a greater need for longitudinal research on sub-elite athletes, utilising a bottom-up, rather than a top-down approach. Being a data rich CGS sport, with high levels of participation at all levels, swimming is likely to provide an excellent exemplar for study.

2.8 Overall aims and objectives of this thesis

In Chapter 3, the aim is to analyse data collected over an 8-year period from an annual international school-level competition to track the performance of the finalists (top eight) and record holders. The idea is to measure and compare the progression of these sub-elite (SE) performances with that of junior-elite (JE) and elite swimmers in order to determine whether there are any differences between the different levels and sexes and to see whether the gap between sub-elite and elite athletes is narrowing.

In Chapter 4, the aim is to test whether the stroke techniques or distances selected by younger swimmers remain stable as they mature. Since swimming allows its athletes to specialise within the sport, it will be determined whether sub-elite (SE) athletes favour one stroke technique or distance over others. Additionally, since swimmers often compete in a multitude of strokes, it will be investigated whether or not preferred stroke combinations exist. Finally, since it is reported that females mature younger than males, the aim is to evaluate whether females specialise at a younger age than males.

The objective of the following chapters is to model the swimming performance of males (chapter 5) and females (chapter 6) in the following seven events: 50 m, 100 m, 200 m freestyle, 100 m breaststroke, backstroke and butterfly and the 200 m individual medley.

The aims and objectives for chapter 5 (males) are twofold. The first is to create a tool that will enable the progression and variability of performances between the ages of 12 and 19 years to be tracked in relation to a modelled mean and as such, assist coaches with the setting of realistic goals when devising training programmes that are individually tailored. The second objective is to produce models that could potentially be used as instruments for identifying talented young male swimmers.

The aims and objectives for chapter 6 (females) are also twofold. Firstly, modelling the performance progression of sub-elite female swimmers in each stroke between the ages of 12 and 19 years will be undertaken. The second aim is to identify the threshold age of peak performance in female swimmers, so as to provide coaches and sporting associations with some potentially useful benchmarking tools to identify talent and possibly provide evidence to determine realistic competition ages for females.

The final study (chapter 7) aims to test and evaluate the models developed in chapters 5 and 6 using an independent sample of Dutch club swimmers. The specific objective is to determine whether the models provide a suitable tool to monitor the performance progression of individual athletes and whether or not the models are fit for purpose in terms of TI. This study will make use of personal interviews and the publicly-available performance data of trained sub-elite athletes that were not part of the original studies.

2.8.1 *Summary of the aims and objectives of this thesis*

This thesis aims to investigate whether :

- The performance of sub-elite finalists will improve in parallel with elite and junior elite athletes (Chapter 3).
- The gender gap of the sub-elite swimmers will narrow similar to those of junior elite and elite-level swimmers (Chapter 3).
- Specific stroke combinations will be discernible, i.e. certain paired stroke combinations will be selected by swimmers in preference over other combinations (Chapter 4).
- There will be a difference between the sexes with females specialising earlier than males in their preferred strokes (Chapter 4).
- The rate of progression in performance of the male swimmers will increase and then plateau (Chapter 5).
- Female swimmers will reach peak performance earlier than males (Chapter 6)
- The models from Chapter 5 and 6 will fit sub-elite swimmers better than their junior elite counterparts (Chapter 7).
- Swimming histories, for example changes in clubs, coaching, training, injury and/or illness, will be able to explain positive and/or negative deviations from predicted modelled performances (Chapter 7).

Chapter 3

3 Tracking the progress of sprint performance in competitive international school swimmers

Abstract: *Numerous long-term training models have been proposed to cater for the development of young athletes in the hope that some will emerge as potential champions. Little research has focussed on recording athletes' performance through adolescence*. **Aims:** *This paper tracked the performance of finalists and record holders at a school-level sub-elite swimming competition. The stability of their performance was compared with that of junior-elite and elite swimmers in order to determine whether they were progressing at a different rate and whether there were differences between genders.* **Method:** *Race speeds for the finalists from the 15 to 18-year age-group (mean age 15.90±0.22 years) of an annual international schools' competition were tracked from 2006 to 2013. Kendall's tau non-parametric correlations were used to analyse the performance progression of each event separately. The records achieved in this competition were compared with the Short Course World Championship and Junior World Championship records over the same 8-year period.* **Results:** *Mean progression in performance times for males showed significant improvement in all strokes with the exception of the 100 m breaststroke. There was little improvement for females except in the 50 m freestyle. The records for these sub-elite swimmers continued to improve largely due to the continual improvement of female records, in contrast to the stable records of the elite and junior-elite swimmers. Mean gender gaps of the record performances over the study period for elite, junior-elite and sub-elite swimmers were, 11.48±0.76%, 11.32±1.06% and 10.37±2.4% respectively. The gender gap for sub-elite swimmers narrowed whereas it has remained fairly stable at both junior and elite level.* **Conclusions:** *Despite elite-level records having stabilised recently, sub-elite swimming performances continued to advance with variable improvement between genders and record holders with no* *clear pattern emerging. Males demonstrated significant improvement in all strokes (excluding breaststroke) in contrast to females who appeared to show more stability but less homogeneity, with only continued mean progression of the finalists in the 50 m freestyle. The positive trends evident in the performance of school-level swimming hints at a wider selection base for talent and the greater participation, motivation and improved coaching methods in this category of swimmer.*

Keywords: talent identification, sub-elite, athlete development, youth sport

3.1 Introduction

In the last decade, much attention has focussed on the development of youth sporting performance. This has included the creation of models for athlete development such as the Long Term Athlete Development (LTAD) model of Balyi (2001) and the Development Model of Sporting Participation (DMSP) of Côté and Fraser-Thomas (2007). In the UK, the LTAD model has been used to develop “The Swimmer Pathway” in an effort to bring more structure to the development of youth swimming. Should any positive benefit become evident from these initiatives, it could be predicted that the performance of youth swimmers would show progression during this period. It has been reported that the performance of the top junior age-group swimmers (Vavrek, Machin, & Tanaka, 2012), like that of elite-level athletes (Stanula et al., 2012), have been stable for a number of decades.

The purpose of this chapter is to track the performance of both the finalists (top eight) and record holders of an annual school-level competition over an 8 year period. The stability of their performance will be compared with that of junior elite (JE) and elite swimmers in order to determine whether they are 1) progressing at a different rate and if so, in which events, 2) whether there is a difference between genders.

3.2 Methods

The top performance times for each of the eight finalists in the 15 to 18 year age-group (448 male and 448 female performances, mean age of 15.90± 0.22 years) in all individual events (50 m, 100 m and 200 m freestyle, the 100 m backstroke, breaststroke and butterfly as well as the 200 m individual medley) were compiled from the official published results of the annual school swimming championships. Relay events and the younger age group category (12-14 years) were excluded from this study. The results were downloaded each year from the host school webpages after each competition from 2006 to 2013. The study was approved by the institutional ethics committee and conformed to the recommendations of the Declaration of Helsinki.

The performance times and records for the competitions were recorded using Omega Electronics timing touch pads. The pads were connected to Ares-21 timing consoles that were connected to a computer running Meet Manager for Swimming software (Active Hy-Tek) in bi-directional mode. The competitions were held on an annual basis and swum at one of four different venues (Egypt, Belgium, The Netherlands and the United Kingdom) in 25 m short course pools. Participants competed predominantly for their school teams that trained on a regular but varied basis. A few swimmers also competed regularly at club and/or national level. For the purposes of this study, these athletes will be referred to as sub elite (SE).

Both the Short Course World Records (SCWR) and the Junior World Records (JWR) for each of the abovementioned events, were obtained from the FINA website. As the Junior World Championships, which have only run since 2006, are held in long course pools, the times were converted to short course equivalents using FINA’s 2013 points conversion table. For the purposes of this study the SCWR and JWR holders will be considered as elite and JE athletes respectively.

3.3 Data analysis

All statistical analyses were performed using SPSS ver. 21 and values are expressed as means (top eight performances) or as a percentage change (record times). Race speeds were calculated as race distance divided by performance time so as to compensate for the different race distances. The datasets of the top eight performance times for each event were tested for normality using the Shapiro-Wilk test. Kendall’s tau non-parametric correlations were used to report the significance of the progression of the performance times across the eight-year study because much of the data was not normal and furthermore the eight measurements for each year created tiered ranks.

For each year, the gender gap for the finalists in the competition was calculated as a percentage difference between the mean male and mean female performance times for each event separately. Similarly, gender gaps were calculated for the record times for each of the schools’ championship, Junior

World Championships and the Short Course World Championships from 2006 to 2013.

3.4 Results

From 2006 to 2013, the mean progression in performance times for sub-elite male finalists have shown improvement in all strokes with the exception of the 100 m breaststroke. In contrast, there has been little overall improvement for sub-elite female finalists in all strokes but the 50 m freestyle event (Table 3.1).

Most of the female performances (50 m freestyle, 100 m backstroke, butterfly, freestyle and the 200 m freestyle and individual medley) initially improved from 2006 but then slowly declined until 2010, but thereafter further improvements were seen up to 2013. A gradual improvement in performance times was evident for the majority of the male events between 2006 and 2013 (100 m backstroke, breaststroke, butterfly and the 200 m individual medley). Marginal fluctuations with no overall improvement were noted in all the freestyle events for males, whereas this was only the case in the 100 m breaststroke for females (Figures 3.1, 3.2 and 3.3). The greatest improvement in performance occurred in the 200 m individual medley for both genders, however the variability in performance of the females over the eight-year period resulted in a non-significant correlation (Figure 3.3). The range between the fastest and slowest speeds in the finals, was generally narrower for males than for females across all events, with the tightest spread occurring in the 50 m freestyle (Figure 3.2). Interestingly, the fastest female times overlapped the slowest male performances most in the 100 m butterfly and 100 m backstroke events (Figure 3.1).

Table 3.1 Correlation analysis for the progression of performance times for sub-elite finalists in all events from 2006 to 2013.

Event	Gender	*r*	Significance
100 m butterfly	female	-0.10	0.293
	male	-0.21	0.018*
100 m backstroke	female	-0.16	0.077
	male	-0.21	0.019*
100 m breaststroke	female	-0.01	0.907
	male	-0.16	0.076
50 m freestyle	female	-0.18	0.046*
	male	-0.27	0.003*
100 m freestyle	female	-0.14	0.115
	male	-0.21	0.017*
200 m freestyle	female	0.13	0.138
	male	-0.19	0.037*
200 m individual medley	female	-0.08	0.407
	male	-0.25	0.007*

* denotes significant at $p<0.05$

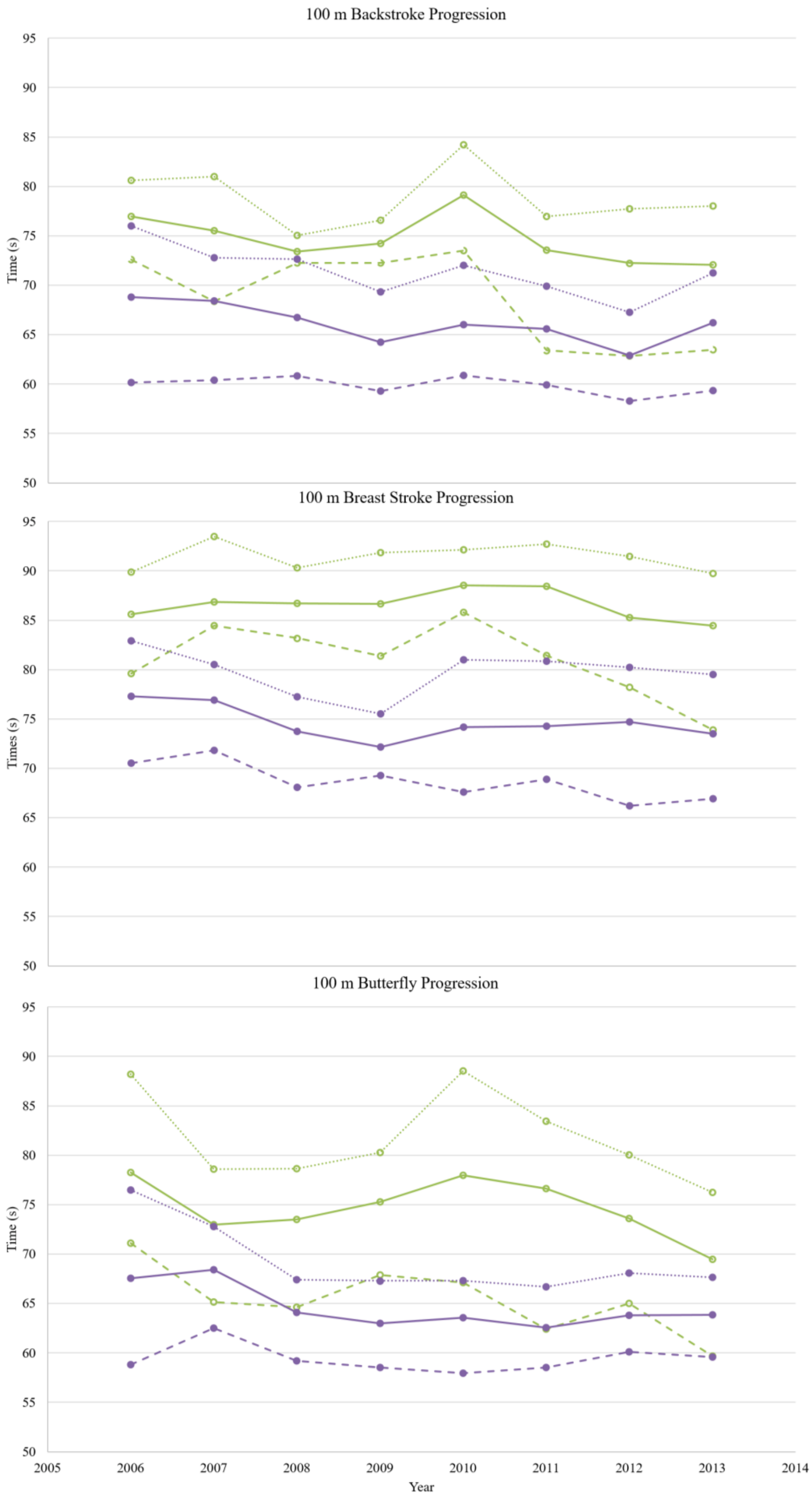


Figure 3.1 Progression of performance times for finalists in 100 m events between 2006-2013, showing fastest (dashed line), slowest (dotted line) and mean (solid line) times for both sub-elite males (closed purple symbols) and females (open green symbols).

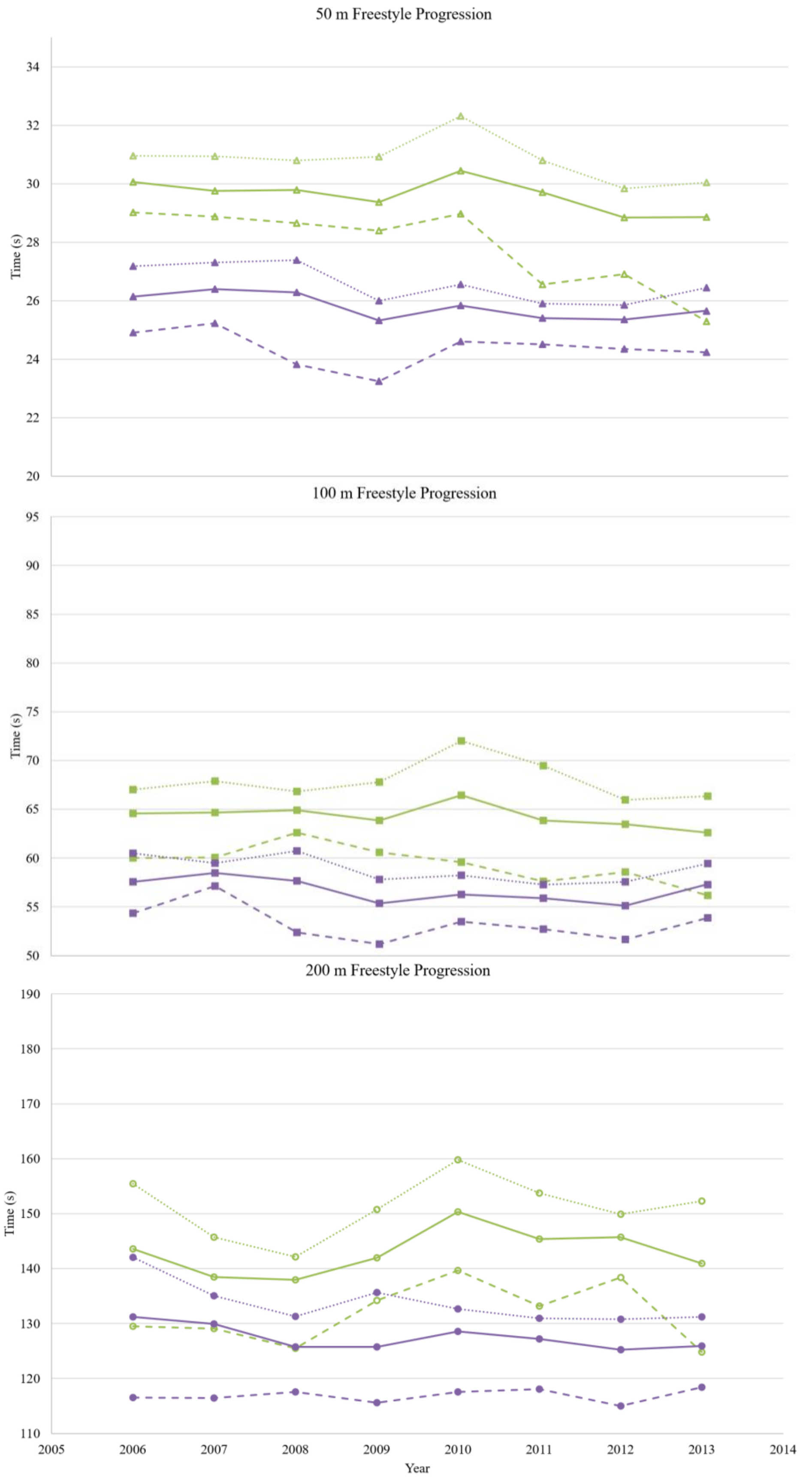


Figure 3.2 Progression of performance times for finalists in freestyle events between 2006-2013, showing fastest (dashed line), slowest (dotted line) and mean (solid line) times for both sub-elite males (closed purple symbols) and females (open green symbols).

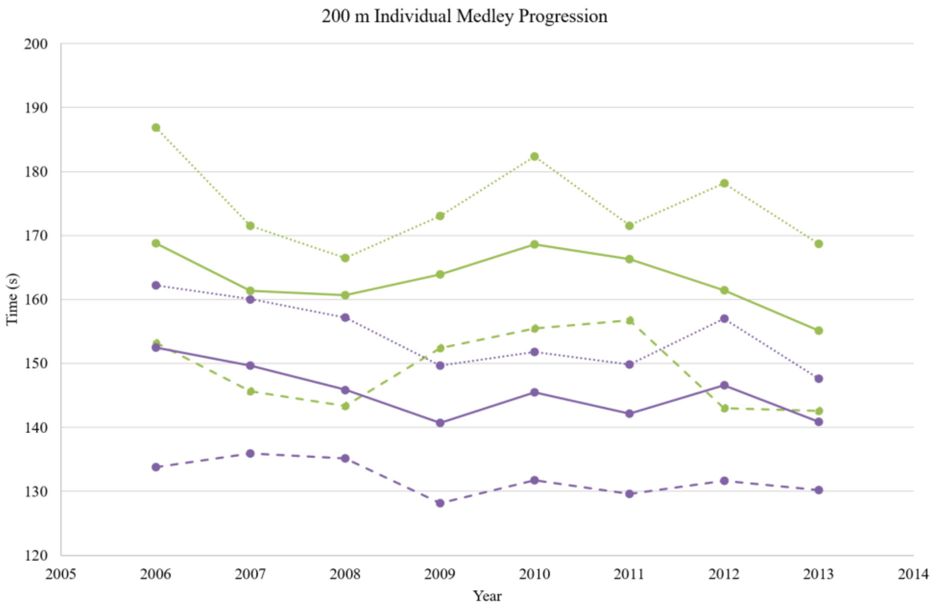


Figure 3.3 Progression of performance times for finalists in the 200 m individual medley event between 2006-2013, showing fastest (dashed line), slowest (dotted line) and mean (solid line) times for both sub-elite males (closed purple symbols) and females (open green symbols)

The record times for the sub-elite swimmers in this study have continued to improve over the eight years, whereas the records for both JE and elite swimmers have remained relatively stable (Table 3.2). The record times for sub-elite males are similar to that of JE females in the 100 m backstroke, breaststroke and butterfly as well as the 200 m freestyle. In the 50 m and 100 m freestyle however, their records surpass the JE females and approach a level comparable to that of elite females.

The largest improvement in record times over the 8-year period occurred in the 100 m butterfly event for sub-elite females, a record that was also broken regularly. Of all the events, this sub-elite record had the smallest performance gap because it is currently the closest to the corresponding elite record when compared by race speed. In contrast, sub-elite males show the least progression and greatest performance gap from the elite swimmers in this event (Table 3.2). The stroke in which there was the widest performance gap for the sub-elite females is breaststroke. However, sub-elite females have in fact shown considerable improvement in advancing their records, achieving nearly double the percentage improvement in their record times over their male counterparts. In addition, the performance gap places the sub-elite females ahead of the sub-elite males in all the events, and all the events except the 100 m breaststroke, when compared against the elite and JE records respectively (Table 3.2). It is the individual medley event in which the sub-elite males are currently closest to their elite level equivalents.

The mean gender gaps of the record performances over the 8-year period for elite, JE and sub-elite swimmers are, 11.48±0.76%, 11.32±1.06% and 10.37±2.4% respectively. The gender gap for sub-elite swimmers has narrowed over the last 8 years, whereas it has remained fairly stable at both JE and elite level during this time. The smallest gender difference occurs in the 200 m freestyle event at all levels. In contrast to both elite and JE swimmers, the sub-elite gender gap was greatest in the 100 m breaststroke, owing predominantly to the poor progression of the sub-elite female record in this event (Table 3.2). The mean gender difference for finalists at sub-elite level between 2006 and 2013 was 12.14±1.21%, however, there has been a considerable amount of variability from year to year (Figure 3.4).

The progression of the sub-elite records was compiled over the eight years analysed. Both the percentage change and the number of times the record had been broken between 2006 and 2013 were determined (Table 3.2).

Table 3.2 Summary of the eight-year progression in sub-elite (SE) records at the school championships between 2006 and 2013 and their comparison with current converted JE (JWR) and elite (SCWR) race speeds.

Event	Gender	% change of SE records (2006-2013)	Times SE record broken (2006-2013)	Current SE record race speeds ($m.s^{-1}$)	Difference in race speeds SE vs JE ($m.s^{-1}$)	Difference in race speeds SE vs elite ($m.s^{-1}$)
100 m butterfly	female	-11.05	4	1.68	0.07	0.14
	male	-1.5	2	1.73	0.23	0.34
100 m backstroke	female	-5.66	2	1.59	0.15	0.22
	male	-3.14	2	1.72	0.22	0.33
100 m breaststroke	female	-6.2	2	1.35	0.19	0.24
	male	-4.84	3	1.51	0.22	0.29
50 m freestyle	female	-7.97	2	1.98	0.06	0.17
	male	-4.63	2	2.15	0.18	0.31
100 m freestyle	female	-6.38	3	1.78	0.09	0.18
	male	-4.48	2	1.95	0.18	0.27
200 m freestyle	female	-2.63	2	1.60	0.11	0.20
	male	-1.34	3	1.74	0.17	0.27
200 m individual medley	female	-4.08	4	1.40	0.13	0.22
	male	-4.21	1	1.56	0.18	0.26

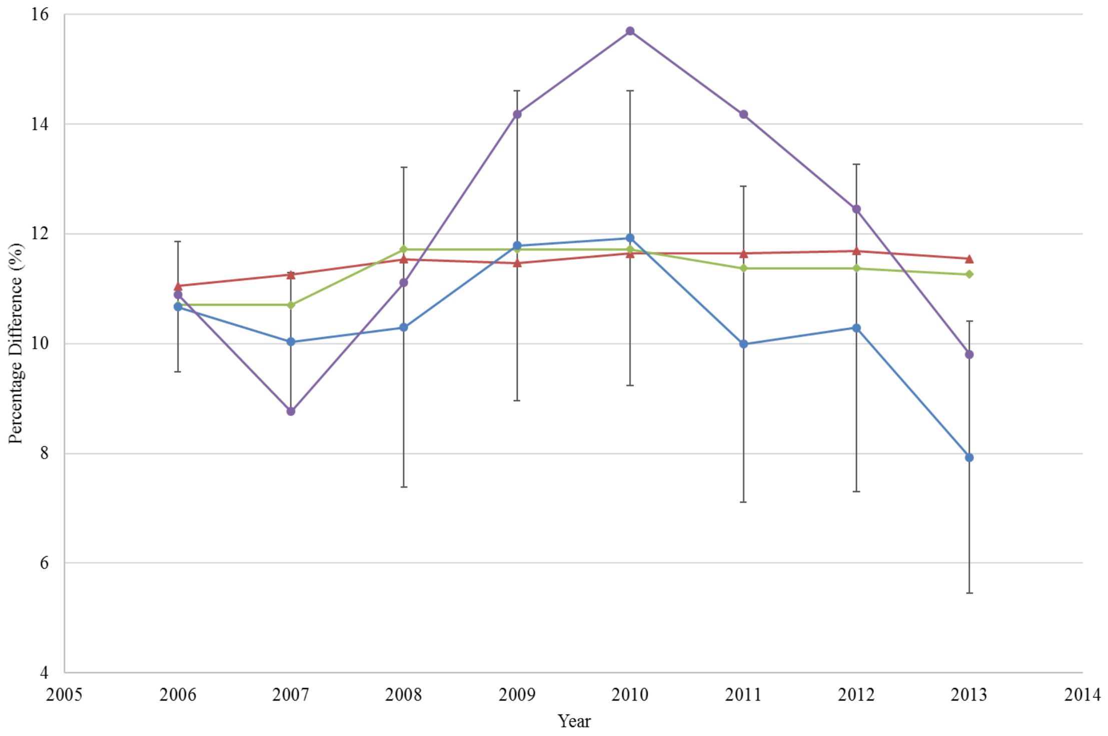


Figure 3.4 Progression of gender gap (using all seven individual events) for finalists in sub elite swimmers (purple), and the records for the elite (red) junior elite (green) and sub-elite (blue) competitions between 2006-2013. Error bars indicate 1SD.

3.5 Discussion

There was considerable variability with no clear patterns emerging in the performance stability of sub-elite swimmers in this study. The 50 m freestyle event exhibited the least variability amongst the sub-elite finalists and is also the only event in which both genders showed significant improvement over the 8-year period (Table 3.1). Freestyle, the fastest and most popular stroke at all competitions, also appears to be the most commonly researched. In the school competition, there are three events for the freestyle with only a single event in each of the remaining three strokes, with the 50 m freestyle event tending to attract the highest number of entries. Since it is considered the most efficient stroke (Maglischo, 2003), it tends to make up the majority of the mileage completed by swimmers in training, despite the Swimmers Pathway prescribing that coaches develop all strokes equally in all phases of LTAD (Amateur Swimming Association, 2003).

Despite the progression of the female 100 m butterfly record at the school-level competition (Table 3.2), there was a wide range between the gold medallist and the slowest finalist (Figure 3.1), highlighting a lack of homogeneity of the swimmers in this event. Notwithstanding the regular presence of numerous national level swimmers at the competition, this disparity is exaggerated by the presence of an international-level swimmer, who competed for one of the participating schools in recent years. This particular swimmer's record supports the literature (Seifert, Delignieres, Boulesteix, & Chollet, 2007) that expert butterfly swimmers require an intimate understanding of the timing and synchronisation of the arms and leg movements that are necessary to swim this stroke most effectively.

A recent paper by A. F. Silva et al. (2013) on young backstroke swimmers highlighted that there were very few technical differences between genders or level of physical maturation, despite males being quicker than females. The current performance of sub-elite swimmers in backstroke support these findings with both genders having similar performance gaps in the records, relative to their elite counterparts (Table 3.2). While the mean performance of female sub-elite backstroke finalists is fairly stable, male sub-elite backstrokers are however still showing some signs of improvement (Table 3.1, Figure 3.1). Nevertheless, caution is required when considering the reliability of a small sample size, i.e. the eight swimmers who competed in each final.

The breaststroke is the only stroke where no significant improvement has been observed for either gender at sub-elite level (Table 3.1). Breaststroke technique in young swimmers has recently received some attention (Strzala et al., 2013), with Hellard et al. (2008) describing the stroke as the most technically complex in terms of timing and coordination. It is a stroke that relies most heavily on the strength and technique of the kick and it has therefore been suggested that breaststrokers devote a large amount of time to developing it (Maglischo, 2003). This approach is however not without problems, as high levels of breaststroke kicking may stress the soft tissue structures in the knee considerably (Knobloch, Yoon, Kraemer, & Vogt, 2008). According to Maglischo (2003) breaststrokers should dedicate between 50-75% of their training to the stroke, however this is improbable at sub-elite level, as these swimmers are less likely to have found or selected their specialist stroke during adolescence. Despite there being some debate as to whether swimming should be classified as an early or late specialisation sport (Balyi, 2001; Light et al., 2013; Moesch et al., 2011), selection of a specialist stroke would naturally occur subsequent to specialising in the sport. This suggests that the sub-elite finalists are lacking in terms of their technical proficiency of the stroke, possibly owing to a lack of experience for females who are adjusting to their newly developed stature and the fact that the ongoing maturation process for males is constantly affecting their stature, making the coordination of the stroke an ever-changing challenge throughout puberty.

In the individual medley event, the record performance of sub-elite males compared most favourably with that of elite males (Table 3.2). This is potentially due to the fact that sub-elite males are less likely to have specialised than females, as they are still maturing and they may still be experiencing improvement in the full range of strokes. This potentially makes the stroke specialisation choice somewhat less clear than for females who may have already reached a physiological performance peak and show poor relative performance in this event (Table 3.2).

The swimmers in this study have been competing for many years in an era where both genders have had equal access to opportunities and facilities

(Chatterjee & Laudato, 1996). Despite the belief of many scientists that the gender gap is narrowing, Thibault et al. (2010) found the gap of elite-level swimming records had stabilised at 8.9±1.54% by 1979, leading them to suggest that women would never reach the same level of performance as men. There are however a number of physical and physiological differences that contribute to the faster performances of males. They are known to be stronger and more powerful than females and tend to be leaner, taller and have greater limb lengths. They also have lower maximum heart rates (owing to greater stroke volumes) and they have greater tidal volumes, all of which have been found to contribute to greater performance in elite male swimmers (Saavedra et al., 2010; Wells et al., 2006). Nevertheless the smaller stature and higher buoyancy of females has been suggested to give them an energy efficiency advantage over males (Ratel, Duche, & Williams, 2006) most noticeable in longer distance events (Chatterjee & Laudato, 1996; Tanaka & Seals, 1997; Thibault et al., 2010).

The current gender gap for elite and JE swimming records is approximately 2.5% larger than that reported by Thibault et al. (2010). This discrepancy may be due to the fact that the calculation of the gender gaps in this study only included the seven events in which the sub-elite swimmers also competed. The absence of longer distance events in this study (i.e. events exceeding 200 m), where female performances have been found to be closer to that of males (Chatterjee & Laudato, 1996), possibly contributed to the slightly wider gender gap reported (Figure 3.4). The narrower gender gap for the sub-elite swimming records (approximately 1% less than gap for JE and elite records) is potentially due to the more advanced maturity of females over males in the 15-18 year age group. While VO_{2max} at all ages is known to be high for swimmers, VO_{2max} for females peaks by the age of 14 years, whereas it continues to develop into early adulthood in males (Armstrong & Welsman, 2000).

Thibault et al. (2010) reported a widening in the gender gap of 1.26% between record holders and top 10 swimmers. Similarly, when comparing the sub-elite records with the sub-elite finalists (top 8) in this study, the gender gap widened by 1.77%. The variability and erratic nature of the gender gap for sub-elite finalists appears to be predominantly as a result of the greater range in performances of the females in relation to males (Figure 3.4). This is possibly due to the fact that males are reported to remain more physically active than females and that females' participation in physical activity appears to decline earlier (Sherar, Esliger, et al., 2007). Since males are still maturing, they can expect to experience continued gains in strength and other physiological parameters such as VO_{2max}, that are known to contribute to performance improvements throughout adolescence. This is likely to have a positive impact on their motivation to compete into their late teens. Females, on the other hand, need to rely on significant levels of strength and speed training to see continued performance gains beyond puberty (Glenmark et al., 1994) and this may contribute to their reluctance to sustain the necessary high levels of training.

Age has also been found to have a considerable influence on performance in youth swimming (Kojima et al., 2012; Saavedra et al., 2010) where older swimmers consistently outperform their younger counterparts (Costa et al., 2011). For this reason, the younger, 12-14 year age group were excluded for the purposes of this chapter. Furthermore Costa et al. (2011) determined that adult performance in males could be more easily predicted from the age of 16 years, similar to the mean age of the 15-18 year old sub-elite swimmers of this study.

3.6 Conclusion

While records continue to be broken, it would appear that elite-level records have stabilised and that the greatest recent improvement occurred in the 2008-2009 era of polyurethane suits, that were later banned by FINA in 2010 (O'Connor & Vozenilek, 2011). While this effect was also noticeable for sub-elite males, it seems to have had a lesser impact on the records of sub-elite females.

Vavrek et al. (2012) found that US youth swimming freestyle records (for the 15-17 year age group) improved most between 1960 and 1970 but that they were improving concurrently with those at the elite level by the year 2000. By comparison the sub-elite swimmers in this study were still showing improvement between 2006 and 2013 that was of a similar but smaller magnitude to those of Vavrek et al. (2012) before 1970. Furthermore unlike the narrowing of the performance gap between the first and last placed Olympic swimming finalists by 2008 providing more evidence for the progression in swimming at this level

(Stanula et al., 2012), there is still considerable variability in the range of performances of the finalists at sub-elite level.

There are a number of reasons that could potentially be responsible for the continued improvement in sub-elite swimming performances. The main findings that are evident in the sub-elite swimmers of this study include:

- little evidence of the performance gap between gold medallists and 8^{th} placed finalist closing for most strokes,
- variable improvement between genders and record holders with no clear pattern emerging, and
- males continuing to demonstrate significant improvement in all strokes (excluding breaststroke) in contrast to females who appear to show more stability but less homogeneity, with only continued mean progression of the finalists in the 50 m freestyle.

In conclusion, the positive trends evident in the performance of school-level swimming hints at a wider selection base for talent, as well as the need for continued improvements in coaching and training to further develop the talent pool in this category of swimmer that has traditionally been overlooked. The results from this study may begin to provide support for the recent attention to the value in improving participation and quality of youth level sport. (Cope et al., 2013; Light et al., 2013).

Chapter 4

4 Stability of within-sport specialisation in competitive adolescent sub-elite swimmers

Abstract: *The study aimed to assess the stability of stroke selection during adolescence and the determination of within-sport specialisation. All swimmers (448 males, 14.1±1.6 y and 518 females, 13.9±1.6 y) who competed in an annual international schools championship from 2006 to 2013 were analysed. Kruskal-Wallis tests identified the significant differences between paired stroke combinations and the relative frequency of each pair was determined from Cohen's Kappa tests. The percentage of swimmers selecting the same event in two of three paired age categories (13-14, 15-16, 17-18 y) was calculated for each sex separately (n = 78). Stability of stroke selections were determined using Cohen's Kappa tests. The most preferred combination of events selected was 50 and 100 m freestyle for males (33.9±5.8%) and females (36.9±6.5%). The least preferred combination was 100 m breaststroke with 100 m butterfly for males (2.7±1.7%), and 200 m freestyle with 100 m breaststroke for females (1.9±1.4%). Males were less stable than females in electing to swim the same events from when first competing until their final competition. Breaststroke was the only stroke where early specialisation was observed. Young swimmers appear to be drawn towards particular stroke combinations over distance specialisation and males choices stabilise later compared with females.*

Keywords: talent-identification, longitudinal, development, maturation, school-level

4.1 Introduction

Over the last decade there has been debate concerning the topic of early specialisation in competitive youth sport (Baker, Cobley, & Fraser-Thomas, 2009; Bridge & Toms, 2013). In particular, the Development Model of Sports Participation (DMSP) by Côté and Fraser-Thomas (2007) described how specialisation involved athletes reducing the number of sports in which they participated, eventually leading to the emergence of a preferred sport. In an evaluation of "The Swimmer Pathway" (Amateur Swimming Association, 2003), Lang and Light (2010) concluded that, according to the Long Term Athlete Development (LTAD) model by Balyi (2001), swimming is a late specialisation sport. Whilst there is support indicating this to be the case (Baker, 2003; Sokolovas, 2006), there appears to be a dearth of literature describing this process of specialisation. In team sports this may involve choosing to play a specific role or position, whereas in swimming this could be to focus on developing and specialising in a single stroke technique or distance.

Lang and Light (2010) stated that both elite and non-elite coaches proposed that "The Swimmer Pathway" placed too much emphasis on mileage and too little on technical development. These viewpoints were supported by Arellano (2010), suggesting that there is potentially a lack of focus on stroke specialisation. The two long-axis strokes (freestyle and backstroke) are often paired since both require similar patterns of left to right alternating co-ordination. Butterfly, probably because it evolved from breaststroke (Maglischo, 2003), requires similar simultaneous patterns of homologous limb co-ordination (i.e. left arm with right arm and left leg with right leg), coupled with movements between the upper and lower limbs with the arms moving alternately to the legs (Seifert, Leblanc, Chollet, & Delignières, 2010). Stewart and Hopkins (2000) highlighted that specialisation in swimming is unusual as swimmers have the opportunity to specialise not only in technique (stroke), but also in distance within a single competition. They concluded that swimmers should focus on specialising within a stroke rather than becoming distance specialists. Sports such as cycling are competed over different distances, utilising similar techniques. In contrast, gymnastics includes different disciplines (techniques) altogether. Interestingly, swimming is one of very few sports in which it is possible for athletes to compete in many events at a single competition.

A cross-sectional study by Saavedra et al. (2010) focussed on identifying key determinants of youth swimming using a single all-embracing parameter combining performance in all four of the strokes. Their analyses were based on the assumption that the determinants of success in swimming are non-stroke specific, although to the best of the authors' knowledge, this has never been tested. Furthermore, with few exceptions (Sokolovas, 2006; Stewart & Hopkins, 2000), the majority of long-term studies on adolescent swimmers have focused on the freestyle technique (Costa et al., 2011; Lätt et al., 2009a, 2009b; Morais et al., 2013). Although longitudinal studies on adolescent swimmers have shown differences in development between the sexes, the focus has tended to either combine all stroke specialisms or favoured freestyle. Possibly due to the volume of data required to follow the progress of athletes, long-term studies of all strokes and distance specialisms are uncommon. Consequently, the stability of event selection during athlete youth development has yet to be considered.

Since elite-level swimmers are required to achieve qualifying times in order to compete at many national/international competitions, objective assessment of their preferred stroke combinations would be impossible. The competition chosen for this study does however provide an almost unique opportunity to assess specialisation because competitors are afforded the freedom to choose their events in this end-of-season championship, for which there are no qualifying standards. Additionally, utilising a longitudinal approach, it is possible to test whether the stroke techniques or distances selected by younger swimmers will remain stable as they mature. It is hypothesised that the sub-elite (SE) swimmers, i.e. those adolescent swimmers who have yet to represent their country internationally as a semi-finalist or finalist in a FINA-sanctioned competition, will favour one stroke technique or distance over others, allowing preferred combinations to be identified. Furthermore, since females are known to mature at a younger age than males (Malina, Bouchard, & Bar-Or, 2004), it is hypothesised that females will specialise at a younger age than their male counterparts.

4.2 Methods

All swimmers who competed in an annual international schools swimming championship from 2006 to 2013 were included in this study. These championships were held in rotation at one of four different venues (Belgium, Egypt, The Netherlands and the United Kingdom) in 25 m short course pools. The entries for all indvidual events were extracted from the official programmes. All data was in the public domain and downloaded from the relevant tournament websites. In order to ensure athlete confidentiality, all data was anonymised and as no individuals were named, written consent from athletes was not sought. All swimmers (448 males, mean age 14.1±1.6 y and 518 females, mean age 13.9±1.6 y) were included in this study and competed in two age groups (12-14 y and 15-18 y). All swimmers were limited to competing in a maximum of three individual events and the format of the competition is presented in Table 4.1.

Table 4.1 Summary of the format of the international schools swimming championships and event abbreviations.

Day	Event order	Abbreviation
1	200 m freestyle	200Fr
1	100 m breastroke	100Br
1	100 m butterfly	100Fly
1	50 m freestyle	50Fr
1	medley relay (4 x 50 m)	excluded from study
2	100 m freestyle	100Fr
2	100 m backstroke	100Ba
2	200 m individual medley	200IM
2	freestyle relay (4 x 50 m)	excluded from study

The participants trained on a regular basis and were chosen as one of the top 20 swimmers to represent their school at these championships. At least 80% of swimmers also competed at club and/or national level. This event was an end-of-season championship where most swimmers achieved their season's best times. The record performance times at these championships (Table 4.2) were compared with the Short Course World Records (Fédération Internationale de Natation, 2013b) for each of the events in Table 4.1. Race speeds were calculated as race distance divided by performance time so as to compensate for the different race distances.

Table 4.2 Summary of the eight-year progression in sub-elite (SE) records between 2006 and 2013 and their comparison with current elite (Short Course World Record) race speeds.

Event	Gender	Current SE record race speeds ($m.s^{-1}$)	Difference in race speeds SE vs elite ($m.s^{-1}$)
100 m butterfly	female	1.68	0.14
	Male	1.73	0.34
100 m backstroke	female	1.59	0.22
	Male	1.72	0.33
100 m breaststroke	female	1.35	0.24
	Male	1.51	0.29
50 m freestyle	female	1.98	0.17
	Male	2.15	0.31
100 m freestyle	female	1.78	0.18
	Male	1.95	0.27
200 m freestyle	female	1.60	0.20
	Male	1.74	0.27
200 m individual medley	female	1.40	0.22
	Male	1.56	0.26

4.2.1 Data processing and statistical analyses

All statistical analyses were performed with SPSS ver. 21 (SPSS: an IBM company, Amarouk, NY) and values are expressed as mean ± standard deviation. Since the data distributions were non-normal, Kruskal-Wallis H tests were utilised to determine the statistical differences between the percentage of swimmers selecting different paired stroke combinations for males and females separately. The threshold percentage, assuming each combination was equally preferred, was calculated as 100/number of stroke combinations. Mann-Whitney post hoc tests, corrected by applying the Bonferroni correction as α = 0.05/number of stroke combinations, conducted for each event separately, were used to locate any differences. Although the data is not presented here, the relative frequency of each pair of stroke combinations, compared with the swimmers in which only one of the two events were swum, was determined from Cohen's Kappa tests using ReCal (Freelon, 2010).

To assess the stability of stroke selection using a longitudinal approach, any swimmer who did not compete in at least two of the following age categories

13-14, 15-16 and 17-18 years was excluded. A total of 78 swimmers satisfied these criteria. The percentage of swimmers selecting the same event in two of the three paired age categories was calculated for each sex separately. Cohen's Kappa tests were then performed to establish the stability of the stroke selection between the three above mentioned age categories. Stability was considered to be high if $\kappa \geq 0.75$, moderate if $0.75 \leq \kappa \leq 0.40$ and low if $\kappa < 0.40$ (Landis & Koch, 1977).

4.3 Results

4.3.1 The selection of event combination preferrences

The most preferred combination of events selected by swimmers was the 50 m freestyle with the 100 m freestyle for both males and females, followed by combinations of the 50 m freestyle with: 200 m freestyle, 100 m breaststroke and 100 m backstroke (Figure 4.1). The two least preferred combinations of events were the 200 m freestyle with the 100 m breaststroke and the 100 m breaststroke with the 100 m butterfly (Figure 4.2). In all cases, except the 100 m butterfly and 50 m freestyle pairing, the least preferred combinations by event, were those pairings that were adjacent to one another in the order of events for this competition (Table 4.1). Neither simultaneous stroke pairings (breastroke and butterfly) nor alternating stroke pairings (freestyle and backstroke), appeared to be specifically favoured by either sex. Furthermore, there was no evidence of swimmers selecting event combinations based on similar distances such as the 200 m freestyle and the 200 m individual medley pairing (Figure 4.1 and 4.2).

The 50 m and 100 m freestyle pairing was not only the most commonly selected combination, but were also more frequently swum together at all ages, except for the youngest (12 year old) females (Tables 4.3 and 4.4). Although less popular than most other stroke pairings (Figure 4.2), the 200 m individual medley was commonly combined with either breaststroke or butterfly at all ages. These combinations were more often selected than either event being swum without the other, except in the oldest (18 year old) group of females (Tables 4.3 and 4.4).

Although fewer 18 year old swimmers competed, there was a notable shift in the magnitude of agreement in the Kappa values for swimmers at this age (Tables 4.3 and 4.4). Some event combinations displayed high levels of concordence, whereas others were rarely swum in combination by swimmers of this age.

Similar patterns in event preferrences were evident for both sexes. The large variability among females (Figure 4.1 and 4.2) for the 50 m freestyle with the 100 m freestyle, 200 m freestyle with the 100 m backstroke, 200 m freestyle with the 100 m butterfly, 100 m backstroke with 100 m butterfly and the 100 m butterfly with the 200 m individual medley was as a result of a peak in the percentage of 18 year old females competing in these combinations (data not shown). This variablity was not seen in males. However, males demonstrated a higher consistency in event pairing agreement than females, as is shown by the higher number of positive Kappa values recorded (Tables 4.3 and 4.4).

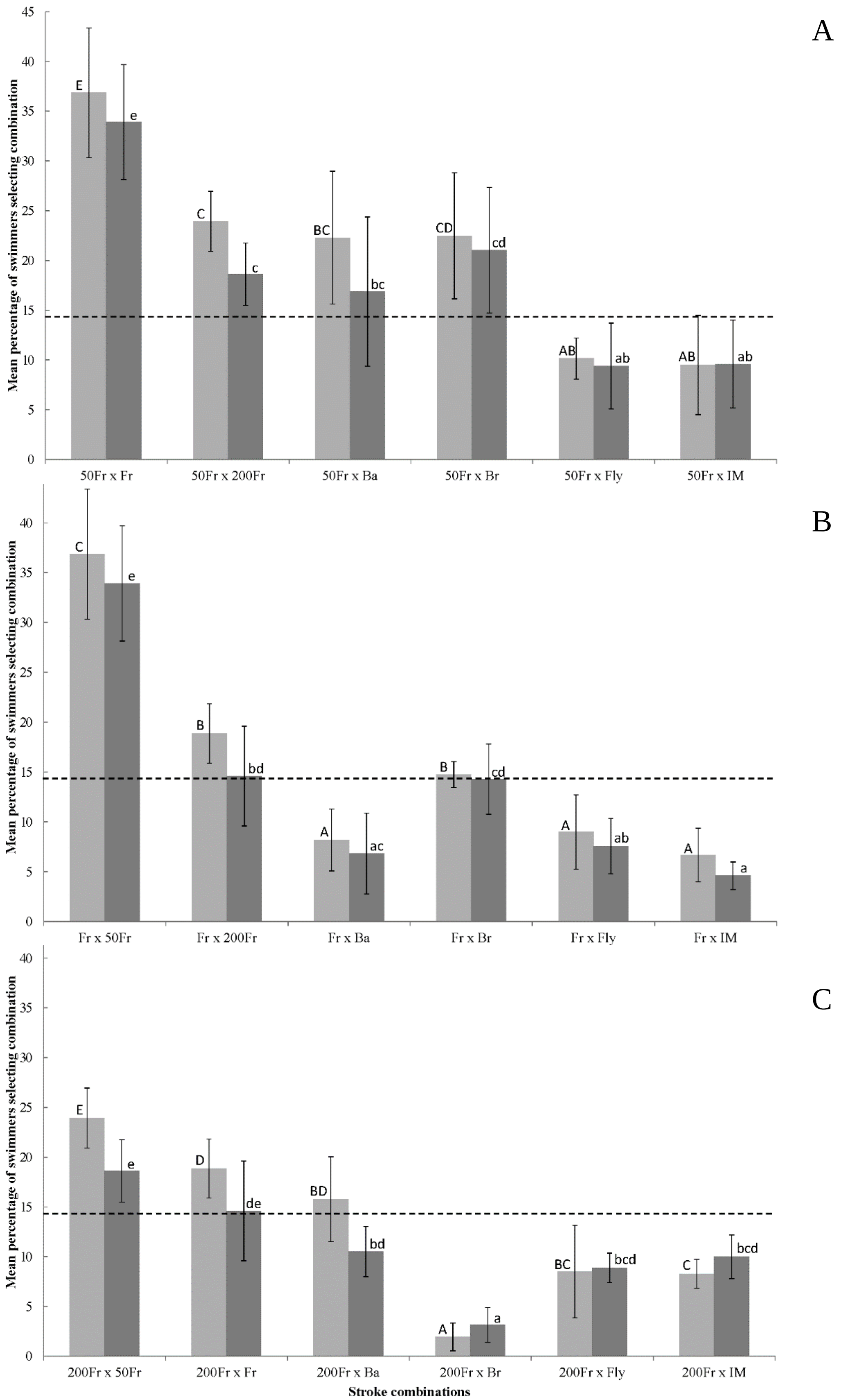


Figure 4.1 Preferred stroke combinations swum with the (A) 50 m freestyle, (B) 100 m freestyle and (C) 200 m freestyle events shown as mean percentage of swimmers by paired stroke combination for all competition ages (12 to 19 years) over an 8 y period, for females (lighter bars) and males (darker bars) separately. Different letters denote significant differences between stroke combinations for each sex separately by letter case ($p<0.05$, $n = 7$). Error bars indicate SD; dashed line represents threshold level of 14.29%.

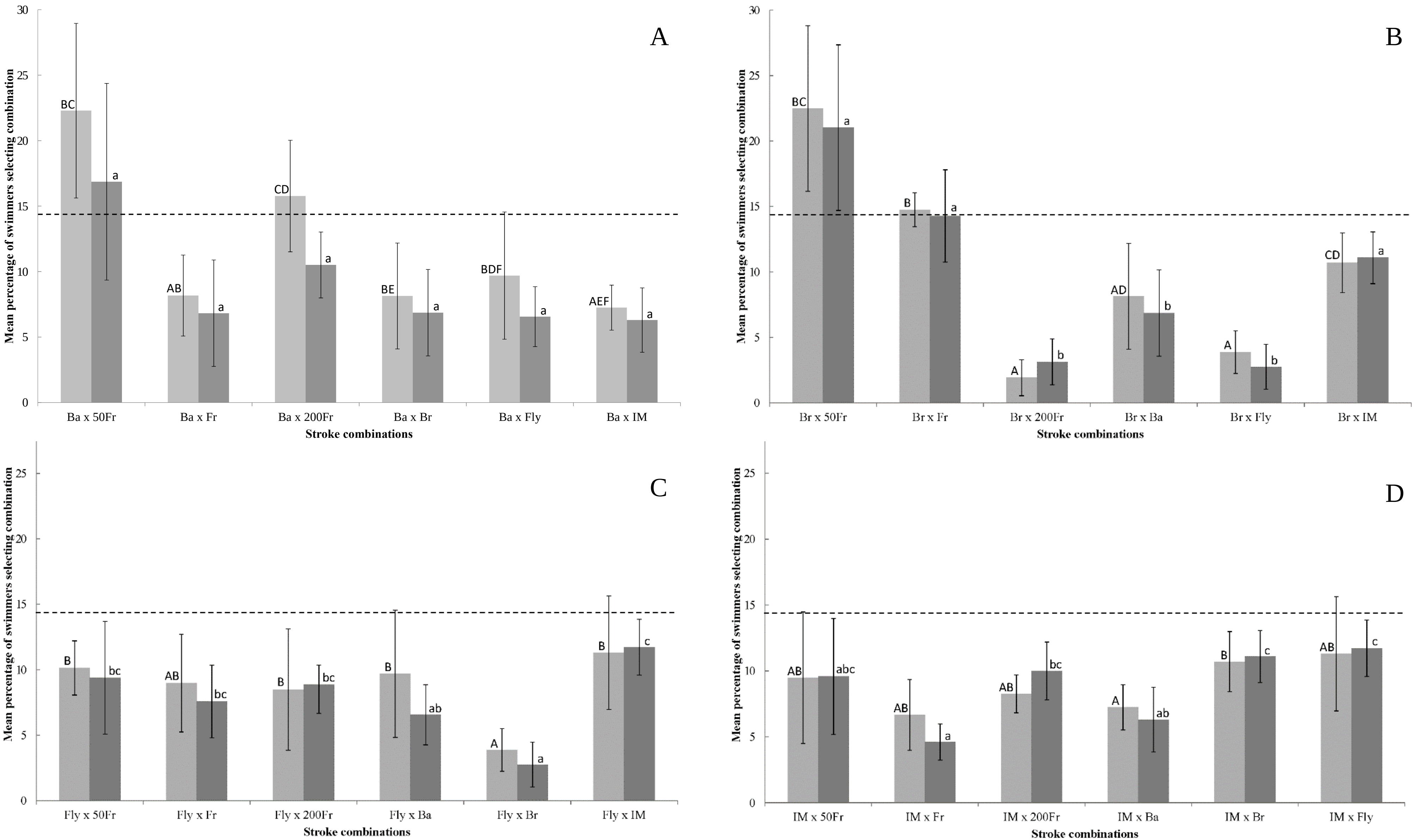


Figure 4.2 Preferred stroke combinations swum with the (A) 100 m backstroke, (B) 100 m breaststroke, (C) 100 m butterfly and (D) 200 m individual medley events, shown as mean percentage of swimmers by paired stroke combination for all competition ages (12 to 19 years) over an 8 y period, for females (lighter bars) and males (darker bars) separately. Different letters denote significant differences between stroke combinations for each sex separately by letter case (p<0.05, n = 7). Error bars indicate SD; dashed line represents threshold level of 14.29%.

Table 4.3 Level of agreement among female swimmers to select paired stroke combinations over those females who swum only one of the strokes in a paired combination, measured using Kappa values, over an 8 y period.

Stroke combination	Competition age (years)						
	12	**13**	**14**	**15**	**16**	**17**	**18**
	n=129	**n=176**	**n=195**	**n=187**	**n=155**	**n=110**	**n=15**
50Fr x 100Fr	-0.03	0.08	0.02	0.07	0.04	0.06	0.34
50Fr x 200Fr	-0.04	-0.15	-0.08	-0.05	-0.15	-0.16	-0.07
50Fr x 100Ba	0.01	-0.11	-0.07	-0.04	-0.02	-0.09	-0.46
50Fr x 100Br	-0.05	0.03	0.04	-0.08	-0.04	0.04	-0.13
50Fr x 100Fly	-0.21	-0.16	-0.11	-0.25	-0.19	-0.24	-0.46
50Fr x 200IM	-0.32	-0.22	-0.20	-0.35	-0.25	-0.28	-0.39
100Fr x 200Fr	0.06	-0.08	-0.01	0.03	0.01	-0.08	-0.20
100Fr x 100Ba	-0.42	-0.31	-0.30	-0.34	-0.44	-0.40	-0.88
100Fr x 100Br	-0.02	-0.03	-0.12	-0.19	-0.13	-0.01	0.12
100Fr x 100Fly	-0.21	-0.13	-0.14	-0.10	-0.09	-0.06	-0.34
100Fr x 200IM	-0.14	-0.38	-0.28	-0.29	-0.17	-0.23	-0.15
200Fr x 100Ba	-0.04	0.16	-0.04	-0.01	-0.04	-0.02	0.34
200Fr x 100Br	-0.57	-0.57	-0.51	-0.48	-0.34	-0.41	-0.13
200Fr x 100Fly	-0.12	0.02	-0.12	-0.08	-0.14	-0.08	-0.20
200Fr x 200IM	-0.09	-0.04	-0.03	-0.10	-0.10	-0.13	-0.39
100Ba x 100Br	-0.10	-0.19	-0.18	-0.17	-0.19	-0.14	-0.13
100Ba x 100Fly	0.05	-0.06	-0.01	-0.04	-0.05	-0.08	0.20
100Ba x 200IM	-0.13	-0.19	-0.18	-0.09	-0.20	-0.09	0.10
100Br x 100Fly	-0.07	-0.23	-0.24	-0.21	-0.25	-0.26	-0.13
100Br x 200IM	0.00	0.04	0.08	0.14	0.00	0.10	-0.11
100Fly x 200IM	0.39	0.18	0.22	0.22	0.16	0.04	0.36

Intensity of shading indicates level of agreement (lighter) or disagreement (darker).

Table 4.4 Level of agreement among male swimmers to select paired stroke combinations over those males who swum only one of the strokes in a paired combination, measured using Kappa values, over an 8 y period.

Stroke combination	Competition age (years)						
	12	13	14	15	16	17	18
	n=90	n=138	n=210	n=189	n=149	n=114	n=24
50Fr x 100Fr	0.15	0.15	0.09	0.11	0.09	0.16	0.74
50Fr x 200Fr	-0.19	-0.17	-0.17	-0.19	-0.21	-0.19	-0.14
50Fr x 100Ba	-0.04	-0.08	-0.11	-0.04	-0.02	-0.02	-0.31
50Fr x 100Br	0.03	-0.07	0.10	-0.02	0.00	-0.12	-0.06
50Fr x 100Fly	-0.22	-0.20	-0.23	-0.27	-0.24	-0.11	-0.57
50Fr x 200IM	-0.30	-0.25	-0.20	-0.31	-0.37	-0.30	-0.62
100Fr x 200Fr	-0.31	-0.19	0.02	-0.08	-0.24	0.06	-0.23
100Fr x 100Ba	-0.24	-0.34	-0.37	-0.21	-0.34	-0.31	-0.44
100Fr x 100Br	-0.08	-0.03	-0.10	-0.05	0.04	-0.23	-0.01
100Fr x 100Fly	-0.16	-0.18	-0.12	-0.15	-0.17	-0.14	-0.52
100Fr x 200IM	-0.35	-0.37	-0.36	-0.40	-0.28	-0.44	-0.58
200Fr x 100Ba	-0.12	0.04	-0.04	-0.05	0.02	-0.06	0.30
200Fr x 100Br	-0.45	-0.48	-0.44	-0.38	-0.44	-0.34	-0.55
200Fr x 100Fly	0.09	0.03	-0.02	-0.04	0.08	-0.14	-0.02
200Fr x 200IM	0.11	0.04	-0.15	0.07	0.12	-0.06	-0.11
100Ba x 100Br	-0.09	-0.11	-0.10	-0.21	-0.17	-0.18	-0.32
100Ba x 100Fly	-0.01	-0.20	0.03	-0.08	-0.06	-0.07	0.22
100Ba x 200IM	-0.26	-0.18	-0.05	-0.07	-0.13	-0.06	0.07
100Br x 100Fly	-0.30	-0.30	-0.34	-0.28	-0.38	-0.26	-0.12
100Br x 200IM	0.09	0.05	0.03	0.07	0.07	0.13	0.32
100Fly x 200IM	0.33	0.40	0.32	0.22	0.16	0.23	0.36

Intensity of shading indicates level of agreement (lighter) or disagreement (darker).

4.3.2 Longitudinal stability of event selection

The female swimmers of this study were more consistent than the males in continuing with the same events when moving from the final two years of the younger multi-age group (12-14 years), into the first two years of the older competition multi-age group (15-18 years). This is shown by the higher Kappa values indicating a higher level of agreement (Tables 4.5 and 4.6). More female swimmers selected freestyle events (50 m = 55.6±4.6%, 100 m = 52.5±1.7%, 200 m = 34.3±4.6%) than the other events in the competition. In contrast, male swimmers did not favour recurrent selection of any specific event over another.

Based on the percentage of female entries in the butterfly (25.3±7.6%), this stroke was one of their least favoured events. The high Kappa values associated with it, do however suggest that it was an event that they were likely to stay with once it was selected (Table 4.5), particularly from 15 years onwards. A similar pattern was found for males in the breaststroke and although it also was not their most popular event (37.0±6.4%), the high Kappa values (Table 4.6), show that those males who selected the event early (13-14 years), chose to swim it repeatedly between the ages of 13 and 16 years.

Like the 100 m freestyle, the 100 m backstroke appeared to be a highly stable event across all age-groups for females. The individual medley was the least stable event, which females tended to select as a one-off event (Table 4.5). In contrast, the 100 and 200 m freestyle events were the least stable for male swimmers (Table 4.6).

Table 4.5 Level of consistency among female swimmers (n = 33) to continue in individual events across 2-year pooled age groups, measured using Kappa values, for all competitions entered over an 8 y period.

Event	13-14 y x 15-16 y	13-14 y x 17-18 y	15-16 y x 17-18 y
50 Fr	0.48	0.48	0.54
100Fr	0.61	0.62	0.48
200 Fr	0.64	0.34	0.57
100Ba	0.47	0.47	0.75
100Br	0.59	0.73	0.57
100Fly	0.54	0.32	0.81
200 IM	0.37	0.30	0.47

Intensity of shading indicates level of agreement (lighter) or disagreement (darker).

Table 4.6 Level of consistency among male swimmers (n = 45) to continue in individual events across 2-year pooled age groups, measured using Kappa values, for all competitions entered over an 8 y period.

Event	13-14 y x 15-16 y	13-14 y x 17-18 y	15-16 y x 17-18 y
50 Fr	0.33	0.46	0.42
100Fr	0.06	0.29	0.20
200 Fr	0.30	0.22	0.44
100Ba	0.55	0.33	0.45
100Br	0.87	0.60	0.72
100Fly	0.27	0.49	0.51
200 IM	0.69	0.43	0.39

Intensity of shading indicates level of agreement (lighter) or disagreement (darker).

4.4 Discussion

This study has focused on two overlooked aspects of swimmer development during adolescence: within-sport specialisation and the stability thereof. In support of the hypothesis, our main finding was that the sub-elite swimmers in this study appear to have favoured technical specialism in a set of specific strokes, regardless of distance. Our findings also show that females are more consistent in their selection of technical specialism by the age of 15 years, whereas males remained undecided up to the age of 18 years (the maximum age investigated in the study). This finding appears to coincide with the chronological ages that females (15+ years) and males (17+ years) are assumed to have reached maturity (Kojima et al., 2012). With the increased attention afforded to talent identification, the opportunity to understand the development of preferences within a sport that includes both distance and technique specialisation has shown that even young swimmers gravitate towards particular combinations of strokes, over distance specialisation but that males stabilise later in their choices compared with females. This implies that coaches should encourage male swimmers to continue developing all strokes for longer than their female counterparts.

4.4.1 Within-sport specialisation: stroke vs distance

In support of the conclusions of Stewart and Hopkins (2000) with national level swimmers, the sub-elite swimmers of this study appeared to swim particular stroke combinations, rather than events of the same distance (Figures 4.1 and 4.2). This is interesting as the national-level swimmers in their study would more than likely have already chosen to specialise in this sport, given their level. By comparison, many of the sub-elite swimmers in this study may only just have left the "sampling years" described by Côté and Fraser-Thomas (2007) in their DMSP model. This difference implies that in swimming, the decision by young athletes to specialise in the sport evolves concurrently with the choice to also specialise within a given set of techniques (strokes), even in those sub-elite athletes who may not aspire to elite-level status. The stroke specialisation shown in Figure 4.1, highlighted freestyle as the most common stroke combination regardless of distance. Furthermore, excluding adjacent events such as the 200 m freestyle and breaststroke, it is clear that the least favoured combination swum with the 200 m freestyle event was the 200 m individual medley (see Figure 4.1), even though more male swimmers opted to swim these events in combination than in isolation (see Figures 4.1 and 4.2).

Swimmers who are mastering either a simultaneous or alternate co-ordination pattern (Seifert, Delignieres, et al., 2007), may favour selecting the pair of strokes requiring a similar co-ordination technique. Combinations of strokes with simultaneous co-ordination patterns (breaststroke and butterfly) were not popular amongst the sub-elite swimmers in this study, although this may well have been negatively influenced by the fact that these strokes were adjacent to each other on the international schools swimming programme (Figure 4.2). Similarly, in the strokes with alternating co-ordination patterns (backstroke and freestyle), swimmers rarely opted for the adjacent events of the 100 m backstroke and the 100 m freestyle, but did not seem averse to swimming either the 50 m or

200 m freestyle in combination with the 100 m backstroke (Figure 4.2). Butterfly and freestyle, strokes that recruit similar muscle groups (McLeod, 2010), have often been successfully combined by elite-level swimmers (see Appendix, Table 9.1). Despite this, the sub-elite swimmers in this study seemed not to have opted for this combination (Figures 4.1 and 4.2) even though these events occurred on separate days (Table 4.1), so this choice is not necessarily a function of concerns related to performance fatigue, given the rest period.

Despite swimming programmes advocating equal attention to all four recognised strokes (Amateur Swimming Association, 2003; Swimming Natation Canada, 2008), the low number of entries in the butterfly event in our study indicates that coaches and/or young swimmers may give this technical specialism less attention during the earlier years of their swimming development (Figure 4.2). Furthermore, those swimmers who did select butterfly, most commonly swam it in combination with the individual medley specialism (Figure 4.2), another unpopular event among the sub-elite swimmers. Therefore, butterfly may have been the limiting factor in the selection of the individual medley for these young swimmers.

In an extensive study on international individual medley swimmers (n = 1643), Saavedra et al. (2012) confirmed the findings of Pyne et al. (2004), with a smaller number of Olympic swimmers (n = 51), that highlighted the important contributions of the backstroke and breaststroke techniques as key determinants of success in this event. Although many sub-elite breaststrokers in the study did elect to also swim the individual medley, but the combination of individual medley and backstroke was uncommon (Figure 4.2), possibly due to their proximity on the schedule (Table 4.1). This finding could add support to our earlier suggestion that butterfly proficiency was necessary as a prerequisite for entry into the individual medley by sub-elite swimmers.

4.4.2 *Longitudinal stability of event specialisation in male and female sub-elite swimmers*

Anthropometric variables (specifically height and arm-span) are key determinants in swimming performance (Grimston & Hay, 1986; Saavedra et al., 2010; Wells et al., 2006) although these studies focussed only on the freestyle technique. However a study modelling the performance progression of the top 16 swimmers at the 2008 and 2012 Olympic Games, revealed that females peaked approximately 2 years earlier than males (Allen et al., 2014). This coincides with the female growth spurt occurring, on average, 2 years earlier than males during adolescence, giving females a head start en-route to reaching peak performance. The sub-elite females of this study (Table 4.5) were more consistent than males (Table 4.6) in the selection of their events, particularly after the age of 15 years. The timing of this stability coincides with the age at which Malina et al. (2004) stated that adolescent females tended to have reached physical maturity. Work on the physical and physiological maturation led Kojima et al. (2012) to recommend that females could start to compete equitably with their adult counterparts from this age, whereas this could only be considered in males after they reached the age of 17 years. Importantly, no anthropometrical measurements were taken as part of their study, suggesting that late maturing athletes may have been overlooked. The apparent lack of stability of the sub-elite males in this study (Table 4.6) could be related to their growth spurts that, according to Morais et al. (2013), requires swimmers to adjust their motor control strategy as they adapt to the growth and physical development their bodies are undergoing during maturation.

In longitudinal studies on the 400 m freestyle performance of young adolescent swimmers, Lätt et al. (2009a, 2009b) concluded that the greatest impact on the performance of females and males was related to improvements in biomechanical (stroke length, stroke rate, stroke index and swimming velocity) over bioenergetic and physical factors, determinants confirmed by Saavedra et al. (2010). Irrespective of the rank order of the key parameters for performance success for young swimmers, the results from this study indicate that it is only from approximately 15 years in females that within-sport specialisation becomes apparent (Table 4.5). Within sports specialisation was absent in the males (from age 13 to 18 years) for all stroke specialisms with the exception of breaststroke (Table 4.6) and adds support to the argument that swimming is a late specialisation sport (Lang & Light, 2010; Moesch et al., 2011). We speculate that selectors who are seeking to identify talent, should only be considering swimmers who have reached physical maturity which will be at least 2 years later in males than females.

Of all the swimming techniques, the selection of the breaststroke specialism was considerably more stable than any other technique in both male and female sub-elite swimmers. The return of many young female (13-14 year old) breaststrokers to the event may have been due to these swimmers having relinquished their preference in favour of older members in the 15-18 year age group (Table 4.5), even though this stroke was probably already a specialism. In contrast, this was the only stroke specialism that the males swam consistently across the entire age range of 13-18 years (Table 4.6). Although breaststroke specialisation has yet to be given as much attention as freestyle, success in this stroke, perhaps more so than any other swimming technique, is reliant on flexibility (Jagomägi & Jürimäe, 2005) as much as it is dependent on the commonly reported determinants of height and technical proficiency (Hellard et al., 2008; Leblanc, Seifert, Tourny-Chollet, & Chollet, 2007; Strzala et al., 2013). Research into the changes in the flexibility of adolescents has been minimal with variable findings (Borms, 1986; Maffulli, King, & Helms, 1994; Viru et al., 1999). In a longitudinal study on national-level male breaststrokers, Costa, Marinho, Reis, Silva, Bragada, et al. (2010) found that it was after the age of 14 years that performance became more stable. As with many of the young female and male breaststroke swimmers in this study, it is probable that some elite breaststrokers may have chosen to specialise in the stroke before reaching full biological maturation.

The female backstroke and butterfly swimmers in this study also showed clear stability in their choice of stroke specialisation, but by the slightly later age of 15-16 years (Table 4.5). However, in contrast, butterfly swimmers seem to reach elite-level status at a slightly later age, even though the sub-elite swimmers in this study seemed to choose this specialism at a similar time to those who opted for backstroke. According to Hellard et al. (2008), butterfly requires precise synchronization between breathing and limb movements, suggesting that this is a highly specialized stroke. Multiple gold medallist Michael Phelps (a freestyle, butterfly and individual medley specialist) provides evidence of an important difference between the medal winning potential of elite-level males and females at a young chronological age, even though he competed at his first Olympic Games at the age of 15 years, he failed to win any medals at his first attempt. Interestingly, Inge Sørensen still holds the record as the youngest ever Olympic medallist in swimming, winning a bronze medal in the 200 m breaststroke at the 1936 Olympic Games at the age of 12 years and 24 days and Ruta Meilutyte recently won the Olympic 100 m breaststroke at the age of 15 years and 5 months (International Olympic Committee, 2013a). This suggests that the variability amongst the sub-elite males in this competition is not unexpected.

There are a number of limitations within this study that need consideration. Biological maturation was not assessed and hence only general inferences to biological maturity were possible. The authors consciously restricted their analyses to this single competition with a consistent format that caters for sub-elite swimmers specifically. Despite some adjacent events being unpopular, this was not always the case. It appears that that the order of events was not the overriding factor influencing event selection, however generalisations should be made with caution. Higher-level swimmers in other competitions are likely to have already specialised and may well show different trends to these sub-elite swimmers. Similar investigations with elite-level swimmers could be considered for future research, however it is important to note that swimmers competing in higher-level competitions are required to qualify for each event in which they wish to compete. Unlike these sub-elite swimmers, elite swimmers' preferences may therefore be less clear, as they are limited to only those events for which they have qualified. Finally, as front crawl was the only event offered in more than one distance, it was not possible to explore distance specialisms in the other strokes, although stroke over distance specialisation has been confirmed in adults (Stewart & Hopkins, 2000).

4.5 Conclusions

This is the first longitudinal study to assess the stability of event specialisation and combination preference. A key finding was that swimmers of either sex who were to specialise in breaststroke did so early and likely before reaching biological maturity: a phenomenon that deserves further investigation. In general, however, young females were more consistent in their event selection than males for the same chronological age. Young swimmers would benefit from training programmes that allow equal opportunities to develop and compete in all four stroke specialisms over a variety of distances. Coaches and talent scouts should avoid labelling young male swimmers in particular as stroke specialists too early.

Chapter 5

5 Modelling the Progression of Male Swimmers' Performances through Adolescence

Abstract: *Insufficient data on adolescent athletes is contributing to the challenges facing youth athletic development and accurate talent identification. The purpose of this study was to model the progression of male sub-elite swimmers' performances during adolescence. The performances of 446 males (12–19 year olds) competing in seven individual events (50, 100, 200 m freestyle, 100 m backstroke, breaststroke, butterfly, 200 m individual medley) over an eight-year period at an annual international schools swimming championship, run under FINA regulations were collected. Quadratic functions for each event were determined using mixed linear models. Thresholds of peak performance were achieved between the ages of 18.5±0.1 (50 m freestyle and 200 m individual medley) and 19.8±0.1 (100 m butterfly) years. The slowest rate of improvement was observed in the 200 m individual medley (20.7%) and the highest in the 100 m butterfly (26.2%). Butterfly does however appear to be one of the last strokes in which males specialise. The models may be useful as talent identification tools, as they predict the age at which an average sub-elite swimmer could potentially peak. The expected rate of improvement could serve as a tool in which to monitor and evaluate benchmarks.*

Keywords: adolescent; specialisation; quadratic functions; talent-identification; sub-elite

5.1 Introduction

Elite-level athletes have been well characterised compared with sub-elite adolescents. Retrospective studies such as those conducted by Sokolovas (2006), Costa et al. (2011) and Allen et al. (2014) have enabled the performance of individual top-ranked swimmers to be tracked as they progressed through their careers, in the anticipation that the process may map the path to potential elite performance. The majority of longitudinal studies in swimming have also focused on adult athletes who had already reached elite status. These studies aimed to characterise both the consistency and rate of development of individual performances (Allen et al., 2014; Anderson et al., 2008; Costa et al., 2011; Trewin et al., 2004) *inter alia* and claimed to enable practitioners the ability to predict potential medallists and/or determine realistic individual performance goals (Avalos et al., 2003; Pyne et al., 2004).

Talent identification (TI) has been defined as the process whereby current performers are recognised as having the potential to become future elite athletes and talent development (TD) as the provision of a suitable, opportunity-rich, learning environment (Bergeron et al., 2015). As improved TI and TD programmes become more widely implemented, former and current elite athletes are unlikely to reflect the pathway of future champions because they were products of an era of rudimentary TI practices. Furthermore, it is likely that there would be a decrease in the mean age to reach elite-level standard and the start of the "peak-performance window", a term coined by Allen et al. (2014). Therefore, current "atypically-young" elite athletes could become the future norm.

To date, the prediction of future talent in young children has seldom shown to be accurate (Abbott & Collins, 2004; Martindale et al., 2005). The majority of TI programmes continue to be based on cross-sectional studies (Abbott & Collins, 2004) despite it being evident that many of the physical components being assessed may change or may not be as important at the elite adult level (Lidor et al., 2009). If future talent is to be successfully identified in adolescents, sporting organisations should aim to avoid summative discrete measurements and rather focus on creating environments conducive to longitudinal formative assessments (Bloom, 1985). This is pertinent because skill acquisition is non-linear and athletes and their training environments should thus be considered as complex dynamic systems (Phillips et al., 2010).

However, since there is a dearth of longitudinal research on athletes of this age, there is a need to better understand the broad pool from which future talent is likely to arise, *viz*. the sub-elite athlete. Sub-elite athletes have been defined as those athletes who are yet to represent their country at international level (Dormehl & Osborough, 2015). Despite the challenges of categorising such an unstable, developing group of athletes, it is important to prioritise this often overlooked category of swimmer if the use of valid performance measures in TI is to progress.

The consequences of poor TI processes result in many late-developing athletes with potential being de-selected, frequently leading to dropout and often result in exclusivity rather than inclusivity (Burgess & Naughton, 2010). Another outcome of many dated TI processes is that they inevitably lead to athletes choosing to specialise early in a sport in which they are believed to show potential. This practice may be due to the fact that immediate successful performance is prioritised over unrealised potential in the long term (Martindale et al., 2005).

A further limitation that potentially explains the lack of success of many TI approaches relates to the types of assessments used. Specifically, many TI assessments fail to accurately represent the competition setting, often relying on generic physical evaluations or closed skill tests that do not correlate well with the demands that athletes will face in competition (Vaeyens et al., 2008). The rationale for undertaking this longitudinal study of male adolescent swimmers, in the competitive setting, was to: (a) model performance progression through adolescence; and (b) predict the ages at which performance plateaued. Advancements in statistical modelling have recently provided researchers with a more refined and rigorous method of interpreting longitudinal data (Costa, Bragada, Marinho, et al., 2013; Morais et al., 2014), but until now, sub-elite athletes have been underrepresented. Additionally, swimming has commonly been considered as a single sport (Allen et al., 2014; Baxter-Jones et al., 1995), rather than a sport with multiple specialisms in the form of different stroke techniques and distances. Where the individual strokes have been characterised, it is still rare to find simultaneous analyses of all strokes together. The aim of this study was to create a tool that will enable the progression and variability of performances throughout puberty to be tracked in relation to a modelled mean and as such, assist coaches with the setting of realistic goals when devising individually-tailored training programmes. Finally, the models produced in this study could potentially be used as instruments for identifying talented young male swimmers.

5.2 Methods

Performance times for all male entrants (n = 446, aged between 12 and 19 years) who competed in one of seven individual events (Table 5.1) were extracted from the official results of an annual international schools swimming championships from 2006 to 2013. The data was in the public domain and downloaded from the relevant tournament websites. All swimmers from the 13 competing schools were assigned individual identity codes to ensure anonimity. The study was approved by the institutional ethics committee and conformed to the recommendations of the Declaration of Helsinki. The number of observations in each of the seven events entered over the 8 year analysis period are described in Table 5.1. The swimmers' ages at the time of each competition were also obtained.

Table 5.1 Cumulative number of performances (between 2006 and 2013) for male swimmers between the ages of 12 and 19 years in each event.

Number of Performances (years)	50 m Freestyle	100 m Freestyle	200 m Freestyle	100 m Backstroke	100 m Breaststroke	100 m Butterfly	200 m Individual Medley
1	376	280	190	178	196	132	139
2	151	103	87	74	69	55	65
3	69	49	37	34	37	26	38
4	25	17	16	14	21	14	18
5	9	3	6	1	9	4	6
6	2	1	1	0	3	2	1

5.2.1 Statistical Analysis

The raw datasets for all performances in each of the seven events were tested for normality using the Shapiro-Francia test in STATA ver. 13. The datasets for all events had non-normal distributions. The trajectories of the curves showing the progression in performance during adolescence were analysed using mixed or multi-level modelling (MLM) in STATA. Time was zero centred at the first point of observation (12 years of age), using an unstructured covariance approach. The fit of the models for fixed and random effects were compared by obtaining maximum likelihoods using a hierarchical method. The final models were quadratic functions for fixed effects ($y = \mathrm{a}x^2 + \mathrm{b}x + \mathrm{c}$). The fixed effects of time represented polynomial changes of the population with age and the random effects reflected individual deviations from the sample mean trajectory. Inter-class correlations were calculated and R^2 values determined in order to measure the difference between and within person variability and effect size respectively.

5.2.2 *Evaluation of Models*

Cross-validation of models is highly recommended to ensure the generalisability of the findings (Witten & Frank, 2005). Cross-validation was therefore performed for each of the seven models separately, whereby the datasets were randomly split into training (66%) and test (33%) sets. Performance of each test set was determined through obtaining the mean difference in model performance.

The percentage rate of improvement was determined through differentiation of the quadratic functions for each event separately, as $y = \left(\frac{2a}{c} \times 100\right)x + \left(\frac{b}{c} \times 100\right)$, where y = % change in performance time and x + 12 = age, in years. The age at peak performance was calculated as the axis of symmetry of the quadratic function *i.e.*, $\frac{-b}{2a}$.

5.3 Results

The models for all three freestyle events and the backstroke event resulted in fixed quadratic random linear functions whereas those for the remaining three events showed the best fit as fixed quadratic random intercept functions (Table 5.2). The high ICC values for all the models indicated a greater variability between- rather than within-swimmers. The model for the means explained 16%–25% of the variance in the changes with age. The results from the cross validation indicated that the fixed effects of the quadratic functions for all events fell within the 95% confidence intervals (C.I.) of those of the full models, with the exception of the 100 and 200 m freestyle events (Table 5.2). The 1/3 and 2/3 subsamples for both of these events fell marginally outside of the C.I. of the full model for their fixed intercepts only.

Table 5.2 Summary of models for all events with cross validation for each of the fixed effects of the quadratic functions.

Predictor	**50 m Freestyle**		**100 m Freestyle**		**200 m Freestyle**		**100 m Backstroke**		**100 m Breaststroke**		**100 m Butterfly**		**200 m Individual Medley**	
	Mean	***P***	**Mean**	***P***	**Mean**	***P***	**Mean**	***P***	**Mean**	***P***	**Mean**	***P***	**Mean**	***P***
Fixed Quadratic (a)	0.21	<0.001	0.48	<0.001	0.93	<0.001	0.47	<0.001	0.50	<0.001	0.41	<0.001	0.97	<0.001
Standard error (SE)	(0.02)	–	(0.06)	–	(0.14)	–	(0.08)	–	(0.08)	–	(0.11)	–	(0.14)	–
95% C.I.	0.05	–	0.11	–	0.28	–	0.16	–	0.16	–	0.21	–	0.28	–
Cross val. 2/3 diff.	0.003	<0.001	0.051	<0.001	0.21	<0.001	0.07	<0.001	−0.068	<0.001	0.05	0.007	0.10	<0.001
Cross val. 1/3 diff.	0.03	<0.001	0.010	<0.001	0.003	0.001	−0.05	0.001	0.097	0.005	−0.13	0.001	−0.22	<0.001
Fixed Linear (b)	−2.78	<0.001	−6.38	<0.001	−12.16	<0.001	−6.37	<0.001	−6.65	<0.001	−6.40	<0.001	−12.56	<0.001
(SE)	(0.18)	–	(0.45)	–	(1.11)	–	(0.62)	–	(0.62)	–	(0.85)	–	(1.06)	–
95% C.I.	0.36	–	0.88	–	2.18	–	1.22	–	1.22	–	1.66	–	2.08	–
Cross val. 2/3 diff.	−0.04	<0.001	−0.44	<0.001	−2.01	<0.001	−0.62	<0.001	0.31	<0.001	−0.41	<0.001	−0.94	<0.001
Cross val. 1/3 diff.	−0.16	<0.001	0.28	<0.001	0.37	<0.001	0.23	<0.001	−0.22	<0.001	1.11	<0.001	1.23	<0.001
Fixed Intercept in seconds (c)	37.23	<0.001	83.81	<0.001	179.45	<0.001	95.33	<0.001	104.35	<0.001	92.79	<0.001	195.98	<0.001
(SE)	(0.38)	–	(0.99)	–	(2.39)	–	(1.37)	–	(1.12)	–	(1.65)	–	(2.21)	–
95% C.I.	0.74	–	1.94	–	4.67	–	2.68	–	2.34	–	3.23	–	4.33	–
Cross val. 2/3 diff.	0.07	<0.001	1.48	<0.001	5.36	<0.001	1.57	<0.001	0.59	<0.001	0.77	<0.001	1.86	<0.001
Cross val. 1/3 diff	0.17	<0.001	−2.47	<0.001	−3.97	<0.001	−0.88	<0.001	0.33	<0.001	−2.19	<0.001	−3.26	<0.001
Interclass correlation (ICC)	0.95		0.97		0.96		0.97		0.91		0.90		0.92	
Wald's χ^2	543.36 (df = 7)		479.95 (df = 7)		315.318 (df = 7)		298.98 (df = 7)		430.27 (df = 5)		318.57 (df = 5)		461.07 (df = 5)	
Total R^2	0.25		0.23		0.16		0.17		0.20		0.22		0.17	
n	376		280		190		178		196		132		139	

Note: Cross val. diff. is the difference between the cross validation split and the whole sample. Wald's χ^2 is Wald's chi-square.

Similar distinct trends in the trajectories of the models were observed when compared to threshold age of peak performance or a fixed age of 18 years (Figure 5.1). The progression of swimmers of 100 m butterfly differed from all the other events. The butterfly swimmers reached a peak performance age more than a year later than those in other events, but displayed the highest rate of improvement (Table 5.3). In contrast, the slowest rate of improvement and joint youngest age of peak performance occurred for swimmers of the 200 m individual medley (IM). Of the remaining events, two groups emerged; 50 and 100 m freestyle events showed very similar trajectories, as did the 100 m backstroke, breaststroke and 200 m freestyle (Figure 5.1, Table 5.3).

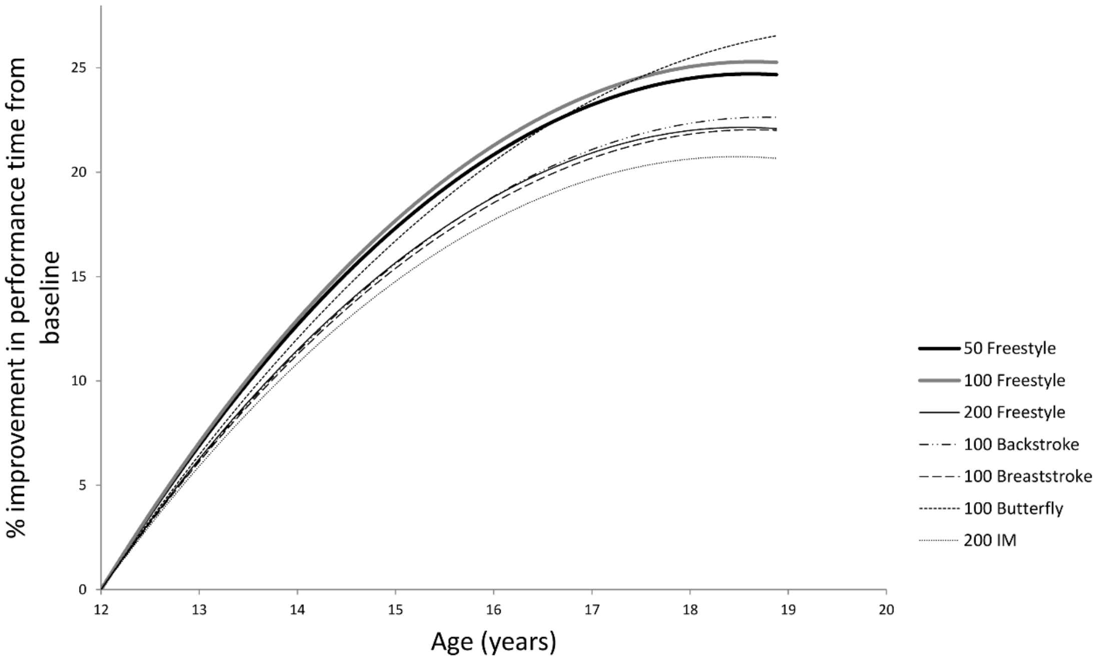


Figure 5.1 Quadratic functions of the progression in performance for each of the seven events modelled for males from the baseline of 12 years through to 19 years of age.

Table 5.3 Descriptors determined for the full models of the seven events.

Predictor	50 m Freestyle	100 m Freestyle	200 m Freestyle	100 m Backstroke	100 m Breaststroke	100 m Butterfly	200 m Individual Medley
% Rate of improvement (12 year—peak age)	24.70	25.29	22.15	22.64	22.03	26.92	20.75
% Rate of improvement (from 12 to 18.5 year)	24.70	25.28	22.15	22.60	22.02	26.16	20.75
Threshold age in peak performance (year)	18.5 (0.12)	18.7 (0.06)	18.6 (0.14)	18.7 (0.08)	18.6 (0.08)	19.8 (0.11)	18.5 (0.14)
Performance time (s) at threshold age	28.26 (0.22)	62.44 (1.53)	139.54 (9.38)	73.94 (2.07)	82.26 (2.40)	67.93 (3.09)	155.35 (9.36)

Data given as mean with standard errors shown in brackets.

5.4 Discussion

This is the first study to longitudinally assess the development of sub-elite adolescent male swimmers in multiple stroke techniques during competition, where the primary purpose was to generate a TI tool for young male swimmers. To achieve this, the performance progression of these swimmers was modelled to identify the mean threshold age at which they could be expected to start competing at the highest level. It was thus unsurprising that for most events, age correlated with the widely accepted age of biological maturity for males (Table 5.3) in agreement with previous work (Baxter-Jones, 1995; Malina, 1994b). Hence it could be surmised that any further gains in performance from this point onwards, would potentially come from the biomechanical and psychological domains. However, the rate of progression in performance of male athletes, including swimmers, during adolescence is known to be attributed predominantly to the tempo of their anthropometric and physiological maturation (Beunen & Malina, 1988).

There was a narrow range of ages (18.5–19.8 years) at which the swimmers approached their peak in performance in the seven events modelled in this study. In a retrospective study of career progression in elite swimmers, Allen et al. (2014) found ages of peak performance that were on average 6.2 years older than those for the corresponding events in this study. The discrepancy between the two studies can be explained by three factors. Firstly, Allen et al. (2014) tracked athletes back over a longer career path (from the ages of 12–30 years). Secondly, their sample only contained athletes who had already progressed to the elite level (probably through simplistic TI systems), whereas the talent pool in this study contained a wider-ranging standard of swimmers. Thirdly, the majority of their sample would have comprised athletes who grew up prior to the long-term athlete development (LTAD) generation of the post millennium era that our sample contains. But there is in fact no discordance between these two studies; they are complementary. While Allen et al. (2014) identified a potential absolute peak in performance of current and past elite swimmers, this study, based on the broad nature of the sample, provides insight into the threshold age of performance; *i.e.*, the cusp of the window of peak performance for future talented swimmers. The discrepancy between the two predicted ages therefore serves as a period of potential performance development that will come about through factors such as training interventions and increased experience, rather than maturational development. The models in Allen et al. (2014) are therefore more likely to provide coaches with a selection tool for swimmers currently in an elite squad, rather than as a means to identify future talent.

Freestyle is the most efficient stroke (Barbosa et al., 2006; Maglischo, 2003) and is most frequently swum in practice. It is therefore unsurprising that two of the three steepest progressions of performance occurred in freestyle events (Table 5.3), since this stroke contributes in excess of 30% of the events on offer at the majority of competitions (see Appendix, Table 9.2) (British Swimming & The ASA, 2015; International Olympic Committee, 2013b; Kiehl, 2014). A study by Costa et al. (2011) on elite Portuguese male freestyle swimmers, found similar rates of progression (14.36%–18.97%) between the ages of 12 and 18 years.

Vaso, Knechtle, Rüst, Rosemann, and Lepers (2013) hypothesised that IM swimmers might peak later than those in freestyle events, due to the additional skills required in mastering all four of the recognised stroke techniques and their unique turns in this complex event. In contrast, our models suggested that male IM swimmers peaked in performance earlier than the majority of other stroke specialisms (Table 5.3), but showed the slowest rate of improvement from 12 to 19 years (Figure 5.1). There are a number of reasons that may explain this observation. Firstly, IM swimmers may have started swimming at a young age, suggesting they may have a more advanced level of biomechanical experience and learning than swimmers in other events. Nevertheless, IM swimmers may not yet have found their specialist stroke. Once they do however, these swimmers may then focus more on other events. Secondly, many LTAD-based programmes advocate that coaches discourage swimmers from specialising too early in one stroke, in favour of focusing on the continued development of all strokes (Amateur Swimming Association, 2003).

The butterfly swimmers in this study reached their threshold in peak performance at a later age than all other events (Table 5.3). They did however demonstrate the greatest rate of improvement. The lag could be related to the need to gain sufficient experience in the stroke in order to efficiently coordinate its propulsive biomechanical actions. The butterfly stroke relies heavily on the precision of timing of its propulsive and recovery phases and consequently when these are not optimised, the rhythm becomes compromised (Seifert, Delignieres, et al., 2007). This means that when these factors do come together, considerable performance improvements are realised.

5.4.1 Limitations

Being a school-level competition, the sample lacks the homogeneity of an exclusive elite-level sample, however cross validation of the models supported their generalisability. This could be seen as a limitation of the study as it does not distinguish between early and late maturers, the former of which would be more likely to have been identified as being talented within this age range (Sherar, Baxter-Jones, Faulkner, & Russell, 2007). But, the decision to use longitudinal competition data, so as to maximise external validity, came at the cost of collecting any corresponding anthropometric data to assess maturation.

The models fit most events well with the exception of the 100 and 200 m freestyle (Table 5.2). The youngest swimmers of these events were markedly variable in standard. Dormehl and Williams (2016), did however find a lack of stability in the continued selection of these events by male swimmers between the ages of 12 and 19 years. Freestyle is also likely to be the stroke most favoured by inexperienced competitive swimmers, since it is the most efficient stroke with which they would be most familiar (Barbosa et al., 2006).

5.4.2 Practical Applications

Until now, quantifying deviations from average performances in adolescents has been subjective, due to the intertwined relationship between puberty, skill acquisition and underlying talent. The value of these models is that they can be used to determine if adolescent male swimmers were under- or over-performing based on their current age, because they were derived using athletes from a wide range of abilities and different stages of development. Consequently, deviations from the projected performance trajectories could be attributed to a swimmer’s stage of maturational development and/or potentially the standard of coaching received. The models could be useful as a TI tool, as they estimate the age at which an average sub-elite swimmer could potentially peak. Furthermore, the expected rate of improvement would serve as a useful target-setting tool for coaches and the authors propose that this model could serve as a prototype, from which further refinements could be expected to evolve.

5.5 Conclusions

Separating the performance gains as a result of the combined effects of maturation and training interventions remains an elusive goal for sports scientists. This is the first study that has attempted to model the progression of sub-elite adolescent male swimmers' performances across a multitude of individual strokes and distances. These models have identified that swimmers improve at different rates and achieve peak performances at different ages in different events ranging from 18.5 and 19.6 years of age. Assessing the gap between reaching biological maturity and peak performance should however continue to be an area of interest to the research community. Effectively identifying the potential "trainability" of young but mature athletes could hold the key to further improvements in athletic performance, especially in late specialisation sports, such as swimming.

Author Contributions: S.J.D. and C.A.W designed the study, S.J.D collected the data, S.J.R. & S.J.D. statistically analysed the data, S.J.D. wrote the first draft, C.A.W. supervised the study. All authors critically reviewed, contributed to and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Chapter 6

6 How Confident Can We Be in Modelling Female Swimming Performance in Adolescence?

Abstract: *The purpose of this research was to determine the expected progression of adolescent female swimming performances using a longitudinal approach. The performances of 514 female swimmers (12–19 year olds) who participated in one or more FINA-regulated annual international schools' swimming championships over an eight-year period were analysed. Quadratic functions for each of the seven individual events (50, 100, 200 m freestyle, 100 m backstroke, breaststroke, butterfly, 200 m individual medley) were determined using mixed linear models. The predicted threshold of peak performance ranged from 16.8±0.2 (200 m individual medley) to 20.6±0.1 (100 m butterfly) years of age, preceded by gradual rates of improvement (mean rate of 1.67% per year). However, following cross validation, only three events (100 m backstroke, 200 m individual medley and 200 m freestyle) produced reliable models. Identifying the factors that contribute to the progression of female performance in this transitory period of life remains challenging, not least since the onset of puberty is likely to have occurred prior to reaching 12 years of age, the minimum competition age for this championship.*

Keywords: puberty; tracking; talent-development; sub-elite; competition

6.1 Introduction

Based on the increasing pressure for nations to develop talented athletes and win medals at the highest level, many sporting bodies have directed strategies and resources to increasing performance levels in all sports; swimming is no exception (Barreiros et al., 2014; Bergeron et al., 2015; Light et al., 2013). Trying to separate the performance gains that are made by athletes due to training as opposed to natural growth and development has been one of the most important challenges to overcome. Malina (1994a) highlighted the need for longitudinal studies to better understand how and when athletes' performances progressed. There have been a number of approaches to predictive modelling in a variety of different sports, including physiological, mathematical or probability strategies (Liu et al., 2012). However, these authors suggest that until all factors such as biomechanical, physiological and psychological parameters that influence human performance are fully understood and accounted for, modelling will continue to lack sufficient accuracy to meaningfully predict future performance. Nevertheless, numerous studies have considered how changes in physical, physiological and biomechanical parameters affect performance during adolescence (Baxter-Jones et al., 1993; Lätt et al., 2009b).

To date, research exploring the development of youth swimmers during adolescence has focussed mainly on male subjects (Barbosa, Costa, et al., 2010; Baxter-Jones et al., 1995; Costa et al., 2011; de Mello Vitor & Böhme, 2010) with comparatively fewer targeting solely young females (Erlandson et al., 2008; Lätt et al., 2009b). In one of the few studies on young female swimmers, Lätt et al. (2009b) found that development of biomechanical factors such as velocity, stroke length, stroke rate and in particular stroke index, rather than bioenergetics, contributed more to improved performance times in the 400 m freestyle event.

The performance gap between adult males and females in swimming has reportedly been stable at 8.9% since 1979 (Thibault et al., 2010). Despite the negligible differences in swimming performance between the sexes before puberty, from age 12 years onwards the performance gap appears to increase (Kojima et al., 2012). Indeed, it is the greater stroke-specific power of males compared with females that is purported to be a key contributing factor to this difference (Toussaint et al., 2000; Wells et al., 2006). However, it has been proposed that since females mature physically earlier than males, they are better equipped to compete equitably with older females after reaching the age of 15 years (Kojima et al., 2012). From a physical standpoint, males can only start competing with an equal chance of success against mature males from the age of 17 years (Kojima et al., 2012).

Baxter-Jones (1995) questioned the age at which athletes should formally start competing and this debate remains as relevant today. In contradiction to competition entry requirements, the Amateur Swimming Association's (ASA) "The Swimmer Pathway" (Amateur Swimming Association, 2003) advocated that only 15 year old female swimmers should consider racing at the "training to compete" stage of the Long Term Athlete Development model (Balyi & Hamilton, 2004a). However, Grange and Gordon (2004) indicated that the youngest competition age was 9 years and the distances over which these younger swimmers competed continued to change, with no distinction being made between sexes (Amateur Swimming Association, 2010). Furthermore, the latest version of the ASA handbook does not make any reference to race distances for these younger swimmers (Amateur Swimming Association, 2014). Despite this, Light et al. (2013) found that, given the appropriate setting, club swimmers drawn from France, Germany and Australia (mean age of 10.39±1.07 years), were in fact demonstrating early specialisation and were not averse to competing at an early age. The findings of Barynina and Vaitsekhovskii (1992) suggested that young swimmers would benefit from later specialisation within the sport (after the age of 12 years) and less training before reaching the age of 11 years. These findings add support to the sampling approach to sport advocated by the Development Model of Sports Participation (Côté & Fraser-Thomas, 2007). However, Erlandson et al. (2008) found the development process of young female elite athletes did not appear to be adversely affected by intensive participation in sports, including swimming. The multitude of conflicting ideas regarding the minimum age for specialisation and/or competition suggested by various research groups, sporting bodies and development models confirms that, as yet, there is no definitive conclusion to this debate.

Longitudinal studies have the potential to help coaches gain perspective on the success of young athletes and enables them to give sound career advice (Costa et al., 2011). A longitudinal study by Sokolovas (2006) was one of the first to draw attention to the value of tracking elite swimmers retrospectively through their careers. With recent improvements in statistical methods, Allen et al. (2014) and Dormehl, Robertson, and Williams (2016b) have extended this concept by creating mixed linear models of elite-level, and sub-elite adolescent male swimmers respectively.

Since there are many challenges associated with constructing accurate models of human performance, besides the performance of young female sub-elite swimmers, it is unsurprising that no quantifiable baseline model currently exists. While it is tempting to create an all-encompassing model of swimming as a single sport, it is of more value to coaches and swimmers to acknowledge the individual specialisms within this multi-disciplinary sport. The aim of the present study was therefore to create the first models of the performance progression of sub-elite adolescent female swimmers for common strokes and distances. Identifying the threshold ages of peak performance in adolescent female swimmers could provide coaches and sporting associations with some potentially useful benchmarking tools to identify talent, and possibly provide evidence to determine realistic qualifying times as well as a justifiable minimum competition age for females.

6.2 Methods

Performance times for all female entrants (n = 514, aged between 12–19 years) who competed in one of seven individual events (Table 6.1) were extracted from the official results of an annual schools' swimming championships from 2006 to 2013. The 13 competing schools were American, British and International schools, predominantly located in Western Europe. Team sizes were limited and the competition rules limited swimmers to a maximum of three individual events per championship. The data were in the public domain and downloaded from the relevant tournament websites. All swimmers were assigned individual identity codes to ensure anonymity. The study was approved by the institutional ethics committee and conformed to the recommendations of the Declaration of Helsinki. The single best performances in each of the seven events entered (in either the heats or the finals) over the 8-year analysis period are described in Table 6.1. The swimmers' ages at the time of each competition were also obtained.

Table 6.1 Cumulative number of performances over the 8-year analysis period (between 2006 and 2013) for female swimmers between the ages of 12 and 19 years in each event.

Number of Performances (Years)	50 m Freestyle	100 m Freestyle	200 m Freestyle	100 m Backstroke	100 m Breaststroke	100 m Butterfly	200 m Individual Medley
1 *	414	310	233	223	217	135	163
2	167	109	92	83	84	48	64
3	69	42	28	34	33	22	23
4	22	17	10	14	12	8	8
5	7	3	5	5	3	6	2
6	2	0	2	0	1	2	0

Note: The drop in the number of repeat performances was likely to have been caused by a change in event choice, team selection, the transitory nature of scholars at international schools, injury or dropout. * This row of data denotes the total number of swimmers competing in each event, since this table sums the consecutive number of years swum. *i.e.*, the total number of entrants in the 50 m freestyle event was 414, 167 of whom competed for two or more years with 2 of whom went on to swim in this event for 6 consecutive years (the maximum number of years over which any swimmer could compete between age 12 and 19 years).

6.2.1 Statistical Analysis

The raw datasets for all performances in each of the seven events were tested for normality using the Shapiro–Francia test (Mbah & Paothong, 2015) in STATA ver. 13 (StataCorp. 2013. *Stata Statistical Software: Release 13*. College Station, TX, USA: StataCorp LP). The trajectories of the curves showing the progression in performance during maturation were analysed using mixed or multi-level modelling (MLM) in STATA. Time was zero centred at 12 years of age, using an unstructured covariance approach. The fit of the models in fixed and random effects were compared with maximum likelihoods, using a hierarchical method. The final models were quadratic functions for fixed effects ($y = ax^2 + bx + c$). The fixed effects of time represented polynomial changes of the population with age and the random effects reflected individual deviations from the sample mean trajectory. Inter-class correlation coefficients were calculated and R^2 values determined in order to measure the difference between and within person variability and effect size respectively.

6.2.2 Evaluation of Models

The datasets for certain events had non-normal distributions. As a result, to validate the proposed models, cross-validations were performed whereby the datasets were randomly split into 1/3 and 2/3 sub-groups. Cross-validation of models is highly recommended under such circumstances in order to determine the generalisability of the findings (Witten & Frank, 2005).

The percentage rate of improvement was determined through differentiation of the quadratic functions for each event separately, as $y = \left(\frac{2a}{c} \times 100\right)x + \left(\frac{b}{c} \times 100\right)$, where y = percent change in performance time and x + 12 = age, in years. The threshold age of peak performance was calculated as the axis of symmetry of the quadratic function *i.e.*, $\frac{-b}{2a}$.

6.3 Results

Many of the probability values for the coefficients of the functions were greater than 0.05 (Table 6.2), resulting in reduced confidence in those models. This included the full model of the fixed quadratic for the 100 m butterfly and at least one of the cross-validation models for the 50 and 100 m freestyle in addition to the 100 m backstroke and breaststroke. Cross validation confirmed that the full models for the 200 m freestyle and the 100 m backstroke events fit the data well in comparison to those for the other events. In the remaining five events however, at least one coefficient of the cross-validation models fell just outside of the standard error (SE) of the full model, but all fell within the 95% confidence interval (C.I.) of the full model. Of all the models, the 100 m freestyle event had the poorest fit.

The models indicate that female swimmers are likely to reach their threshold of peak performance earliest in the 200 m individual medley (16.8 years) and latest in the 100 m butterfly, the latter of which was predicted to occur beyond the age range of the dataset (Figure 6.1 and Table 6.3). The slowest rate of improvement between the ages of 12 and 16.8 years was observed in 100 m butterfly swimmers, whereas the greatest rate of improvement (over the same age range) was predicted to occur in the 200 m freestyle event. For the modelled improvement rates from 12 years through to the threshold age, 200 m freestyle swimmers remain the fastest improving, while breaststroke swimmers replace butterfly swimmers as the slowest to improve (Table 6.3).

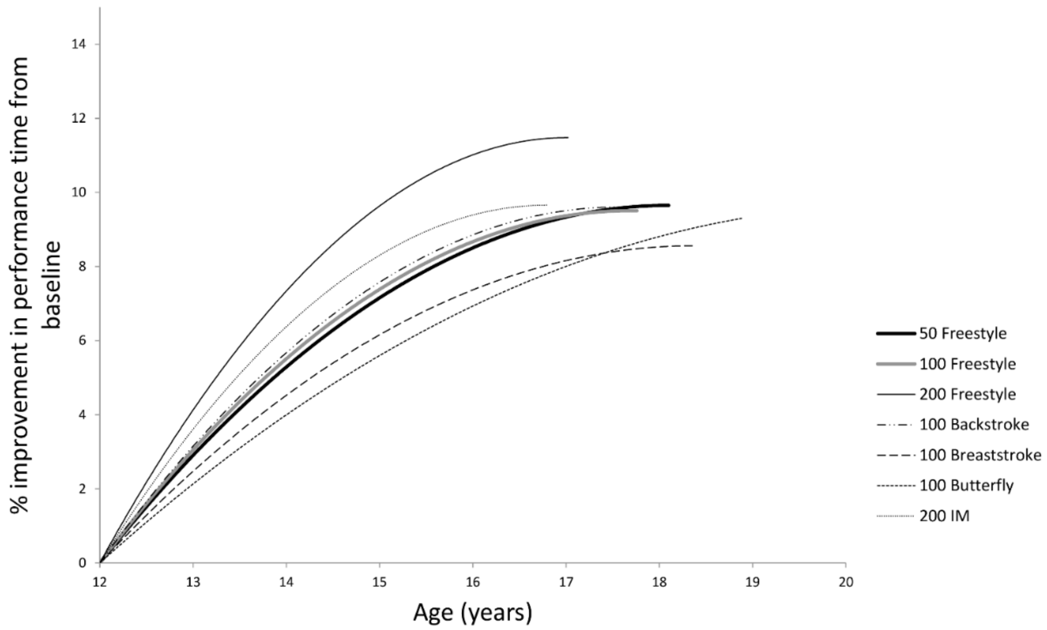


Figure 6.1 Quadratic functions of the progression in performance for each of the seven events modelled for females from the baseline age of 12 years to the threshold age of peak performance.

Table 6.2 Summary of models for all events with cross validation for each of the fixed effects of the quadratic functions.

Predictor	**50 m Freestyle**		**100 m Freestyle**		**200 m Freestyle**		**100 m Backstroke**		**100 m Breaststroke**		**100 m Butterfly**		**200 m Individual Medley**	
	Mean	***p***	**Mean**	***p***	**Mean**	***p***	**Mean**	***p***	**Mean**	***p***	**Mean**	***p***	**Mean**	***p***
Fixed Quadratic (a)	0.095	<0.001	0.24	<0.001	0.83	<0.001	0.29	<0.001	0.217	0.012	0.12	0.333	0.83	<0.001
(SE)	(0.02)		(0.06)		(0.13)		(0.07)		(0.09)		(0.12)		(0.19)	
95% C.I.	0.05		0.11		0.25		0.13		0.17		0.24		0.37	
Cross val. 2/3 diff.	−0.03	<0.001	0.10	0.072	0.071	<0.001	−0.05	<0.001	−0.001	0.054	0.048	0.637	0.035	0.001
Cross val. 1/3 diff.	0.03	0.089	−0.11	<0.001	0.045	0.001	0.01	<0.077	−0.03	0.128	−0.09	0.299	−0.26	0.001
Fixed Linear (b)	−1.16	<0.001	−2.73	<0.001	−8.31	<0.001	−3.22	<0.001	−2.77	<0.001	−2.05	0.031	−7.96	<0.001
(SE)	(0.17)		(0.45)		(0.97)		(0.52)		(0.63)		(0.95)		(1.40)	
95% C.I.	0.34		0.87		1.90		1.02		1.24		1.86		2.73	
Cross val. 2/3 diff.	0.22	<0.001	−0.73	<0.001	−0.53	<0.001	0.19	<0.001	0.22	<0.001	−0.54	0.196	−0.202	<0.001
Cross val. 1/3 diff.	−0.15	<0.001	0.72	<0.001	−0.30	<0.001	−0.51	0.001	−0.67	0.027	1.13	0.045	1.26	0.002
Fixed Intercept in seconds (c)	36.69	<0.001	81.66	<0.001	181.21	<0.001	93.06	<0.001	103.25	<0.001	90.59	<0.001	197.62	<0.001
(SE)	(0.32)		(0.92)		(2.1)		(1.10)		(1.19)		(1.79)		(2.86)	
95% C.I.	0.62		1.81		4.11		2.15		2.33		3.51		5.60	
Cross val. 2/3 diff.	−0.27	<0.001	1.29	<0.001	1.03	<0.001	0.59	<0.001	−0.42	<0.001	1.37	<0.001	1.36	<0.001
Cross val. 1/3 diff	−0.12	<0.001	−1.27	<0.001	−0.03	<0.001	−0.68	<0.001	1.30	<0.001	−2.89	<0.001	−2.44	<0.001
ICC	0.90		0.96		0.97		0.97		0.95		0.90		0.97	
χ^2 df	133.12 [df = 5]		70.41 [df = 7]		93.31 [df = 7]		60.32 [df = 7]		46.47 [df = 7]		26.4 [df = 5]		45.41 [df = 7]	
Total R^2	0.03		0.05		0.08		0.04		0.02		0.04		0.17	
n	414		310		233		223		217		135		163	

Notes: Cross val. diff. is the difference between the cross validation split and the whole sample mean; SE = standard error; C.I. = confidence interval; df = degrees of freedom.

Table 6.3 Descriptors determined for the full models of the seven events.

Predictor	50 m Freestyle	100 m Freestyle	200 m Freestyle	100 m Backstroke	100 m Breaststroke	100 m Butterfly	200 m Individual Medley
% Rate of improvement (12 year−threshold age)	9.65	9.50	11.48	9.60	8.56	9.66	9.66
% Rate of improvement (from 12 to 16.8 year)	9.21	9.28	11.46	9.43	8.04	7.81	9.66
Threshold age at peak performance (year)	18.1 (0.02)	17.8 (0.06)	17.0 (0.13)	17.6 (0.07)	18.4 (0.09)	20.6 (0.12)	16.8 (0.19)
Performance time (s) at threshold age	33.15 (0.14)	73.81 (0.14)	160.42 (4.87)	84.04 (0.36)	94.42 (0.32)	81.85 (0.11)	178.50 (6.70)

6.4 Discussion

The aim of the study was to model the performance of female swimmers in all strokes between the ages of 12 and 19 years. However, only the 200 m freestyle, the 100 m backstroke and, to a lesser extent, the 200 m individual medley events produced functions that can be interpreted with any confidence (Table 6.2).

Although Kojima et al. (2012) did not aim to determine a peak age—they predicted that females could already start competing equally with older females from as young as 15 years of age. In contrast, the quadratic functions of this study indicated thresholds of peak performance occurred later, i.e. from the age of 16.8 years (Table 6.3). A possible reason for this apparent discrepancy is that our dataset only included females from the age of 12 years (Figure 6.1), as this was the minimum entry age for the particular competition studied, while in the Kojima study there were swimmers as young as 7 years of age (Kojima et al., 2012). The unexpectedly late age of predicted peak performance for swimmers competing in the 100 m butterfly (20.6 years), was largely due to the shallow gradients (approx. 1.1% per year) of modelled improvement for this event. According to Malina et al. (2004), puberty begins at approximately 8 to 10 years of age for females and the mean age of menarche has been reported as 12.9 years (Whincup, Gilg, Odoki, Taylor, & Cook, 2001). It is therefore possible that the majority of females in this study may already have experienced meaningful gains in performance due to maturational development prior to competing in these events.

The threshold age of peak performance for the sub-elite female swimmers in this study were on average only 0.7 years younger than their male counterparts at the same championships (Dormehl et al., 2016b), even though females are expected to mature approximately 2 years earlier (Malina et al., 2004). This finding supports the authors' concerns about combining data on all strokes and distances into one single model, as the relatively late predicted age of peak performance in the butterfly will undoubtedly have contributed to the higher mean threshold age calculated for the females in this study. However, the relative rate of improvement for adolescent female swimmers is confounded by numerous additional factors. Since females mature earlier than males, their improvement between the ages 12 and 19 years is likely to be affected less by biological processes and potentially more by external factors, including biomechanical development, psychological and social pressures (Saavedra et al., 2010). While the growth and maturational process to adulthood starts prior to the age of 12 years for females, it has been questioned whether they have sufficient cognitive development to deal with the rigours of high level competition and the concomitant pressures (Wiersma, 2000), or whether they should be specialising at such a young age (Côté, Lidor, & Hackfort, 2009).

The expected plateau in performance as biological maturation nears its peak, experienced earlier in females than males, is a factor possibly leading to waning interest and commitment to training and potentially higher dropout rates in females (Erlandson et al., 2008). In accordance with the findings of Cornett and Stager (2015), who examined the effect of the number of entrants in a 50 yard freestyle event on the level of performance, it is also possible that the lower number of entrants in the older age groups (data not shown) may also have contributed to reduced competitiveness in these groups. Nevertheless, these sub-elite females were predicted to attain their threshold of peak performance 5.1 years earlier than the peak performance age reported for elite-level swimmers in the same events analysed by Allen et al. (2014). The difference is likely due in part to their study exclusively containing a narrower sample of elite swimmers and, importantly, included performance data that progressed beyond their teenage years.

While the predicted models in this study provide poor fit for many of the events, there is value in examining the comparisons between events. Females reach their threshold of peak performance in longer distance events such as the 200 m individual medley and the 200 m freestyle at a younger age than shorter distance events (Table 6.3), confirming a phenomenon reported on by Arellano et al. (1994) and Allen et al. (2014). Swimmers competing in the 200 m freestyle event also demonstrated the highest rate of improvement between the ages of 12 and 16.8 years (Figure 6.1). It is possible that females improve most in the longer distance events due to changes in body composition as a result of puberty. Post-pubertal females are known to have greater buoyancy, which has been suggested to give them an energy efficiency advantage over males (Ratel et al., 2006) and is most noticeable in longer distance events (Chatterjee & Laudato, 1996; Thibault et al., 2010).

6.4.1 Practical Applications

Rather than being limited to mere mathematical comparisons of combined threshold times of numerous specialisms within swimming, the value of the individual models developed in this study promotes many potential applications for coaches, swimmers and governing bodies. Swimmers can set realistic targets for the following season and coaches can measure the performance of their adolescent female swimmers against the average expected progressions for each of the events modelled. Furthermore, swimmers who consistently exceed the modelled rates of progression might be considered for talent development or alternatively may be identified as early or late maturers. With further refinements of the models, they could one day also assist governing bodies in the setting of justifiable qualifying times for national and international competitions.

6.5 Conclusions

Despite the poor fit of some of the models generated, the novel analysis of individual events allows for some interesting comparisons to be made. The authors feel that this approach is of more value than a one size fits all model for the sport. The models suggest that females achieve thresholds of peak performance earlier in longer distance events. Use of this particular international schools' swimming competition provided a consistent minimum age over many consecutive years and consequently ensured high validity of the dataset. However, the slow rate of progression seen in the quadratic functions generated in comparison to those found for the male adolescents by Dormehl et al. (2016b) indicates that the process of maturation had likely already begun for many of the females in this study. Compared with data for male swimmers (Dormehl et al., 2016b), confidently identifying the contribution of maturation to performance improvement in females through adolescence remains an elusive goal. Future research should therefore consider collecting longitudinal data on very young swimmers in competition, as these could generate more robust models and higher levels of confidence. Finding a suitable sub-elite competition setting for this may however prove difficult until such time as a consensus is reached on a suitable minimum age of competition, and whether this age should be the same for both males and females. Overcoming these issues could lead to the development of useful benchmarking tools for potential talent identification of sub-elite athletes or the setting of realistic development goals.

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Conflicts of Interest: The authors declare no conflict of interest.

Chapter 7

7 Confirming the value of adolescent swimming performance models

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

7.1 Introduction

Advancements in measurement instruments, quantifiable performance indicators (Quarrie & Hopkins, 2015; Robertson, Back, & Bartlett, 2016), the availability of large public datasets and statistical tools (Edelmann-Nusser et al., 2002; Heazlewood, 2006; Simonton, 1999) have precipitated the development of performance modelling in team and non-CGS (centimeter, grams and seconds) sports (Quarrie & Hopkins, 2015; Robertson et al., 2016). 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 (Moesch et al., 2011).

To date, most swimming performance models have focused on predicting future performance and talent identification using methods including neural models and networks (Edelmann-Nusser et al., 2002; Maszczyk et al., 2012; A. J. Silva et al., 2007), repeated-measure ANOVAs (Costa, Marinho, Reis, Silva, Bragada, et al., 2010) and mixed linear modelling (Allen et al., 2014; Dormehl, Robertson, & Williams, 2016a; Dormehl et al., 2016b). Predictive models of performance are commonly assessed using cross or external validation (Allen, Vandenbogaerde, Pyne, et al., 2015; Edelmann-Nusser et al., 2002; Maszczyk et al., 2012). However, to date there have been equivocal outcomes with some researchers reporting high levels of accuracy (Edelmann-Nusser et al., 2002; Maszczyk et al., 2012), and others (Allen, Vandenbogaerde, Pyne, et al., 2015) 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 (Rees et al., 2016). 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 (Ericsson et al., 1993; Güllich & Emrich, 2006). 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 (Rees et al., 2016; Simonton, 1999). 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. (2016a, 2016b) 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 Swimming Performance models (Dormehl et al., 2016a, 2016b), 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 (Koninklijke Nederlandse Zwembond, 2016), known as Dutch limits (DL). Additionally, the JSP models were considered in relation to the Allen et al. (2014) 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.

7.2 Methods

7.2.1 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.

7.2.2 Data collection

7.2.2.1 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, and Law (2005), 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 (Geisinger, 2003).

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 (Côté et al., 2005). Quantifiable information provided by the participants was independently verified by their current coach and against Swimrankings (2016), 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 (Côté et al., 2005), 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.

7.2.2.2 Performance times

Season's best (short course) performance times, achieved between the ages of 12 and 19 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 (Allen et al., 2014), 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. (2016b) and Dormehl et al. (2016a). 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 (2016). 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 males are only eligible between the ages of 13 and 18 years.

7.2.3 Data analysis

7.2.3.1 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 (Koninklijke Nederlandse Zwembond, 2016) 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),

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

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 7.1) 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):

$$\frac{gradient\ of\ improvement_{DRW} - gradient\ of\ improvement_{swimmer}}{gradient\ of\ improvement_{DRW}} \times 100. \qquad \text{Eq. 2}$$

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.

7.2.3.2 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, and Hoppenbrouwers (2009). The mean and standard deviations for the enjoyment and motivation scores, and the corresponding percent relative improvement for each group were also calculated.

7.3 Results

7.3.1 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 7.1.

Table 7.1 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.

7.3.2 Quantitative comparison between the JSP models and the DL quadratic functions

As illustrated in Figure 7.1, 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 7.1).

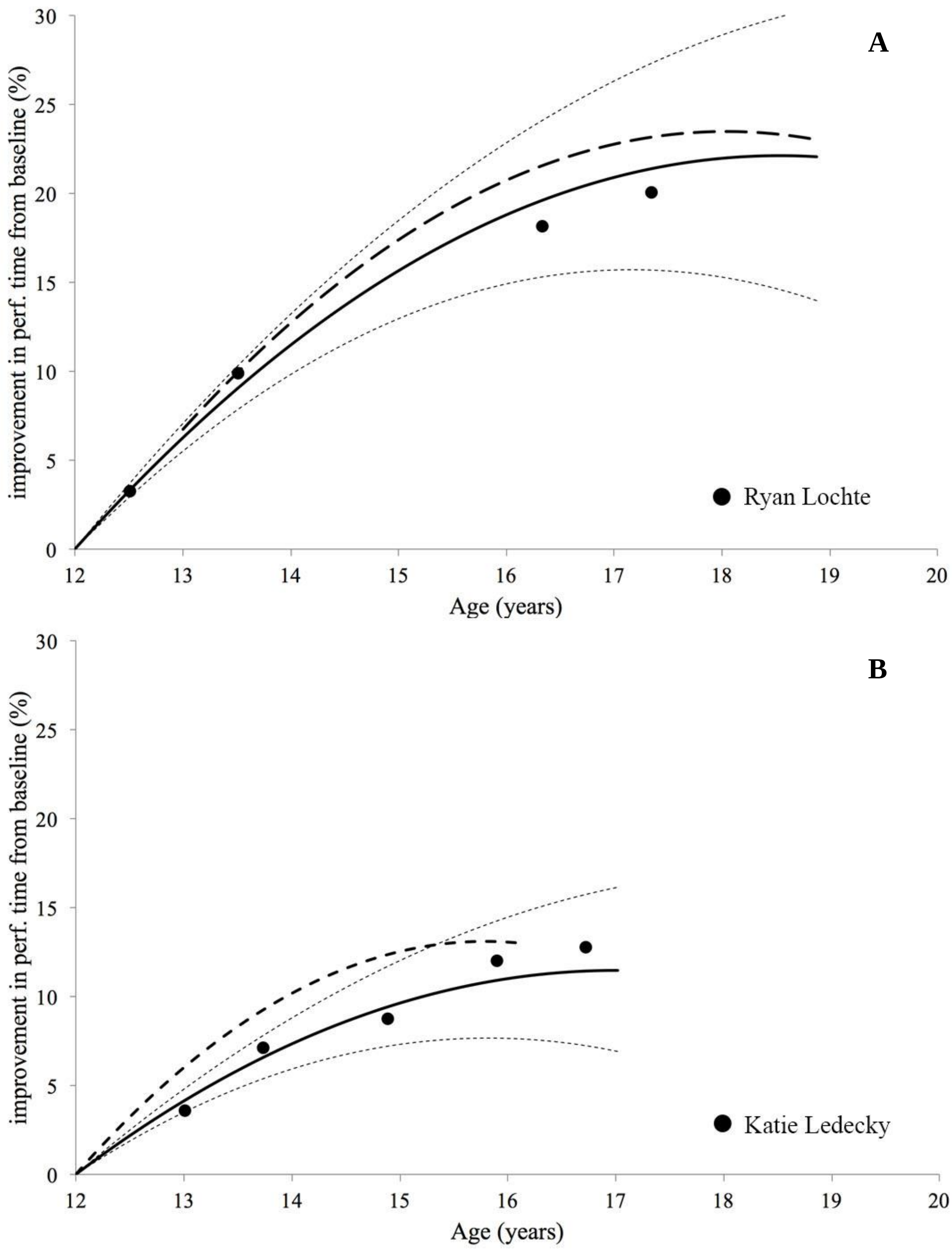

Figure 7.1 Quadratic functions of the progression of performance in the 200 m freestyle event modelled from a baseline of 12 years for adolescent male (A) and female (B) swimmers. The dashed lines represent the DL quadratic functions and the solid lines and dotted lines represent the mixed linear model functions and standard errors, replotted from Dormehl et al. (2016b) & Dormehl et al. (2016a) respectively.

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 7.2). 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 (orange, bottom right zone in Figure 7.2). Most notable was that this group of swimmers were all young (less than 13.5 years of age in the 100 m freestyle, Figure 7.2). 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 7.2). 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.

Table 7.2 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.

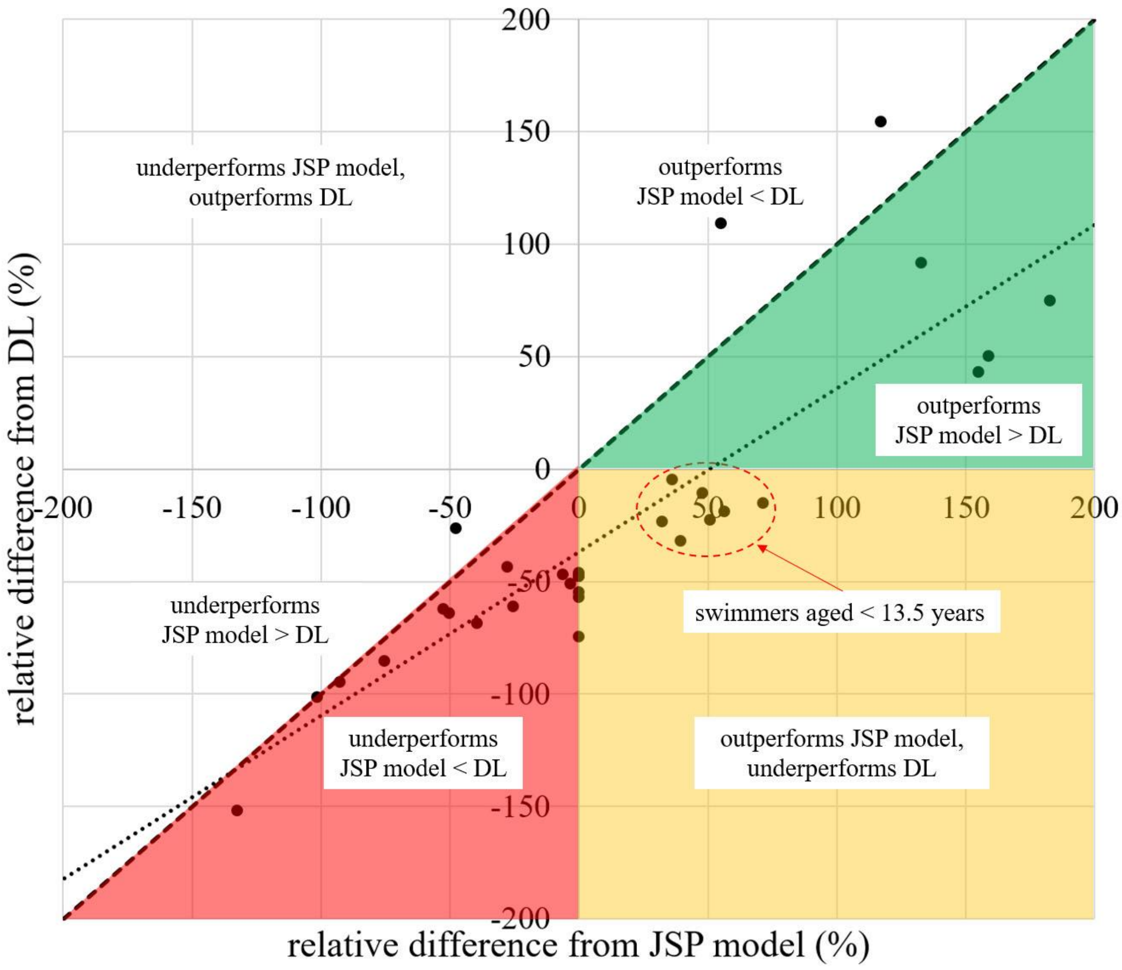

Figure 7.2 Comparison of the percent relative improvement of female Dutch swimmers from the JSP model compared with their percent relative improvement from the DLs for the 100 m freestyle event. The dashed line represents y = x *and the dotted line represents the linear regression for Dutch swimmers (Table 7.2).*

7.3.3 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 7.3). 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 7.3).

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 7.3). 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.

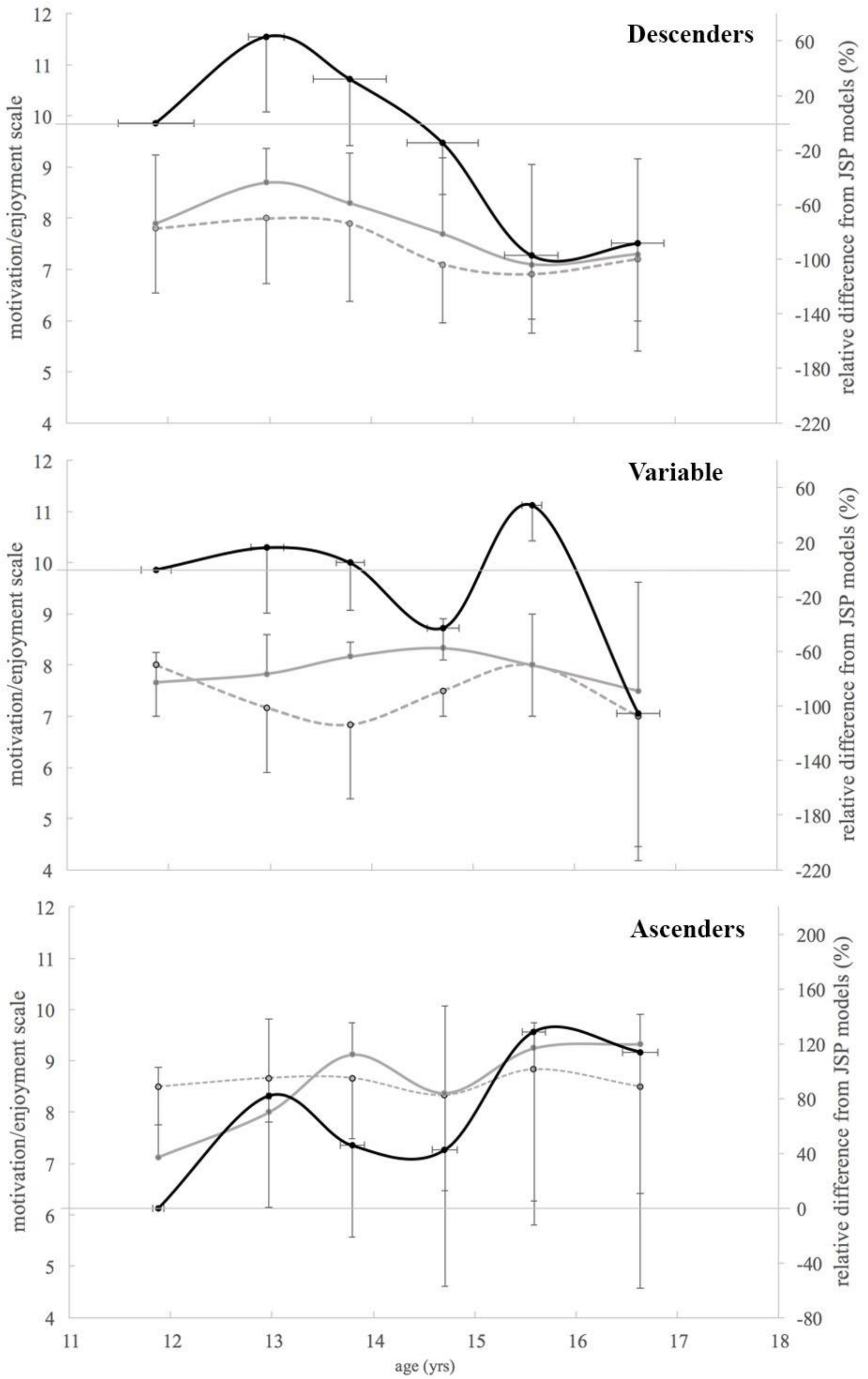

Figure 7.3 The progression in mean percent relative improvement from the JSP models (solid black line), enjoyment (dashed grey line) and motivation (solid grey line) of Dutch swimmers between the ages of 12 and 18 years, grouped as 'descenders', 'variable' and 'ascenders' respectively. The flattened JSP modelled lines are shown at y = 0. Error bars show 1SD (Descenders: n = 5; Variable: n = 4; Ascenders: n = 4).

Table 7.3 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 et al. (2009), 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).

7.4 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 (Edelmann-Nusser et al., 2002; Maszczyk et al., 2012). The models of Dormehl et al. (2016a, 2016b) 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. (2014) models and DL quadratic functions were selected for this purpose. The *y*-axis reference for all swimmers' performance times in the Allen et al. (2014) 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. (2014) 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. (2014) are shown in Figure 7.1. 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 7.1) to novice. Young, inexperienced swimmers would fall far from the fixed points of the Allen et al. (2014) models to be considered for selection, but these models (Allen et al., 2014) 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 (Koninklijke Nederlandse Zwembond, 2015b). 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 7.2, Figures 7.2, 9.1 to 9.6) 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 (Allen, Vandenbogaerde, Pyne, et al., 2015; Costa et al., 2011; Sokolovas, 2006). 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 (Allen, Vandenbogaerde, & Hopkins, 2015). Interestingly, Dormehl et al. (2016a) 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 7.2, Table 7.2).

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 7.3). 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 7.3). 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 7.3, Table 7.3). 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 (Light & Lemonie, 2010) and that effort remains a precursor to success (Lee, 2004). 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 7.3).

7.5 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.

7.6 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

The authors thank Titus Mennen, Junior National Coach and Program Manager of Talent Development, KNZB (Koninklijke Nederlandse Zwembond) for his contributions and insights into the Dutch Junior National selection programme.

Chapter 8

8 General Discussion

8.1 Summary of findings

With the current spotlight on youth sport, the overall purpose of this thesis was to investigate and develop an understanding of the mean progression in performance of youth sub-elite swimmers as they mature. Since previous research has focused mainly on elite, often adult, athletes and characterised swimming as a single specialism sport, it was felt that these gaps in the literature needed to be addressed.

In order to achieve this, a suitable sample of youth competitive swimmers was identified and tracked longitudinally from 2006 until 2013. An annual international schools' competition that attracted trained swimmers from numerous countries was selected as it provided a reliable and consistent standard of competition. Since the majority of schools were in Europe, following either the British or American systems of education, it was highly likely that the swimmers would have grown up in one of the first eras during which they would have been exposed to some form of long-term athlete development.

Progress in swimming as a sport has often been judged on the basis of the narrowing of the gap between the first and last placed athletes in the finals of individual events. The first study (Chapter 3) investigated whether the performance of sub-elite finalists was improving in parallel with elite and junior elite athletes but in fact it was found that this gap was narrowing (Figures 3.1, 3.2 and 3.3). Additionally, it was found that the gender gap of the sub-elite swimmers narrowed unlike those of junior elite and elite-level swimmers over the same time period (Figure 3.4). This study confirmed that despite the lack of any focussed talent development, long-term athlete development seems to have benefited these swimmers, and that the pool of sub-elite athletes with potential was substantial and worthy of further attention.

Specialisation is a key theme of athlete development and the sub-elite swimmers in this thesis provided a unique opportunity to develop a better understanding of this process. Unlike most elite-level competitions, no restrictions were placed on these sub-elite swimmers regarding in which events they chose to participate. The hypothesis that specific stroke combinations would be identifiable was confirmed with the 50 and 100 m freestyle events being most popular for males and females alike (Tables 4.3 and 4.4, Chapter 4). More importantly, it was expected that there would be a difference between the sexes with females specialising in their preferred strokes earlier than males. This difference was confirmed but interestingly breaststroke stood out as the only stroke in which both sexes specialised relatively early (Table 4.5 and 4.6), despite research by Knobloch et al. (2008) indicating a high incidence of knee injuries in breaststroke swimmers.

The findings of these first two studies highlighted how sub-elite swimmers had improved over the 8-year period and helped to enhance the understanding of how they specialise within the sport. This led naturally to a need to describe the progression in performance of these athletes as they matured. Since it was evident from these studies that sub-elite male and female swimmers in this thesis were progressing differently, it was decided to use the same approach, but focus on each sex separately. In Chapter 5, with the aid of the relatively new statistical methods of mixed-linear modelling, the rate of progression in performance of the male swimmers was modelled in an effort to shed some light on how performance improves between the ages of 12 and 19 years. It was found that threshold ages of peak performance occurred within a relatively narrow range between 18.5 (50 m freestyle, 200 m IM) and 19.8 years (100 m butterfly) (Table 5.3). As expected, it was more challenging to confidently model sub-elite female swimmers. Chapter 6 describes their trajectories with thresholds of peak performances ranging from 16.8 (200 m IM) and 20.6 years (100 m butterfly) (Table 6.3). The results of these two studies highlighted that females reached their peak in performance approximately 1 year prior to males, but additionally that males appeared to experience performance gains that were nearly twice the magnitude of that of females between the ages of 12 and 19 years.

It follows coherently that the conclusion to this thesis was to assess and evaluate the efficacy of all the models developed in Chapters 5 and 6. This was successfully achieved in Chapter 7 through a novel mixed-methods approach, using quantitative and qualitative data from an independent sample of Dutch junior national level swimmers. It was concluded that since the models were designed without fixed y-intercepts they were equally applicable to youth swimmers of all levels and could be used by coaches to track performance and set goals. A summary of the links between these research studies is illustrated in Figure 8.1 with the distinction between key findings in terms of age differences between males and females shown in Figure 8.2.

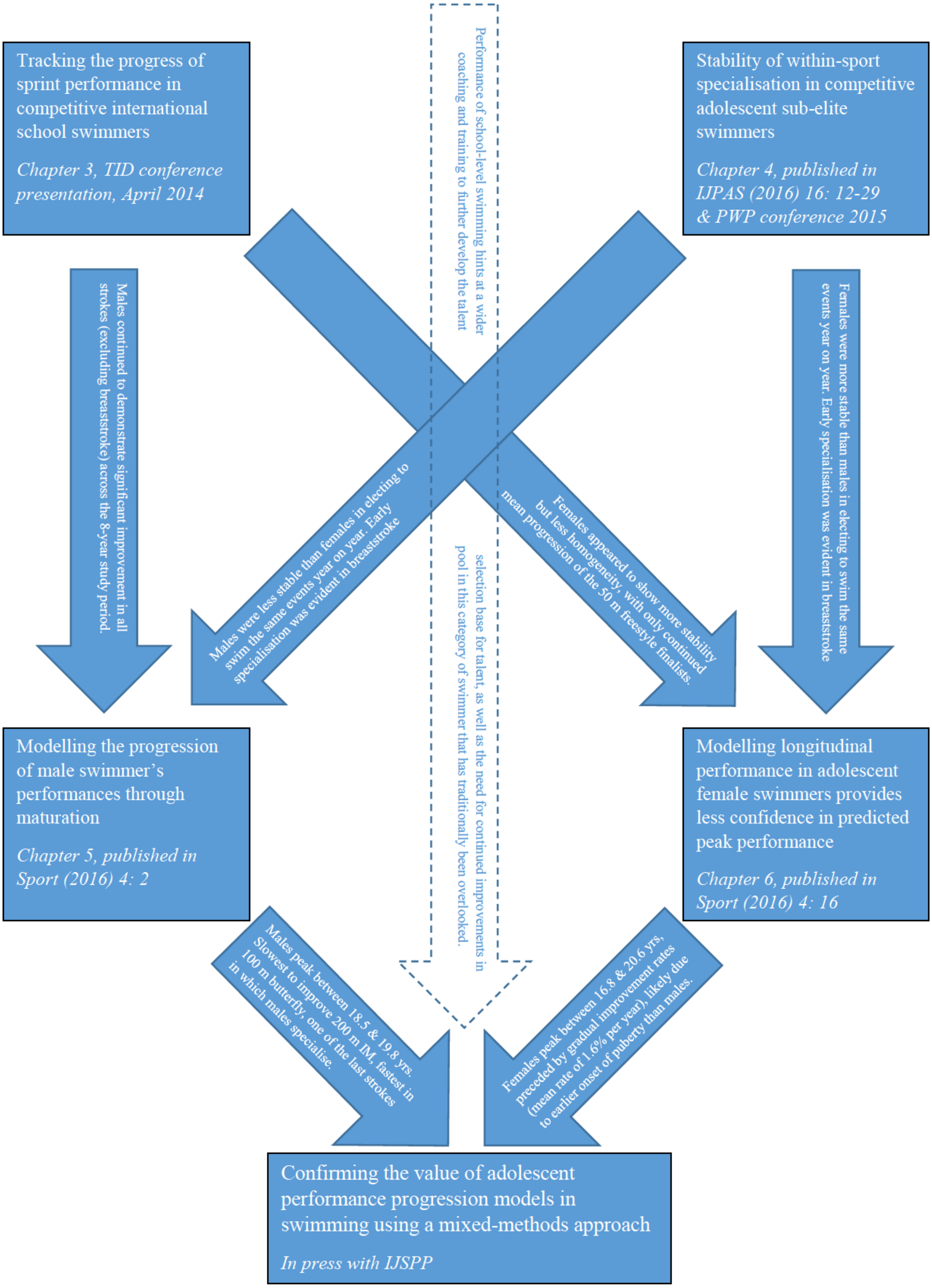

Figure 8.1 Synopsis of the links between the research chapters in this thesis.

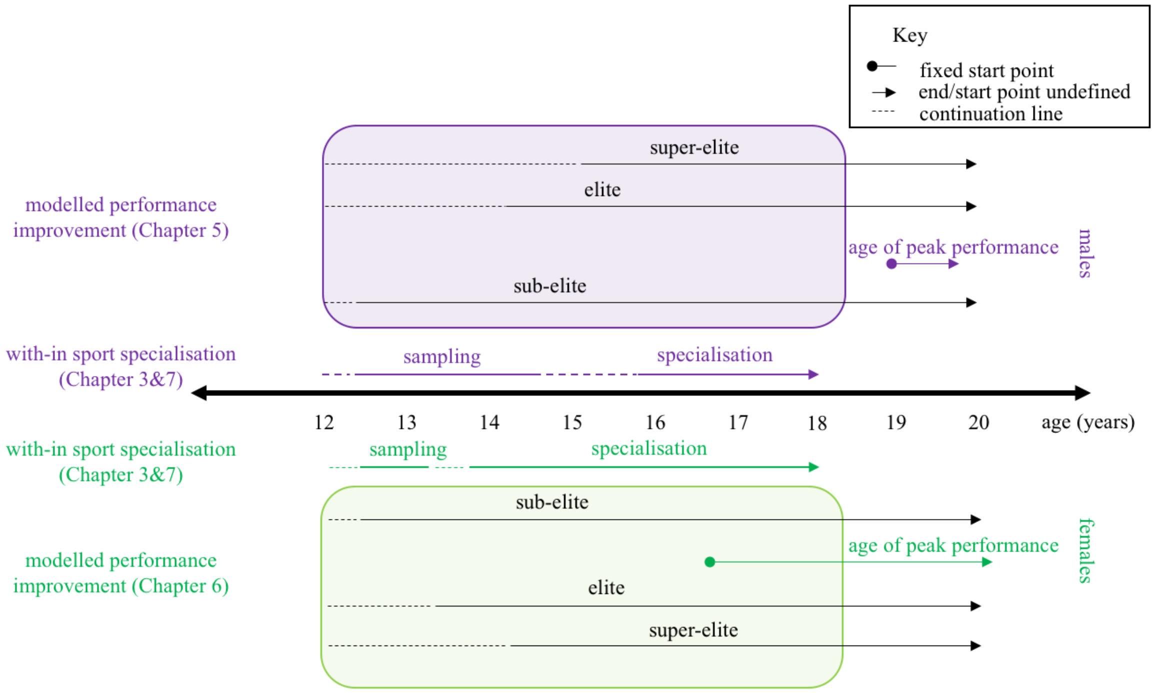

Figure 8.2 Summary of differences in the age between sexes of key parameters determined in this thesis and level of skill. The shaded boxes (purple for males and green for females) indicate the skill levels and ages for which the derived models in Chapters 5 and 6 are proposed to be applicable.

8.2 Impact on current understanding of athlete development through adolescence

The motivation behind the most popular athlete development models (Balyi, 2001; Côté & Fraser-Thomas, 2007) and their implementation by various governing bodies has tended to be the development of future talent (Sport England, 2016b). Although their success might have traditionally been measured in terms of medal tallies at international championships (British Swimming & The ASA, 2013a), the conclusion in Chapter 3, that the sub-elite swimmers in this thesis have been progressing at a faster rate than their elite and junior-elite counterparts, point towards an underrepresented but important category of swimmer that appear to have benefitted from these athlete development programmes.

Sport specialisation is an underlying theme of all youth athlete development models. Interestingly even during the time that this thesis has been undertaken, swimming has been classified as both a late specialisation sport (Amateur Swimming Association, 2003; Moesch et al., 2011) and an early-specialisation sport (Balyi et al., 2014; Bergeron et al., 2015), as well as having received criticism as to its classification (Bailey et al., 2010; Lang & Light, 2010). Whereas the classification of swimming was not a factor considered in this thesis, all the swimmers interviewed as part of the final study (Chapter 7) had begun learning basic water competencies at a very young age (data not shown).

Many authors have recently expressed concern for the mental and physical well-being, as well as dropout, of athletes being encouraged to specialise in a sport from a young age (Bergeron et al., 2015; Côté & Hancock, 2016; Smith, 2015). The minimum age of the swimmers, for the schools' competition selected for this thesis, was 12 years and it is not known when these swimmers began or may leave the sport. However, their specialisation within swimming was investigated (Chapter 4). This study has offered insight into a relatively unusual situation, where athletes have the opportunity to sample and then specialise within the numerous disciplines within the sport i.e. preferred strokes or distances. Interestingly it was found that the pattern of within-sport specialisation closely followed the between-sport sampling and -specialisation described by the DMSP of Côté and Fraser-Thomas (2007). To this end two of the pathways, recreational and early specialisation of Côté and Fraser-Thomas (2007) model have been modified to reflect this within-sport specialisation specifically for swimming (Figure 8.3). Unlike the DMSP, recommended ages have purposefully been excluded from Figure 8.3 for two reasons: 1) the on-going debate regarding the classification of swimming as an early or late specialisation sport and 2) the differences observed between the sampling and specialisation between females and males in this study (Table 4.5 and 4.6, Figure 8.2). A recommendation might therefore be that swimming be considered as an early engagement but late specialisation sport i.e., children should be encouraged to start early, in order to learn the basic concepts of floatation, drag and propulsion, where the emphasis is on fun and not specifically stroke development. This could then be followed by a period where they are introduced to the four main stroke techniques, but importantly they would still be participating/sampling other sports whilst also possibly specialising within their preferred swimming discipline(s).

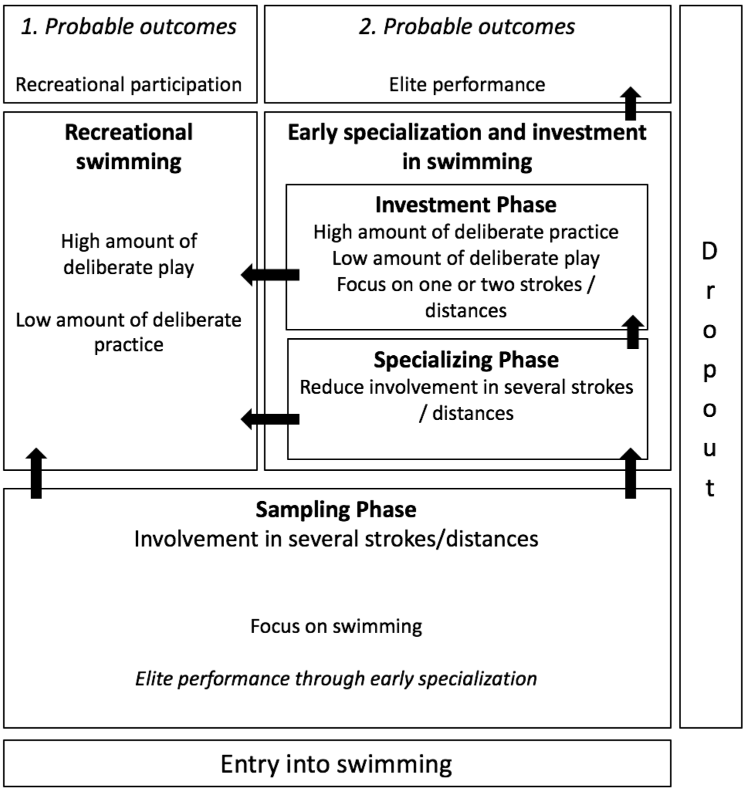

Figure 8.3 Proposed swimming-specific modifications of the Côté and Fraser-Thomas (2007) DMSP model to reflect within-sport specialisation.

LTAD has been more prominent in its implementation than the DMSP among swimming governing bodies, UK (Amateur Swimming Association, 2003), Australia (Raleigh, 2011), Canada (Swimming Natation Canada, 2008), South Africa (Department: Sport and Recreation South Africa, 2015) and The Netherlands (Koninklijke Nederlandse Zwembond, 2015a). Unlike the swimmers in this thesis, athletes of the next generation are likely to benefit from the most recent iteration of LTAD, i.e. LTAD 2.0 where criticisms with respect to the lack of attention to the psychosocial aspects of youth development were largely redressed (Balyi et al., 2014). Based on the interviews with the independent sample of Dutch junior national swimmers (Chapter 7), it was clear how important the psychosocial aspects, including enjoyment, motivation and peer involvement, were to them in being able to justify the significant investment they had made to swimming over their teenage years. These observations highlight the relevance of these factors in the careers of young swimmers. However, it is also evident that research on brain function and individual differences still require significant development before we can confidently understand their true influence and value to the developing athlete (Segalowitz, 2016).

Comparisons of the performance models developed in Chapters 5 and 6 provide evidence for differences between the sexes during adolescence. Allen et al. (2014) reported a ~2 year difference in the peak performance age between the sexes for elite-level swimmers but in fact the ~1 year difference in the mean threshold of peak performance for the sub-elite swimmers of this thesis (Figure 8.2) corresponds directly with the post 2nd World War mean difference between the male and female Olympic Gold medallists in the 100 m freestyle (Schulz & Curnow, 1988). Although this gap also aligns well with that proposed by LTAD 2.0, it is important to note that the range in the threshold ages of peak performances between stroke techniques were considerable i.e. ~1 year and ~4 years for males and females respectively (Figure 8.2). The ASA intends to implement changes to their swimmer pathway based on the new LTAD 2.0 later this year (Freeman, 2016); it will be interesting to learn how these changes are incorporated into the evolution of their swimmer pathway and what sex and stroke differences might be recommended.

8.3 Limitations

Undertaking research investigating the progression of an adolescent population including both sexes was a challenging and daunting task, not least of all due to the variability between the sexes, but also due to the inherent differences that exist within them. Despite even the most robust of study designs, one must accept that limitations will inevitably occur and this thesis is no exception.

First and foremost, longitudinal studies require large data sets and while the number of observations for this population were more than sufficient, more performance data almost always provides a higher resolution which potentially leads to greater confidence in the predicted outcomes. Repeated measure data, is also reliant on having a consistent and equal amount of observations for each participant and despite mixed linear modelling catering for gaps in the data set (Hoffman, 2015), a complete set for all participants would have been preferable, however unlikely. It is also important to note that use of the models relies on a longitudinal approach whereby a minimum of two performances, preferably from consecutive seasons, would be required.

The WHO regularly adjust their expected growth curves as a result of the population constantly evolving. With improvements in living standards, nutrition, education, science, technology and the advancement in medicine leading to improved health, research modelling the progression of human populations unfortunately will also become dated, it has as it were a “limited shelf life”. This thesis has highlighted some of the effects that even slightly flawed long term athlete development programmes have had on adolescent swimmers over the last decade. It will therefore be interesting to see how the more refined evolutions of LTAD will affect adolescent athletes over the next decade.

To ensure the external validity, all data was collected at an end of season championship, i.e. during competition. There were however a number of limitations pertaining to the competition. It was selected as it provided a consistent measure of performance during one of the most important peak periods during the season for the majority of these swimmers. While this allowed for a stable annual measurement point, the fact that it was a school competition meant that the sample was not homogenous. As a consequence, the models produced from this data had limited degrees of confidence and effect size (Table 5.2 and 6.2). This was most notable in the female models, where the threshold ages of peak performance were (in some cases) predicted to occur outside of the age range of the sample and hence caution is advised in the interpretation of these models. While the variability in the standard of the swimmers could be seen as a limitation, it is felt that this is one of the factors that contribute to the wide applicability of the models, as they have catered for a wide ability base. Furthermore, despite modelling the four main strokes and the individual medley, the thesis did not fully assess the effects of distance, as it covered mainly sprint distances from 50 to 200 m in length. The competition also had a minimum entry age of 12 years for both males and females and as previously stated, meant that the models for the females, were perhaps missing some data covering their early adolescence, a period where significant biological changes are known to occur.

Since the majority of the data were collected retrospectively, no anthropometrical measurements were carried out. The sheer number of swimmers analysed would have made this an impractical option and gaining access to the swimmers during a major competition would likely not have been sanctioned by many athletes and/or their coaches. As a result, no assessment of biological maturation was conducted. This meant that it was unknown whether there was any bias in the sample based on the pubertal status of the athletes.

Finally, while some effort was made to conduct some qualitative assessments in evaluating the models (Chapter 7), the first four studies did not assess any elements of the psychosocial domain.

8.4 Practical Applications

Although limited research has been conducted on this population group, it has focussed on creating models using retrospective data of previously identified elite athletes. Mixed linear modelling is growing in popularity as are neural network models, but their inherent complexity often limits their practical application for practitioners. With this in mind, this thesis was undertaken to explore numerous aspects in the development of swimming through the adolescent years, with the goal of not only improving our current understanding of this population, but also with the aim of making the results practically accessible to coaches and swimmers alike.

Chapter 3 created a baseline from which further refinements of LTAD could be quantified in future. Chapter 4 was unique in terms of investigating the combinations of strokes chosen by swimmers. Improving our understanding of stroke preferences and successful combinations could aid coaches in designing programmes that optimise their swimmers' training and potentially identify issues where overuse injuries could occur. Chapter 5 and 6 have created individual models for all strokes for both sexes. It is hoped that coaches will be able to use this information to track the performance of their athletes against the expected progression modelled in these chapters. It is important to note however, that the models are not designed to talent identify swimmers based on a one-off performance, i.e. that a swimmer's single performance time appears to lie above that of the modelled mean is of no significance.

The models are designed to be used longitudinally over a period of at least two seasons so that the swimmer's relative performance improvement over time can be quantified against the expected modelled mean. This needs to be used in conjunction with other factors such as their absolute performance times and their level of biological maturity. For example, an athlete may well find their performance times exceed that of the model, but their rate of improvement between two seasons may be accelerating at a lower rate relative to the modelled progression for a given chronological age period. In this case the athlete could be identified as a potential early maturer, but tracking their performance over subsequent seasons would still be advised.

The models will not only help coaches to set realistic performance goals for successive seasons, but could help them to identify in which strokes swimmers are making the most progress. This is possible because there are 14 different models covering all four recognised strokes for both sexes. The application of the models could therefore help coaches identify areas of weakness for further development or alternatively provide some indication as to which strokes swimmers could potentially consider specialising. Rather than a replacement for any current TI methods, these models could prove to be another useful tool whereby possible late maturers, who demonstrate the potential to outperform the relative modelled performance trajectories, are still included, rather than the current reliance on one-off cross sectional methods that tend to almost exclusively select young age-group champions. Finally, coaches could assess the progress of their cohort, helping them to evaluate and potentially refine their periodised programmes.

8.5 Conclusions and directions for future research

The majority of modelling studies have focussed on the development and progression of individual sports and in particular CGS sports. Although swimming fits into this category of sport, it does have some team element to it in the form of relays. The models could therefore potentially be developed to assess not only the individuals that comprise a relay team but also the progression of the relay itself. This could then create a framework on which other team sports could build.

The models developed in Chapters 5 and 6 were created using a “less is more” approach. Further research could however refine the models by adding additional parameters in the form of random effects, however caution is advised. Additional variables may improve resolution of the models, but at the same time would add to their complexity, once again making the practical application of them more difficult to promote to the practitioners for whom they essentially have been designed. The models could further be refined by collecting data on younger female swimmers (from 10 years onwards) during competition as this would then cover the adolescent years in their entirety. This could help to shed more light on the eerly effects of maturation on female swimming performances. Additionally, the collection of anthropometrical and/or biological maturity data could help to account for some of the variability found within the current models.

Finally, future research could also consider tracking swimmers beyond the end point of this study in an effort to understand the career paths of sub-elite adolescents. It has been demonstrated that sub-elite swimmers hold valuable information into the understanding of the progression and choices made by adolescents with respect to their early sporting careers. Understanding their path through adolescence will further enhance our practices of identifying and developing their talent for future success.

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Appendix

9.1 Initial certificate of ethical approval (Chapters 3 to 6)

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

St. Luke's Campus
University of Exeter
Heavitree Road
Exeter
EX1 2LU
United Kingdom

Certificate of Ethical Approval

Title: Performance development in competitive international school swimmers: a longitudinal study of sub-elite adolescents.

Applicants: Shilo Dormehl

The proposal was reviewed by a Representative on the Committee.

Decision: This proposal has been approved until July 2014.

Signature: Date: 11/12/2013

Name/Title of Ethics Committee Reviewer: Dr Mark Wilson

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

9.2 Poster presented at the Talent Identification Conference, “Identifying Champions”. Doha, Qatar 2-3 April 2014. (Chapter 3)

Tracking the progress of sprint performance in competitive international school swimmers

Shilo Dormehl and Craig A. Williams

Children's Health and Exercise Research Centre, Sport & Health Sciences, University of Exeter

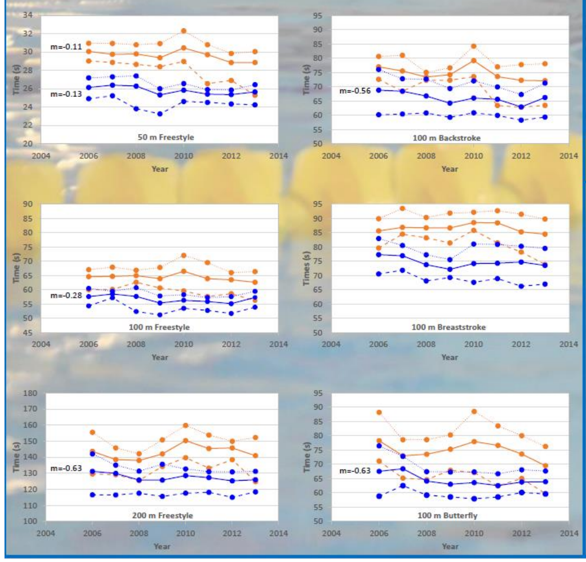
Introduction

In the last decade much attention has focussed on the development of youth sporting performance. This has included the creation of models for athlete development e.g., the Long Term Athlete Development (LTAD) model of Balyi (2001) and the Development Model of Sporting Participation (DMSP) of Côté and Fraser-Thomas (2007). If any positive benefits become evident from these models, it could be hypothesised that the performance of adolescent athletes would show performance progression during this period.

The purpose of this research was to track the performance of the finalists (top eight) and record holders of an annual international school-level competition over an 8 year period. The stability of their performances were compared with that of junior elite (JE) and elite swimmers in order to determine whether any progression was evident for these sub-elite (SE) swimmers and whether there was a difference between genders.

Results

Figure 1 Progression of performance times for finalists in the six individual events analysed between 2006-2013, showing fastest (dashed line), slowest (dotted line) and mean (solid line) times for both males (blue) and females (orange). m denotes the gradient of the significant trends at p<0.05



Methods

The performance times for all finalists in the 15 to 18 year age-group (384 male and 384 female entries, mean age 15.90 ± 0.22 y) in all individual events (50 m, 100 m and 200 m freestyle, the 100 m backstroke, breaststroke and butterfly) were compiled from the official published results. All times and records were recorded using Omega Electronics timing touch pads, connected to an Ares-21 timing console that was linked to a computer running Meet Manager for Swimming software (Active Hy-Tek).

The competitions were held on an annual yearly basis and swum in 25 m short course (SC) pools in Egypt, Belgium, United Kingdom and The Netherlands.

Participants competed predominantly for their school teams and trained on a regular but varied basis. A few swimmers also competed regularly at club and/or national level. For the purposes of this study, these athletes were classified as sub elite (SE). Short Course World Records (SCWR) and Junior World Records (JWR), which were converted to SC equivalents using FINA's 2013 points conversion table, were used for comparison in each of the abovementioned events. The SCWR and JWR holders were considered as elite and JE athletes respectively. Kendall's tau non-parametric correlations were used to report the significance of the progression of the performance times.

Table 1. Summary of the 8 year progression in SE records at an annual international school-level competition between 2006 and 2013 and their comparison with current converted JE (JWR) and elite (SCWR) race speeds.

Event	Gender	% change of SE records (2006-2013)	Times SE record broken (2006-2013)	Current SE record race speeds ($m.s^{-1}$)	Difference in race speeds SE vs JE ($m.s^{-1}$)	Difference in race speeds SE vs elite ($m.s^{-1}$)
100 m	female	-11.05	4	1.68	0.07	0.14
butterfly	male	-1.5	2	1.73	0.23	0.34
100 m	female	-5.66	2	1.59	0.15	0.22
backstroke	male	-3.14	2	1.72	0.22	0.33
100 m	female	-6.2	2	1.35	0.19	0.24
breaststroke	male	-4.84	3	1.51	0.22	0.29
50 m	female	-7.97	2	1.98	0.06	0.17
freestyle	male	-4.63	2	2.15	0.18	0.31
100 m	female	-6.38	3	1.78	0.09	0.18
freestyle	male	-4.48	2	1.95	0.18	0.27
200 m	female	-2.63	2	1.60	0.11	0.20
freestyle	male	-1.34	3	1.74	0.17	0.27

Key Findings

The main findings are that in the SE swimmers there was:

- little evidence of the performance gap between gold medallists and 8th placed finalist narrowing for most strokes,
- variable improvement between genders and record holders with no clear pattern emerging, and
- males continuing to demonstrate significant improvement in all strokes (excluding breaststroke) in contrast to females who appear to show more stability but less homogeneity, with only continued mean progression of the finalists in the 50 m freestyle.

Discussion

Vavrek et al. (2012) found that US youth swimming freestyle national records (15-17 year olds) improved most between 1960 and 1970 but that they were improving concurrently with those at the elite level by the year 2000. By comparison the SE swimmers in this study were showing improvement between 2006 and 2013 that was of a similar but smaller magnitude to those of Vavrek et al. (2012) before 1970. There is still considerable variability in the range of performances of the finalists at SE level. This is unlike the narrowing of the performance gap between the first and last placed Olympic swimming finalists providing evidence for the progression in swimming at elite level (Stanula et al., 2012). While records continue to be broken, elite-level records appear to have stabilised and the greatest recent improvement occurred in the 2008-2009 era of polyurethane suits, that were later banned by FINA in 2010. This effect was also noticeable for SE swimmers (Figure 1).

In conclusion, the positive trends evident in the performance of school-level swimming hints at a wider selection base for talent, as well as the need for continued improvements in coaching and training to further develop the talent pool in this category of swimmer that has traditionally been overlooked. The results from this study may begin to provide support for the recent attention to the value in improving participation and quality of youth level sport.

References

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Stanula, A., Maszczyk, A., Roczniok, R., Pietraszewski, P., Ostrowski, A., Zajac, A., et al. (2012). The development and prediction of athletic performance in freestyle swimming. *Journal of Human Kinetics,32*, 97-107.

Vavrek, J., Machin, D. R., & Tanaka, H. (2012). Progression of athletic performance in age-group swimmers in the past 50 years. *International Journal of Performance Analysis in Sport, 12*(3), 608-613.

Table 9.1 Summary of selected best multiple individual medal performances at each Olympic Games from 1972 to 2012 (Chapter 4)

Swimmers Name (Gender)	Specialist stroke/s	Specialist distance/s (m)	Olympic Games at which maximum medals obtained: Name of competition (year)	Olympic Games at which maximum medals obtained: No. of Medals (individual events only)
Mark Spitz (M)	Butterfly	100, 200	Munich Olympic Games (1972)	4 Gold
	Freestyle	100, 200		
Shane Gould (F)	Freestyle	100, 200, 400, 800	Munich Olympic Games (1972)	3 Gold 1 Silver 1 Bronze
	Individual Medley	200		
Kornelia Ender (F)	Butterfly	100	Montreal Olympic Games (1976)	3 Gold
	Freestyle	100, 200		
Ines Diers (F)	Freestyle	100, 200, 400, 800	Moscow Olympic Games (1980)	1 Gold 2 Silver 1 Bronze
Vladimir Salnikov (M)	Freestyle	400, 1500	Moscow Olympic Games (1980)	2 Gold
Tiffany Cohen (F)	Freestyle	400, 800	Los Angeles Olympic Games (1984)	2 Gold
Michael Gross (M)	Butterfly	100, 200	Los Angeles Olympic Games (1984)	2 Gold 1 Silver
	Freestyle	200		
Mary Meagher (F)	Butterfly	100, 200	Los Angeles Olympic Games (1984)	2 Gold
Matthew Biondi (M)	Butterfly	100	Seoul Olympic Games (1988)	2 Gold 1 Silver 1 Bronze
	Freestyle	50, 100, 200		
Janet Evans (F)	Freestyle	400, 800	Seoul Olympic Games (1988)	3 Gold
	Individual Medley	400		
Kristin Otto (F)	Backstroke	100	Seoul Olympic Games (1988)	4 Gold
	Butterfly	100		
	Freestyle	50, 100		
Krisztina Egerszegi (F)	Backstroke	100, 200	Barcelona Olympic Games (1992)	3 Gold
	Individual Medley	400		
Alexander Popov (M)	Freestyle	50, 100	Barcelona Olympic Games (1992)	2 Gold
Summer Sanders (F)	Butterfly	200	Barcelona Olympic Games (1992)	1 Gold 1 Silver 1 Bronze
	Individual Medley	200, 400		
Amy van Dyken (F)	Butterfly	100	Atlanta Olympic Games (1996)	2 Gold
	Freestyle	50		
Pieter v.d. Hoogenband (M)	Freestyle	100, 200	Sydney Olympic Games (2000)	2 Gold
Inge de Bruijn (F)	Butterfly	100	Sydney Olympic Games (2000)	3 Gold
	Freestyle	50, 100		
Kosuke Kitajima (M)	Breaststroke	100, 200	Athens Olympic Games (2004) Beijing Olympic Games (2004)	2 Gold
Aaron Peirsol (M)	Backstroke	100, 200	Athens Olympic Games (2004)	2 Gold
Michael Phelps (M)	Butterfly	100, 200	Beijing Olympic Games (2008)	5 Gold
	Freestyle	200		
	Individual Medley	200, 400		
Kirsty Coventry (F)	Backstroke	100, 200	Beijing Olympic Games (2008)	1 Gold 3 Silver
	Individual Medley	200, 400		
Ryan Lochte (M)	Backstroke	200	London Olympic Games (2012)	1 Gold 1 Silver 1 Bronze
	Individual Medley	200, 400		
Missy Franklin (F)	Backstroke	100, 200	London Olympic Games (2012)	2 Gold
Ranomi Kromowidjojo (F)	Freestyle	50, 100	London Olympic Games (2012)	2 Gold
Ye Shiwen (F)	Individual Medley	200, 400	London Olympic Games (2012)	2 Gold

Note: Data sourced from International Olympic Committee (2013)

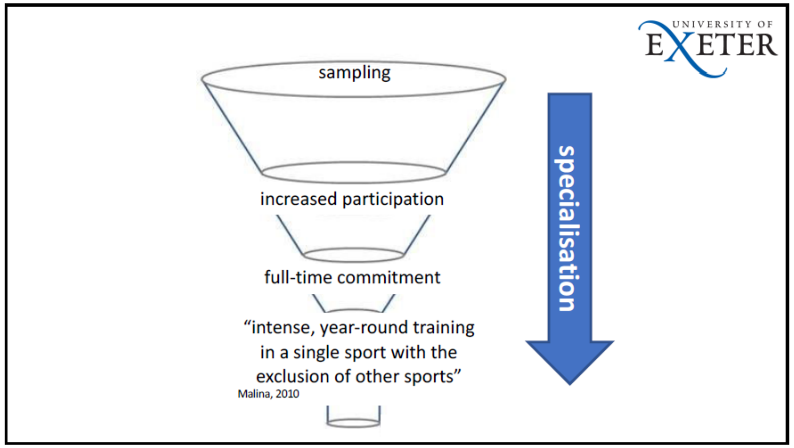
Table 9.2 Competition schedules for recent Olympic Games (OG), Short Course World Championships (SCWC) and Junior World Championships (JWC) (Chapter 4)

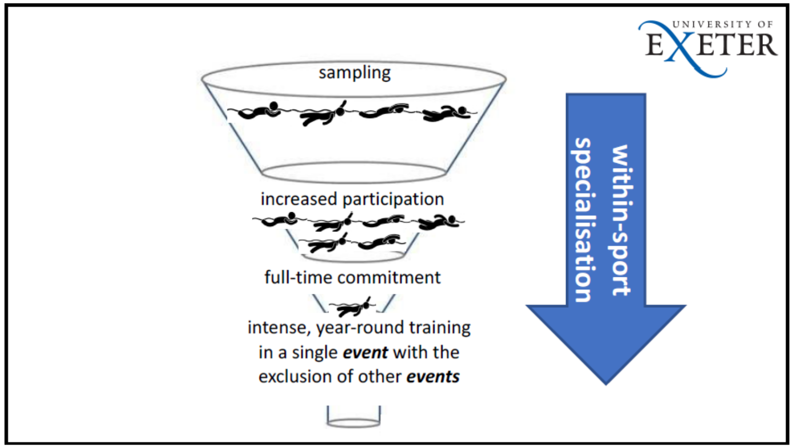
Day 1			**Day 2**			**Day 3**			**Day 4**			**Day 5**			**Day 6**		**Day 7**	**Day 8**
OG	**SCWC**	**JWC**	**OG**	**SCWC**	**JWC**	**OG**	**SCWC**	**JWC**	**OG**	**SCWC**	**JWC**	**OG**	**SCWC**	**JWC**	**OG**	**JWC**	**OG**	**OG**
400 IM M	200 Fr M	400 Fr M	100 Ba F	4x50MR M	200 IM M	200 Fr F	4x50 MR F	50 Fly F	100 Fr M	4x50 Fr M	50 Ba F	100 Fr F	4x50 F	100 Fr M	50 Fr M	200 Ba M	50 Fr F	
100 Fly F	50 Br F	50 Br F	200 Fr M	100 Fr F	100 Fr F	200 Fly M	50 Ba M	50 Ba M	200 Fly F	50 Ba F	50 Fly M	200 Ba M	200 Ba M	100 Fly F	800 Fr F	200 Br F	1500Fr M	
400 Fr M	100 Ba M	100 Ba M	100 Br F	400 IM M	100 Fly M	200 IM F	200 Ba F	100 Br F	200 Br M	100 Fr M	400 Fr F	200 Br F	200 Br F	400 IM M	100 Fly M	200 Fly M	4x100M R	
400 IM F	200 Fly F	400 IM F	100 Ba M	50 Fly F	200 Fly F		50 Fly M	50 Fr M	4x200Fr M	50 Fr F	200 Br M	200 IM M	200 Fly M	50 Fr F	200 Ba F	200 Fr F	4x100M R	
100 Br M	100 Br M	100 Br M	400 Fr F	50 Fr M	200 Fr M		100 Br F	200 Ba F		100 IM M	200 IM F	4x200Fr F	200 Fr F	50 Br M		4x100M R		
1x100Fr F	100 Ba F	100 Ba F	4x100Fr M	100 IM F	4x100M R		400 Fr M	4x100Fr Mixed		100 Fly F	4x200Fr M		4x100M R	4x100Fr F		4x100M R		
	100 Fly M	4x100Fr M		4x200Fr M	800 Fr F		200 IM M	800 Fr M		200 IM F			4x100M R	1500Fr F		1500Fr M		
	400 IM F	4x200Fr F		4x50MR Mixed			400 Fr F			50 Br M			1500Fr M					
	4x100Fr M			800 Fr F			200 Br M			4x50Fr Mixed								
	4x200Fr F						4x100Fr F											
400 IM M	**200 Fr M**	**400 Fr M**	**100 Fly F**	**4x50 MR**	**100 Ba M**	*200 Fr F*	**4x50MR F**	*50 Fly F*	*100 Fr M*	**4x50Fr M**	*50 Ba F*	**200 Br M**	**4x50Fr F**	**1500Fr F**	*50 Fr M*	**100 Fr M**	**200 Ba F**	**50 Fr F**
100 Fly F	*50 Br F*	*50 Br F*	*200 Fr M*	*100 Fr F*	**200 Fly F**	**200 Fr M**	*50 Ba M*	*50 Fr M*	**200 Fr F**	**100 Br F**	**200 Br M**	*100 Fr F*	**100 Fr M**	*100 Fr M*	**200 Br F**	**200 Br F**	**100 Fly M**	**1500Fr M**
400 Fr M	*100 Ba M*	*100 Ba M*	*100 Br F*	**400 IM M**	**200 Fr M**	**100 Ba F**	**100 Fr F**	**200 Ba F**	**200 Fly M**	**50 Ba M**	**50 Fly F**	*200 Ba M*	**50 Ba F**	*100 Fly F*	**200 Ba M**	**200 Ba M**	**800 Fr F**	**4x100M R**
400 IM F	**200 Fly F**	**400 IM F**	**100 Br M**	**50 Br F**	**50 Br F**	**100 Ba M**	*50 Fly M*	**100 Fly M**	*200 Fly F*	*50 Ba F*	**50 Ba M**	**200 Fly F**	**200 Ba M**	**50 Fly M**	*200 Ba F*	**100 Fly F**	**50 Fr M**	**4x100M R**
100 Br M	*100 Br M*	*100 Br M*	**400 Fr F**	**100 Ba M**	*100 Fly M*	**100 Br F**	**200 Ba F**	*100 Br F*	*200 Br M*	*100 Fr M*	**100 Br F**	**100 Fr M**	**200 Br F**	*50 Fr F*	**200 IM M**	**1500Fr M**	*50 Fr F*	
4x100Fr F	*100 Ba F*	*100 Ba F*	*100 Ba M*	*50 Fly F*	*100 Fr F*	*200 Fly M*	**200 Br M**	*50 Ba F*	**200 IM F**	*50 Fr F*	*50 Fly M*	*200 Br F*	**100 IM M**	*50 Br M*	**100 Fr F**	**50 Fr F**		
	100 Fly M	**4x100Fr M**	*100 Ba F*	*50 Fr M*	**100 Br M**	*200 IM F*	**50 Fly F**	**100 Fr F**	**4x200Fr M**	**50 Fly M**	**400 Fr F**	*200 IM M*	**100 Fly F**	**50 Ba F**	*100 Fly M*	**200 Fly M**		
	400 IM F	**4x200Fr F**	**4x100Fr M**	**100 Ba F**	**100 Ba F**		**400 Fr M**	**800 Fr M**		*100 Fly F*	**50 Fr M**	**4x200Fr F**	**50 Br M**	**400 IM M**		**50 Br M**		
	4x100Fr M			**100 Br M**	**200 IM M**		*100 Br F*	**4x100Fr Mixed**		*100 IM M*	**200 IM F**		**50 Fr F**	**4x100Fr F**		**200 Fr F**		
	4x200Fr F			*100 IM F*	**800 Fr F**		**100 IM F**			**200 IM F**	**4x200Fr F**		**200 Fly M**			**4x100M R**		
				100 Fly M	**4x100M R**		**50 Fr M**			*50 Br M*			**1500Fr M**			**4x100M R**		
				800 Fr F			**400 Fr F**			*4x50Fr Mixed*			**200 Fr F**					
				4x200Fr M			**200 IM M**						**4x100M R**					
				4x50MR Mixed			**4x100Fr F**						**4x100M R**					

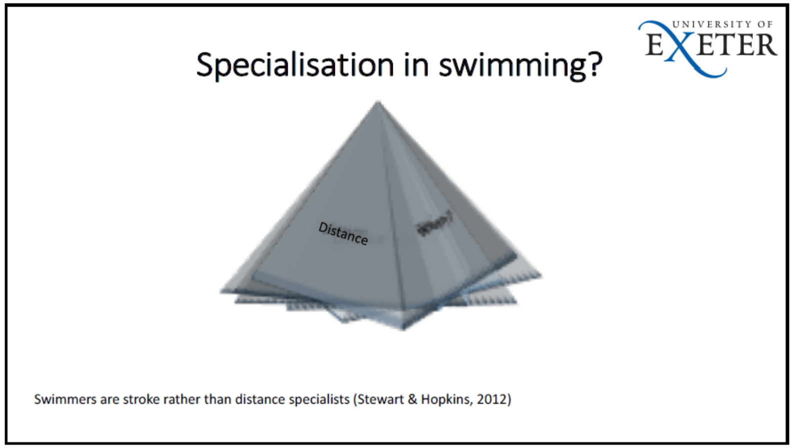
Note: All distances are in meters. Event codes are as follows, Ba = backstroke, Br = breaststroke, Bu = butterfly, Fr = freestyle, IM = individual medley. M = male, F = Female, Mixed = M + F

Heats are in normal font, semi finals in *italics* and finals in **bold**.

Slides from Pediatric Work Physiology conference, Utrecht 2015.







Purpose of this study

Part 1 - Selection of event combination preferences

- To identify if preferred stroke combinations exist.
- To assess whether females specialise at a younger age than males.

Part 2 - Longitudinal stability of event selection

- To test whether stroke techniques / distances selected by younger swimmers remain stable as they mature.
- To determine whether sub-elite athletes will favour one stroke technique / distance.

Study Design

- International schools (Austria, Belgium, Egypt, France, Germany, Switzerland, The Netherlands, UK)
- Annual, end-of-season tournament
- Times ratified on SwimRankings
- Short course format; 7 individual events and 2 relays over 2 days of competition
- 8 consecutive years of data
- 966 male and female competitors (12 – 18 years of age)
- Variable levels of training and experience

2014 International Schools' Championships…

Data analysis

Part 1 – Stroke combination preferences

- Mean % of pooled age group swimmers selecting paired stroke combinations were calculated.
- Kruskal-Wallis tests followed by Mann-Whitney post hoc tests, corrected by applying the Bonferroni correction as α = 0.05/number of stroke combinations.

Part 2 – Event stability

- Longitudinal study (n=78)
- Excluded swimmers that did not swim in all of the paired age categories (13-14, 15-16, 17-18 years)
- Kohen's Kappa tests used to establish the stability of stroke selection.

Mean % of swimmers by preferred paired stroke combinations

<14.29% | ≥14.29% males
<14.29% | ≥14.29% females

	50 Free	100 Free	200 Free	100 Back	100 Breast	100 Fly	200 IM
50 Free		33.91 (5.77)	18.60 (3.15)	16.90 (7.51)	21.00 (6.32)	9.40 (4.30)	9.60 (4.40)
100 Free	36.85 (6.52)		14.60 (5.01)	6.80 (4.06)	14.28 (3.52)	7.58 (2.78)	4.60 (1.37)
200 Free	23.91 (3.02)	18.87 (2.98)		10.50 (2.51)	3.12 (1.55)	8.87 (1.48)	9.99 (2.19)
100 Back	22.29 (6.67)	8.17 (3.09)	15.77 (4.26)		6.86 (3.30)	6.56 (2.29)	6.30 (2.45)
100 Breast	22.48 (6.33)	14.75 (1.30)	1.92 (1.38)	8.13 (4.04)		2.75 (1.71)	11.10 (1.97)
100 Fly	10.14 (2.07)	8.98 (3.73)	8.49 (4.64)	9.69 (4.86)	3.87 (1.63)		11.70 (2.14)
IM	9.49 (4.99)	6.66 (2.69)	8.26 (1.45)	7.25 (1.71)	10.70 (2.28)	11.31 (4.33)	

Discussion

- Stroke combinations with similar co-ordination techniques (alternating, eg. or simultaneous, eg.) favoured (Seifert et al 2007).

but...

- Stroke combinations with similar muscle groups, eg favoured (McLeod, 2010).

Order of events

Day 1

200 m Freestyle

100 m Breaststroke

100 m Butterfly

50 m Freestyle

4 x 100 m Medley Relay

Day 2

100 m Freestyle

100 m Backstroke

200 m Individual Medley

4 x 100 m Freestyle Relay

Key findings

Part 1 - The selection of event combination preferences

- Most commonly selected combinations were:
  - 50 m & 100 m freestyle
  - breaststroke & IM
  - butterfly & IM
- Males more consistent in stroke combinations choices than females.
- Unpopular combinations may be avoided because of:
  - proximity on the programme, or
  - employment of different muscle groups.
- Stroke choice combinations became more stable as swimmers matured (data not shown).

Stability of event choices: females *(measured using Kappa values)*

Event	13-14 yrs x 15-16 yrs	13-14 yrs x 17-18 yrs	15-16 yrs x 17-18 yrs
50 Free	0.48	0.48	0.54
100 Free	0.61	0.62	0.48
200 Free	0.64	0.34	0.57
100 Back	0.47	0.47	0.75
100 Breast	0.59	0.73	0.57
100 Fly	0.54	0.32	0.81
200 IM	0.37	0.30	0.47

Intensity of shading indicates level of agreement (lighter) or disagreement (darker).

Stability of event choices: males *(measured using Kappa values)*

Event	13-14 yrs x 15-16 yrs	13-14 yrs x 17-18 yrs	15-16 yrs x 17-18 yrs
50 Free	0.33	0.46	0.42
100 Free	0.06	0.29	0.20
200 Free	0.30	0.22	0.44
100 Back	0.55	0.33	0.45
100 Breast	0.87	0.60	0.72
100 Fly	0.27	0.49	0.51
200 IM	0.69	0.43	0.39

Intensity of shading indicates level of agreement (lighter) or disagreement (darker).

Discussion

- Growth spurts cause swimmers to adjust motor control strategies (Morais et al. 2013).
- Butterfly relies on precise synchronisation – a highly specialized stroke (Hellard et al. 2008).

Key findings

Part 2 - Longitudinal stability of event selection

- Females were more stable with choices than males, as they mature.
- Once selected, females remained with butterfly, but males remained with breaststroke.

Conclusion

- Young swimmers prefer stroke combinations over distance specialisation.
- Breaststroke is an earlier specialisation (than other strokes).
- Avoid labelling young male swimmers as stroke specialists too early (approx. 2 year gap from females).

Thank you for your time

9.4 Second certificate of ethical approval (Chapter 7)

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

**St. Luke's Campus
University of Exeter
Heavitree Road
Exeter
EX1 2LU
United Kingdom**

Certificate of Ethical Approval

Title: Performance development in competitive international school swimmers: a longitudinal study of sub-elite adolescents.

Applicants: Shilo Dormehl

The proposal was reviewed by a Representative on the Committee.

Decision: This proposal has been approved until July 2014.

Signature: Mark Wilson Date: 11/12/2013

Name/Title of Ethics Committee Reviewer: Dr Mark Wilson

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

9.4 Participant information sheets in Dutch (Chapter 7)

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Versie #1 18 Januari 2016

Deelnemer Informatieblad

Studie onderwerp

Validatie van zwemprestatie rekenmodellen voor talentherkenning bij de jeugdcompetitie zwemmers.

Uitnodiging en korte uitleg

Graag nodigen wij je uit om deel te nemen aan een research onderzoek dat ontworpen is om rekenmodellen en tools voor talentherkenning bij jeugdcompetitie zwemmers te testen. Deelname aan deze studie is geheel vrijwillig en voordat je beslist om hieraan deel te nemen, is het belangrijk om te begrijpen waarom deze studie is opgezet en wat de studie inhoudt. Lees de volgende informatie rustig door en bespreek dit met anderen voordat je beslist om hier wel of niet aan deel te nemen.
Alvast hartelijk bedankt voor je tijd die je besteedt aan het lezen van deze informatie.

Wat houdt de studie in?

Dit research onderzoek is opgezet als proefschrift dat een vereiste is om te promoveren (het behalen van de PhD titel).

Het missen van gegevens over jonge atleten is de aanleiding om de atletische ontwikkeling en de talentherkenning bij de jeugd nauwkeurig in kaart te brengen. Traditionele talentherkenningsprogramma's zijn gebaseerd op eenmalige/individuele beoordelingen, hoewel de criteria daarvoor veranderden of minder belangrijk zijn voor topsport niveau. Veel sportfederaties willen graag overstappen van eenmalige metingen naar trajectmetingen waarbij de ontwikkeling van de sporter op de lange termijn in kaart wordt gebracht. Het doel van deze studie is om basis rekenmodellen die zwemprestatieverbeteringn van jeugd clubzwemmers in verschillende landen bijhouden, te valideren.

Wat houdt deelname voor jou in?

We nodigen jou uit om deel te nemen, omdat we op zoek zijn naar getrainde clubzwemmers die hebben deelgenomen aan de KNZB Nationale Competitie gedurende de laatste vier opeenvolgende seizoenen. Als je instemt met deelname, zullen jouw PR's die op swimrankings.net worden gepubliceerd, de basis vormen voor het opstellen van een prestatiegrafiek gedurende je jeugd.

Deze data wordt vergeleken met de basis rekenmodellen. Om afwijkingen uit de modellen te kunnen begrijpen, zul je door de onderzoeker geïnterviewd worden en zul je gevraagd worden om een vragenlijst in te vullen. Gevraagd zal o.a. worden naar je geboortedatum, frequentie en trainingsintensiviteit, blessure geschiedenis, favoriete zwemslagen en zwemafstanden alsmede het beoefenen van eventuele andere sporten.

Wat zijn de voordelen om deel te nemen?

De belangrijkste voordelen van het onderzoek zijn van educatief belang en van beperkt persoonlijk nut voor jezelf. Ons inzicht in de resultaten van de vooruitgang van de zwemprestaties gedurende de jeugdjaren zullen echter toenemen. Deze informatie kan behulpzaam zijn bij de ontwikkeling van talentidentificatie en tools voor coaches.

Wat zijn mogelijke nadelen en risico's om deel te nemen?

Voor zover bekend, zijn er geen nadelen aan deelname aan deze studie. Het enige dat je hoeft te doen, is een vragenlijst in te vullen (duur: ongeveer 15 minuten) en jouw vrijwillige deelname aan een kort interview dat niet langer dan ongeveer 60 minuten duurt.

Ben ik verplicht om deel te nemen?

Deelname aan deze studie is geheel vrijwillig. Het is geheel aan jou om wel of niet deel te nemen en als je beslist om deel te nemen, dan kun je je deelname aan de studie op elk gewenst moment beëindigen zonder opgave van reden. Als je beslist om deel te nemen aan deze studie, dan zul je gevraagd worden om bij de start een toestemmingsformulier te ondertekenen. Je ontvangt vervolgens een kopie van het ondertekende toestemmingsformulier alsmede een kopie van dit informatieblad.

Worden mijn resultaten vertrouwelijk behandeld?

Als je instemt met deelname aan deze studie, dan heb je een privacy recht. Jouw naam zal gekoppeld worden aan een ID-nummer met een password dat gekoppeld is aan een beveiligde database. Alleen deze ID-nummers zullen als gebruikt worden tijdens data analyses.

Wat wordt er gedaan met de studieresultaten?

De resultaten zullen ons inzicht in zwemprestaties bij jeugdzwemmers verbeteren. Wij zijn voornemens om de bevindingen te publiceren in onderzoekspublicaties alsmede deze te presenteren tijdens conferenties in de UK of elders. Jouw informatie blijft altijd anoniem en je naam zal nergens worden vermeld.

Wie beoordeelt deze studie?

Teneinde jouw belangen te beschermen, worden alle onderzoeksactiviteiten die bij de Exeter Universiteit plaats vinden, geëxamineerd en goedgekeurd door de ethische commissie van de studie Sport- en Gezondheidswetenschappen van de Exeter Universiteit in Engeland.

Contactpersonen

Als je meer informatie wenst of vragen hebt, neem dan gerust contact op met de onderstaande onderzoekers:

Professor Craig Williams	Mr. Shilo Dormehl
School of Sport and Health Sciences	School of Sport and Health Sciences
Children's Health and Exercise Research Centre	
St. Luke's Campus	St. Luke's Campus
Exeter University	Exeter University
EX12LU	EX12LU
Tel: ***** *****	Tel: ***** *****
Email: C.A.Willaims@exeter.ac.uk	Email ***** @exeter.ac.uk

9.5 Participant informed consent form

UNIVERSITY OF EXETER

Sport and Health Sciences
College of Life and Environmental Sciences

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Heavitree Road
Exeter
Devon
Telephone: +44 (0)1392 724890
Email: sshs-school-office@ex.ac.uk
Web: www.ex.ac.uk/sshs

Studie	: Validatie van zwemprestatie rekenmodellen voor talentherkenning bij de jeugdcompetitie zwemmers
Hoofd Analist	: S.J. Dormehl
Onderzoeker	: S.J. Dormehl
Organisatie	: Exeter Universiteit
Versie	: #1.18.01.2016: beoordeelt door de ethische commissie van de Exeter Universiteit
Deelnemer ID-nr.	: ID nr.

Toestemmingsformulier voor volwassen deelnemers

Kruis het vakje ter bevestiging aan:

1. Ik bevestig dat ik het informatieformulier versie #1 gedateerd 18.01.2016 inzake bovengenoemd onderzoek gelezen en begrepen heb. Ik ben in de gelegenheid gesteld om de informatie te overwegen, vragen hierover te stellen en waarbij de gestelde vragen naar tevredenheid zijn beantwoord. ☐

2. Ik begrijp dat mijn deelname vrijwillig is en dat ik op elk gewenst moment mij kan terugtrekken, zonder een opgave van reden hiervoor te hoeven geven. ☐

3. Ik begrijp dat de door mij verstrekte informatie gebruikt kan worden door het research team in toekomstige rapporten, artikelen of presentaties. ☐

4. Ik begrijp dat mijn naam niet genoemd zal worden in rapporten, artikelen of presentaties. ☐

5. Ik zal gevraagd worden om een online vragenlijst in te vullen en ik begrijp het doel van deze vragenlijst. ☐

6. Ik zal gevraagd worden om deel te nemen aan een interview dat niet langer dan ongeveer 60 minuten zal duren en ik begrijp het doel van het interview. ☐

7. Ik ga akkoord met deelname aan de bovengenoemde studie. ☐

______________________	______________	______________
Naam deelnemer	Datum	Handtekening
______________________	______________	______________
Onderzoeker	Datum	Handtekening

9.6 Participant ascent form

Sport and Health Sciences
College of Life and
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Studie : Validatie van zwemprestatie rekenmodellen voor talentherkenning bij de jeugdcompetitie zwemmers
Hoofd Analist : S.J. Dormehl
Onderzoeker : S.J. Dormehl
Organisatie : Exeter Universiteit
Versie : #1. 18.01.2016: beoordeelt door de ethische commissie van de Exeter Universiteit
Deelnemer ID-nr. : ID nr.

Toestemmingsformulier voor minderjarige deelnemers

Kruis het vakje ter bevestiging aan:

1. Ik bevestig dat ik het informatieformulier versie #1 gedateerd 18.01.2016 inzake bovengenoemd onderzoek gelezen en begrepen heb. Ik ben in de gelegenheid gesteld om de informatie te overwegen, vragen hierover te stellen en waarbij de gestelde vragen naar tevredenheid zijn beantwoord. ☐

2. Ik begrijp dat mijn deelname vrijwillig is en dat ik op elk gewenst moment mij kan terugtrekken, zonder een opgave van reden hiervoor te hoeven geven. ☐

3. Ik begrijp dat de door mij verstrekte informatie gebruikt kan worden door het research team in toekomstige rapporten, artikelen of presentaties. ☐

4. Ik begrijp dat mijn naam niet genoemd zal worden in rapporten, artikelen of presentaties. ☐

5. Ik zal gevraagd worden om een een online vragenlijst in te vullen en ik begrijp het doel van deze vragenlijst. ☐

6. Ik zal gevraagd worden om deel te nemen aan een interview dat niet langer dan ongeveer 60 minuten zal duren en ik begrijp het doel van het interview. ☐

7. Ik ga akkoord met deelname aan de bovengenoemde studie. ☐

______________________	______________	______________
Naam deelnemer	Datum	Handtekening
______________________	______________	______________
Onderzoeker	Datum	Handtekening

9.7 Swimming histories questionnaire

Onderzoek vragenlijst van zwem verleden

1. Naam:

2. Geboortedatum:

Deel A

3. Op welke leeftijd begon je met zwemmen?

4. Op welke leeftijd begon je met wedstrijdzwemmen?

5. Wat bracht je ertoe om aan wedstrijdzwemmen deel te nemen?

6. Met welke slag nam je deel in je eerste zwemwedstrijd?

7. Welke afstand/afstanden zwom je in je eerste zwemwedstrijd?

8. Met welke slag heb je als laatste aan wedstrijdzwemmen deelgenomen?

9. Hoe oud was je toen je met alle slagen aan zwemwedstrijden kon deelnemen?

10. Op welke leeftijden bereikte je limieten voor kwalificatie voor een of meerdere NJJKs?

Deel B

11. Je zwemvereniging

11. (a) Tussen de leeftijd van 12 & 13:

11. (b) Tussen de leeftijd van 13 & 14:

11. (c) Tussen de leeftijd van 14 & 15:

11. (d) Tussen de leeftijd van 15 & 16:

11. (e) Tussen de leeftijd van 16 & 17:

11. (f) Tussen de leeftijd van 17 & 18:

11. (g) Tussen de leeftijd van 18 & 19:

12. Aantal zwemtraining uren per week

12. (a) Tussen de leeftijd 12 & 13:

12. (b) Tussen de leeftijd 13 & 14:

12. (c) Tussen de leeftijd 14 & 15:

12. (d) Tussen de leeftijd 15 & 16:

12. (e) Tussen de leeftijd 16 & 17:

12. (f) Tussen de leeftijd 17 & 18:

12. (g) Tussen de leeftijd 18 & 19:

13. Gemiddeld aantal kilometers gezwommen per week

13. (a) Tussen de leeftijd 12 & 13:

13. (b) Tussen de leeftijd 13 & 14:

13. (c) Tussen de leeftijd 14 & 15:

13. (d) Tussen de leeftijd 15 & 16:

13. (e) Tussen de leeftijd 16 & 17:

13. (f) Tussen de leeftijd 17 & 18:

13. (g) Tussen de leeftijd 18 & 19:

14. Gemiddeld aantal (zwem specifieke) land training uren per week

14. (a) Tussen de leeftijd 12 & 13:

14. (b) Tussen de leeftijd 13 & 14:

14. (c) Tussen de leeftijd 14 & 15:

14. (d) Tussen de leeftijd 15 & 16:

14. (e) Tussen de leeftijd 16 & 17:

14. (f) Tussen de leeftijd 17 & 18:

14. (g) Tussen de leeftijd 18 & 19:

15. De volgende vragen gaan over de slag/slagen die je het meest in competitie hebt gezwommen (je eigen slag dus).

15. (a) Tussen de leeftijd 12 & 13:

15. (b) Tussen de leeftijd 13 & 14:

15. (c) Tussen de leeftijd 14 & 15:

15. (d) Tussen de leeftijd 15 & 16:

15. (e) Tussen de leeftijd 16 & 17:

15. (f) Tussen de leeftijd 17 & 18:

15. (g) Tussen de leeftijd 18 & 19:

16. De volgende vragen gaan over de afstand/en die je het meest in competitie hebt gezwommen.

16. (a) Tussen de leeftijd 12 & 13:

16. (b) Tussen de leeftijd 13 & 14:

16. (c) Tussen de leeftijd 14 & 15:

16. (d) Tussen de leeftijd 15 & 16:

16. (e) Tussen de leeftijd 16 & 17:

16. (f) Tussen de leeftijd 17 & 18:

16. (g) Tussen de leeftijd 18 & 19:

Deel C

17. Deelname aan sporten anders dan zwemmen

17. (a) Indien je aan andere gestructureerde activiteiten buiten zwemmen deelnam, vink de desbetreffende leeftijd aan wanneer dat plaatsvond:

17. (b) Indien je aan gestructureerde activiteiten buiten zwemmen deelnam, geef dat hieronder aan:

17. (c) Had je deelname invloed op je zwemmen (positief of negatief)?

18. Onderbrekingen van reguliere training en/of wedstrijden

18. (a) Heb je ooit een onderbreking in je training gehad die langer dan 3 weken duurde? Geef dat dan aan in de ruimte betreffende de leeftijd wanneer dit invloed had:

18. (b) Indien je een onderbreking van 3 of meer weken in je training had, beschrijf (korte uitleg) hoe het je training en/of prestatie beïnvloedde.:

19. Heb je ooit overwogen om met wedstrijdzwemmen te stoppen, zo ja, geef dat aan in de ruimte betreffende de leeftijd wanneer dat was:

20. Ik was het meeste gefocust op mijn zwemmen toen ik (leeftijd) .... was:

21. Ik was het meest gemotiveerd met mijn zwemmen toen ik (leeftijd) .... was:

22. Ik geloof dat ik volgroeid was toen ik (leeftijd) .... was:

23. Ik weet dat ik op die leeftijd niet meer groeide, omdat ....:

24. Tussen de leeftijd 12 en 18 jaar, was mijn meest succesvolle slag/nummer...:

25. Op dit moment is mijn favoriete slag/nummer...:

9.6 Example of Interview Questions

Opzet interview vragen

1. Op het eerste grafiek markeer je op een schaal van 1 tot 10 je zwemplezier en op het andere grafiek je motivatie voor zwemmen op elke leeftijd, beiden op een dusdanige manier dat dit je leeftijd -naar je beste herinnering- weergeeft tussen 12-18 jaar oud. Aan het einde kan je een lijn tussen alle punten tekenen.

2. Verklaar de vormen van jouw twee grafieken.

3. Geef de volgende 5 zwemslagen een waarde van 1 tot 10 gebaseerd op jouw preferentie. Als twee slagen dezelfde waarde hebben voor jou, kan je ze ook allebei hetzelfde cijfer geven.

   a. Vlinderslag
   b. Rugslag
   c. Schoolslag
   d. Vrije slag
   e. Individuele wisselslag

4. Wat heeft het meeste bijgedragen aan jouw verbeteringen (in het zwemmen) tussen je 12e en 18e jaar?

5. Als je denkt aan je belangrijkste/beste/eigen zwemslag: heeft deze voorkeur of jouw succes hierin jou beïnvloed om je te focussen op deze slag (leg uit)

6. Wanneer je hebt meegedaan aan wedstrijden (anders dan bijvoorbeeld een NJJK) welke factoren waren hierbij van invloed op jouw keuze om aan bepaalde wedstrijden mee te doen?

7. Heeft de volgorde van de nummers in een competitie invloed op jouw keuze?

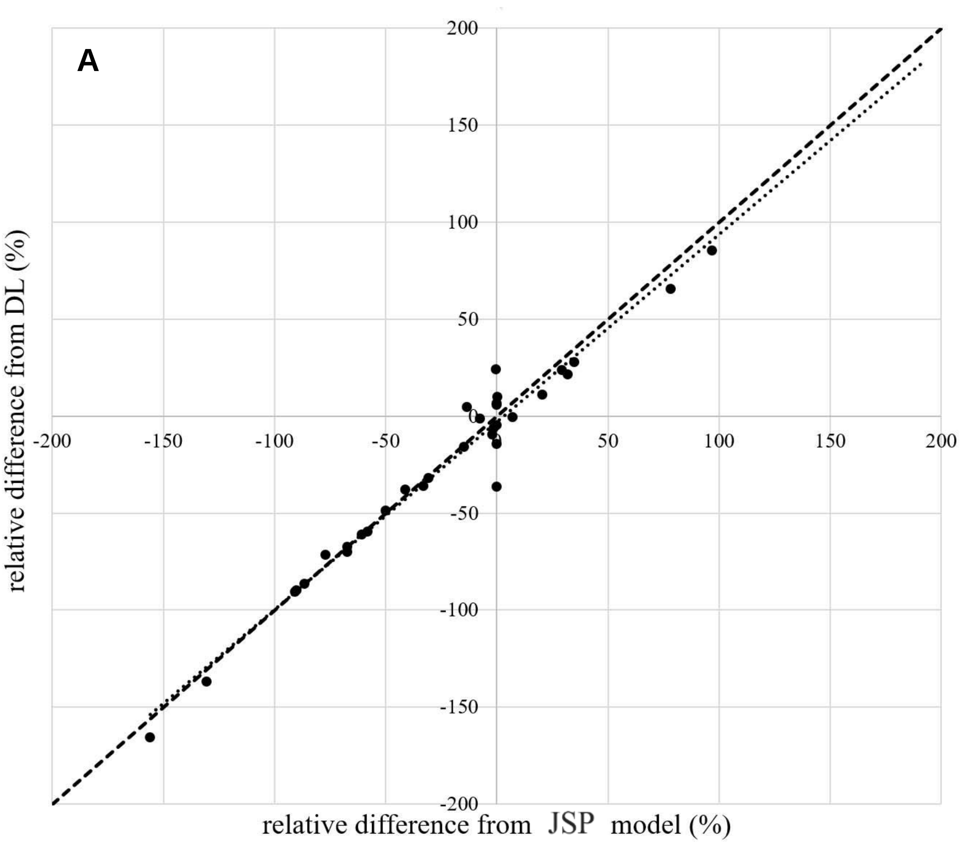
8. Zie je je zelf als een slagspecialist of een afstand specialist?

9. Wat is je beste sportieve prestatie of highlight in je zwemcarrière, of als atleet (als je iets anders dan zwemmen hebt gedaan).

10. Wanneer heb je dit behaald?

Kijk kort naar de resultaten van de vragenlijst.

Bedankt voor je deelname!



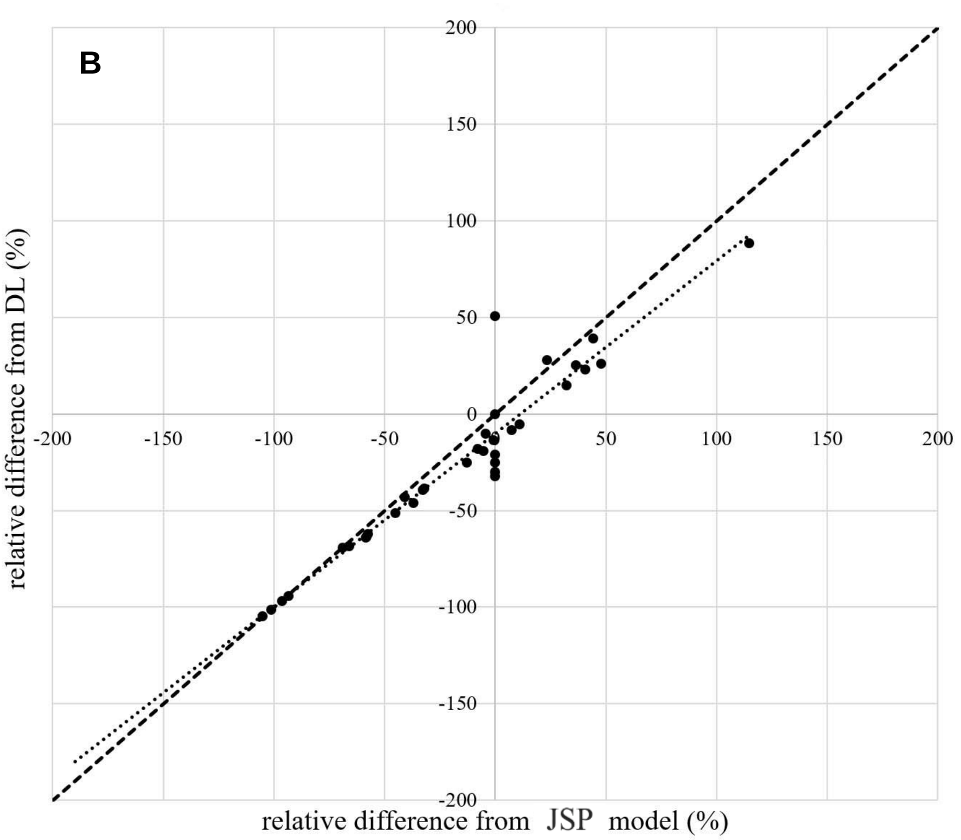


Figure 9.1 Comparison of the percent relative improvement of male Dutch swimmers from the JSP model compared with their percent relative improvement from the DLs for the 100 m (A) and 200 m (B) freestyle events. The dashed line represents y = x and the dotted line represents the linear regression for Dutch swimmers

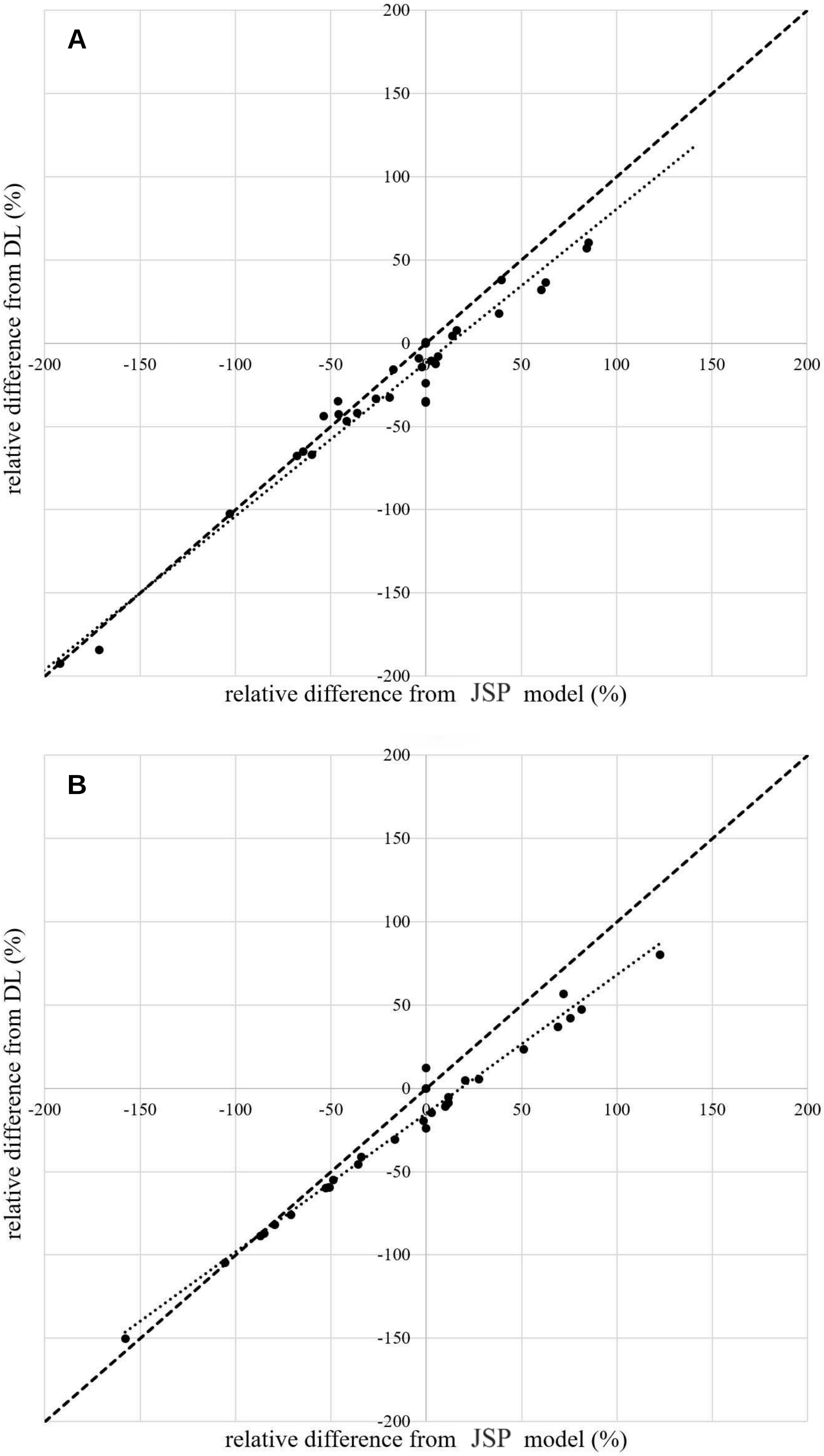


Figure 9.2 Comparison of the percent relative improvement of male Dutch swimmers from the JSP model compared with their percent relative improvement from the DLs for the 100 m backstroke (A) and 100 m breaststroke (B) events. The dashed line represents y = x and the dotted line represents the linear regression for Dutch swimmers

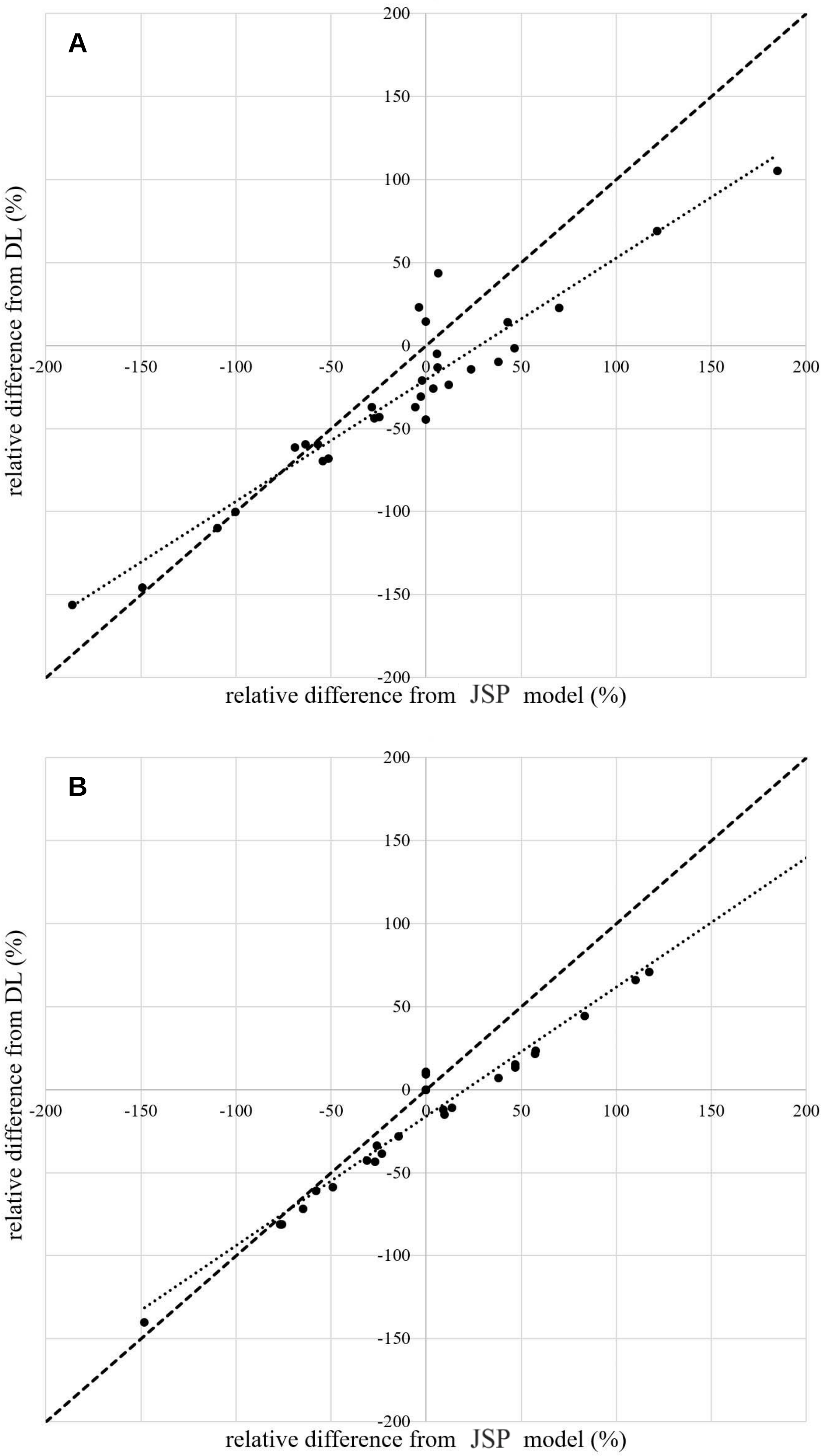
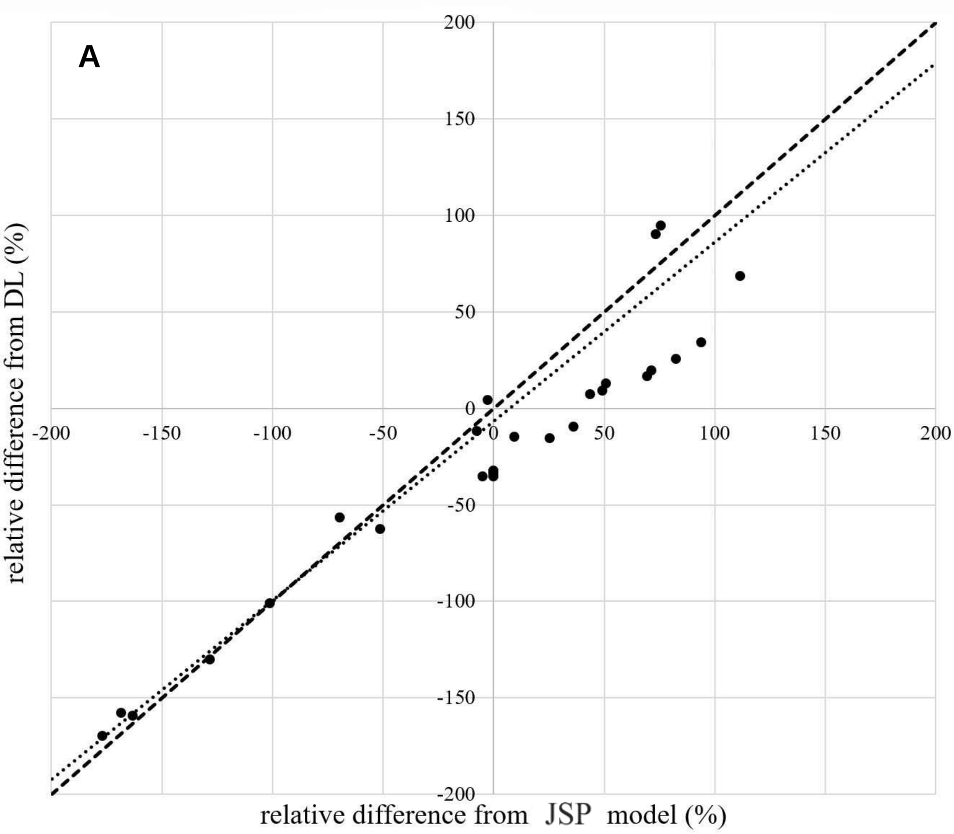


Figure 9.3 Comparison of the percent relative improvement of male Dutch swimmers from the JSP model compared with their percent relative improvement from the DLs for the 100 m butterfly (A) and 200 m individual medley (B) events. The dashed line represents y = x and the dotted line represents the linear regression for Dutch swimmers



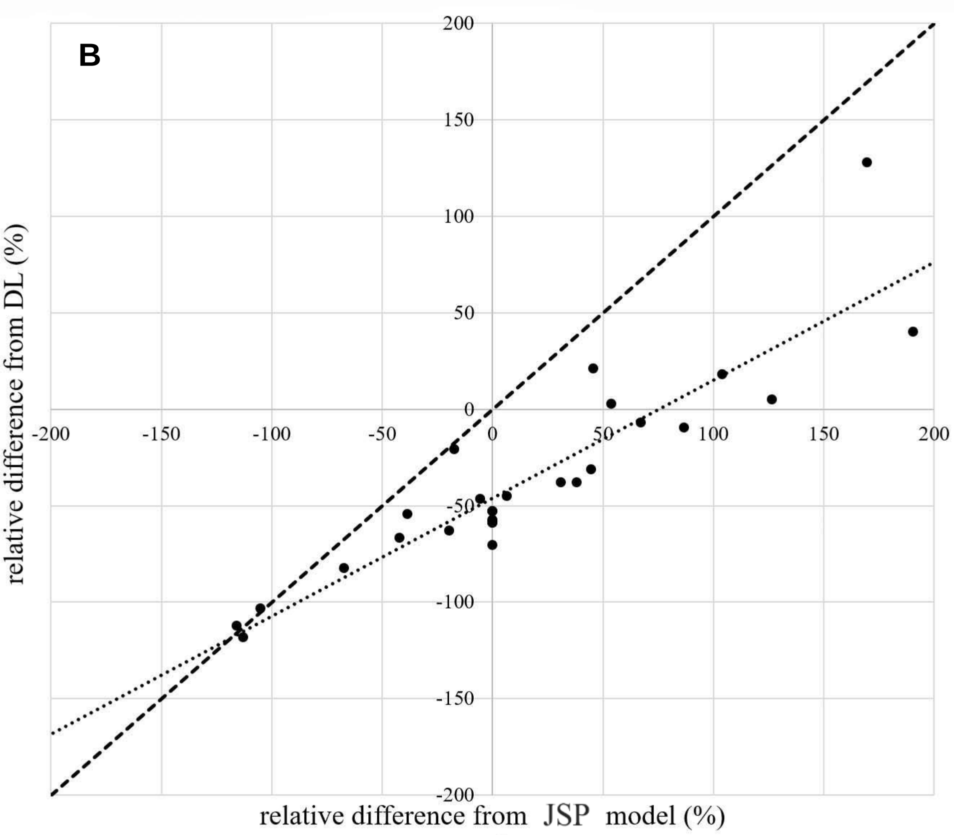


Figure 9.4 Comparison of the percent relative improvement of female Dutch swimmers from the JSP model compared with their percent relative improvement from the DLs for the 200 m freestyle (A) and 100 m backstroke (B) events. The dashed line represents y = x and the dotted line represents the linear regression for Dutch swimmers

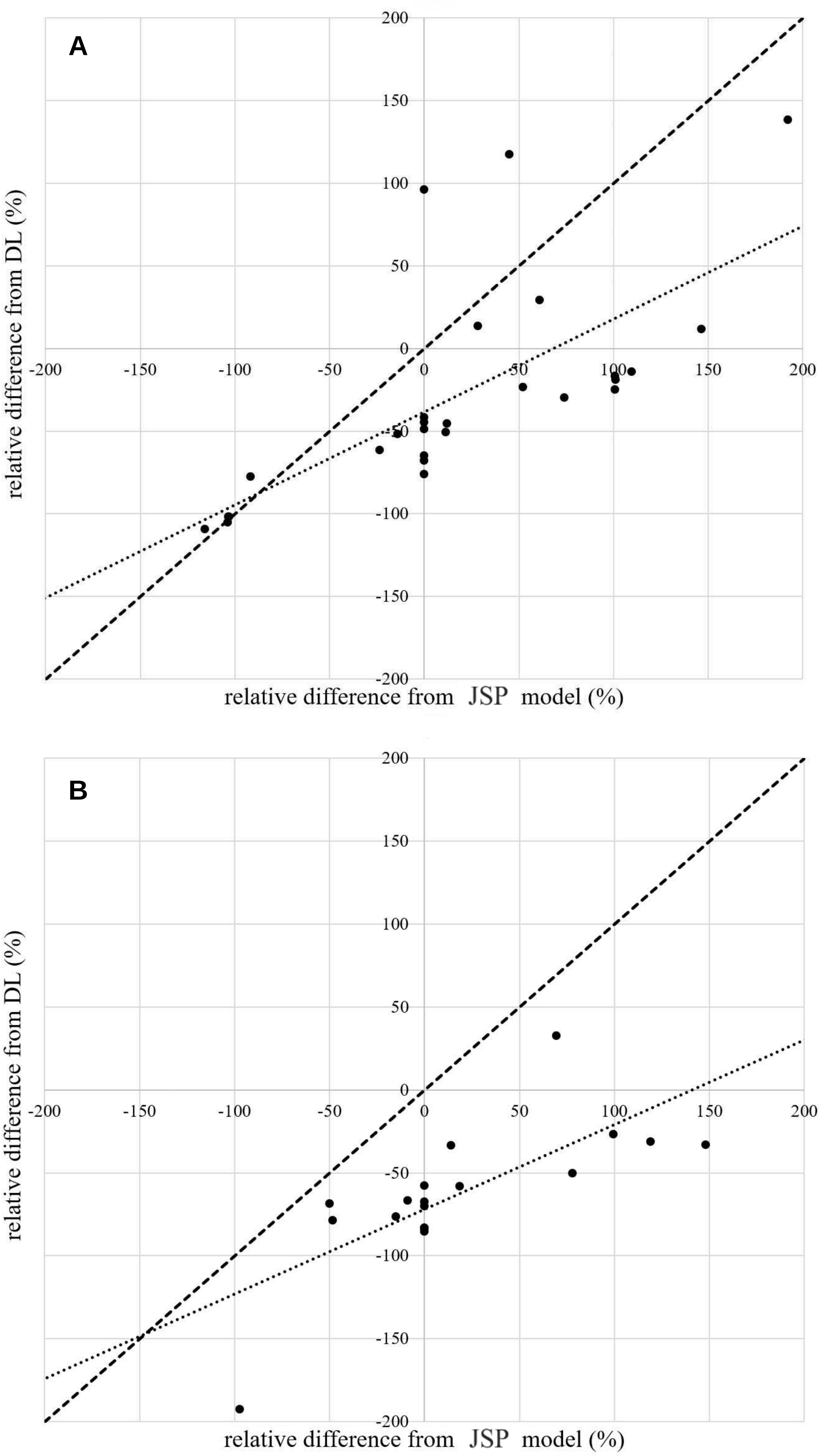


Figure 9.5 Comparison of the percent relative improvement of female Dutch swimmers from the JSP model compared with their percent relative improvement from the DLs for the 100 m breaststroke (A) and 100 m butterfly (B) events. The dashed line represents y = x and the dotted line represents the linear regression for Dutch swimmers

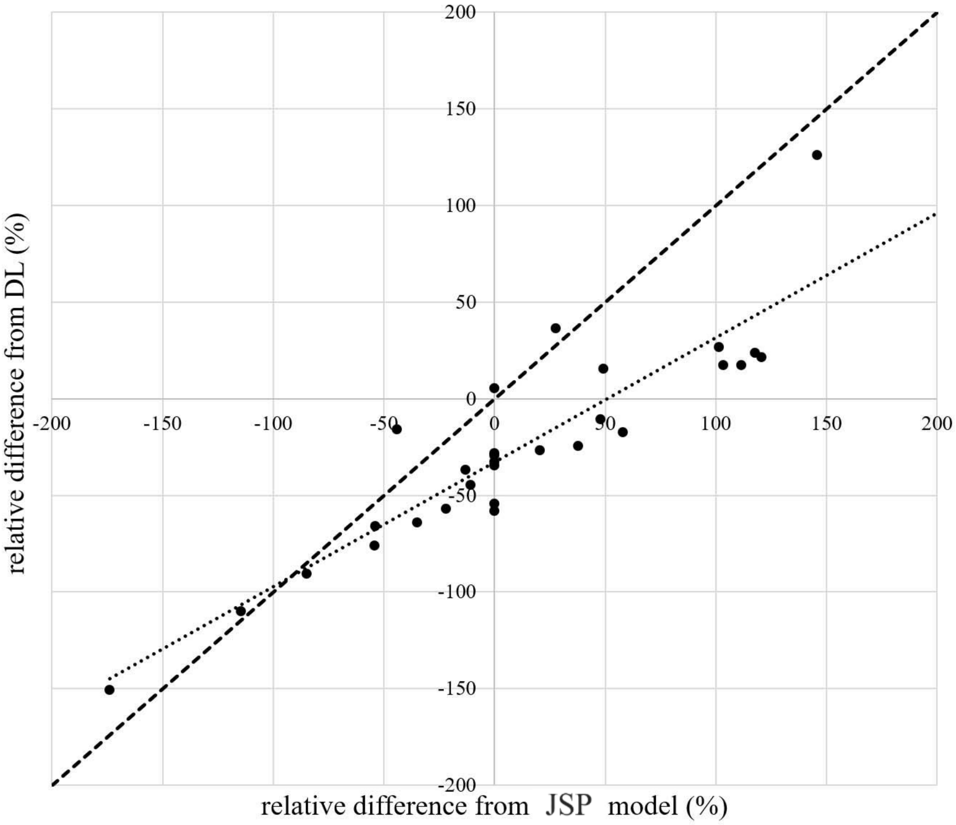


Figure 9.6 Comparison of the percent relative improvement of female Dutch swimmers from the JSP model compared with their percent relative improvement from the DLs for the 200 m individual medley event. The dashed line represents y = x and the dotted line represents the linear regression for Dutch swimmers