Performance Progression of British Swimmers Through Adolescence: A Longitudinal Study

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Declaration

‘No part of this thesis has been submitted in support of an application for any degree or other qualification of the University of Kent, or any other University or Institution of learning.’

Signed: 

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Finally, this thesis is dedicated to the memory of two inspirational swimming coaches, John Sadler and Tony Smith.

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Abstract

Introduction: Current research suggests that there are differences in the sporting performance of males and females. It has also been noted that the career trajectories of swimmers are affected by gender. Part I of this study used historic rankings data to analyse the trajectories of male and female swimmers to their peak performance. Additionally, it examined the difference in the development of successful junior and successful senior swimmers. The Swimming Discussion Paper was published by British Swimming (2018) to highlight some of the patterns of performance at the National championships, which observed a general decline in the performance of females from the national qualification events to the national championships. Part II of the study aimed to confirm and develop the findings of the Swimming Discussion Paper to identify differences in the short-term performance progression of males and females between qualification and National championships.

Methods: In part I of the study, male and female swimmers with the top 10 junior and top 10 senior all-time British rankings for each event were included for analysis. In total, 44901 historic performance observations for 269 unique swimmers were obtained from the British Rankings database. Swimmers who were successful in both the junior and senior rankings lists were allocated to the Junior & Elite (JE) group. Mean ages of peak performance were determined for each swimming event for each group of swimmers. A quadratic model was fit to the data and assessed using a multi-variate ANOVA with a significance level of $p<0.05$. Part II of the study used data from the British Summer Meet (National championships) from 2016-2019. This resulted in 13477 national qualification swims and their associated national championship swims in the same year by 2716 unique swimmers. A multi-variate ANOVA was used to assess the significance of each factor (sex, age group, distance, stroke and year) upon the percentage change in performance time between qualification and nationals.

Results: Part I found that more females than males converted their top-ranking junior performance into a top-ranking senior performance. Females were confirmed to achieve their peak performance at a younger age than males (19.7±3.0 and 21.3±3.3 years respectively, $p<0.05$). When events were grouped by stroke and distance, the largest gap in the mean age of peak performance between males and females in the same event was found in breaststroke (2.9 years) and for the 200m events (2.1 years). Generally, the difference between males and females was least in longer events. Career trajectories of swimmers in different groups were found to be significantly different, as were the trajectories of male and female swimmers. Part II found that breaststroke events showed the least progression between qualification and nationals, particularly for females. Events of 200m in length were found to show the least progression. On average, females show less of a performance progression than males. However, females showed a more consistent pattern of performance change across age groups. Faster, higher ranked male and female swimmers were consistently producing positive performance progressions from qualification to nationals.

Conclusion: This study confirmed that there are differences in the progression of male and female swimmers throughout adolescence. A greater proportion of females translated their successful junior performances into a top senior ranking, but good junior performance is not a prerequisite to a successful senior performance. This study corroborated the overall finding of the Swimming Discussion Paper, but revealed that the results are more nuanced than previously reported. To ensure success for the country on an international level, talent development programmes should aim to include as many swimmers as possible at all levels, as junior performances are not always an indicator of senior success.

Chapter 1 - Introduction

Competitive swimming involves athletes competing against the clock across a variety of different strokes; Freestyle, Backstroke, Breaststroke, Butterfly and Individual Medley. Individual Medley is a race involving a combination of all strokes. There are large databases of competitive swimming results which provide an opportunity to study the evolution of performance in these disciplines over time. Indeed, there have been a number of previous publications investigating career trajectories of competitive swimmers across the junior to senior age groups (Costa *et al.*, 2010; Costa *et al.*, 2011, 2014; Morais *et al.*, 2013; Dormehl, Robertson and Williams, 2016a). However, as with most sports, the research body around females in sport and exercise is limited, due to the gender bias towards male participants (Costello, Bieuzen and Bleakley, 2014). Furthermore, the body of knowledge surrounding adolescent female performance is even more sparse. The existing literature suggests that male and female performance differs in a number of ways, including, but not limited to; growth and maturation (Erlandson *et al.*, 2008; Morais *et al.*, 2013), physiological capacity (Jürimäe *et al.*, 2007; Klika and Thorland, 2016), preparation for competition (Mujika, Padilla and Pyne, 2002; Papoti *et al.*, 2007; Hellard *et al.*, 2017) and psychosocial aspects (Chalabaev *et al.*, 2013; Warner and Dixon, 2015).

The current literature suggests that sporting success at a junior age is not necessarily a prerequisite to a successful senior performance (Schumacher *et al.*, 2006; Yustres *et al.*, 2017; Boccia, Cardinale and Brustio, 2020). Furthermore, there is limited evidence to suggest that the pathway to success might be different for males and females, despite their physiological and developmental differences (McLean and Hinrichs, 1998; Handelsman, 2017).

In their 2018 report, British Swimming identified that when aggregated by club, female athletes showed a regression between qualification events for the national championships and the national championships itself (British Swimming, 2018). Whereas, male clubs showed a trend for progression between their qualification and event swims. The hypothesis presented by British Swimming is that females demonstrate a regression in performance between the national qualification events and the national championships. However, there are no other studies investigating this apparent performance regression in adolescent female swimmers. Moreover, the British Swimming study analysed data aggregated by swimming club and did not provide an analysis of individual data or compare to age matched males. Thus, it is not clear whether the trends shown are the indicative for all adolescent female swimmers, and how they compare to their male counterparts.

The aim of this research is to compare male and female populations to identify the differences in their long-term progression (Chapter 3 Part 1) and short term (Chapter 3 Part 2) performances. It is hoped that the findings of the two studies mentioned will contribute to the current knowledge base on female swimming performance, potentially helping to inform selection policies for competitions, funding and pathway programmes. Additionally, it may act as comparison tool for coaches to assess their athletes' progress in line with the best swimmers in the country. This, in turn, may give coaches areas to focus on specifically to narrow the gap between male and female performance stability.

Chapter 2 - Literature review

2.1 Athletic Development

The Long-Term Athlete Development (LTAD) model was proposed by Istvan Balyi in the early 1990s. Since then, many authors have collaborated to produce a comprehensive model of development for grassroots sport. Sports were categorised into either early specialisation or late specialisation by the model, the former using four progressive stages and the latter using six to describe the levels of participation in each category; from FUNdamentals to Retirement/retainment. Swimming is established as one of the late specialisation sports, categorised by a six-stage model (Balyi, 2004). Although further studies have demonstrated that swimmers, specifically females, show characteristics of early-maturing adolescents (Erlandson *et al.*, 2008; Dormehl, Robertson and Williams, 2016b, 2016a).

The LTAD model has been adapted by many National Governing Bodies (NGB) for individual sports. In 2004, the original LTAD model for swimming was published by the Amateur Swimming Association (ASA, now Swim England) to rectify some of the global issues in athletic development. Amongst the issues identified were: young athletes under-training and over-competing, adult competition and training being imposed upon junior athletes, male programmes imposed upon females, lack of optimisation of training around critical periods, inability to “correct” poor training experienced from 6-16 years of age and coach education not including growth, development and maturation of young people in general (Gordon, 2004).

In a survey of coaches, a number of problems with the implementation of LTAD in UK swimming club programmes were identified. The guidance within the swimming LTAD pathway required swimmers under 13 in the SwimSkills phase to be completing high volumes of training at the expense of technical practice, which should be of paramount importance in this young age group, as stated by the LTAD. The view of coaches was that this seemingly excessive volume was having a negative impact upon the motivation of the young swimmers at this stage of the LTAD, especially as they were being asked to compete in races of 200m and above in competition. It was suggested by the coaches in the study that a more general model of athletic development could be more useful in the long-term development of their athletes (Lang and Light, 2010), as it has been recommended that athletes compete in a variety of sports until they specialise at a later age (Blagrove, Bruinvels and Read, 2017). The coaches also suggested that if long-term development is the goal, then the emphasis of training programmes should be on technical development until such time as swimmers are competing at a high level (Lang and Light, 2010).

The original LTAD model has been adapted by Swim England, to produce the Athlete Development Support Pathway (ADSP) model (Figure 1), as a tool for clubs to structure their programmes (Swim England, 2020 [Accessed: 14/02/2020]). The ADSP puts emphasis on the technical development of a range of aquatic skills for swimmers within the learning to train phase (previously SwimSkills), rather than stipulating a potentially detrimental mileage for swimmers in this stage of development.

The Youth Physical Development Model (YPDM) was constructed by Lloyd and Oliver (2012), as a new approach to LTAD, in which, it is acknowledged that young athletes can train to improve most components of fitness throughout childhood. They state that prior to puberty, strength, functional movement skills, speed and agility should be targeted as the main physical attributes. They also mention that during adolescence, other physical qualities become more important, mainly sport specific skills, power and hypertrophy, due to the increased levels of androgenic hormones for both males and females (Lloyd and Oliver, 2012).

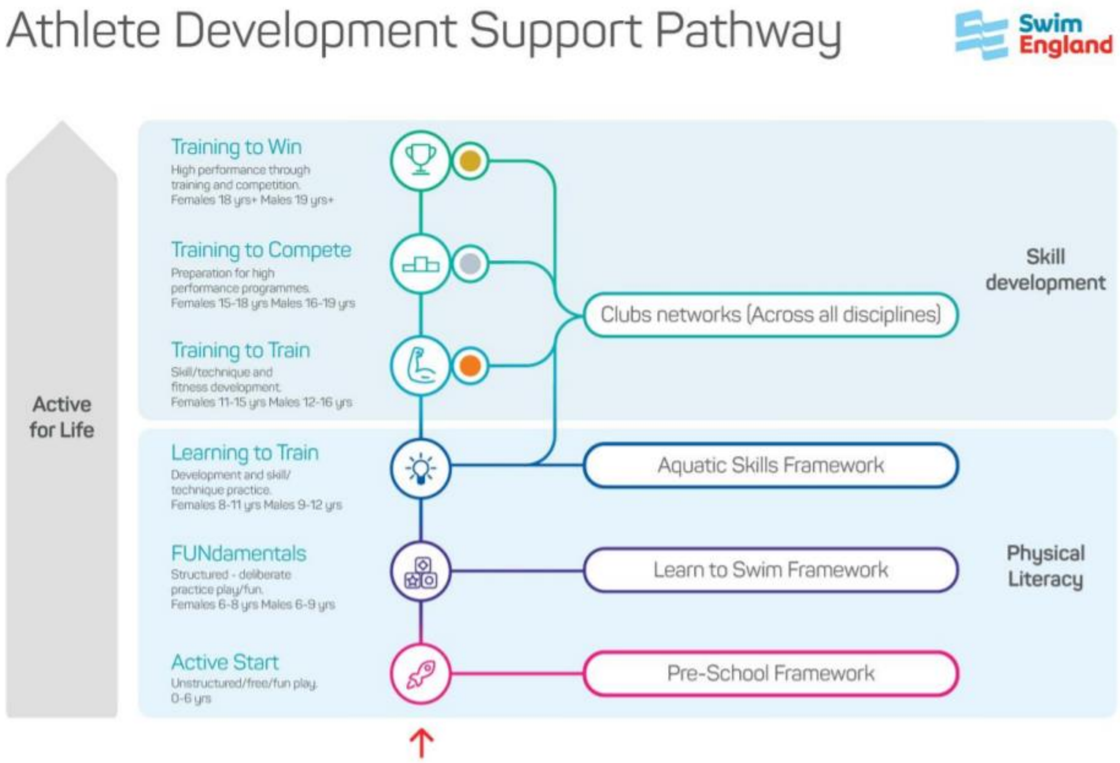

Figure 1 - Swim England Athlete Development Support Pathway (Swim England, 2020 [Accessed: 14/02/2020])

2.2 Factors influencing performance

It has been documented that there is no single path to enhancing performance, and that the same performance can be achieved using a multitude of methods, influencing a variety of determinants of performance (Barbosa, Costa and Marinho, 2013). That said, it has been shown that a factor affecting performance times by as little as 0.5% can determine the placing of a top junior swimmer (Stewart and Hopkins, 2000). The following section will consider various factors that have been suggested to influence performance of adolescent male and female swimmers.

2.2.1 Age and Maturation status

In a study of male adolescent swimmers (aged 10-13 years) it was found that faster swimmers were taller, heavier and had longer limbs (Barbosa *et al.*, 2019). From adolescence to adulthood, it has been shown that physical and physiological parameters of females including anthropometric measurements and biological maturation significantly increase every year from 12-14 years (Lätt *et al.*, 2009). In a study of male swimmers, it was shown that the speed of growth slows at around 17-18 years of age, meaning that their performance could begin to plateau at this age (Junior, Popov and Bulgakova, 2007).

It has been suggested that despite exhibiting attributes of early-maturing individuals, female swimmers undertaking intensive training at a young age could adversely affect their growth and delay sexual maturation (Erlandson *et al.*, 2008). This, in turn could actually improve their adolescent performance in the short term, due to decreased drag due to more streamlined bodies, which is especially advantageous in longer race distances (Frisch *et al.*, 1981). It was found the tempo of maturation of female swimmers was in line with female athletes from other sports and they were found to have a comparable age of onset of menarche to the median for British girls (Erlandson *et al.*, 2008). However, other studies dispute this, stating that on average, menarche was delayed in their sample of teenage swimmers (Brooks-Gunn, Gargiulo and Warren, 1986).

There is still much contention around the interaction of biological rhythms, including the menstrual cycle, in the performance of female athletes due to the potential variability of performance throughout the cycle (VanHeest and Mahoney, 2007; Vanheest *et al.*, 2014). The menstrual cycle can be categorised into four phases: menstruation, follicular, ovulation and luteal (McNulty *et al.*, 2020). Studies have yielded different results, but most are anecdotal due to their small sample sizes and subjective ratings of performance. In the existing literature, some authors point towards best performances occurring during the menstrual phase (Brooks-Gunn, Gargiulo and Warren, 1986), whereas others state that best anaerobic performances occur in the follicular phase (Bossi *et al.*, 2013; Pallavi, Souza and Shivaprakash, 2017). However, many studies are inconclusive, or show no significant difference in performance between phases (Abramson and Torghele, 1961; Quadagno *et al.*, 1991; Bossi *et al.*, 2013; Ozbar *et al.*, 2016). That said, in a study of adolescents, their slowest performance was observed during the luteal phase (Brooks-Gunn, Gargiulo and Warren, 1986).

Menstrual cycle research struggles with small sample sizes and often subjective ratings of mood and performance change. Training phases and periodisation are rarely taken into account, which could have a significant impact upon their results. Due to the differing views of authors and largely inconclusive results of studies that have been completed, it is clear that more research into the effect of the menstrual cycle on performance is needed (McNulty *et al.*, 2020). With collaboration between coaching staff, medical personnel and sports science, it may be possible to devise a programme in which circamensal biology can be used to develop optimal periodisation models for female athletes (VanHeest and Mahoney, 2007). A number of authors have identified that coaches working with adolescent female athletes should approach their training programme with an holistic approach. This includes participation in a wide range of sports until specialisation, monitoring athletes' health status and ensuring the nutritional requirements of training are satisfied by daily caloric intake throughout training and competition cycles. (VanHeest and Mahoney, 2007; Vanheest *et al.*, 2014; Blagrove, Bruinvels and Read, 2017).

Some studies that have looked into how an athlete's birth month could influence their performance and how to advise selection policies as a result of this information. A study of Portuguese adolescent swimmers by (Costa *et al.*, 2013), grouped athletes into the quarters of the year in which they were born and analysed their performances in 2010. All Olympic events of the time were included, which excluded 50m Backstroke, Breaststroke and Butterfly. Their results showed that there were a higher number of male athletes born in the first and second quarters of the year and very few in the last quarter. Patterns in the data were not so obvious for females, but the third and fourth quarter of the year were always relatively underrepresented. This showed that male swimmers are more susceptible to the relative age effect and that for swimmers aged 12-15 for males and 12 years old for females, the effect was more pronounced (Costa *et al.*, 2013). Similar research on male Australian 100m freestyle swimmers aged 13-16 found a similar result when grouping by selection level i.e., top 50, 20 and 10% (Cobley *et al.*, 2019). The most evident effect of relative age was in the youngest, 13/14 age group, but dissipated in older age groups and was largely absent across all age groups and selection levels (Cobley *et al.*, 2019).

One of the main documented differences between males and females is their age of maturation and therefore their age of peak performance. It has been established by a majority of studies that women achieve their peak performance at an earlier age than men. This has been confirmed for Freestyle (Rüst, Knechtle and Rosemann, 2012; Vaso *et al.*, 2013), Backstroke (Kollarz *et al.*, 2013), Breaststroke (Wolfrum *et al.*, 2013) and Individual Medley (Buhl *et al.*, 2013; Vaso *et al.*, 2013). In some research, the pattern appears to be similar to that of other sports, with females achieving their peak performances at younger ages than males (Schulz and Curnow, 1988). However, in runners, the effect of sex upon the age of peak performance was unclear (Weippert *et al.*, 2020). In another study of runners, it was found that the age of peak performance of males increased with the length of the race, whereas longer distances are associated with women of younger ages (Schulz and Curnow, 1988). This is a concept echoed in swimming, that longer distances are associated with peak performance at a much younger age for women, but not for men (Junior, Popov and Bulgakova, 2007). A study by Wolfrum *et al*, (2013) showed that the distance of Breaststroke race didn't have an effect upon the age of peak performance for females, but males achieved their best times at younger ages for longer distances of Breaststroke. Peak swimming speed was found to be younger in breaststroke than in freestyle (Wolfrum *et al.*, 2013). In a study by Dormehl, Robertson and Williams (2016b), results from a national schools' competition were used to establish the age of the peak performance of male swimmers for different events. It was found that the youngest age of peak performance was in 50m Freestyle and 200m Individual Medley, whilst the oldest was in the 100m Butterfly, although the sample was limited as the competition only included school age swimmers (Dormehl, Robertson and Williams, 2016b). Using data from the same competition for females, longer distances (200m) appeared to have the youngest ages of peak performance (Dormehl, Robertson and Williams, 2016a). A systematic review of studies estimating the peak performance age of swimmers, found that age decreased from 50-200m, but then increased again for longer events. They also identified that this reversal occurred at approximately 21 years of age (Allen and Hopkins, 2015). The increase of peak performance age was found to be at around 4 minutes, equating to 200-400m in swimming, where it has been documented that there is an equal contribution of both the aerobic and anaerobic energy systems into the performance of these events (Maglischo, 2003).

2.2.2 Competition Level & Experience

Inter-individual variability is higher for swimmers at regional and international level, but lower for swimmers at national level (Seifert *et al.* 2011). Swimmers' success at international level has been found to correspond to the duration of international experience of the swimmer, rather than simply the length of their career (Junior, Popov and Bulgakova, 2007).

For all pool freestyle races, it has been determined that the age of peak performance is on average 2 years lower for women than for men (Rüst, Knechtle and Rosemann, 2012). This is a concept also found by Vaso *et al.* (2013), also using the Swiss high score list. They found that the age of peak swim speed for females was around 21 years of age, whereas males produced their peak speed between the ages of 22 and 25 for 200m and 400m freestyle and medley races. They also concluded that there was no significant difference in the peak performance age of these races, suggesting that they have similar skill and technical requirements. Another study with similar results was of historic Olympic data, finding that men reached their peak at 20 years of age, whereas women peaked on average 2 years earlier, at 18 years of age (Schulz and Curnow, 1988). In a more recent review of 21st century research Allen and Hopkins (2015), it was suggested that peak performance age decreases linearly with increasing event duration for sprint events of up to 100m, but increase linearly for endurance events of 200m and above. However, it seems that the reverse is true from events lasting over 4 minutes, which would include swimming races of 400m and above. They concluded that the wide age ranges found to be successful in different sports were due to the differing components of fitness and physical attributes required for success in each discipline and the age at which these variables reach their peak capacity.

In a study by Wolfrum et al. (2013), there was no evidence to suggest that that race distance affected the age of peak performance in women's breaststroke, but the age of peak breaststroke speed was found to be 4 years older for international women than for those at national level. The same study found that men achieve peak performance in breaststroke at younger ages for longer events, suggesting that the shorter breaststroke races are more technical in nature, with experience level an influence on performance. There was also a larger gap from success at national level to success at international level, with swimmers at the world championships an average of 6 years older than their swiss counterparts. Male and female swimmers achieved peak swimming speeds at younger ages for breaststroke than in freestyle (Wolfrum *et al.*, 2013). Another Swiss study by Kollarz *et al.* (2013) looked at a similar dataset, this time for backstroke swimming. In concurrence with a majority of other articles on the subject, they discovered that women reach their peak swimming speed at younger ages than men, 18-23 years and 21-26 years of age respectively. In agreement with Wolfrum *et al.* (2013), it was determined that freestyle and backstroke peak performances at international level happened on average 1-2 years later than those at national level. There was a marked increase in the age of peak performance from 1994 to 2011 for women in the 50m backstroke at national level from 16 to 22, and a small increase from 22 to 23 years of age for men. No difference was observed at international level. However, they did conclude that swimming speed had increased in all backstroke events from 1994 to 2011 at both national and international level (Kollarz *et al.*, 2013). A comparative study (Elmenshawy, Machin and Tanaka, 2015) across 4 sports showed that the age of female medal winners has increased since the first modern Olympics in 1898 until the most recent Olympic event in 2014, but also in modern times since 1980. For men, peak performance age has not changed in any event studied for swimming. A study of elite swimmers found that faster swimmers experienced more consistent swims in the same event between competitions than slower swimmers (Stewart and Hopkins, 2000). Interestingly, it has been shown that inter-individual variability was higher for regional and international level swimmers and lower for national level swimmers (Barbosa, Costa and Marinho, 2013).

A study by Yustres *et al.* (2017) found no evidence to suggest that a finalist position in the Junior World Swimming Championships had an influence upon achieving a finalist position at the Senior World Swimming Championships. Seventeen percent of swimmers appeared in both junior and senior finalist positions, with 83% of athletes making senior finals having not been finalists at junior level (Yustres *et al.*, 2017). In the same study, swimmers with exceptional junior performance times or those with a higher rate of progress were more likely to be successful at the senior World Championships. It was found that 27.1% of top 10% juniors were in top 10% of the Senior World Championships. A total of 50.7% of athletes in bottom 10% of Junior World Championships were in the bottom 10% of Senior World Championships. The mean age of the top 30% of swimmers at the Senior World Championships (20.4±2.7 years) was higher than the mean age of swimmers in the bottom 70% (18.8±2.4 years), but both groups of swimmers first competed at similar ages. Mean performance variation over a swimmer's career was highly variable. The age at which an athlete competes at the World Championships for the first time does not fluence their position in senior World Championships. The top 30% of athletes achieve their best times later than swimmers in bottom 70%. Optimal annual performance progression from junior World Championships positively affects chances of success at senior World Championships. (Yustres *et al.*, 2020). In a study of cyclists, only 29.4% of elite athletes had competed at a Junior World Championships (Schumacher *et al.*, 2006). Age of peak performance for international swimmers was 4 years older than for national level swimmers (Wolfrum *et al.*, 2013). This was confirmed by a study on Backstroke and Freestyle swimmers, finding that ages of peak performance were 1-2 years younger at national level than at international level (Kollarz *et al.*, 2013).

2.2.3 Physiological factors

VO_{2max} has been suggested to be one of the most important factors for younger swimmers and older swimmers (Jürimäe *et al.*, 2007; Klika and Thorland, 2016). A study by Hellard et al. (2018) found that faster elite level swimmers also had higher VO_{2max} values and were able to reach this level faster than the slower swimmers in the sample, at around 50m in a 100m race. The same authors also concluded that anaerobic factors become more important with age. Anthropometric factors are also thought to affect performance in swimmers, including height, weight, arm span and body fat percentage (Siders *et al.*, 2009; Zuniga *et al.*, 2011; Morais *et al.*, 2013; Klika and Thorland, 2016; Barbosa *et al.*, 2019). One study concluded that faster swimmers in the male 100m Freestyle event were taller, heavier and had longer limbs (Barbosa *et al.*, 2019). Similarly, fastest 10-13 year old males and females in the same event were taller, with larger surface areas on their hands and feet (Morais *et al.*, 2013). In a different study involving swimmers, arm span was seen to be one of the best predictors of Freestyle performance in younger swimmers (Jürimäe *et al.*, 2007). There has been much deliberation over the effect of body fat percentage upon performance in swimmers.

Some studies have noted an important tracking effect of body fat percentage and performance (Zuniga *et al.*, 2011), whilst others have concluded a non-significant interaction (Lätt *et al.*, 2009; Barbosa *et al.*, 2019). In young adults, leanness was deemed as a more important factor than for children (Klika and Thorland, 2016). It has been further suggested that body composition and somatotype may be an indicator of swimming performance in women, but not for men (Siders, Lukaski and Bolonchuk, 1993). Some studies have looked further into body fat percentage, looking instead at lean mass. For teenage female swimmers, body fatness is relatively unimportant, but lean body mass has an influence on performance (Stager, Cordain and Becker, 1984). It was found by other authors that male swimmers experience double the increase in lean mass than females within and between seasons for eight years (Pyne, Anderson and Hopkins, 2006). It has been shown that for female athletes, lean body mass affects performance, but that percentage of body fat is unimportant (Stager, Cordain and Becker, 1984). Furthermore, another study concluded that measurements of body composition were a predictor of swimming performance for women, but not for men (Siders, Lukaski and Bolonchuk, 1993).

A key problem experienced by female athletes is Relative Energy Deficit Syndrome (Vanheest *et al.*, 2014). Controversially, there is a suggestion that speed of female swimmers may be increased by decreasing their body fatness, as this was stated to be the only mean difference between males and females by one set of researchers (Zuniga *et al.*, 2011). However, restriction of energy intake by athletes during increased energy expenditure during exercise can frequently result in ovarian suppression. It was found that in ovarian suppressed athletes, there was an 9.8% decline in Freestyle performance, compared with an 8.2% improvement for the cyclic females (Vanheest *et al.*, 2014). More holistic studies have revealed that actually the most crucial factor in female performance success is maintaining a nutritional energy balance, rather than focusing on anthropometric measurements (VanHeest and Mahoney, 2007). Most authors on this subject have suggested that tackling relative energy deficit syndrome in female athletes should take a multi-disciplinary approach for the athlete with support from their coach, medical personnel and sports science support (Vanheest *et al.*, 2014).

2.2.4 Biomechanical Factors

There are several biomechanical factors affecting swimming performance. Kinematic stroke parameters are often used as an indicator of performance, including stroke length and stroke rate (Barbosa *et al.*, 2011; Kennedy *et al.*, 1990). Indeed, faster 10-13 year old males and females have been shown to have better stroke mechanics, including stroke lengths (Morais *et al.*, 2013). Stroke index, a product of average velocity and stroke length, has also been found to be a good predictor of performance in young Freestyle swimmers (Jürimäe *et al.*, 2007; Barbosa *et al.*, 2019). Biomechanical factors were further investigated in a study of young, female, 400m Freestyle swimmers, which concluded they were the more important than bioenergetic and physical factors (Lätt *et al.*, 2009). Force generation potential was found to be one of the most important factors for children (Klika and Thorland, 2016), and power delivered by swimmers in the water was significantly higher in faster swimmers (Barbosa *et al.*, 2019).

Changes in training load of as little as 10% have been found to make a difference to swimming performance (Hellard *et al.*, 2017). Furthermore, improvement in performance has been shown to significantly correlate with the average intensity of training sessions rather than volume or frequency of training sessions (Mujika *et al.*, 1995). Successful performance has also been linked to training periodisation, including tapering (Jorge E. Morais *et al.*, 2014). Swim speed improved by 1.6% after an 11-day tapering of training which reduced volume without reducing intensity, showing that training load is a factor affecting swimming speed (Papoti *et al.*, 2007). A further observational study of training loads found that a small reduction in volume was more effective than larger reductions in the period from 6-11 weeks away from competitions. They also suggested cyclical periodisation should be specific to swimming events, particularly different distances. Sprinters require highly periodised training, whereas middle and long distance swimmers require a more progressive, continuous approach towards periodisation (Hellard *et al.*, 2017).

2.3 Performance Progression of Swimmers

A comparative study across 4 sports showed that the age of female medal winners has not only increased since the first modern Olympics in 1898 until the most recent Olympic event in 2014, but also in modern times since 1980. For men, peak performance age has not changed in any swimming event (Elmenshawy, Machin and Tanaka, 2015). In a separate study of Olympic Freestyle swimmers from 1957 onwards, the age of peak performance of men and women increased, from 20 to 21 years of age for males, and from 18 to 19 years of age for females (Nevill *et al.*, 2007). More recent studies of swimmers, but also athletes in general, have also suggested that the age of peak performance may be increasing with time (Junior, Popov and Bulgakova, 2007; Nevill *et al.*, 2007; Kollarz *et al.*, 2013; Elmenshawy, Machin and Tanaka, 2015). Between the Olympic games in 2008 and 2012, it was concluded that the age of peak performance for male and female swimmers has increased by around 1.5-2 years (Allen, Vandenbogaerde and Hopkins, 2014). When Backstroke was analysed alongside Freestyle events, no changes were found in the age of peak performance of international swimmers from 1994-2001 (Kollarz *et al.*, 2013). In a study of more than 2000 male swimmers from 1962 to 2004, Junior, Popov and Bulgakova (2007) found that the average age of the best 10 swimmers in the world had increased with time from 20 to 23 years. Additionally, there was a significant increase in the maximum age of males within the top 10, which reached almost 35 in 2004. It is hypothesised that modernised changes in sociocultural and political landscapes have influenced and supported the surge of older, specifically female athletes (Elmenshawy, Machin and Tanaka, 2015).

Alongside changes in the age of peak performance, some studies have also looked at the change of swimming speed across time (Nevill *et al.*, 2007; Kollarz *et al.*, 2013; Elmenshawy, Machin and Tanaka, 2015). The rate of female improvement for Freestyle events has been faster than the rate of male improvement since 1957, with generally the degree of improvement being greater for longer races (Nevill *et al.*, 2007). Most studies analysing swimming performance focus on Freestyle, as it is the stroke with the most variation in distance, 50-1500m. However, in a project investigating speed in elite Freestyle and Backstroke swimmers, Kollarz et al. (2013) discovered that speed increased in both strokes and all distances (50-200m) from 1994 to 2011 at both a national and international level.

It is universally accepted that there is a general enhancement in sporting performance from adolescence to adulthood in a variety of sports (De Koning *et al.*, 1994; Lätt *et al.*, 2009; Costa *et al.*, 2010; Costa *et al.*, 2011, 2014; Dormehl, Robertson and Williams, 2016b, 2016a). This enhancement in performance has been shown to fit a quadratic model. Analysis of the results of an annual national schools' competition's 7 events over 8 years, a quadratic model was fit to the swimming progression of individual males to their peak performance using mixed linear models. It was found that the slowest rate of improvement was in the 200m Individual Medley event and that the fastest progression was in the 100m Butterfly. It was also concluded that Butterfly is one of the last strokes in which males specialise (Dormehl, Robertson and Williams, 2016b). In a similar study of female swimmers, only three events showed reliable models; 100m Backstroke, 200m Individual Medley and 200m Freestyle (Dormehl, Robertson and Williams, 2016a). Moreover, Allen et al. (2014) studied elite male and female swimmers, showing the most progression in Butterfly over 4 and 8 years leading up to the Olympic Games. Interestingly, males demonstrated the least progression in Backstroke, whilst women progressed less in Breaststroke events (Allen *et al.*, 2014). Weippert *et al.* (2020) also found that quadratic equations give the best fit performance progression for runners in 800m, 1000m and 1500m races from 14 years of age to the individual's peak performance. When compared to swimming races by duration, these distances are equivalent to swimming events of 200m and longer. In cycling, it was calculated that the performance progression between junior and elite riders was around 5% for males and 6% for females (Schumacher, Mueller and Keul, 2001). These studies have shown that the performance progression experienced throughout adolescence for male and female athletes is similar across sports.

The Olympic Games is a quadrennial opportunity to gather performance data for athletes in all sports, as it is undeniably the most prestigious event of the athlete's year and usually the culmination of a four-year cycle of training. Few studies track the patterns in performance from one Olympics to the next, due to the length of time between the two events. Some of the published research has tracked the progression of athletes to the Olympic Games. Over 5 seasons leading to the 2008 Olympics, it was found that the performance of swimmers in the male Freestyle events improved 0.6-1% between seasons and 3-4% across the whole time period. Additionally, it was concluded that performance stability increased in the third season of the Olympic cycle, equivalent to the year before the competition (Costa *et al.*, 2010). A similar study of progression to the 2008 and 2012 games yielded similar results, women and men showed a similar rate of progression to their peak performance over 4 years (2.4±1.2%) and eight years (9.5±4.8%) (Allen, Vandenbogaerde and Hopkins, 2014).

It is generally accepted that swimmers should peak for the season leading up to and including the Olympic Games, as it is the biggest sporting event in the four-year cycle. For this reason, it is expected that times achieved in qualification meets for the Olympic Games are likely to be slower than those achieved at the Olympic Games themselves, as athletes aim to peak to produce their best performance for the Olympics. In a study involving 51 swimmers from Australia and the USA (Pyne, Trewin and Hopkins, 2004), swimmers proceeding to finals showed an average progression of 1.2% on their heat time. The authors also noted that to stay in contention for a medal, swimmer should aim to improve their performance by around 1% in the year before the Olympics and a further 1% within the competition period itself. It was found that a further improvement of 0.4% substantially increases a swimmer's chance of achieving a podium finish (Pyne, Trewin and Hopkins, 2004). Other studies have also agreed with the notion that higher performing swimmers tend to show more progression in performance than swimmers not achieving finalist or medallist positions (Mujika *et al.*, 1995; Issurin *et al.*, 2008). Entry and competition times for 301 swimmers from the Athens Olympic Games were used to analyse the relative performance gain between qualification events and the Olympic games. It was determined that the average performance gain was 0.58±1.13%, equating to a performance decline in 68.2% of Olympic swims. However, medallists and finalists do not fit this pattern, improving their personal best time by an average of 0.35% and 0.12% respectively (Issurin *et al.*, 2008). In a separate observational study, swimmers were tracked over two seasons. Those swimmers who achieved a personal best in the season before were more likely to maintain their performance in the following year. Whereas swimmers who had not achieved a personal best time in the preceding season were more likely to swim a best time in the final season (Mujika *et al.*, 1995).

There is some published research on the stability of performance (Stewart and Hopkins, 2000; Dormehl and Williams, 2015). Males showed less consistency in opting to swim the same events at a National Schools' competition throughout their development (Dormehl and Williams, 2015). However, in a study of elite swimmers, males showed the most consistent performance in the same events between competitions (Stewart and Hopkins, 2000). This could explain why swimmers specialise in Breaststroke at a younger age than other strokes (Dormehl and Williams, 2015).

2.3.1 Performance Progression of British Swimmers

The Swimming Discussion paper (British Swimming, 2018) aimed to discover whether swimmers were producing their best times of the season at the British Summer Championships. From these results, they concluded that on average, females showed a negative progression in performance, getting slower between the qualification events and the national championships, and that this pattern was observed in every single female event. Males, on the other hand, were shown to produce a positive performance progression, achieving faster performances at the National championships than at the qualification events earlier in the season. A significant proportion (86%) of female clubs showed a regression, while only 49% of male clubs showed the same trend. Only 14% of female clubs showed a progression from the qualifying window, and the worst female club produced a regression of 3.34% between the two swims. Their analysis was simplistic, comparing clubs and therefore overlooking the performance progression of individuals within the sample. This raised questions as to why females were underperforming at what for many of them will be the key meet for the year and why this was so different to the pattern of male performance observed in the same study. However, unfortunately the paper was a descriptive report, without any robust analysis techniques to look at performance of individual athletes and so it is unclear how representative the findings are, and whether the differences identified are statistically significant. Moreover, as the results were reported at club level, the data does not allow for analysis of performance at the individual swimmer level.

2.3.2 Performance Progression of International Swimmers

A number of studies have looked at the performance stability of athletes over time and how this can affect predictions of future performance (Costa *et al.*, 2010; Costa *et al.*, 2014; Morais *et al.*, 2014; Mostaert *et al.*, 2021). Performance stability using race times and therefore prediction potential was moderate for all Breaststroke events, except 50m, which saw a low prediction of performance (Costa *et al.*, 2010). It has been suggested by the same group of authors that 13-14 years of age is a key milestone for boys for the stability of performance in the 200m Freestyle and 100m Breaststroke. At this point, the ability to predict a swimmer's final performance level strongly increases (Costa *et al.*, 2010; Costa *et al.*, 2014). However, it was concluded in a cycling study that there was a lack of prediction possible in the U15 age group, but that it was more accurate to predict the senior performance of athletes who were in the U17 age group (Mostaert *et al.*, 2021). Although it has been shown that there is no evidence that measuring anthropometric or physiological factors in junior skaters could be used to predict a senior performance (De Koning *et al.*, 1994), it has been suggested that assessments of fitness, health and training of athletes could improve prediction capacity of these models (Bullock and Hopkins, 2009).

2.4 Gender differences

Although the literature surrounding female sporting performance is limited, some research has been published which demonstrate the difference between male and female sporting performance (Kennedy *et al.*, 1990; Morais *et al.*, 2013; Dormehl, Robertson and Williams, 2016a, 2016b; Handelsman, 2017). An early piece of research on gender gaps in swimming revealed that males had superior performances to females, primarily due to stature, age and longer stroke lengths (Kennedy *et al.*, 1990). In a study measuring anthropometric, kinematic and energetic variables, it was found that there is no significant difference in Freestyle swimming performance at younger ages (10-13 years) between males and females, despite there being a small difference in stroke frequency and the surface area of hands and feet (Morais *et al.*, 2013). From the age of 12-13, males and females show a divergence in performance, thought to be correlated with the rise in circulating testosterone in males (Handelsman, 2017). Females have been shown to undergo a slower progression than males as females have begun to mature earlier than males, by 12 years of age (Dormehl, Robertson and Williams, 2016a, 2016b).

Gender differences have been observed to decrease with increasing race distances in freestyle events (Rüst, Knechtle and Rosemann, 2012). The age of peak performance has been observed to be older for increasing running race distances, but the opposite is true for swimming, with younger historic gold medallists for longer races (Schulz and Curnow, 1988). Using retrospective data analysis, this pattern of decreasing sex differences with increasing speeds was confirmed for 50m and 1500m events. However, they did note increased variation between men and women in the 800m Freestyle (Rüst, Knechtle and Rosemann, 2012). Another study also confirms this, it was observed that sex-related differences in performances decreased significantly with an increase in distance for both national and international level swimmers in both Freestyle and Breaststroke (Wolfrum *et al.*, 2013).

It is well documented that senior athletes outperform junior athletes, but the level of swimmer is also important when considering differences between the sexes. When comparing international level finalists with the top swiss swimmers, Wolfrum *et al.* (2013) found that sex differences were more pronounced in freestyle events than breaststroke races over 50-200m for national but not international level swimmers. In a study of cyclists, it was found that the overall gender gap between males and females was around 12%, but that for athletes achieving a ranking of first to fifth, this decreased to 2-3%. This suggests that faster athletes do not experience the same gender gap (Schumacher, Mueller and Keul, 2001).

Summary

There has been a great volume of research conducted on the various components of swimming performance and longitudinal studies for elite swimmers (Mujika *et al.*, 1995; Pyne *et al.*, 2000; Avalos, Hellard and Chatard, 2003; Costa *et al.*, 2010; Costa *et al.*, 2013; Hellard *et al.*, 2018). There have also been few other papers dedicated to longitudinal monitoring annual performance progression of the same swimmers over time (Pyne et al., 2004; Stewart and Hopkins, 2000; Trewin et al., 2004). However, very little research is focused on the sub-elite swimmers, who ultimately make up the pool of athletes from which elite swimmers are trained. Whilst their study had limitations due to the nature of its participants, Dormehl, Robertson and Williams (2016) are one of the few collectives to have observed this critical age group.

The current research into female performance is limited, either focusing on elite swimmers, already at the height of their career (Costa et al., 2010) or on male adolescent swimmers (Dormehl et al., 2016a). The body of research pertaining to female adolescent swimmers is very sparse, especially as a longitudinal study. It has been shown that, particularly female, swimmers reach their age of peak performance before their counterparts in other sports, especially in the longer, endurance-based events (Allen and Hopkins, 2015; Schulz and Curnow, 1988). For this reason, when looking at the progression of female swimmers it is vital to look at the adolescent and youth athletes that are currently on their journey through the pathway to podium.

The experimental chapter will be split into two parts. The aim of Part I is to explore the patterns in performance within and between seasons, comparing performance trajectories of males and females from the national qualification events to the British Summer Championships in the same year, using data from 2016-2019. Using 4 years of data will allow a longitudinal view of the championships over a full quadrennial cycle, taking into account periodisation and major international competitions, which are generally biennial or quadrennial.

The aim of Part II is to determine if any factors available for analysis are affecting the performance of swimmers, specifically related to stroke, distance, level and age of the swimmer. Similarly to the British Swimming study, any strokes or distances showing a significantly different progression towards the national championships will be identified and the significance of the effect of stroke and distance on performance progression will be determined. The effect of the level of swimmer will also be examined, to find out if higher level swimmers experience a greater progression in performance between qualification events and the National championships. Using age data, the aim is to discover at which point male and female performance progression diverges, if at all.

Based upon the findings, it is hoped that the study will help to inform future practice to identify any gaps in the performance progression of female swimmers during and leading up to the national championships. This, in turn, can be used to inform future research into successful programming for females to perform optimally at the National championships.

The main hypotheses for part I are that females reach their peak performances before males, that the difference between male and female performance is smaller in longer events and that fewer females progress their successful junior swims to successful senior swims.

For part II, the main hypotheses are that females demonstrate a regression in performance between the national qualification events and the national championships, older female swimmers show the least progression between two events and that Breaststroke performance represents a problem for British females.

Chapter 3 – Experimental Chapter

Part I – Performance trajectories over a swimming career

Methods

Data Collection and Analysis

The top 10 historic junior and senior performances of all time were obtained for each swimming event from the British Rankings database. Events included were; 50m, 100m, 200m, 400m, 800m and 1500m Freestyle; 50m, 100m and 200m Backstroke, Breaststroke and Butterfly; 200m and 400m Individual Medley. All events were recorded in long course competitions. The junior top 10 includes the best times achieved by swimmers up to the age of 18, the senior top 10 includes the best performances for swimmers 19 years and over. Historic times for all swimmers identified were also obtained from the Rankings database (swimmingresults.org, 2021) for the event in which they achieved their top 10 ranking to allow a longitudinal approach to the data across the entire career of the swimmer. In total, 44901 observations for 269 unique swimmers were recorded. In a subsequent step, swimmers only appearing on the Junior list were allocated to the Junior Only group (JO), those appearing only on the Senior list were given the group Senior Only (SO), and those on both the Junior and Senior top 10 lists were allocated to a Junior to Elite group (JE). The total number of observations for each event was counted, and the number of male and female observations for each event was calculated. The number of swimmers within each group was calculated and the proportion of each group for each sex was determined. The fastest swim in each event for each individual was filtered to obtain average age of peak performance for both males and females.

Statistical Analysis

Data was initially checked for normality of distribution. A linear model using the restricted maximum likelihood method was fit to establish the significance of each factor (sex, distance, stroke, group and age) upon the peak speed produced by each individual in their events. A multivariate ANOVA was subsequently used to assess the significance of each factor within the linear model. A 2^{nd} degree polynomial (quadratic) model was then fit to the historic performances of each individual over the length of their career to establish a mean career trajectory to compare the development of males and females. The model was also used to compare the mean career trajectories of swimmers in the three groups; JO, JE and SO. The fixed effect was the individual, with random effects of sex, group, age, stroke and distance on the best speed achieved by that individual. Data is presented as mean ± standard deviation unless otherwise stated. Statistical analysis was conducted in R Studio (RStudio Inc., 2019) and statistical significance was set as $p<0.05$.

Results

Total numbers of individuals in each group were 190 JO, 150 JE and 190 SO, a breakdown is included in Table 1. Occasionally, swimmers do not wish to have their results visible on the rankings website and these swimmers appear on the rankings table as "Member Hidden". There were three hidden swimmers on the female senior rankings list, so data for these swimmers was not available for analysis. As there were no hidden swimmers on the female junior rankings list, it can be assumed that these hidden swimmers would have been in the female SO group. The female rankings tables show an almost equal split between the three groups, whereas there are fewer male JE swimmers, both in number and as a percentage.

Table 1 - Number of individuals included for analysis in each group (JO, JE, SO), including 3 swimmers hidden on database (Female, SO). Average age of peak performance and number of FINA points at peak performance (Mean ± SD).

	Male				Female			
	JO	**JE**	**SO**	**Total**	**JO**	**JE**	**SO**	**Total**
Number of Individuals	104	66	104	274	86	84	86	256
Percentage (%)	38.0%	24.1%	38.0%		33.6%	32.8%	33.6%	
Unique Individuals	68	35	63	143	62	46	52	126
Age of peak performance (Mean ± SD)	18.7 ± 1.9	21.4 ± 2.3	23.8 ± 3.1	21.3 ± 3.3	17.3 ± 1.6	19.6 ± 2.3	22.5 ± 2.4	19.7 ± 3.0
FINA Points	824 ± 35	897 ± 44	885 ± 36	865 ± 49	817 ± 43	892 ± 36	875 ± 43	861 ± 52

Thirty-five swimmers (10.42%) of swimmers appearing on the senior rankings list (from groups JE and SO) achieved their best times for their event whilst in the junior age group (aged 18 and under). Twenty-eight of these swimmers were female, with the youngest 15 years old at the time of her peak performance, the other 7 swimmers were male and all aged 17 or 18 at the time of their peak performance. All swimmers achieving their career fastest time in the junior age group, but appearing on the senior rankings list were from the JE group. Forty-one (39.4%) male JO swimmers achieved their best time in the senior age group, whereas only 11 (12.6%) females in the same group achieved their best times in the senior age group. Fifty-six (66.7%) females in the JE age group achieved their career best performances in the senior age group, but 59 (90.8%) males obtained their peak performance in the senior age group. All athletes in the SO group achieved their peak performance in the senior age group. Out of a total of 17 events, 15 male events had a best time performed by a swimmer from the JE group, 2 from SO. Whereas the JE group accounted for 12 of the 17 best times for females, 5 from SO. The average age of peak performance by each group is shown in Table 1.

The average FINA points achieved by the population of males was 865 ± 49 and for females was 861 ± 52. The average FINA points produced by the top male swimmer in each event was 946 ± 44, with the top female swimmers in each event achieving an average of 950 ± 27.

For each individual event, females achieved their peak performance earlier than males (Table 2). The average age of peak performance for females (19.7±3.0 years) and males (21.3±3.3 years) was significantly different ($p<0.05$) when all groups were considered across all events. The age of peak performance of the top male in each event was 22.2 ± 1.8 years and the top female in each event was 21.2 ± 3.0 years, which did not represent a significant difference ($p<0.05$).

1500m Freestyle was the event with the youngest age of peak performance for males (20.1 ± 2.4 years). The event with the oldest age of peak performance for males was 100m Breaststroke, 22.8 ± 3.6 years. For females, the event with the oldest age of peak performance was 400m Freestyle (21.1 ± 2.9 years) and the youngest was 400m Individual Medley (18.5 ± 2.3 years).

Table 2 - Number of individuals per group, age of peak performance and FINA points for each event individually.

	Male				Female			
	Number of Swimmers		Age of Peak Performance (Mean ± SD)	FINA Points (Mean ± SD)	Number of Swimmers		Age of Peak Performance (Mean ± SD)	FINA Points (Mean ± SD)
	JO / SO	JE			JO / SO	JE		
50m Freestyle	6	4	21.6 ± 5.1	823 ± 55	7	3	20.6 ± 3.6	839 ± 47
50m Backstroke	6	4	20.6 ± 2.8	849 ± 51	4	6	20.5 ± 3.5	881 ± 41
50m Breaststroke	7	3	21.8 ± 3.6	839 ± 56	4	6	19.5 ± 3.0	878 ± 46
50m Butterfly	7	3	21.1 ± 3.9	809 ± 46	9	1	19.2 ± 3.7	765 ± 48
100m Freestyle	7	3	20.7 ± 3.1	872 ± 38	8	2	19.6 ± 2.9	851 ± 40
100m Backstroke	6	4	21.6 ± 3.4	873 ± 35	5	5	20.4 ± 3.1	893 ± 39
100m Breaststroke	6	4	22.8 ± 3.6	862 ± 57	4	6	19.1 ± 2.2	874 ± 41
100m Butterfly	8	2	21.2 ± 2.9	859 ± 35	5	5	20.6 ± 3.3	865 ± 34
200m Freestyle	6	4	21.8 ± 2.9	871 ± 25	6	4	20.0 ± 2.6	886 ± 30
200m Backstroke	4	6	20.9 ± 3.2	858 ± 38	5	5	18.9 ± 2.3	881 ± 26
200m Breaststroke	7	3	21.4 ± 2.7	914 ± 54	4	6	18.6 ± 2.8	867 ± 68
200m Butterfly	5	5	20.5 ± 3.3	862 ± 32	5	5	19.9 ± 2.9	860 ± 37
200m Individual Medley	5	5	22.2 ± 2.8	890 ± 33	4	6	18.8 ± 1.9	880 ± 38
400m Freestyle	6	4	22.1 ±3.3	906 ± 24	3	7	21.1 ± 2.9	882 ± 40
400m Individual Medley	7	3	21.2 ± 2.8	871 ± 32	3	7	18.5 ± 2.3	865 ± 36
800m Freestyle	6	4	20.6 ± 2.8	857 ± 37	4	6	20.4 ± 2.8	873 ± 40
1500m Freestyle	5	5	20.1 ± 2.4	893 ± 37	6	4	19.9 ± 2.7	823 ± 35

When grouping the same stroke and distance together, females were still younger than males in every group (Table 3). On average, the youngest age for a male peak performance was in 1500m (20.1 ± 2.4 years) and the oldest age was in the 400m events 21.6 ± 3.1 years). Female swimmers produced their best performances at a younger age on average in the 200m distance (19.3 ± 2.6 years) and at an older age in the 800m distance (20.4 ± 2.8 years). Strokes at which swimmers produced their peak performance at a younger age on average were Butterfly for males (20.9 ± 3.4 years) and Individual Medley for females (18.7 ± 2.1 years). The strokes with the oldest ages of peak performance on average were the male Breaststroke events (22.0 ± 3.4 years) and the female Freestyle events (20.2 ± 3.0 years). When comparing the average age of peak performance between males and females, Freestyle showed the least difference between the sexes, whilst Individual medley showed the most difference in the average age of peak performance. When distance is considered, the longer events, 800m and 1500m showed the least difference between males and females and the 200m distance showed the largest difference between the average age of peak performance for males and females (Table 3).

A linear model was fit for the best speed achieved by each individual with the main effects of sex, distance, stroke, group and age. In an ANOVA of the main effects of the linear model; group, sex, distance, stroke, group and age all had a highly significant effect upon speed (p<0.001). An interaction between sex and stroke was considered and showed that there are highly significant differences between the speed difference between strokes for males and females (p<0.001). An interaction between group and event showed that the speed difference between events differs for each group (JO, JE, SO), p<0.001. An interaction between sex, group and stroke showed a highly significant interaction p<0.001.

Table 3 - Age of peak performance and FINA points when events are grouped by stroke and distance.

		Male		Female		Difference	
		Average Age of Peak Performance (Mean ± SD)	**Peak FINA Points (Mean ± SD)**	**Average Age of Peak Performance (Mean ± SD)**	**Peak FINA Points (Mean ± SD)**	**Average Age of Peak Performance ($Male - Female$)**	**Sex with Most FINA Points**
Stroke	**Freestyle**	21.1 ± 3.4	870 ± 46	20.2 ± 3.0	858 ± 45	0.9	Male
	Backstroke	21.0 ± 3.2	860 ± 43	19.9 ± 3.0	885 ± 36	1.1	Female
	Breaststroke	22.0 ± 3.4	871 ± 64	19.0 ± 2.7	873 ± 54	2.9	Female
	Butterfly	20.9 ± 3.4	843 ± 45	19.8 ± 3.4	825 ± 63	1.1	Male
	Individual Medley	21.7 ± 2.8	880 ± 34	18.7 ± 2.1	873 ± 37	3.0	Male
Distance	**50m**	21.3 ± 4.0	830 ± 54	19.9 ± 3.5	835 ± 66	1.4	Female
	100m	21.5 ± 3.3	866 ± 43	19.9 ± 2.9	870 ± 42	1.6	Female
	200m	21.4 ± 3.0	880 ± 43	19.3 ± 2.6	875 ± 43	2.1	Male
	400m	21.6 ± 3.1	888 ± 34	19.8 ± 2.9	874 ± 39	1.8	Male
	800m	20.6 ± 2.8	857 ± 37	20.4 ± 2.8	873 ± 41	0.1	Female
	1500m	20.1 ± 2.4	894 ± 37	19.9 ± 2.7	823 ± 35	0.2	Male

The mixed effects quadratic model (Figure 2 -Figure 5) was fit using the restricted maximum likelihood method for each event. The random effect was of the individual swimmer, and fixed effects were sex, age, group and event. In addition, combinations of sex and event, group and age and age and sex were also included. An ANOVA was carried out on the model and highly significant differences were observed between sexes, events and groups, p<0.001. Table 4 provides a summary of the AVOVA output, showing the degrees of freedom, F-statistic, sum of squares and the p-value for each of the variables and combinations of variables that had a significant effect upon speed. Age had a significant effect upon speed (p<0.001). A significant interaction was observed between sex and event (p<0.001), meaning that the degree of difference between males and females depends upon which group they are in. There was a significant interaction between sex and age (p<0.001), so the development trajectories of males and females are different. A further significant interaction was observed between group and age, so the trajectories of performance are different between the groups JO, JE and SO. Overall, this quadratic model accounted for 95.1% of the variation within the dataset.

Table 4 - Table showing the output of the multivariate ANOVA on the quadratic model showing degrees of freedom (Df), F-statistic (F), Sum of squares ($\Sigma(x_i - \bar{x})^2$) & p-value (p).

ANOVA	Df	F	$\Sigma(x_i - \bar{x})^2$	p
Sex	1	859	1.95	p<0.001
Age	2	72155	327.58	p<0.001
Group	2	314	1.42	p<0.001
Event	16	6369	231.32	p<0.001
Sex:Age	2	4753	21.58	p<0.001
Age:Group	4	1295	11.76	p<0.001
Sex:Event	16	61	2.20	p<0.001

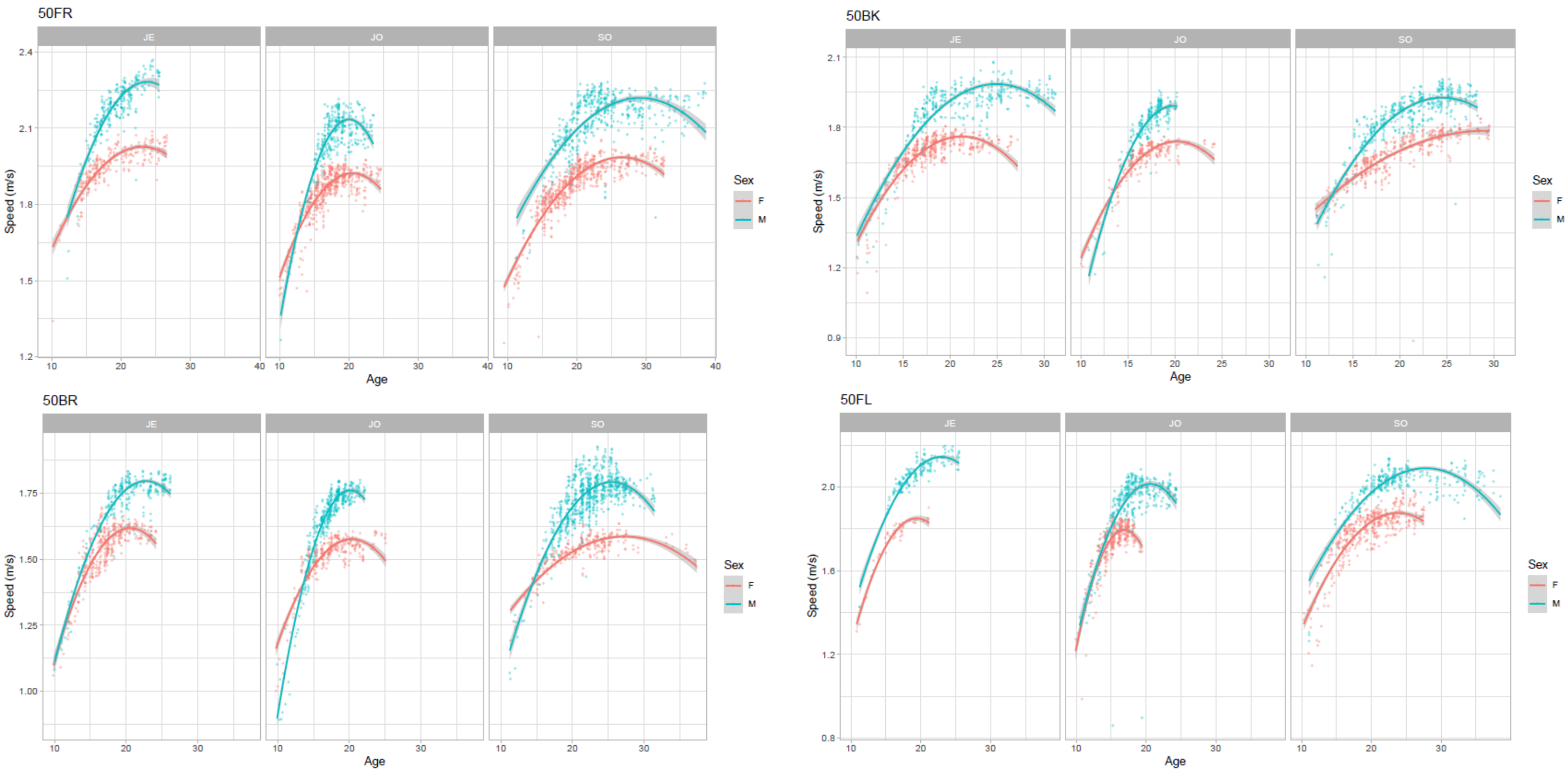

Figure 2 - Quadratic model for 50m Freestyle (50FR), Backstroke (50BK), Breaststroke (50BR) and Butterfly (50FL), comparing males and females in each group; Junior & Elite (JE), Junior Only (JO) and Senior Only (SO).

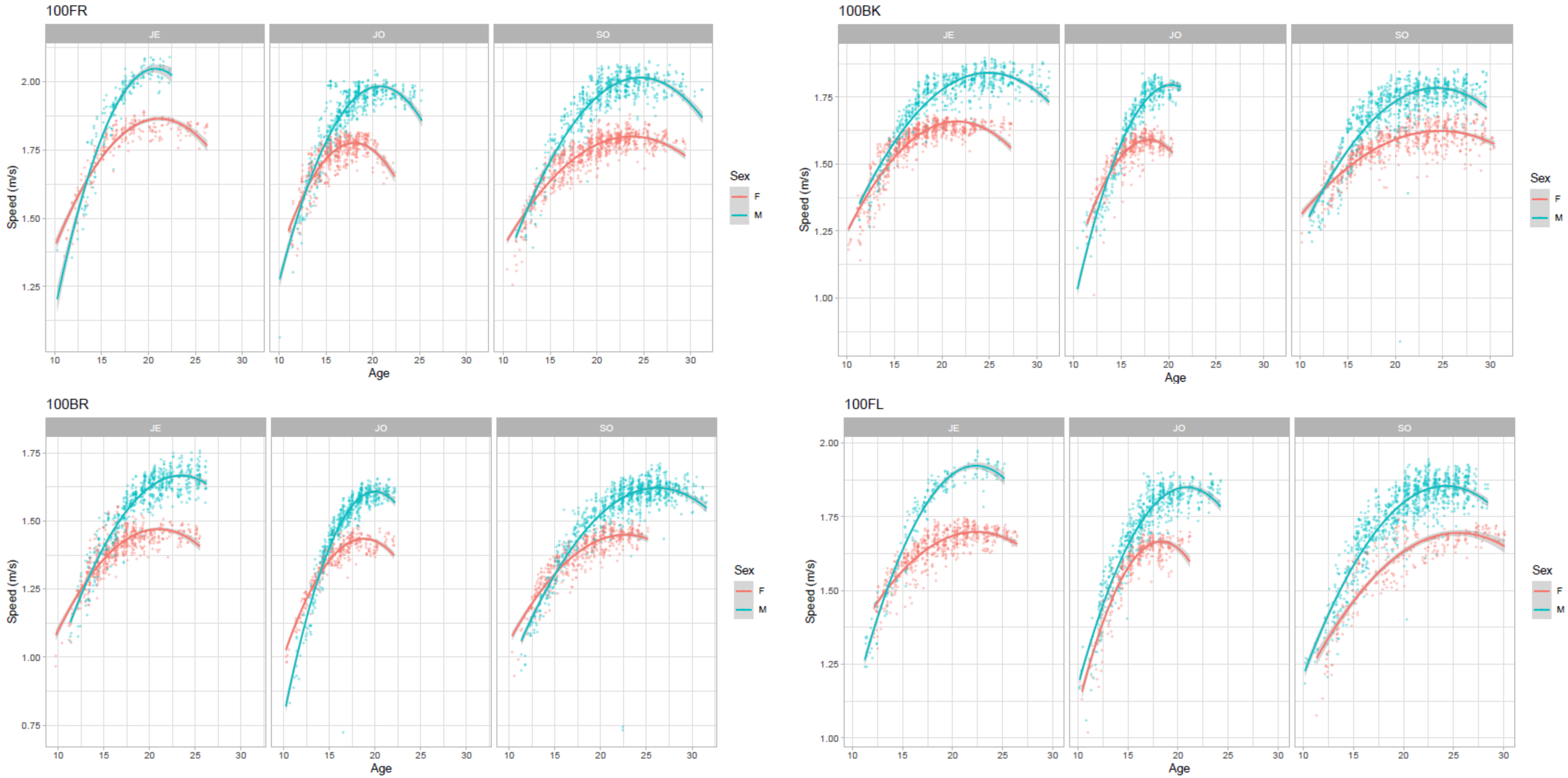

Figure 3 - Quadratic model for 100m Freestyle (100FR), Backstroke (100BK), Breaststroke (100BR) and Butterfly (100FL), comparing males and females in each group; Junior & Elite (JE), Junior Only (JO) and Senior Only (SO).

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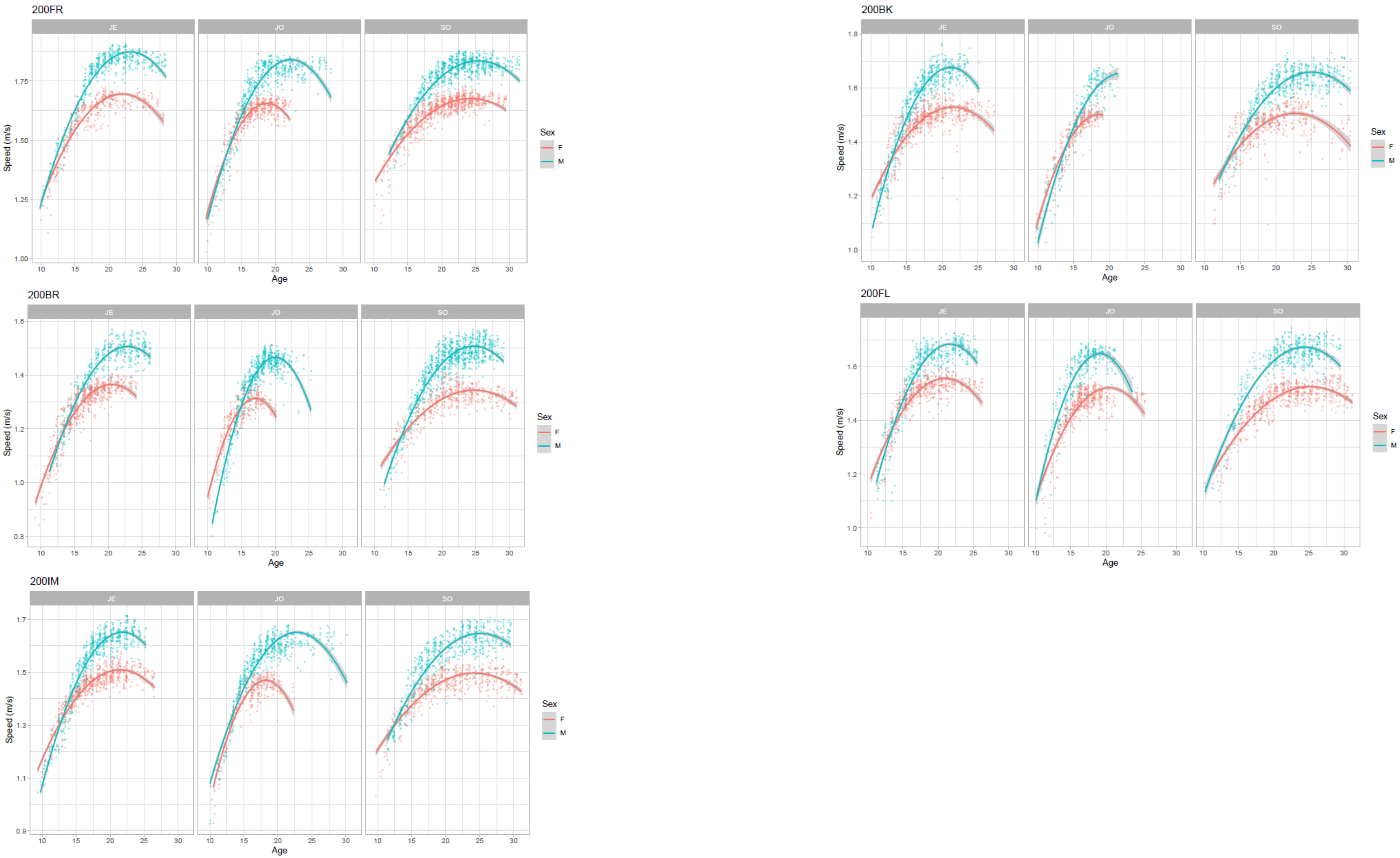

Figure 4 - Quadratic model for 200m Freestyle (200FR), Backstroke (200BK), Breaststroke (200BR), Butterfly (200FL) and Individual Medley (200IM), comparing males and females in each group; Junior & Elite (JE), Junior Only (JO) and Senior Only (SO).

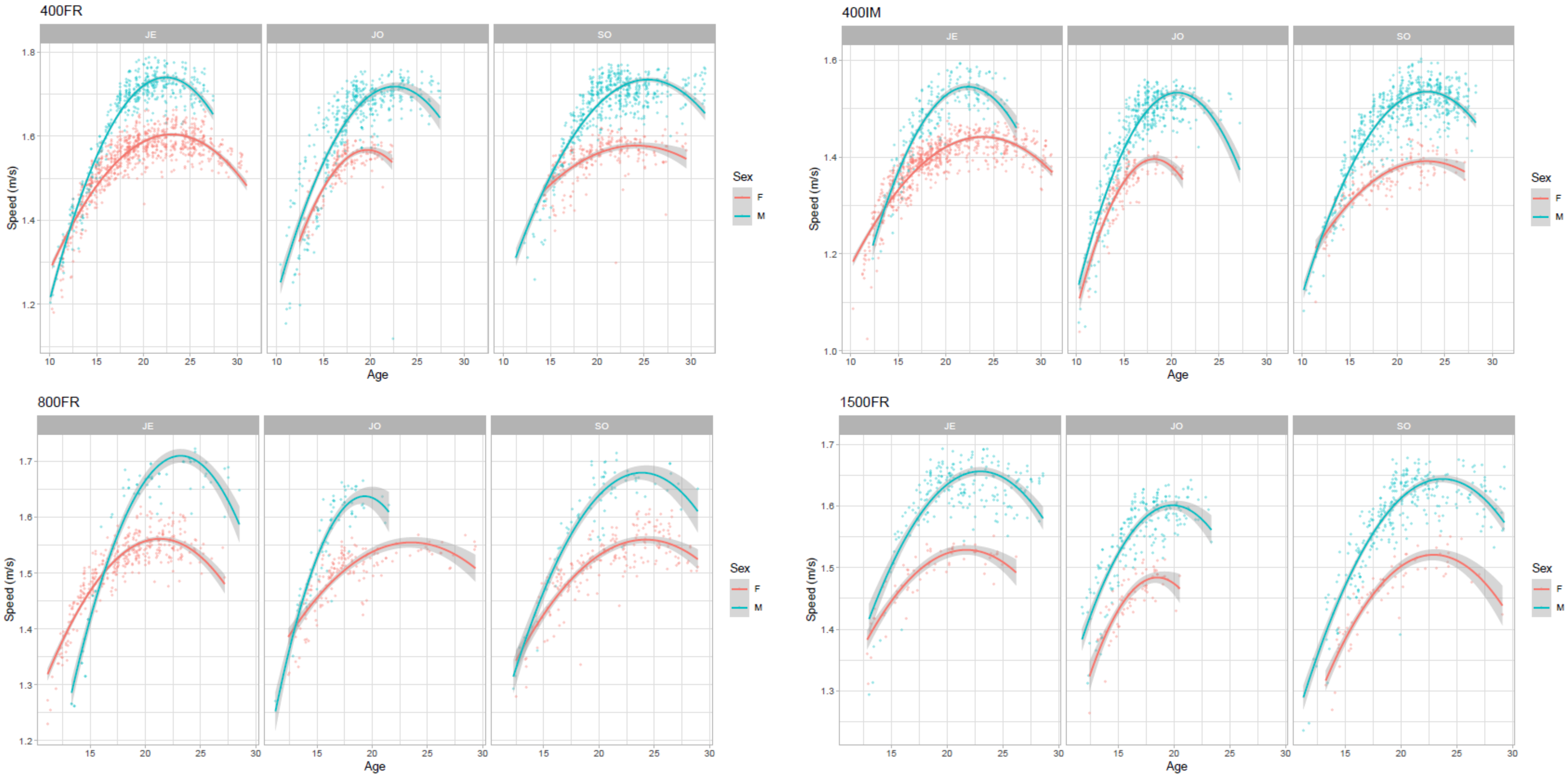

Figure 5 - Quadratic model for 400m Freestyle (400FR) & Individual Medley (400IM), 800m Freestyle (800FR) & 1500m Freestyle (1500FR), comparing males and females in each group; Junior & Elite (JE), Junior Only (JO) and Senior Only (SO).

Summary

The first study has found that on average females achieved their peak performance at a younger age than males and that females were also more likely to convert their top-ranking junior swims to top-ranking senior swims. In agreement with the Swimming Discussion Paper (British Swimming, 2018), it was also found that there was a disparity between male and female age of peak performance which was most prominent in Breaststroke and 200m events. The next section will aim to explore these patterns within a season, comparing performances of swimmers during the national qualification window to performances by the same swimmers at the national championships.

Part II - Performance Trends at the British Summer Championships

Methods

Swimming Calendar

Across the course of a swimming season various licensed events are held throughout the country at county, regional and national level (Figure 6). Each year, qualification events for the National championships are held during the qualification window (Figure 6) across the country and times achieved by each swimmer are uploaded to the British Rankings Database. At the end of the qualification window (March to May), the top 24 (18 for 800m and 1500m Freestyle) swimmers in each event (combination of stroke and distance) for males and females are invited to the British Summer Championships in July. The next 24 swimmers in each event, for males and females, are invited to the home nation summer meets (Swim England, Scottish Swimming, Swim Wales). Where an invitation is declined in advance, the next fastest swimmer in that event and distance will be invited (British Swimming, 2020). To qualify for a national championship event, a swimmer must be ranked in the top 48 for their age group (age at 31st December of the year of the championships). The ranking swim must occur during the qualifying window. The qualifying window for 2020 was between Friday 13th March and Sunday 10th May 2020. The national championships for 2020 would have been; British Summer Meet (National championships) from 23rd to 28th July and Swim England Summer Meet from 29th July to 2nd August. Figure is a schematic layout of the season by week, showing the position of the qualifying window in relation to both the English and British national meets. The top 24 swimmers from these qualification events attend the British Summer Meet

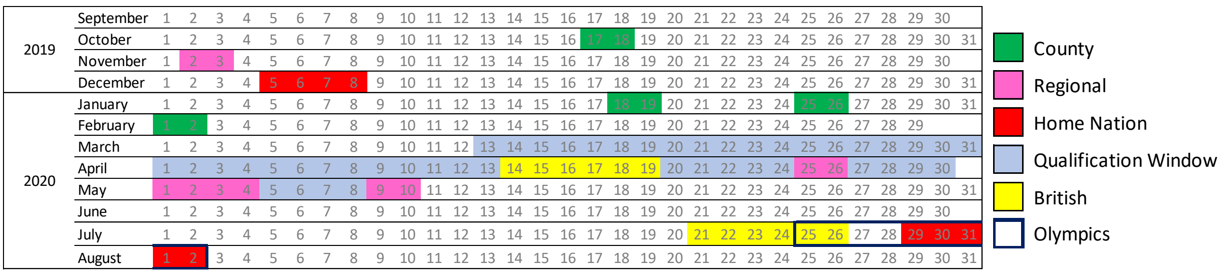

Figure 6 - Schematic layout of the planned 2019-2020 season

(National championships), whilst swimmers ranking 25-48 will be invited to their home country's national summer meet (Swim England Summer Meet). Occasionally, when swimmers have qualified for multiple events and do not wish to swim all of them at the nationals, lower ranked swimmers will be invited to the national championships to fill the 24 places.

Data Collection

Data from the British Summer Meet (National championships) and related qualification events in the most recent 4 years from 2016-2019 were obtained from the British Swimming website (database accessed April 2020).

Swimmers from all age groups were included in the analysis; 13/14, 15, 16, 17/18, 19+. Ages were determined as age at 31st December in the year of the championships. This ensures that age groups are the same for both the national qualification window and the National Championships. A breakdown of the number of swimmers in each age category for each year is listed in Table 5.

All National Championship events were included: 50m, 100m, 200m, 400m, 800m and 1500m Freestyle; 50m, 100m and 200m Backstroke, Breaststroke and Butterfly; 200m and 400m Individual Medley, swum in a long course pool. For the 2016 and 2017 events, males were not included in the 800m Freestyle and the girls were not included in the 1500m Freestyle, as these events were not introduced until the 2018 season.

The final place achieved by each individual within the age group at the national championships for each event was included as a variable for analysis, based upon the fastest time achieved at the national championships in that event and year. Swimmers who were disqualified or did not start at the National Championships event were not included in the analysis.

Sex	Female						Male					
Age Group	**13/14**	**15**	**16**	**17/18**	**19+**	**Total**	**13/14**	**15**	**16**	**17/18**	**19+**	**Total**
2016	353	331	319	325	229	1557	343	352	353	329	202	1579
2017	346	346	316	287	266	1561	357	345	325	288	286	1601
2018	367	380	368	343	292	1750	366	366	352	347	289	1720
2019	387	382	376	369	333	1847	382	379	378	368	355	1862
Total	1453	1439	1379	1324	1120	6715	1448	1442	1408	1332	1132	6762

Table 5 - Number of swimmers by year, age group and sex

All 4 years of results were included in the analysis to provide an overview over one full quadrennial Olympic cycle. The qualification window is the period of time in which swimmers can record a time to be submitted to the rankings database, which puts them in contention for a qualification place. The length of the qualification window was 91 days in 2016, 2017, but reduced down to 89 days in 2018 and 67 days in 2019. The qualification window closes at the end of May with 57 days between the end of the window and the start of the National Championships, which last for 6 days.

Data obtained from the British Swimming database included the heat and final performance times in each British Summer Championships event, stroke discipline, distance, and the name, sex and age of the swimmer. This resulted in 13477 national qualification swims and their associated national championship swims in the same year by 2716 unique swimmers from 412 clubs. The fastest time achieved by each athlete from either the heat or final of each event at Nationals was used for analysis, alongside their entry time, which was the fastest time achieved within the qualification window by the same athlete in the same event.

Data Analysis

Performance change was calculated using Equation 1, below:

$$Performance\ Change\ (\%) = \frac{Fastest\ ime\ at\ nationals\ (s) - Entry\ time\ from\ window(s)}{Entry\ time\ from\ window\ (s)}$$

Equation 1 - Calculation of change in performance variable

A negative result from the use of this equation indicates that a faster time was achieved at the national championships when compared to the entry time from the qualification window. A positive result indicates a decline in performance between the national qualification window and the national championships, with a slower time at nationals.

Statistical Analysis

After assessing data for normality of distribution, a multi-variate analysis of variance (MANOVA) was conducted to determine the effect of multiple independent variables of sex, age group, distance, stroke and year, on the dependent variable, percentage change in performance. Where significant effects on change in performance were found between qualification and final events, Tukey's Honest Significant Difference (Tukey's HSD) post-hoc testing was conducted on each single independent variable to identify any statistical differences between different measures for males and females.

A Wilcoxon test was used to determine significant differences between the paired data of overall percentage performance change from the national qualification events and the national championships between males and females. This determined if there was a statistically significant between-group difference in the change in performance by sex ($p<0.05$).

As a follow-up to the MANOVA analysis, a Tukey's HSD test was used to identify the within-group statistical differences for each dependent variable; distance, stroke and year.

A linear model was used to assess the relationship between final placing and performance change in order to investigate whether the percentage performance change is dependent upon a swimmer's ability as indicated by their final placing. This was carried out using the least squares method, with an adjusted R^2 value. As part of the model, an ANOVA was used to assess the interaction of final placing on the change in performance between qualification and nationals for males and females of different age groups. The same analysis was also completed using age group as the independent variable to determine the differences between the males and females of each age group.

All statistical analysis was undertaken using R software (RStudio Team, 2019), with statistical signific ance being accepted at $p<0.05$.

Results

The mean number of female swimmers in each club was 3.26 and the mean number of male swimmers per club was 3.11. A similar pattern was observed with the average number of events per female was 2.68 and the average number of male events per individual was 2.60 across the 4 years.

Performance Change

The mean performance change between the national qualification window and the national championships for males and females combined was shown to be 0.16 ± 1.72%. The mean change in performance progression in males was found to be -0.14%, with their Nationals swims faster than their qualification swims. Females showed a change in performance of 0.46%, meaning their Nationals times were slower than the qualification window. A post-hoc Wilcoxon test determined that the mean performance change was significantly greater in males than females ($p<0.001$). Table 6 presents the average performance change between the qualification events and the national championships across years 2016-2019 for each stroke in male and female swimmers.

Table 6 – Average performance change between qualifications and national championships by males and females in each stroke (yellow), distance (blue) and stroke and distance combination (main table). Positive number indicates a positive progression, negative number indicates a regression in performance. FL = Butterfly, BK = Backstroke, BR = Breaststroke, FR = Freestyle, IM = Individual Medley.

Female		FL	BK	BR	FR	IM	Male		FL	BK	BR	FR	IM
		0.38	0.38	0.69	0.42	0.43			-0.18	-0.27	-0.11	-0.09	-0.10
50m	0.28	0.16	0.27	0.30	0.39	-	**50m**	-0.23	-0.02	-0.55	-0.25	-0.10	-
100m	0.51	0.44	0.33	0.89	0.39	-	**100m**	-0.26	-0.32	-0.24	-0.29	-0.17	-
200m	0.60	0.55	0.56	0.89	0.43	0.57	**200m**	0.03	-0.19	-0.01	0.20	0.19	-0.03
400m	0.46	-	-	-	0.64	0.29	**400m**	-0.20	-	-	-	-0.23	-0.17
800m	0.33	-	-	-	0.33	-	**800m**	-0.46	-	-	-	-0.46	-
1500m	0.16	-	-	-	0.16	-	**1500m**	0.05	-	-	-	0.05	-

A MANOVA found no significant interaction between independent variables of year, sex, stroke, distance and age group and the performance change experienced between the qualification events and the National Championships (all p>0.05). A significant interaction was found between performance change and sex, stroke and distance (p<0.001). There were also significant interactions between sex and distance (p<0.01), sex and stroke (p<0.05), and sex and age group (p<0.001). There was also an interaction between event and distance (p<0.01). There were also main effects found for year, sex, event, distance and age group on performance change between qualification and championships (p<0.001). Post hoc analysis demonstrated that performance change between qualification and national championships was worst for female breaststroke and significantly different to all other strokes (p<0.05). In addition, the means of change in performance for the 200m events were significantly worse than 50m, 100m and 1500m events (p<0.05).

Final Placing

A linear model was fit using the least squares method to examine the relationship between change in performance (between qualification and championships) and final placing at the national championships (Figure 7). The model is highly significant for both females ($adjusted\ R^2 = 0.468$, p<0.001; Equation 3), and males ($adjusted\ R^2 = 0.423$, p<0.001; Equation 2). The linear model suggests a disparity in performance change between males and females of between 0.53% and 0.72%, depending on final position, with males demonstrating more positive performance progression than females. The general pattern for finalists was a positive progression for both sexes, but there was still a disparity between magnitude of male and female change in performance.

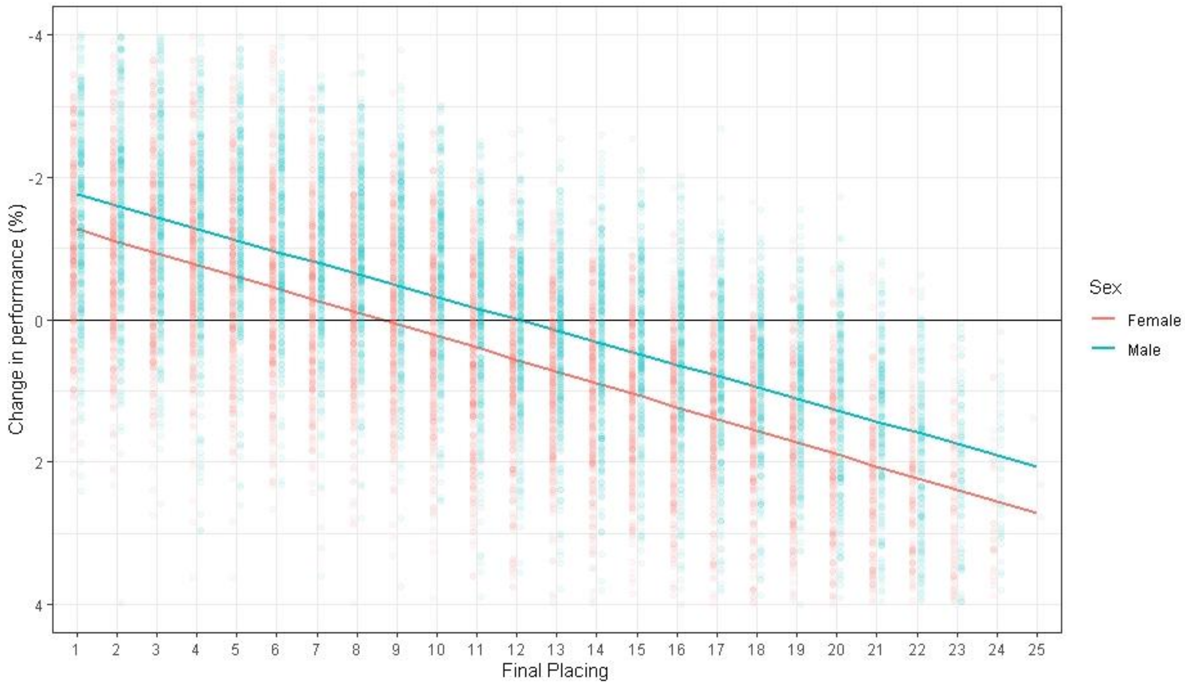

Figure 7 - Fit of linear model for prediction of final placing by change in performance

$$Male\ Final\ Placing = \frac{\%\ Change\ in\ Performance + 2.078}{0.176}$$

Equation 2 – Male final placing by performance linear model

$$Female\ Final\ Placing = \frac{\%\ Change\ in\ Performance + 1.557}{0.184}$$

Equation 3 - Female final placing predicted by change in performance

Figure 8(a) demonstrates the relationship between performance change and final placing across the age groups. Finalists (places 1-10) in the 13/14 age group show the greatest magnitude of performance progression between the qualification window and the National championships. Finalists in the 19+ age group show the least progression when compared to the other age groups.

When each age group is separated and males and females are compared, first placed females show a steady decline in average first place performance progression from the 13/14 years age group to the 19+ age group (Table 7). Males show a steady decline in performance progression until 16 years, when there is a dramatic drop in their progression to 17/18 and 19+ age groups.

Comparing males to females, the youngest 3 age groups; 13/14, 15, 16 (Figure 8b-d), show a disparity in their performance, whereas the oldest two age groups; 17/18, 19+ (Figure 8e-f), show less of a disparity between males and females, especially in swimmers achieving a higher placing. The R^2value becomes lower as the disparity decreases, decreasing the reliability of the model for the older age groups (Table 7). The linear models fit for males and females in the 13/14, 15 and 16 year age groups show strong significant differences between the sexes ($p<0.001$). The 17/18 year age group shows a much less significant difference ($p<0.1$) and the 19+ age group shows a non-significant difference ($p>0.1$).

Table 7 – Performance progression by swimmers in 1st position of each age group, disparity between the male and female 1st to 25th swimmers and the adjusted R^2value for males and females.

Age Group	1st Place Performance change (%)		Male to Female Disparity (%)		Adjusted R^2	
	Male	Female	1st Place	25th Place	Male	Female
13/14	-2.66	-1.98	0.69	0.88	0.562	0.617
15	-2.43	-1.52	0.91	0.70	0.547	0.527
16	-2.19	-1.28	0.91	0.79	0.516	0.464
17/18	-1.34	-1.17	0.17	0.36	0.370	0.430
19+	-0.91	-0.92	0.01	0.93	0.224	0.290

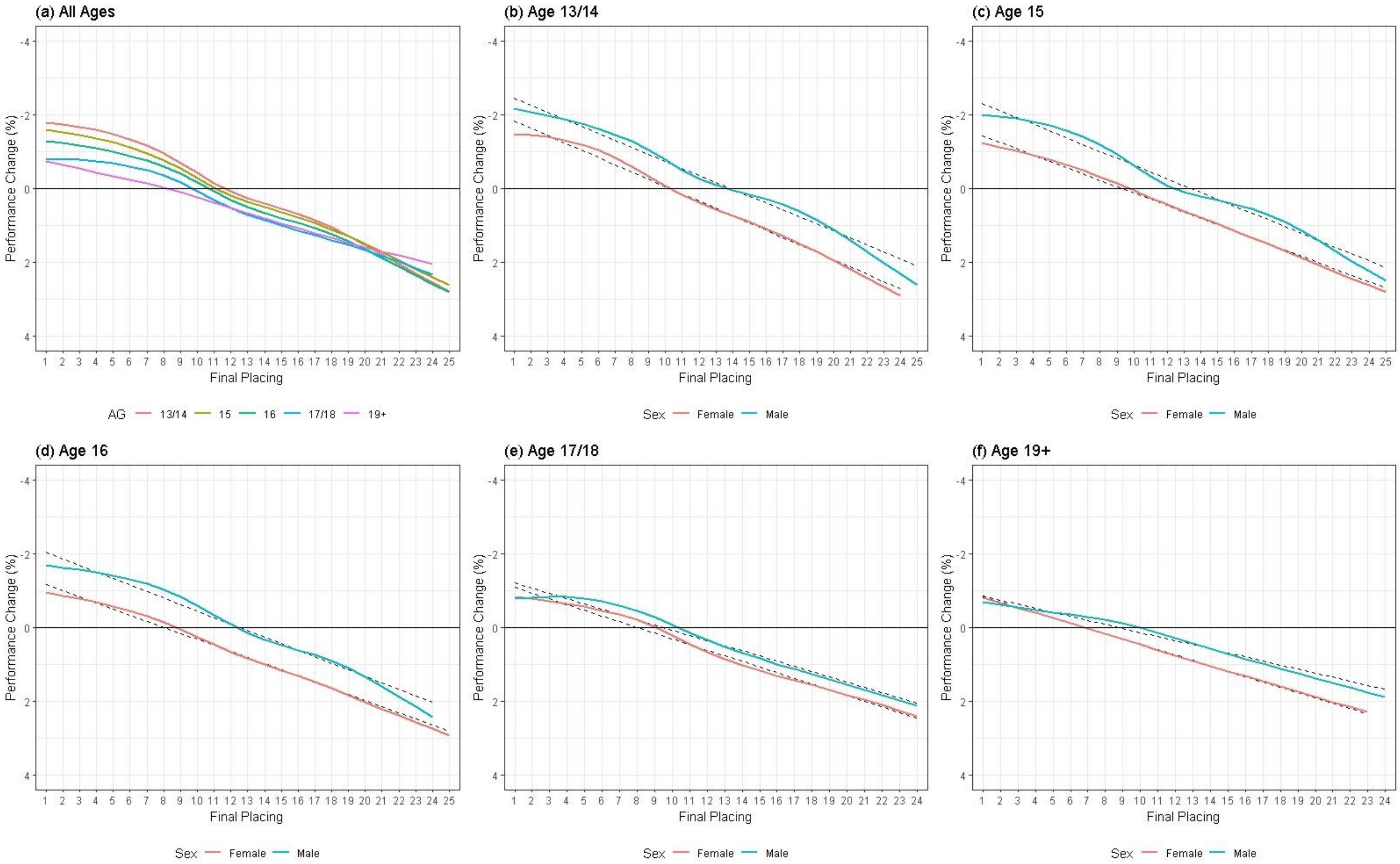

Figure 8 - Change in performance by age group & sex. (a) Average pattern for both sexes by age group, (b) Change in performance by final placing for 13/14 year old males and females, (c) Change in performance by final placing for 15 year old males and female, (d) Change in performance by final placing for 16 year old males and females, (e) Change in performance by final placing for 17/18 year old males and females, (f) Change in performance by final placing for 19+ year old males and females.

Chapter 4 – General Discussion

This study set out with the aim to examine the differences observed in short- and long-term performance development between males and females in Britain. Part I of the study used the 10 best historic performances of all time in all events for both the junior and senior age group to examine the development trajectory of performance for male and female swimmers. Part II focused on 4 years of National Championships results to explore the comparability of performances in adolescent swimmers between qualification and national championship events. Specifically, the tendency for females to underperform at the national championships, swimming slower than they did to qualify.

Performance Progression

The female rankings tables show an almost equal split between the three development groups; Junior & Elite (JE), Junior Only (JO) and Senior Only (SO). There are fewer male JE swimmers, both in number and as percentage of the total number of male swimmers. In total, 24.1% of males achieving a junior rankings list progressed to appear on the senior rankings list, but 32.8% of females progressed. In a similar study on track & field events, Boccia, Cardinale and Brustio (2020) found that more females (21%) progressed from a junior ranking to a senior ranking when compared to males (17%). They also concluded that top ranked senior athletes achieve their peak performances later than top ranked junior athletes. Similarly, the current study suggests that only 10% of swimmers appearing on the senior rankings list achieved their best times in the junior age group. Unsurprisingly, these swimmers were all part of the JE group, their successful swimming careers spanned both the junior and senior age groups. It has been hypothesised that increased experience in a sport, starting earlier, could lead to an increase in motivation and decrease the likelihood of drop-out (Salguero *et al.*, 2003). Using a similar methodology to the current study, Schumacher et al. (2006) found that 29.4% of the elite athletes had participated as a junior, and that 34% of the participants in junior later participated in major elite competitions. The equivalent JE group had their first and last elite result at younger age than SO athletes, which is a similar conclusion to that of this study. Only 39.4% of male swimmers in the JO age group managed to further improve their times in the senior age group, but these were not fast enough for them to be included in the senior rankings list. As all competitive performances are recorded on rankings, they are all eligible to appear on either the junior or senior rankings list, depending on the age of the swimmer. Therefore, this could be attributed to the phenomenon of drop-out, that JO swimmers are not as successful in the senior rankings as they were in the junior rankings, causing a lack of motivation and therefore drop-out (Monteiro *et al.*, 2017). Equally, their lack of senior success could be attributed to drop-out and therefore not recording any times in the senior age group that would be eligible for the rankings list. Perhaps the most striking of this set of results was that 66.7% of females in the JE age group achieve their best times in the senior age group, but 90.8% of males in JE achieve their best times in the senior age group. Unsurprisingly, all athletes in the SO group achieved their peak performance in the senior age group. Five of the 17 top female swimmers (1 for each event) were from the SO group, whereas only 2 of the top 17 best males were from the SO age group. As boys are known to develop later than girls, it might be expected that there would be more males in the SO group, as they have been shown to achieve their peak performances around 2 years after girls (Allen & Hopkins, 2015). Since this is not the case, it could be hypothesised that the current talent development pathway is favouring individuals who are peaking early, translating their successful junior ranked swims into senior ranked swims.

FINA points are a measure of success of a swim based upon the world record in the same year. It is expressed as a number that is generally over 1000 for a swim beating the world record and under 1000 for a swim slower than the world record (FINA, 2011). These scores give an idea of the potential international success of every swim recorded in a licensed meet worldwide. Using FINA points as a metric for international success, in part I of the study, it was found that of the 17 events, males had more success in 8 events and females showed more success in 9 events. In power events including 50m Butterfly and 100m Freestyle, males showed more dominant performances. They also showed better performances in the longer, more technical or tactical events including 200m Breaststroke, both 200m and 400m Individual Medley events and the 1500m Freestyle. British females showed better international potential in the 800m Freestyle and most 100m events.

Overall, males showed a positive performance progression of 0.46% between the fastest performance in the national qualification window and their fastest performance at the national championships. This demonstrates a mean disparity between males and females of 0.60%. It has been revealed that this disparity also existed in swimmers competing at the 2000 Olympic games (Pyne, Trewin and Hopkins, 2004). Female swimmers had a mean percentage change in performance between the 2000 Olympic qualification events and the 2000 Olympic games of 0.0% but males showed an average performance improvement of 0.2% (Pyne, Trewin and Hopkins, 2004). As a group, females demonstrated a regression in performance for every single national championship event. This means their fastest time at the national championships was slower than their fastest time from the qualification window. However, the fastest female swimmers in each age group, particularly those making finals at the National championships, show more of a positive progression in performance between the two competition periods. Swimmers at the National championships showed an average disparity between male and female performance change of between 0.52 - 0.75%, with females showing less positive progression between their fastest swim during the national qualification events and their fastest performance at the national championships. Although the average progression between qualification and nationals for both males and females demonstrated by this study is larger than the results of the current literature (Pyne, Trewin and Hopkins, 2004), this could be due to the younger, sub-elite sample, which have previously been shown to possess a greater magnitude of improvement throughout the season (Costa *et al.,* 2011). Even though Costa et al. (2011) only included male swimmers in freestyle events, there was a clear trend for a slowing rate of performance progression with increasing age during adolescent years.

Population

The mean number of swimmers per club was found to be lower for males than females, with the average just over 3 swimmers per club. This raises a problem with the previously mentioned research conducted by British Swimming (2018), which only considered results from clubs with 3 or more swimmers and so it is likely that a high proportion of individuals were excluded from their analysis. The difference in the number of swimmers per club could suggest that the male championship is more competitive and therefore more specialised, whilst the female championship is less competitive and therefore fewer individuals make up the population of national swimmers. This is an idea supported by the number of events per swimmer, which was marginally more for females than males, again, suggesting that males show slightly more specialisation than females. In a study of competition and gender in competitive sport, 58.3% of women stated that they felt competition detracted from their sporting experience, stating that intra-club competition was a negative factor to their sport, whereas none of the men studied held this belief (Warner and Dixon, 2015). The findings from previous research suggest that there should be fewer female swimmers per club competing at Nationals if intra-club competition is seen as detrimental by female swimmers. As this was not the case, intra-club competition may not be seen as a problem by female swimmers, but this is not certain, as attitudes towards competition were not analysed as part of this research.

Year of Competition

When considering differences between the years of competition, it is important to note that 2016 was an Olympic year, and therefore the top swimmers, usually in the oldest age groups, would not have attended the national summer championships. Swimmers are encouraged to attend the highest level of competition they have been selected for and as such they would have been preparing for and competing at their respective international competitions. Therefore, 4 years of competition were studied, as different biennial and quadrennial events throughout the cycle could affect the attendance of the country's best swimmers at the national championships. This was not acknowledged by British Swimming (2018) in their analysis, but quadrennial variation has been considered by several authors (Bullock and Hopkins, 2009; Costa *et al.*, 2010; Allen *et al.*, 2015) in their study design. The only factor that changes between the layout of each year 2016-2019 in the current study is the length of the qualification window, from 91 days down to 67 days. The period between the national qualification window and the start of the national championships for all years was 57 days, equating to around 8 weeks. In a study of Olympic qualifiers (Pyne, Trewin and Hopkins, 2004), it was found that trials held 5 weeks before the games resulted in less progression than by swimmers whose trials were 17 weeks from the games. It was supposed that 17 weeks gave swimmers sufficient time to improve their performances, whereas 5 weeks did not (Pyne, Trewin and Hopkins, 2004). This would suggest that any senior swimmers would struggle to demonstrate a positive progression between the window and the championships.

Millard *et al.* (1985) found that women had lower creatine phosphokinase levels following heavy training when compared to men, suggesting that women are able to recover faster, as their muscles do not experience the same damage that male swimmers experience. This was corroborated by a study by Kenitzer (1998), who discovered that an optimum female taper was 2 weeks, after which performance declined. Another study found that males demonstrated more of a progression in performance than females over the course of a 3-4 week taper (Mujika, Padilla and Pyne, 2002). Alongside these isolated studies on the differences between tapers for males and females, it is thought by many coaches that females require a shorter taper than males (Maglischo, 2003). This could be a contributing factor when considering the “underperformance” of females between the window and the national championships, especially for clubs with many swimmers completing the same training load and taper, regardless of their gender. Most authors agree that a targeted, individualised programme is necessary to achieve the optimum taper for the best performance (Bompa and Haff, 2009). Interestingly, data from the current study demonstrates a biennial pattern of underperformance by both males and females, in 2017 and 2019, with greater performance progression being observed in 2016 and 2018. In the years showing underperformance, the World Swimming Championships were from the middle to the end of July, meaning that the top swimmers in the country would not be able to attend the national championships at the same time. The World Junior Championships were in the same years at the end of August, suggesting that the best juniors, females aged 14-17 and males aged 15-18, would either be away on preparatory training camps, or using the national championships as a preparatory or exhibition competition, with the aim of peaking for the international event.

Effect of Stroke & Distance

Part I of this study shows that for the longer distance Freestyle races (800m and 1500m), the sex difference in age of peak swim speed decreases. This is a phenomenon also noted by Rüst, Knechtle and Rosemann, (2012). It has been supposed that the difference between the age of peak male and female performance decreases with increasing race length for all strokes. When comparing against other strokes, research has found that the difference in age of peak swimming speed is greater for Freestyle events than Breaststroke events of 50-200m in swimmers of national level (Wolfrum *et al.*, 2013). However, the current study of elite swimmers in the UK found the opposite; Breaststroke demonstrated a greater difference between the age of peak performance in males and females than Freestyle. Moreover, the current study found that the sex differences in Freestyle events decrease with distance, but this disagrees with Wolfrum *et al.* (2013) in that the same pattern was not obvious for Breaststroke races. However, there is agreement between the current study and that of Wolfrum *et al.* (2013) in that swimmers achieving their peak performances in 200m Breaststroke were younger on average than swimmers in 50m and 100m events. British male swimmers were younger at their peak performance in Breaststroke than Freestyle in 50-200m events, but females achieved their peak times older in Breaststroke than Freestyle for the 50m and 100m events. Wolfrum *et al.* (2013), found that both sexes were younger in Breaststroke than in Freestyle.

In part II, the influence of the interaction between sex, stroke and distance upon the performance change between the qualification window and the national championships was highly significant (p<0.001). Although all female events showed a regression in performance, with 100m and 200m breaststroke and breaststroke showing the most regression. In a study of the career trajectories of Olympic swimmers Allen et al. (2014), demonstrated that females had slower rates of progression towards their fastest time for breaststroke than for any other stroke. The current analysis shows that the event showing the least short-term progression to the national championships for males was the 200m breaststroke. When this study grouped results by stroke, the events showing the least average progression were freestyle, individual medley and breaststroke. British Swimming has also suggested that Breaststroke is a particular problem area for adolescent British swimmers (British Swimming, 2018), which is supported by the findings of the current study. However much of this underperformance could be attributed to the late development of factors including power and muscle development associated with breaststroke performance. Interestingly, the current study also found that Freestyle rates of progression were lower than in other events, but this may have been skewed by the 1500m, one of the only events which showed a regression in performance between the window and the championships for males. This could be due to the tactical nature of this event, relying heavily on pacing, which is dependent upon the level of competition on the day of the final event. Individual Medley races are highly technical events, requiring proficiency of all four strokes and their turns. With Individual Medley excluded, it could be noted that breaststroke was the worst performing form stroke for males. Indeed, (Dormehl, Robertson and Williams, 2016b) found that for male adolescent swimmers, the slowest rate of improvement was in the 200m Individual Medley and 100m Breaststroke, which is consistent with the findings of the current study. A different paper by the same authors (Dormehl, Robertson and Williams, 2016a) also concluded that 100m Breaststroke was the stroke showing the slowest progression for females, with their fastest improvement happening in the 200m Freestyle. Dormehl et al. (2016a) also stated that 100m Butterfly and 200m Individual Medley were the second-fastest improving strokes for females, and in a separate study of male adolescents (Dormehl, Robertson and Williams, 2016b), it was found that 100m Butterfly was the fastest improving stroke. Butterfly appears to be one of the last strokes that males specialise in, and could explain the relatively similar performances of males and females in the Butterfly events, especially in the 50m distance as found by the current study.

In part II of this research, the most disparity between progression of male and female performances was found in the 100m distance events. When grouped by distance, the best events showing the most positive performance at national championships for female swimmers were 50m distances, which is also the distance showing the least disparity between males and females. An event showing a minimal sex difference was the 50m Butterfly, which was also the second-best female event. For females, their worst distance was 200m. For males, their worst distance was 1500m. However, as previously mentioned, due to the tactical nature of this event, this result will be excluded. Males also performed badly in the 200m events, showing the least positive progression and in fact, regression between the window and the championships. It has been suggested that the 200m events, lasting from 90-180 seconds, require a great deal more aerobic contribution than 50m and 100m events and is therefore more similar to a 400m event in terms of energy metabolism (Serresse *et al.*, 1988; Nomura *et al.*, 1996; Ring *et al.*, 1996; Trappe, 1996; Maglischo, 2003).

It has been hypothesised that triathletes show least sex difference in swimming events of 1500-3800m when compared to running and cycling (Lepers, Knechtle and Stapley, 2013) and the performance gap between males and females is smaller in longer events (Knechtle *et al.*, 2020). The findings of both current studies show that in the longer swimming races, particularly 1500m Freestyle, males and females showed the least difference in performance. Moreover, in part I of the study, the age of peak performance for males and females were closest together in the 1500m Freestyle. It has been further hypothesised that at distances requiring characteristics of endurance, including 30km open water events, that women may be capable of out-performing men (Knechtle *et al.*, 2020). In part II of the study, 1500m Freestyle was the event in which females showed the most positive progression between the qualification events and the national championships. In addition, males and females showed the least difference in their performance progression to the national championships. This could be partly due to the event being new for women, as it first appeared on the National Championships programme in 2018 and will be added to the programme in the postponed Tokyo 2020 Olympic Games. This would lead to the suggestion that swimmers are still becoming familiar with this event, gaining a great deal of experience with every repetition of the race, hence the dramatic improvement in performance between the national qualification window and the national championships. This suggestion would agree with Yustres et al. (2019) who suggest that experience of high-level competition has a positive impact upon performance, with more experienced swimmers experiencing improved times, placings and rates of progression. Another reason for the decreased gap between males and females in the 1500m Freestyle could be that the longer events require more tactics and pacing strategies, so speed becomes more subjective during the race, i.e., at qualification meets, the standard is likely to be lower than at the national championships, leading to a faster performance at nationals. Indeed, a recent study by Knechtle et al. (2020) showed that the disparity between men and women over longer pool swimming events is diminishing, and for some older and younger age groups, females are outperforming males.

Age

It has been hypothesised that females reach their peak performance at a younger age than males (Allen and Hopkins, 2015), and the current study agreed with this hypothesis in every event, age group and grouping of distance and stroke. In support of the findings of the current study, Buhl *et al.* (2013) investigated performance in four events, comparing the 400m and 200m Freestyle and Individual Medley events, finding that the age of peak performance was less for women than for men. However, Vaso et al. (2013) found that there was no significant difference in the age at which peak swimming times were achieved between males and females in the same selection of events. Kollarz *et al.* (2013), looked at each distance of backstroke, concluding that females (18-23) were on average 2-3 years younger than males (21-26). They also concluded that swimmers at national level are 1-2 years younger at their age of peak performance than swimmers at international level, which can be corroborated by the current study. In the current analysis, the top male swimmer for each of the events had an average age of 22.2 years and the top female in each event was 21.2 years. Whereas the average for each event overall was 21.3 years for males and 19.7 years for females, a 0.9-1.6 year difference between the two groups of swimmers. In a study comparing the Freestyle events, Rüst, Knechtle and Rosemann (2012) found that women achieved their peak performance earlier than men in all Freestyle events from 50m to 1500m, except 800m. Indeed, Rust et al (2012) also concluded that women peak at an earlier age to men in all Freestyle events, including the 800m. In a study comparing a similar programme of events, Allen, Vandenbogaerde and Hopkins (2014) found that men have an older age of peak performance than women (24.2 ± 2.1 vs. 22.5 ± 2.4 years, respectively). It was also found by the same authors that swimmers older in age had more success in shorter distances (Allen, Vandenbogaerde and Hopkins, 2014). The current study found the same trends, that the longer distances of each stroke tend to include younger ages of peak performance.

The use of an age group variable rather than age assumes that the groups selected are biologically sensible. Since some age groups are combined for qualification and the national championships, it has to be assumed that the swimmers in each category are at a similar level of maturation, regardless of their actual chronological age as they have qualified with a similar time to the others in their age group (13/14, 15, 16, 17/18, 19+). British Swimming (2018) state that they would expect the cohort of swimmers at the national championships to exhibit a positive progression in their performances between the qualification window and the national championships. This is due to the increased rate of natural growth and maturation experienced by the younger age groups in the weeks between the window and the national championships. Whilst this general idea is reflected in the results by each age group, it only accounts for a proportion of the best-performing athletes, with final placings of around 1-12. The lower ranking swimmers still experienced a regression in their performance. Higher placed swimmers produce consistently better performances and a more positive progression when compared to lower-ranked swimmers of the same sex and age group. In a study of Olympic swimmers, Pyne, Trewin and Hopkins (2004) demonstrated that 5 weeks between a qualifying event and the Olympic games did not give sufficient time for a senior athlete to significantly improve their performance, but that 17 weeks did. Their finding would support the results of this study, that senior athletes experience less of a progression effect than athletes in lower age groups in the period amounting to 8 weeks between the qualification window and the national championships. As mentioned previously, younger swimmers have been found to experience greater improvements throughout the season, as shown by Costa *et al.* (2011).

Prediction

The initial difference in the performance progression of males and females corroborates the idea that male and female performance diverges at around 12-13 years of age due to the levels of circulating testosterone in boys, accelerating their progression when compared to females (Handelsman, 2017). Data from the current study demonstrates that, on average, first placed females show a steady decline in their percentage of progression between the qualification events and the National championships, with the largest drop in performance between the 13/14 and 15 age groups. Whereas male swimmers demonstrated a significant decline in their percentage of progression between the 16 and 17/18 age groups. This can be interpreted as their performances for females and males becoming more stable at the age of 15 and 17 respectively, which echoes current literature on teenage sporting performance (Handelsman, 2017). Interestingly, these align with the minimum ages of peak performance found in part I of the study for swimmers with the top 10 senior performances of all time for each event. Although this accounts for a small number of individuals, performance can be said to stabilise at these ages for both males and females. Existing research suggests that 13-14 years of age is a key milestone for boys for the stability of performance in some swimming events (Costa *et al.*, 2010; Costa *et al.*, 2014), but a cycling study concluded that prediction of senior performances by boys in the U17 age group was more accurate than predictions for U15 athletes (Mostaert *et al.*, 2021).

Talent Development

The current Swim England pathway programme (Table) is made up of eight different stages and at the top level, comprised of swimmers who are expected to achieve medals at international championships, there are only up to 24 swimmers selected to cover the 34 Olympic events.

Table 8 - Summary of Swim England and British Swimming talent development pathway programmes 2019/2020 (Swim England, 2019)

Pathway Stage	Age	Number of Individuals
County Development Programme	11 yrs	792-1188
Regional Development Programme	12 yrs	288
National Development Programme	13-14 yrs	288
National Event Camps	15-16 yrs	90
Swim England Junior Squad	18 yrs & under	40
Swim England Performance Squad	22 yrs & under	≤20
British Swimming Podium Potential Programme	15+ yrs	≤30
British Swimming Podium Programme	16+ yrs	≤24

Whilst the Athlete Development Support Pathway accounts for the developmental differences between males and females from the FUNdamentals stage, the pathway programmes by Swim England (Table) do not seem to take these into consideration for either the national championships, or the pathway programmes. Over half of the swimmers studied in part I only appeared on the senior rankings list, without a highly ranked junior performance. Despite this, the current pathway programme does not take this into account, with swimmers being selected for the podium potential and podium programmes from 15 years of age. This study has suggested that the current talent pathway may be favouring individuals who peak in the junior age group, specifically males. Allen *et al.* (2015), published a suggestion that to achieve the maximum number of Olympic qualifiers, huge squad sizes would be needed in order to guarantee that 90% of qualifying swimmers are included in the talent development squad. However, fewer than 60 swimmers currently make up the British Swimming performance squads (Swim England, 2019). The small size of this performance squad means that funding is likely to be channelled to the top swimmers, leading to lack of funding for other swimmers who could make up a larger and potentially more successful talent programme at some of the country's many swimming clubs, rather than just the centralised talent programme (Allen *et al.*, 2015). Inevitably not all swimmers selected for the talent programmes will progress to the top level, due to dropout or injury, among other reasons. It is also a commonly held belief by coaches that females are more susceptible to drop out and therefore the pool of swimmers from which to pick a national team is even smaller. This could be having a negative effect upon female performance as there will be a gap between the performances of those at well-resourced performance centres and swimmers in club programmes. As a result of this disparity, the level competition at a national level, used for selection, could be having a detrimental effect upon results at an international level. There is a conflicting approach by the National governing bodies of swimming, from a holistic approach at the Athlete Development Support Pathway level, to an elite approach in the pathway programmes. To move forwards, it is suggested that the pathway is more inclusive of swimmers developing on a trajectory that may suggest a successful performance in the senior age group, rather than just pushing the currently successful junior athletes, as some will not progress to the senior age group.

Limitations

Prior to the Covid-19 pandemic, a field-based study was planned and ethical approval gained to assess the effect of physiological determinants upon performance change between the national qualification window and the national championships (Appendix I & II). Due to the national lockdown in March 2020, the qualification window and subsequently the national championships were cancelled, as well as all training activities, meaning the original study could not be completed.

Due to the availability of data and study design, there were several limitations with the current study. Although the data acquired for the study contained the age and year of birth of each individual, their exact date of birth is not available and therefore relative age effect cannot be determined. Costa *et al.* (2013) suggest that although successful competitive swimmers are more likely to have birth dates in the first half of the year, it is an effect experienced more by males and they concluded there was mostly no effect upon performance of the top-50 swimmers. Additionally, as the results of the British swimming selection policies are based around the performance in their allocated age groups, the relative age effect is of limited use within the analysis of results for this study.

Although the number of swimmers in each age bracket is similar for each year, it is not the same. This could affect the reliability of the findings. As the selection method for the national championships is now by qualification window and ranking position, the swimmers at the national championships will be some of the fastest swimmers in the country, so may not account for many of the club swimmers up and down the UK.

Lastly, there are many other determinants of performance that were not measured during this study. Research has shown that factors such as anthropometrics, biomechanics, experience level, psychology and physiology can have a dramatic effect on performance (Jürimäe *et al.*, 2007; Lätt *et al.*, 2010; Barbosa *et al.*, 2011; Klika and Thorland, 2016). However, the current study design is based solely on the freely available performance data for British swimmers.

Practical Application & Future Direction

The main findings of the study were that females consistently underperform at the British Summer Meet when compared to their own performances during the qualification window. Females also show a disparity in their performance change when compared to males, but both sexes show similar patterns of performance in relation to their final placing, age group and some strokes. Rather than trying to identify why girls are underperforming in all events, the emphasis for future research should be shifted to identifying why there is such a disparity in male and female performance progression. It seems that males experience a more rapid decline in performance from the 16 years age group, whereas it had previously suggested that females were demonstrating a notable drop in their stability of performance. More evidence is required to establish whether this is a pattern and to determine why this might be the case.

To further explore the phenomenon of successful juniors failing to convert their junior performances into senior ranking performances, it is suggested that a qualitative approach could be used to gather information about the reasons behind a change in performance. Similar studies have been carried out around the tendency of junior athletes to drop-out before reaching the senior age group (Salguero *et al.*, 2003). This information could contribute towards determining the reason why male and female performance differs across the age groups.

Whilst the current study shows the general patterns for swimmers grouped by the factors available to analyse from the national championships results, further research into the determinants of swimming performance is required. Further studies should aim to identify the potential cause of the patterns of performance demonstrated by females, but also by males in order to address the disparity in performance progression between males and females. Further research should also focus on what is causing the differences in stability of performance between males and females, in order to give a clear direction for coaches to pursue in the club environment to address the difference in the performance of their male and female swimmers.

Conclusion

This research suggests that females achieve their peak performances at younger ages than males, but they show the most progression to the senior age group, whereas males show less of a progression from junior to senior age group. It was found that the pathway to a successful senior performance is not just a progression from the junior age group, but that many swimmers only appear on the rankings list in the senior age group. Whilst the idea of female underperformance at the nationals was confirmed, the patterns of performance progression were similar throughout the age groups and lower ranked, slower swimmers are showing the most drastic underperformance. Faster, higher ranked males and females consistently showed a positive performance progression between qualification events and the national championships across all age groups.

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Appendix I – Research Proposal for Original Project

Research Proposal

How do physiological determinants affect performance change between the national qualifying window and the national championships in sub-elite female youth swimmers?

Research Context

Following the publication of the Swimming Discussion Paper, questions were raised over the preparation of female athletes due to the regression of performance by female clubs between the national qualification window and the national championships (British Swimming, 2018a). The paper showed that 86% of female clubs showed a regression, when compared with a 49% regression for male clubs.

The ability to identify variables impacting upon female performance is particularly important for coaches and their athletes at international level, as they need to be able to produce their optimum performance at a specific targeted meet, for example, the world championships or Olympic games.

There are several physiological determinants of athletic performance in swimmers. It has been found that until boys and girls reach puberty, girls have a performance advantage. However, when testosterone is produced by boys during puberty, this enables them to progress much faster than girls, leading male athletes to faster performances. The same study also demonstrated that swimming performance follows a quadratic growth curve until plateau occurs at the age of 15 for girls and 17 for boys (Senefeld *et al.,* 2019). Costa *et al.* (2013) found that there was hardly any effect of birth date on the difference of performance in swimmers.

Training load can have a huge impact upon the performance of swimmers, with a difference of 10% making a considerable difference to performance (Hellard *et al.*, 2017). When a training load is too high or increases too quickly, it can lead to fatigue but also illness, overreaching or injury (Halson, 2014). Mujika (1995) found that previous episodes of detraining could have a negative effect on future performances. Matthews *et al.* (2010) saw that there was a small increase in the incidence of illness in athletes with a higher training load and that athletes experience longer episodes of illness when compared to recreationally active individuals. However, Pyne *et al.* (2000) found that presence of respiratory tract illnesses did not have an effect on performance of swimmers.

Lowensteyn, Signorile and Giltz (1994) suggest that increased levels of body fat can contribute significantly to a decline in performance in both male and female swimmers. When focusing on stature, taller swimmers, with greater arm spans can move more water and therefore increase their speed (Mazzilli, 2019). It has been found that although female lean mass has little variation throughout the season, it does increase from pre-season to taper (Pyne, Anderson & Hopkins, 2006). Bossi *et al.* (2013) found that although not significant in their study, performance improved in the follicular phase of the menstrual cycle. Another paper agreed with this idea, stating that muscle strength is also greater during the follicular phase (Pallavi, D Souza & Shivaprakash, 2017).

Aim

Study 1

The aim of the first part of the study is to establish whether individual female performance for swimmers in the 13-18 year age groups shows a regression between the qualification window (March to May) and the national championships (July and August) using historic performance data.

Study 2

The second element of the study will focus on the factors affecting the performance of female swimmers from the qualifying window to the national championships. It will compare performance data with associated physiological variables including; age, menstrual cycle, training load, freshness & fatigue, health and anthropometrics.

Hypotheses

Study 1

The performance of female youth swimmers between the qualifying period and the national championships shows greater regression than their male equivalents (British Swimming, 2018a). Swimming performance follows a quadratic growth curve until plateau occurs at the age of 15 years for females and 17 years for males (Senefeld *et al.*, 2019).

Study 2

Athletes show increased stress responses in the lead up to the national championships when compared to their preparation for competitions within the qualifying window (Rushall, 1990). Athletes with a greater level of illness before the national championships show more of a regression in performance than athletes who experience illness before events in the qualifying window (Matthews *et al.*, 2010). Athletes who have a period of non-training exhibit a regression between the national qualifying window and the national championships (Mujika, 1995). Athletes with greater raw skinfold measurements before the national championships experience a decline in performance at the national championships (Lowensteyn, Signorile & Giltz, 1994). Athletes that experience a decline in performance between the qualifying window and the national championships perceive their workload to be less than those who show a progression in performance (Hart & Staveland, 1988). Girls produce better performances when they are in the follicular phase of the menstrual cycle (Bossi *et al.*, 2013; Pallavi, D Souza & Shivaprakash, 2017).

Research Design

Study 1

The performances of the subjects (described in *Subjects* section) will be plotted against time. The performance trajectory for each individual will be mapped, which will then contribute towards the grouped trajectory for performance. From this, the expected performance bounds can be determined, which could be used to create a predictive model of performance across a swimming career. A similar analysis will be used to map the performance of each swimmer within each season, to determine whether there is a change in performance across the season, but particularly between national qualification events and the national championships (analyses described in *statistical analysis* section).

Study 2

Table 1 shows the weekly layout of the season, including the qualification window and the national championship events (British Swimming, 2019; Scottish Swimming, 2019; Swim England, 2019 and Swim Wales, 2019). Swimmers will qualify for the National Championship events in accordance with the invitation policy (British Swimming, 2018b).

Participants will be monitored over an 8-month period from January to August 2020, to include the qualifying window (13th March to 10th May 2020) and the national championship events (17th July to 2nd August 2020). Baseline tests will be completed in the initial month of the study. These will include a health questionnaire, initial anthropometric measures, performance and familiarisation with the study. Participants will be required to complete their normal training as prescribed by their individual coaches at their different clubs. Training diaries will be used by the participants throughout to provide data on their training load, health, menstrual cycle, fatigue and freshness. Test sets will be completed by participants fortnightly, under the guidance of their coaches. The lead researcher will visit participants every month to measure their anthropometric parameters including height, seated height, arm span, weight and raw skinfold measurements (details of each parameter are within *measures* section).

	06-Jan	13-Jan	20-Jan	27-Jan	03-Feb	10-Feb	17-Feb	24-Feb	02-Mar	09-Mar	16-Mar	23-Mar	30-Mar	06-Apr	13-Apr	20-Apr	27-Apr	04-May	11-May	18-May	25-May	01-Jun	08-Jun	15-Jun	22-Jun	29-Jun	06-Jul	13-Jul	20-Jul	27-Jul	03-Aug
Significant Dates											Qualification window																				
Training Diary																															
Test Sets																															
Anthropometrics																															
Baseline Tests																															

Table 1 *- Research design over the study period, showing British Summer Championships and Home Countries Summer Meets*

Subjects

Study 1

For the initial study within this research, the subjects will be the top 50 boys and girls in each national championship event, both long and short course in the 13-18 years age group from 2014-2019 (age at 31st December). This is to allow a full analysis of their performances from 13 to 18 years of age. Performance will be compared between seasons and within the season to establish the relationship between performance at the national qualifying events and performance at the national championships.

Study 2

Participants for the research will be female swimmers in the 13-18 year age groups (on 31st December 2020) from clubs in the Swim England Kent County. They will be selected from the top 50 times within the last year for each event, distance and course. This measure of their current performance would suggest that they have potential to qualify for the national championships in 2020. This will be achieved by using the rankings qualifying times generator (Swimmingresults.org, 2019a, Appendix 1), alongside the national rankings database (Swimmingresults.org, 2019b) as a basis for selection. Participants will be selected in December 2019, allowing data collection to begin in January 2020. The proposed completion date for the study is 31st August 2020.

Participants will be provided an information sheet summarising the study. They will then be required to complete an initial health questionnaire and consent form prior to the commencement of the study.

Measures

The lead researcher is a qualified and DBS checked Swim England coach, but a member of the coaching staff from the relevant swimming club will be present for the collection of measurements on each visit day.

Baseline Assessments

Baseline assessments will take place at the beginning of the study. They will include a standard health screening questionnaire (Appendix I), an assessment of current performance and an overview of the weekly routine of each participant (see page 1 of training diary, Appendix IV).

Performance

Measurements of performance will be two-fold. First, an estimate of the athlete's critical swim speed (CSS) or critical velocity (V_{crit}) and secondly, their competition results. CSS will be calculated from the results of a fortnightly test set. The test set comprises 2 maximum effort swims, one of 400m, the other of 200m (Pelayo *et al.*, 2000). The gradient of the regression line between the two results will give the V_{crit} in metres per second (ms^{-1}):

$$V_{crit} = \frac{400 - 200}{t_{400} - t_{200}}$$

Where t_{400}= time for 400m in seconds (s) and t_{200}= time for 200m in seconds (s). This speed can be converted into a time per 100m ($100 \div V_{crit}$) in seconds (s) (Wakayoshi *et al.,* 1992a and 1992b). Test sets will be performed at similar levels of fatigue and freshness. Either a morning or evening session on the testing day will remain constant on each testing week for the duration of the study (e.g. on a Wednesday morning). Participants will swim their usual 15 minute warm up as directed by their coach, followed by the test set.

The second measure of performance will be the results of any races swum throughout the study period. These times will automatically be uploaded to the rankings database (British Swimming, 2016) as a time ($mm{:}ss.00$), which can be converted to $ssss.00$ to enable analysis.

Anthropometrics

Height, arm span, body mass and skinfold thickness measurements will be taken every month, using standard protocols. Height, seated height and arm span will be measured in metres (m) using the same portable tape measure on each of the measurement days. Body mass will be measured in kilograms (kg), using the same portable set of scales on each measurement date. Distribution of subcutaneous fat will be assessed via raw skinfold thickness measurements from 7 sites: triceps, biceps, subscapular, suprailiac, abdominal, thigh and calf using standard protocols (Saw et al., 2018; Pyne, Anderson & Hopkins, 2006). Due to the age of the swimmers, these will be taken in the presence of a chaperone, over the participant's swimsuit where necessary. This means that the thickness of the swimsuit will also have to be measured and considered when recording the data.

Training Load

Training diaries will be completed by the participants to monitor their training. A brief outline of the session will be recorded in the training diary, with the session RPE, total duration and total distance. Training load will be calculated using the session RPE method suggested by Foster *et al.* (2001):

$$Training\ Load\ (AU) = Session\ RPE\ (CR10\ scale) \times Session\ Duration\ (mins)$$

Athletes will be introduced to and given a copy of the CR10 scale (Appendix III, Foster *et al.*, 2001) before completing their training diaries.

NASA-TLX

Participants will give a subjective evaluation of workload for each session, using a modified Task Load Index (NASA-TLX) questionnaire (Hart & Staveland, 1988). This is within the training diary and has an unlabelled 7-point response between the two endpoints.

DALDA

The athletes' subjective responses to training will be quantified using the daily analyses of life demands for athletes (DALDA) questionnaire, which will be completed daily by the participants as part of their training diary. Part A will assess the sources of life stress using 9 descriptors and the 25 descriptors in part B will evaluate the symptoms of this stress (Rushall, 1990).

Health

By using a modified comprehensive survey to assess any symptoms of illness, an illness load can be calculated for each day (Matthews *et al.*, 2010):

$$Total\ Illness\ Load\ (AU) = \sum Cumulative\ Daily\ Severity\ Scores\ (AU)$$

Statistical Analysis

Study 1

Improvement over time and with age will be compared using a univariate ANOVA of performance (swimming velocity, ms^{-1}) against time (Senefeld *et al.*, 2019). From this, bounds will be put in place to map the common trajectory of performance. A comparison between the change in performance of girls and the change in performance of boys between the national championships will be made with a sample paired t-test, using the means of performance change for each.

Study 2

Change in performance over time will be evaluated using a univariate ANOVA, similar to part 1 of the study. To compare all other studied variables against performance, a multivariate ANOVA will be used. There will be a test for significance at 5%, so values of $P<0.05$ will be considered statistically significant. To compare performances at qualification and nationals of the participants for part two of the study, the same t-test will be used as in part 1, using a series of performances from the qualification period and a series of performances from the national championships.

Appendix I – Health screening

HEALTH QUESTIONNAIRE

Participant Number……………………………………………………

Please answer these questions truthfully and completely. The sole purpose of this questionnaire is to ensure that you are in a fit and healthy state to complete an exercise test.

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL.

SECTION 1: GENERAL HEALTH QUESTIONS

Please read the 10 questions below carefully and answer each one honestly: check YES or NO.

	YES	NO
1. Has your doctor ever said that you have a heart condition or high blood pressure?	☐	☐
2. Do you feel pain in your chest at rest, during your daily activities of living, or when you do physical activity?	☐	☐
3. Do you lose balance because of dizziness or have you lost consciousness in the last 12 months? (Please answer NO if your dizziness was associated with over-breathing including vigorous exercise).	☐	☐
4. Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?	☐	☐
If yes, please list condition(s) here:		
5. Are you currently taking prescribed medications for a chronic medical condition?	☐	☐
If yes, please list condition(s) and medications here:		
6. Do you currently have (or have you had within the past 12 months) a bone, joint or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer NO if you had a problem in the past but it *does not limit your ability* to be physically active.	☐	☐
If yes, please list condition(s) here:		
7. Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

8. Are you, or is there any chance you could be, pregnant?	□	□
9. Are you currently taking any nutritional supplement? If 'YES' please inform the researcher what supplements are being taken	□	□
10. Are you involved in any other research project? If 'YES' please inform the researcher about details of the project	□	□

If you answered NO to all of the questions above, you are cleared to take part in the exercise test

Go to SECTION 3 to sign the form. You do not need to complete section 2.

If you answered YES to one or more of the questions in Section 1 - PLEASE GO TO SECTION 2.

SECTION 2: CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.

		YES	NO
1.	Do you have arthritis, osteoporosis, or back problems? If YES answer questions 1a-1c. If NO go to Question 2.	□	□
1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	□	□
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebrae (e.g. spondylolisthesis), and/or spondyloysis/pars defect (a crack in the bony ring on the back of the spinal column)?	□	□
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	□	□
2.	Do you have cancer of any kind? If YES answer questions 2a-2b. If NO, go to Question 3.	□	□
2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head and neck?	□	□
2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	□	□

3.	Do you have heart disease or cardiovascular disease? This includes coronary artery disease, high blood pressure, heart failure, diagnosed abnormality or heart rhythm. If YES answer questions 3a-3e. If NO go to Question 4.	□	□
3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	□	□
3b.	Do you have an irregular heartbeat that requires medical management? (e.g. atrial fibrillation, premature ventricular contraction)	□	□
3c.	Do you have chronic heart failure?	□	□
3d.	Do you have a resting blood pressure equal to or greater than 160/90mmHg with or without medication? Answer YES if you do not know your resting blood pressure.	□	□
3e.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	□	□

		YES	NO
4.	Do you have any metabolic conditions? This includes Type 1 Diabetes, Type 2 Diabetes and Pre-Diabetes. If YES answer questions 4a-4c. If NO, go to Question 5.	□	□
4a.	Is your blood sugar often above 13mmol/L? (Answer YES if you are not sure).	□	□
4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, OR the sensation in your toes and feet?	□	□
4c.	Do you have other metabolic conditions (such as thyroid disorders, current pregnancy related diabetes, chronic kidney disease, or liver problems)?	□	□
5.	Do you have any mental health problems or learning difficulties? This includes Alzheimer’s, dementia, depression, anxiety disorder, eating disorder, psychotic disorder, intellectual disability and down syndrome. If YES answer questions 5a-5b. If NO go to Question 6.	□	□
5a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	□	□
5b.	Do you also have back problems affecting nerves or muscles?	□	□
6.	Do you have a respiratory disease? This includes chronic obstructive pulmonary disease, asthma, pulmonary high blood pressure. If YES answer questions 6a-6d. If NO, go to Question 7.	□	□
6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	□	□

6b.	Has your doctor ever said you blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	☐	☐
6c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	☐	☐
6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	☐	☐
7.	Do you have a spinal cord injury? This includes tetraplegia and paraplegia. If YES answer questions 7a-7c. If NO, go to Question 8.	☐	☐
7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
7b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	☐	☐
7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as autonomic dysreflexia)?	☐	☐

		YES	NO
8.	Have you had a stroke? This includes transient ischemic attack (TIA) or cerebrovascular event. If YES answer questions 8a-8c. If NO go to Question 9.	☐	☐
8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
8b.	Do you have any impairment in walking or mobility?	☐	☐
8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	☐	☐
9.	Do you have any other medical condition which is not listed above or do you have two or more medical conditions? If you have other medical conditions, answer questions 9a-9c. If NO go to Question 10.	☐	☐
9a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?	☐	☐
9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, and kidney problems)?	☐	☐
9c.	Do you currently live with two or more medical conditions?	☐	☐
	Please list your medical condition(s) and any related medications here:		

10.	Have you had a viral infection in the last 2 weeks (cough, cold, sore throat, etc.)? If YES please provide details below:	☐	☐
11.	Is there any other reason why you cannot take part in this exercise test? If YES please provide details below:	☐	☐
12.	Please provide brief details of your current weekly levels of physical activity (sport, physical fitness or conditioning activities), using the following classification for exertion level: **L** = light (slightly breathless) **M** = moderate (breathless) V = vigorous (very breathless) <u>Activity</u> <u>Duration (mins.)</u> <u>Level (L/M/V)</u> Monday Tuesday Wednesday Thursday Friday Saturday Sunday		

Please see below for recommendations for your current medical condition and sign this document:

If you answered NO to all of the follow-up questions about your medical condition, you are cleared to take part in the exercise test.

If you answered YES to one or more of the follow-up questions about your medical condition it is strongly advised that you should seek further advice from a medical professional before taking part in the exercise test.

This health questionnaire is based around the PAR-Q+, which was developed by the Canadian Society for Exercise Physiology www.csep.ca

Appendix II – Qualifying times for study. Age at 31st December 2019 (Swimmingresults.org, 2019a)

Minimum qualifying times for study inclusion																			
Event code:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Age	**Type**	**50m Fr**	**100m Fr**	**200m Fr**	**400m Fr**	**800m Fr**	**1500m Fr**	**50m Br**	**100m Br**	**200m Br**	**50m Fl**	**100m Fl**	**200m Fl**	**50m Ba**	**100m Ba**	**200m Ba**	**100m IM**	**200m IM**	**400m IM**
12	**LC**	30.16	01:06.1	02:23.4	05:05.4	10:44.9	21:31.0	38.73	01:25.2	03:03.8	32.9	01:14.5	02:52.7	34.7	01:15.3	02:40.9		02:42.7	05:50.9
	SC	29.54	01:04.6	02:21.3	04:58.2	10:20.7	20:33.1	37.74	01:22.5	02:58.4	32.51	01:13.4	02:46.6	33.63	01:12.6	02:36.1	01:15.4	02:39.5	05:38.5
13	**LC**	29.12	01:03.3	02:17.0	04:50.6	10:03.7	19:38.7	36.91	01:20.9	02:55.4	31.21	01:09.9	02:37.7	33.26	01:11.7	02:33.8		02:35.3	05:31.3
	SC	28.5	01:01.9	02:14.8	04:43.5	09:49.2	19:18.7	36.08	01:18.7	02:50.8	30.91	01:09.3	02:35.9	32.13	01:09.3	02:30.0	01:12.0	02:31.8	05:22.4
14	**LC**	28.47	01:01.6	02:13.3	04:41.8	09:43.8	19:02.4	35.76	01:18.4	02:49.4	30.32	01:07.9	02:33.8	32.37	01:09.4	02:29.4		02:30.5	05:21.5
	SC	27.97	01:00.3	02:11.1	04:36.5	09:38.2	18:54.3	35.24	01:16.6	02:45.2	30.14	01:06.9	02:31.4	31.33	01:06.9	02:25.1	01:09.9	02:28.1	05:14.8
15	**LC**	27.98	01:00.4	02:11.2	04:37.3	09:37.1	18:35.2	35.39	01:17.6	02:47.5	29.79	01:06.5	02:28.9	31.65	01:08.1	02:27.8		02:28.9	05:17.5
	SC	27.66	59.73	02:09.5	04:34.1	09:30.7	18:31.5	34.94	01:15.3	02:44.7	29.82	01:06.0	02:28.5	30.9	01:06.0	02:23.6	01:09.3	02:26.0	05:12.0
16	**LC**	27.89	01:00.4	02:11.0	04:38.6	09:38.9	19:16.0	35.31	01:17.7	02:47.9	29.71	01:06.3	02:30.2	31.73	01:08.0	02:27.7		02:28.0	05:18.8
	SC	27.37	59.34	02:08.9	04:34.1	09:36.7	19:34.2	34.74	01:15.4	02:44.8	29.63	01:05.7	02:28.2	30.66	01:06.2	02:24.3	01:08.7	02:25.5	05:12.5
17	**LC**	27.94	01:00.2	02:10.9	04:35.5	09:37.4	19:43.1	35.53	01:18.9	02:50.4	29.8	01:06.0	02:30.6	31.58	01:07.9	02:27.4		02:28.6	05:15.9
	SC	27.59	59.18	02:08.7	04:32.6	09:39.3	20:11.5	35.32	01:16.1	02:46.6	29.9	01:06.0	02:30.8	30.94	01:06.5	02:24.3	01:08.8	02:25.9	05:13.1

Appendix III – Borg CR-10 Scale (Foster *et al.*, 2001)

0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	-
7	Very hard
8	-
9	-
10	Maximal

Appendix IV – Example of training diary

Participant Number:

Training Diary

Normal training schedule

Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			
Sunday			

Date:			
Are you currently on your period? YES / NO			
Training day (pool or dryland training)	Planned non-training day (planned rest days)	Unplanned non-training day (holidays, illness etc.)	Competition day (including all races)

Summary of all training activities		
(1) Type: Pool / Dryland / Race	**(2)** Type: Pool / Dryland / Race	**(3)** Type: Pool / Dryland / Race
Time:	Time:	Time:
Brief session/race outline:	Brief session/race outline:	Brief session/race outline:
Total distance:	Total distance:	Total distance:
Total duration:	Total duration:	Total duration:
Session-RPE (0-10):	Session-RPE (0-10):	Session-RPE (0-10):

NASA-TLX. For each session, please rate how you felt using the session number (1, 2 or 3) on each line)

Overall Workload – total workload associated with the session, considering all sources and components.
Low High

Task difficulty – Whether the session was easy or demanding, simple or complex, exacting or forgiving.
Low High

Performance - How successful you think you were in doing what we asked you to do and how satisfied you were with what you accomplished.
Failure Perfect

Physical effort – The amount of mental and physical activity that was required.
None Impossible

Frustration level – How insecure, discouraged, irritated and annoyed versus secure, gratified, content and complacent you felt.
Fulfilled Exasperated

Stress Level – How anxious, worried, uptight and harassed or calm, tranquil, placid and relaxed you felt.
Relaxed Tense

Fatigue – How tired, weary, worn out and exhausted or fresh, vigorous and energetic you felt.
Exhausted Alert

DALDA

Please respond by circling the appropriate response alongside each item in Part A and Part B.

A = worse than normal
B = normal
C = better than normal

PART A

1	Diet	A	B	C
2	Home life	A	B	C
3	School/college	A	B	C
4	Friends	A	B	C
5	Sport training	A	B	C
6	Climate	A	B	C
7	Sleep	A	B	C
8	Recreation	A	B	C
9	Health	A	B	C

PART B

1	Muscle pains	A	B	C
2	Techniques	A	B	C
3	Tiredness	A	B	C
4	Need for a rest	A	B	C
5	Supplementary work	A	B	C
6	Boredom	A	B	C
7	Recovery time	A	B	C
8	Irritability	A	B	C
9	Weight	A	B	C
10	Throat	A	B	C
11	Internal	A	B	C
12	Unexplained aches	A	B	C
13	Technique strength	A	B	C
14	Enough sleep	A	B	C
15	Between sessions recovery	A	B	C
16	General weakness	A	B	C
17	Interest	A	B	C
18	Arguments	A	B	C
19	Skin rashes	A	B	C
20	Congestion	A	B	C
21	Training effort	A	B	C
22	Temper	A	B	C
23	Swellings	A	B	C
24	Likability	A	B	C
25	Running nose	A	B	C

Illness Questionnaire

Do you have any symptoms of illness today? YES / NO

If yes, please rate your symptoms below as:

1 = minimal (no change to training)
2 = moderate (modified training)
3 = severe (no training)

1	**Upper respiratory** *Blocked/runny nose, sore throat, sneezing*	1	2	3
2	**Chest infection** *Coughing, sputum, chest congestion, wheezing*	1	2	3
3	**Muscles & joints** *Aching or swollen (not injury)*	1	2	3
4	**Gastrointestinal** *Nausea, vomiting, diarrhoea, abdominal pain, bloating, loss of appetite*	1	2	3
5	**Head** *Headache, migraine, dizziness, light intolerance*	1	2	3
6	**Eye irritation** *Itchiness, redness, sticky discharge, watery eyes*	1	2	3
7	**Skin infections** *Sores, athletes' foot*	1	2	3
8	**General fatigue** *Lethargy, tiredness*	1	2	3
9	**Ears** *Ear ache, ringing, hearing loss*	1	2	3
10	**Urinary tract** *Increased frequency, pain/burning*	1	2	3
11	**Menstruation** *Increased or heavy flow, abdominal pain, irregularity*	1	2	3
12	**Other** *(please state)*	1	2	3

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Appendix II – Ethics Approval Letter

University of Kent

School of Sport & Exercise Sciences
Research Ethics and Advisory Group (REAG)
University of Kent at Medway
Chatham Maritime
Kent
ME4 4AG

Ethics Reference: Prop 34_2019_20

Date: 03.02.20

Dear Yolanda,

Re: How do physiological determinants affect performance change between the national qualifying window and the national championships in sub-elite female youth swimmers?

I am delighted to confirm that SSES REAG has approved your research study (Prop 34_2019_20) and you are now permitted to recruit participants and commence your research.

If you need to amend any aspect of your research, please ensure you inform SSES REAG by completing a request for amendment form and submitting all revised paperwork (e.g. participant information sheet, questionnaires).

If there should happen to be any adverse event during your study, please also ensure SSES REAG is kept informed.

I hope your study is successful.

With kind regards,

K. Hambly

Karen Hambly

(Chair SSES REAG)