VARIATIONS IN AGE-RELATED PERFORMANCE PROGRESSION IN COMPETITIVE SWIMMING

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Kosuke Kojima

VARIATIONS IN AGE-RELATED PERFORMANCE PROGRESSION IN COMPETITIVE SWIMMING

Introduction: Early identification of 'talented' young athletes has been gaining substantial consideration from youth sports stakeholders as a means to maximize these athletes' performance potential and their future chances of elite-level, international success. However, the concept of 'talent' is complex. For example, maturation-related disparities seemingly affect superiority in sports performance among adolescents (Kojima et al., 2012; Malina et al., 2004). During adolescence, early maturing children are typically more successful athletes than late-maturing children, and as a result they are often perceived as being more 'talented.' In contrast, research shows that older, physically mature, elite-level athletes are typically late-maturers (le Gall et al., 2010; Malina et al., 2005). This tends to call into question the importance and benefits of early talent identification programs. There is a general lack of empirical evidence regarding the inter-relationship among talent identification, long-term athlete development, and elite sporting success. Thus, it is currently unclear whether or not top-level young athletes are able to maintain their success throughout adolescence and into adulthood. More importantly, no study has yet to reveal factors potentially contributing to (maintaining) the long-term success of top-level young athletes. Furthermore, because the timing of maturational events has been reported to differ among ethnic populations/regions (Eveleth & Tanner, 1990), it may be possible to exploit interpopulation variations in physical growth patterns as a means to investigate how timing in maturation is related to athletic performance progressions.

Purposes: Two separate studies were completed. The purpose of the first study (variations in performance progression within a population) was designed to profile the performance progression and dropout rate of the successful preadolescent swimmers in the U.S. and to examine factors contributing to their subsequent success throughout adolescence and into adulthood. The second study (variations in performance progression between populations/regions) was initiated in order to determine 1) the

relationship between age-related height growth and swim performance progression for two ethnically and geographically disparate populations (the U.S. and Japan), known to differ in the timing of maturation and 2) the extent to which interpopulation differences (between American and Japanese) in age-related height growth pattern are related to differences in age-related swim performance progression.

Methods: Study 1: The USA Swimming database and NCAA rankings were used to track the top 100 nine-year-old girls and boys in the 45.7-meter (50-yard) freestyle in 2004. The following data were analyzed: 1) annual best swim times and 2) corresponding rankings in all swim events for each of the subsequent nine years and 3) collegiate rankings from 2013 to 2016. In addition, an online survey was sent to the top 100 nine-year-old girl and boy swimmers in order to examine identifiable factors contributing to senior athletic achievements. A mixed-effect logistic regression was used to illustrate the top 100 sustainability and dropout rate in the 200 nine-year-old swimmers (boys plus girls), and to determine factors contributing to the US top 100 attainments in the sport of competitive swimming across adolescence and into adulthood. Study 2: *All* available 50-meter long course freestyle times of girl and boy swimmers in 2008, in the U.S. (US) and Japan (JPN), were compiled from the USA Swimming and Japanese swimming federations' database, respectively. Growth reference data (median height for adolescent ages) were also acquired for US. (Kuczmarski et al., 2002) and JPN (MEXT, 2000). Cross-correlation analysis was used to demonstrate the relationship between age-related height growth and swim performance progression for US and JPN, and to examine the extent to which interpopulation differences in height growth (US to JPN ratio) are related to those in swim performance progression.

Results: Study 1: An effect of age on the odds that the top nine-year-old swimmers ranked within the top 100 in 45.7Fr across adolescence was revealed for both sexes. Nearly half of the US top 100 nine-year-old swimmers continued to rank within the US top 100 during late adolescence in both sexes, while approximately one third of the early successful swimmers dropped out from competitive swimming

(and/or USA Swimming) by age 18 years. Patterns of the performance retention at a successful level throughout adolescence were similar between sexes but not participation retention (dropout rate), especially at late adolescence. Based on the survey responses (19 girls and 21 boys), the early successful preadolescent swimmers were not necessarily early maturers but were, on average, a group of taller children, especially at early adolescence (above the 95 percentile of US growth data). In addition, there were six significant factors identified for the sustainability of the US top 100 status in competitive swimming. Study 2: A significant association between age-related height growth and swim performance was revealed for both sexes in US and JPN. Japanese girls and boys appeared to be early maturers as compared with US peers (approximately a two-year difference in the age at peak height gain), while swimmers in JPN appear to develop their performance (i.e., gaining growth-related advantages in performance improvements) at earlier ages than US counterparts. The interpopulation difference in height growth was significantly associated with swim performance progressions in both sexes.

Conclusions: Study 1: Early success appears to be an important predictor for future success in competitive swimming, and dropout rate of early successful young swimmers during adolescence is lower than the commonly reported rates. Contributing factors for future success would differ based on the characteristics of athletes (e.g., age, sex, and competitive levels) and types of domain sports examined. Therefore, persistent participation may represent a strategic priority on the local as well as the national level. Study 2: Maturation-related superiority in swim performance was observed between populations. Interpopulation variations in the timing of maturational events (as measured by age-related peak height gain) partially explain differences in adolescent athletic performance. Thus, maturity status may also be an interesting consideration in predicting performance outcomes at international competitive events.

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CHAPTER 1: INTRODUCTION

Introduction

Dominance occurs at any level of competition in athletic world. It is achieved by a few 'talented' or 'gifted' athletes or teams when they perform far better than the rest of the field at a competition and/or repeatedly win championship titles over time. What factors contribute to or discern superior performances of such athletes and exceptional variations in human athletic performance (e.g., what constitutes the differences between elite and non-elite athletes)? This has been, and will continue to be, an everlasting question and frequent topic for competitive sports stakeholders and sports scientists.

Outstanding athletes and sports teams frequently originate from known isolated populations and or distinct geographic areas within a country or continent. Some figural examples and world-leading teams in competitive sports are the central European and South American countries for soccer, Canada for ice hockey, and the U.S. for swimming. Within the U.S., the state of Iowa is well-known for wrestling and the state of California is known as the geographic center for water polo. In terms of sport dominance, the U.S. leads the total Olympic medals counts in swimming (men's and women's results combined) by being awarded three times (520 medals) more than the second place country (Australia: 178) (up to London 2012 Olympic Games). For the all-time top ten gold medalists, nine out of ten men swimmers are from the U.S., with five US women swimmers also ranked within the top ten (out of 12 swimmers due to ties). On an individual level, U.S. women's distance swimmer, Katie Ledecky, is currently considered as one of the most dominant athletes in the world (across all sports) as she wins international championships by an incredible distance relative to the rest of the field. The question remains; what are the important factors contributing to these extra-ordinary performances?

Excellence at the elite level in sporting events inspire spectators, especially those associated with the athlete's native country, and benefit the sport from the logistic and financial perspective. From the viewpoint of a pyramidal structure model of sports participation (Bloomfield, 1973; shown in Figure

1.1) success in elite sports is a strategic administrative approach by which national federations in turn promote the prosperity of that sport (Hindson et al., 1994; Horgan & Norton, 2000). It is expected that national, elite, sporting-success at international competitions will eventually act to increase sport participation from athletes higher up the high-performance apex of the pyramid by first inspiring grass-roots interest lower down. This concept is referred to 'trickle-down' effect or 'top-down' approach (Horgan & Norton, 2000), originating from economic policies (Boyle & Simms, 2009), and is a prevalent strategy across the world as a means to produce an increased proportion of outstanding athletes. On the other hand, a 'bottom-up' approach (Horgan & Norton, 2000) is to direct financial investments at the grass-root levels. The goal of this approach is to increase regional facilities and sporting opportunities ("build it and they will come," the Field of Dreams approach) for a wide cross-section of community, presumably resulting in an increase in young participants in sports which hopefully will ultimately contribute to an enhancement in elite sporting success.

Figure 1.1. Framework of sports participation model (Bloomfield, 1973; page 10)

Talent identification

An additional common, proactive strategy by sports federations (as well as private and/or professional sports club teams) that is used to presumably accelerate sport programs is talent

identification and talent development (TID) programs. Early identification of talented young athletes has been gaining substantial consideration as a means to maximize youth program success, hopefully leading to enhanced future chances of elite-level, international success. However, children and adolescents are acknowledged as 'unstable' variables. This means that variables that may convey success at one age may be detrimental to success at another. For example, maturation-related disparities and superiority in sports performance among adolescents have been well documented within a population (Kojima et al., 2012; Lätt et al., 2009a, 2009b, 2010; Malina et al., 2004; Moreira et al., 2014; Pelayo et al., 1997; Saavedra, Escalante, & Rodriguez, 2010). When all children within a cohort are young, early maturing children are typically more successful athletes than late-maturing children and often account for the majority of individuals identified by TID or talent selection programs during adolescence (Figueiredo et al., 2009; Kanitz & Bar-Or., 1974; Helsen et al., 2000; le Gall et al., 2010; Malina, 2009a & 2011; Malina et al., 2004; Ostojic et al., 2014; Till et al., 2014; Torres-Unda et al., 2013). Contrariwise, late-maturing children tend to catch up to their precocious counterparts when they hit their growth spurt, and appear to dominate elite and professional levels when reaching final adult (maturational) status (le Gall et al., 2010; Malina et al., 2005). In line with this phenomenon, data from little league baseball in the U.S. show that few professional Major league baseball (MLB) players exceled at the top youth levels when they were young. Only 50 players among the many thousands in 100 years of MLB history participated in little league world series (source of data, Little League Baseball and Softball: www.littleleague.org). Similar situations have been observed and reported for many types of sports within a population.

Developmental pace

Physiological factors associated with sports performance (e.g., muscle growth and aerobic and anaerobic capacities) have been reported to be dramatically increased within approximately one year

from the age of peak height gain for both sexes (Malina et al., 2004; Philippaerts et al., 2006). The onset and timing at which maturational events occur, however, are individualistic and vary considerably among adolescents. This fact compromises the concept of 'talent' and TID program.

Another example of the maturation-related superiority in sports performance are frequently highlighted between sexes during early- to mid-adolescence. Girls are, on average, early maturers as comparted with boys. When assessing somatic growth in children, girls' peak height growth occurs approximately at age 12 years, while boys are at age 14 years (Malina et al., 2004). Although it is expected that boys and men outperform girls and women in physical tasks and sports performances (Shephard, 2000), studies have shown no sex-related difference or superiority in girls in sports performance during the girls' growth spurt (around age ten to 12 years) where (Kojima et al., 2012; Pelayo et al., 1997). In fact, it is often seen that time standards for championships meets in girls aged 11-12 years old are faster than boys of the same chronological ages in the sport of competitive swimming (Indiana Swimming: www.inswimming.org).

Similar to what we have seen regarding maturation-related disparities and superiority in sports performance within a population and between sexes, it has been observationally indicated that maturational events appear to occur at earlier ages in Asian, Hispanic (Latino), and Black-American children when compared with Caucasian and White-American children (Eveleth & Tanner, 1990; Haas & Campirano, 2006; Malina, 2009a). This would suggest that Asian, Hispanic (Latino), and Black-American populations are early maturers, as compared to Caucasian/White populations (late maturers).

International youth sports competition outcomes

Superiority in sports performance among ethnically and/or geographically disparate populations at international competitions has been anecdotally observed to change from youth to senior levels. For example, soccer is one of the most popular and most organized sports throughout the world, and

multiple age-group world championships prior to the senior level are offered for international level competitions: such as under-17 (U-17), U-20, and U-23. U-23 World Championships are modeled after the format of the Olympic Games since 1992. Although it is well acknowledged that European and South American countries dominate the senior World Cup, it does not appear to be always the case in U-17 and U-20 World Championships (Figure 1.2). Some Asian and African countries have been present at semi-finals and won the championships titles in U-17 and U-20. On the other hand, as the ages of the competitors increases, the proportion of European (or Caucasian dominant) countries achieving semi-finals or winning championship titles increases. In the past six Olympic Games (men's soccer), however, only one European country has won an Olympic title (Spain 1992). African countries have won the titles twice (Nigeria in 1996 and Cameroon in 2000). Argentina won twice in 2004 and 2008, and Mexico won in 2012 London Games. A similar trend is seen in women's side with a greater proportion and appearance of Asian populations. Is this as a result of cultural differences, societal diversity, or reflective of physiological differences?

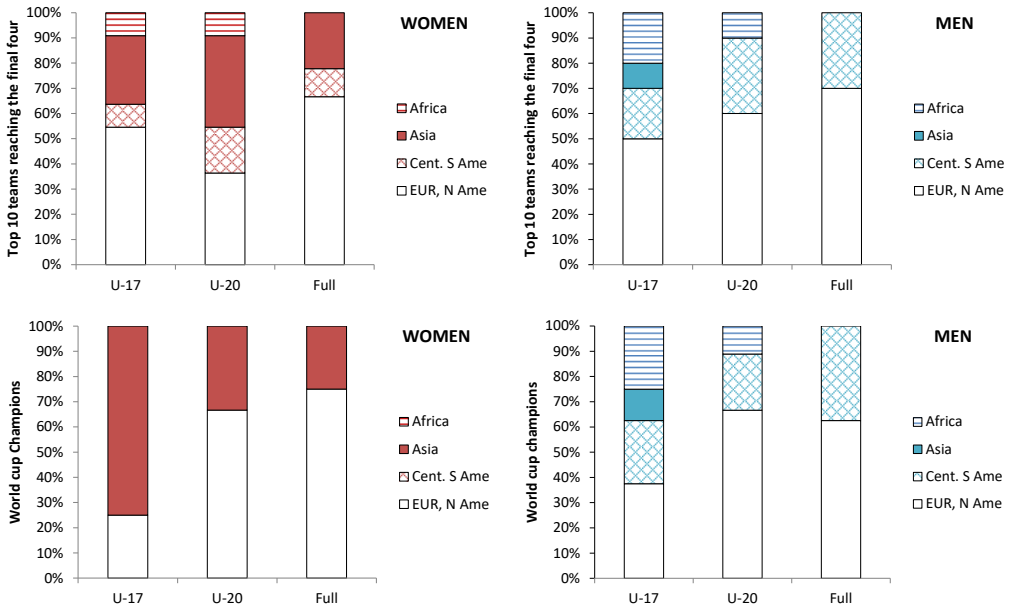


Figure 1.2. Proportions of geographic-based areas (countries) advancing to the semi-finals (top figures) and winning the championship title (bottom) in the World Cup history in soccer.

Cent S Ame, Central and South American countries (Hispanic and Latino); EUR N Ame, European and North American countries (Caucasians)

In the sport of competitive swimming, similar observations concerning ethnic- and or geographic-based performance superiority are evident. Caucasians seemingly dominate the sport of competitive swimming and its world records in both women and men. Surprisingly, almost all world records in swimming are held either by Caucasians or Asians (Chinese and Japanese) as of April, 2016, for both junior (age under 18 years) and senior levels. There are two swimmers whose junior world record(s) are fast enough to hold senior world record(s): Katie Ledecky (the US) and Akihiro Yamaguchi (Japan). As shown in Figure 1.3, there is a distinct difference in the proportion of Asian and Caucasian world record holders when junior and senior levels are compared. This is especially true for men. It is evident from Figure 1.3 that Asian swimmers are more comparable to (women) and excel over (men) Caucasians in the junior level, while the situations change in the senior level. These data must support 'anecdotal' observations in international youth sports events that some geographic or ethnic populations, such as (East) Asians and Africans, may outperform other populations (e.g., Caucasians) at an early age, which may not necessarily be the case later in senior-level international competitions.

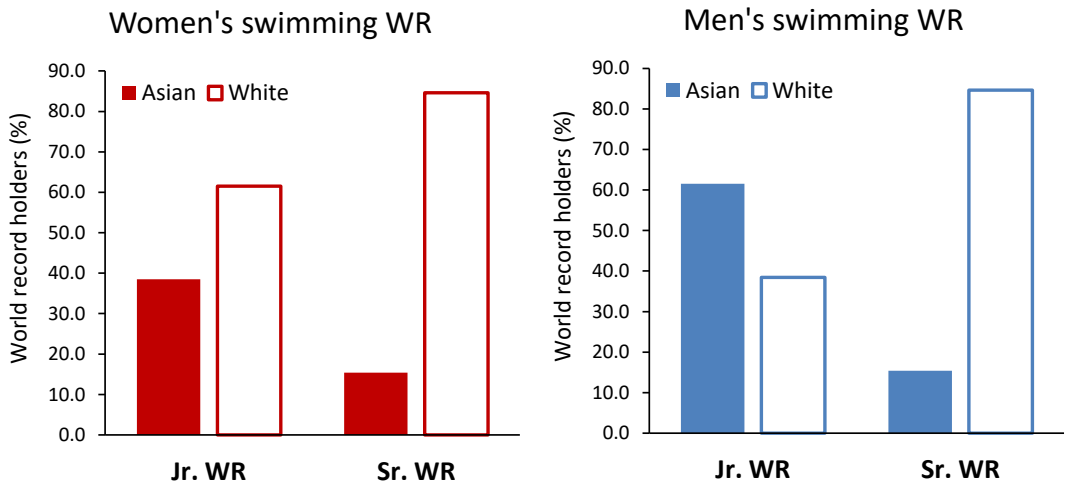


Figure 1.3. Proportion of Asian and Caucasian (White) for the junior (age 18 and younger) and senior world record holders (as of April, 2016).
WR, world record.

Note: Junior world records were established in March, 2014. Since the records do not count any times made before the establishment date, the data here are in fact based on the fastest time made by swimmers aged 18 and younger in the history of competitive swimming.

Once again, is this observation reflective of differences in developmental pace or differences in other factors such as socio-economic status? To date, no systematic research, however, has indicated that adolescent sport performance of populations with different ethnic status (but similar or dissimilar socio-economic status) differ in a manner that is reflective of their unique pattern of growth and maturation, and thus this question remains to be determined.

Early (youth-level) success to elite-level success

Due to the fact that growth and maturation are identified as two of the most influential factors dictating the development and progression of youth athletic performance and youth talent selection, the importance and consequence of commonly deployed early adolescent TID programs come into question. Because of variations in the timing of growth and maturation and its influence in youth sports performance outcomes, a question remains; are early TID systems capable of predicting the eventual success of a preadolescent?

Unfortunately, evidence suggests that instead of positive outcomes, TID programs designed to filter out talented and gifted individuals at an early age may discourage many potential participants away from sports. They may act to restrict access to better facilities and coaching, science and technologies to only designated athletes; ultimately minimizing competition and eliminating other opportunities from the broad participation base (Fraser-Thomas et al., 2008a; Fraser-Thomas et al., 2008b; Hindson et al., 1994). The greater gap between what new or developing young sports participants receive and what experienced or top-levels young athletes receive (opportunities and supports for their sports), the greater likelihood of dropout from sports appears to be (Horgan & Norton, 2000). Therefore, one perspective is that TID programs may actually be counterproductive to the broad objective of increasing sports participation.

That TID programs may be counterproductive to its main objective, i.e., promoting success in elite sports can be hypothesized to be related to maturational pace. As shown earlier, there is some incongruity in the proportion of early vs. late maturers existing between youth and senior sports performance outcomes. What youth sports stakeholders deploy regarding an administrative approach for promoting success in elite sports (talent selection) may not be in line with what has been shown to be optimal for long-term athletic development in young athletes. This suggests that adolescents and their early performances are 'unstable' variables, and consequently, by their very nature, increase the complexity of predicting future success.

In addition, TID programs habitually lead to early specialization and intensification of youth sports training and competition (Barreiros et al., 2014; Faigenbaum, 2009; Fraser-Thomas et al., 2008a; Fraser-Thomas et al., 2008b; Gould et al., 1996; Hecimovich, 2004; Malina, 2009a; Martens, 1996; Martindale et al., 2005; Martindale et al., 2007; Petlichkoff, 1996; Vaeyens, et al., 2008; Wiersma, 2000). Early specialization is currently debated as being helpful or harmful for later mature performance. The ideas behind TID programs and training methodologies in youth sports are commonly based on generic, intuitive perceptions or the personal experiences of coaches based upon their experiences during their own sports careers. Methodologies tend to trickle down from training programs used for training elite, mature athletes. It can be argued that there is insufficient scientific evidence to allow for appropriate objective judgments of long-term athletic development in young children. In addition, available research indicates a lack of agreement and no coherent understanding by stakeholders of the research supporting the basic principles of TID programs (Pakhurst et al., 2013). These circumstances, along with socioeconomic (or often parental) pressure, often result in coaches' focus on short-term performance outcomes and immediate success of their youth athletes (an excessive emphasis on winning) during an early phase of youth sports participation and early adolescence. Consequently, TID programs have the potential of overwhelming successful, top young athletes within these programs while at the same time

ignoring the potential future stars at the participation base. In the worst case, this scenario can burn out (drop out) young athletes from youth sports participation and practice. This is unfortunate and the too frequently observed outcome is in direct contrast to the stated objectives of the top-down or bottom-up approach on the basis of the pyramidal participation model (Figure 1.1).

There have been research studies assessing the effectiveness of TID programs or the top-level retention rate of (successful) young athletes. However, to date, these studies only provide insights into the question of how current successful, senior elite athletes became elites by investigating their youth sports careers retrospectively (Barreiros et al., 2014; Baker et al., 2003; Baker et al., 2005; Bridge & Toms, 2013; Güllich & Emrich, 2014; Hodges et al., 2004; Moesch et al., 2011; Ostojic et al., 2014; Schumacher et al., 2006; Vaeyens et al., 2009). These retrospective investigations tend not to analyze the youngest ages and only examine those 14 years or older in girls and 16 years or older for boys. Julio et al. (2011), on the other hand, retrospectively analyzed state-level competitive success (top 4 players/medalists in each age-group) for 10 years in the sport of Judo in Brazil. The authors show that the probability of wining the medals 10 consecutive years for less than 10%. However, there is no informative data or causative factor regarding the developmental process of the young athletes or dropouts (neither from the top four performances nor entirely from the sport of Judo). Therefore, relatively little is known how successful young athletes mature into successful late- and post-adolescent athletes, and there is no data regarding dropout rate of highly successful young individuals in a sport throughout adolescence.

Youth sports participation and dropout

An increase in the number of participants per se has been shown to contribute to an increase in the probability of producing elite performances within any given group (Charness & Gerchak, 1996; Cornett & Stager, 2015). This tends to support a 'bottom-up' approach to program development. In

most of competitive sports, the majority of participants are children and adolescents at the beginning and developmental levels. This again is illustrated in the pyramidal structure in sport participation (Figure 1.1). Efforts to either retain existing outstanding young athletes or recruit more participants within any given sport community should result in an enhancement of competition levels and ultimately the prosperity of the sport. However, the top-down approach at youth sports levels (i.e., TID programs) may not be as effective as youth sports stakeholders assume.

Once again, there has been no systematic study reporting dropout rate in highly success young individuals in a sport. It is simply presumed from the results of Julio et al. (2011) that there may be more dropouts for early maturers or early successful young athletes. Most of dropouts may consist of them during mid- to late-adolescence. It is possible that while average and late maturing children catch up to early maturers in sports performance, improvements in early maturers or early successful children may be reaching plateau at the same time, leading presumably to discouragement or discontinuation. This may also be the case between girls and boys. Girls, who mature earlier than boys, may drop out from a sport more at mid- to late- adolescence as compared with boys. In fact, USA Swimming's demographic reports indicate that dropout rate in girls are more than boys after the age 14 years when is after the girls' growth spurt but in the boys' growth spurt (USA Swimming, 2016).

It is reasonable to hypothesize that early TID programs which only consider successful athletes and their progress at younger chronological ages may actually jeopardize the chances for other children to succeed. Once again, the concern is for the success of the late-starting and late-maturing children. More importantly, too much emphasis placed upon competition, winning, early specialization, and intensification could prejudice the motivation of young athletes and decrease the retention rate of youth sports participants. At this time, there are very little data on participation retention or dropout rates in consort with the long-term athletic development in highly successful young athletes. This needs to be done in order to evaluate the effectiveness of TID programs: whether or not such young athletes

maintain and enhance their athletic success and how they develop their athletic performance into senior elite careers.

It is also unclear, when considering long-term athlete development, how successful young athletes develop their involvement in youth sports training and competition, and what factors differentiate or contribute to their late-adolescent and senior-level athletic achievements. For example, previous studies investigating youth sports careers and biographies of senior elite athletes suggest that factors such as multi-sports experience (early diversification and late specialization) appear to have attributed to future athletic success (Güllich & Emrich, 2014). However, once again there is almost no longitudinal research investigating causal inferences of early athletic success to senior athletic success throughout adolescence. Pursuing these perspectives and tracking developmental athletic careers of successful youth sports athletes would provide stakeholders with more useful, practical insights into implications of TID and critical elements within long-term athlete development programs.

Competitive swimming

Competitive age-group swimming has perhaps the most extensive database available allowing for tracking performances as athletes age. For example, beginning in 2004, all swim performances across the country of the United States were made publicly accessible and were well organized by USA Swimming. The database provides the means of determining participant dropout rate, simply by examining presence or absence of performance data (times) of individuals at any given time period. Participation is generally reported as starting at a fairly young age in swimming (Figure 1.4: Vaeyens et al., 2009). Figure 1.4 shows that the majority (60%) of Olympic swimmers at Athens 2004 started their career by the age of eight years (80% started by age 10 years). As well, US rankings enable us to classify age-group or older swimmers into different success levels, while all-time data provide generic insights. It is assumed again from previous literature that highly successful youth athletes may be associated with

their maturity status. Therefore, the combination of longitudinal prospective and retrospective analyses of performance in highly successful, preadolescent swimmers over adolescent ages and into adulthood can provide valuable evidence-based information regarding TID, as well as a long-term athletic development and career path of such young individuals. In addition, retrospective examination of dropout rates with additional information on other youth sport involvement, training biographies, multi-sports experience, timing of specialization, and maturational information might provide useful insights into the factors contributing to the success of the eventual, better athletes.

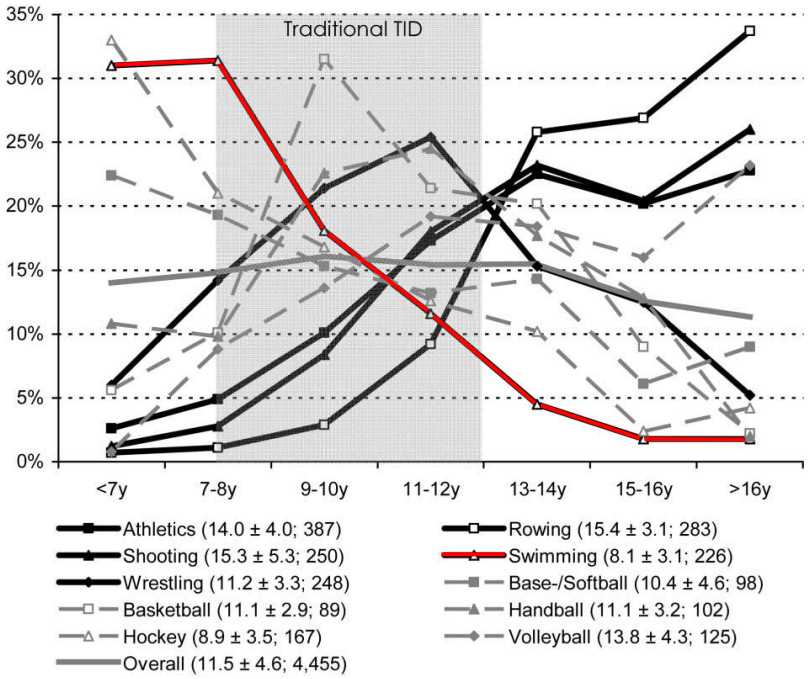


Figure 1.4. Proportion of age at onset of training for the main sport among athletes in the Olympic Games in 2004 (Vaeyens et al., 2009, page 139).
Note 1: Numbers in brackets denote average ages (± S.D.) and sample size
Note 2: The sum of percentages (plots) for each line (sport) is 100%.
Ethnic/geopolitical differences

It has been well documented that variations in growth and development are associated with the ability of adolescents to perform physical tasks. From micro (within a population) to macro (among

populations) analysis, comparing populations that are known to contrast in maturational pace might allow confirmation of the importance of maturational pace in regard to mature performance. Comparing growth reference data with swim performance data across adolescent ages between the U.S. and Japan, for example, enables us to determine the extent to which interpopulation variations in physical growth are related to those in athletic performance and age-related progression. The U.S. and Japan are identified as having distinct ethnic backgrounds, comparable socioeconomic status, and being representatives of successful (highly competitive) swimming countries in the world. In addition, perhaps most importantly, a database for adolescent swim performance currently (and uniquely) exists for these two countries.

Purpose of the Study

Two separate and independent studies were executed. The first study was largely descriptive and was conducted to 1) profile the performance progression with age and 2) gain insight into the dropout rate of successful preadolescent swimmers in the United States (US). Both parameters would be compared and contrasted to the progressions and or dropout rates of the entire US age-group swimming cohort. The focus was directed at these swimmers in order to determine 1) whether or not early success in youth sports is predictive of future success, 2) how successful young athletes develop their involvement in youth sports training and competition, and 3) what factors differentiate or contribute to their late adolescent- and senior-level athletic achievements and success. The purpose of the second study was to extend these initial findings by examining 1) the relationship between age-related height growth and swim performance progression for two ethnically and geographically disparate populations (the United States and Japan), and 2) the extent to which interpopulation variations (between the U.S. and Japan) in age-related height growth are related to their swim performance progression. If a significant relationship existed between age-related height growth and

swim performance progression for each country, analyses were performed to determine whether or not the patterns of the observed relationship are different between countries (e.g., ages at the peak height gain and at the peak performance improvement). The purpose was to gain a better understanding of the contribution of maturational pace on athletic success.

Research Questions and Hypotheses

This study consisted of two projects: 1) performance progression, participation retention, and developmental career path in the U.S top 100 nine-year-old swimmers (variation within population) and 2) interpopulation variations in height growth and swim performance progression between the U.S. and Japan (variation between populations). The research questions and hypotheses for both projects are presented below.

Study 1: Performance progression, participation retention, and developmental career path in U.S top 100 nine-year-old swimmers

Question 1: What is the percentage of the U.S. top 100 nine-year-old swimmers maintaining the top 100 status through adolescent ages and beyond?

Hypothesis 1: The percentage of the nine-year-old swimmers (qualifying as a top 100 swimmer at age nine years old) maintaining the top 100 status decreases with age.

Question 2a: Do the U.S. top 100 nine-year-old swimmers improve their performance times (45.7-meter freestyle: 45.7Fr) across adolescent ages?

Hypothesis 2a: The U.S. top 100 nine-year-old swimmers will improve their performance in 45.7Fr across adolescence.

Question 2b: Do the U.S. top 100 nine-year-old swimmers improve their performance times (45.7Fr) more than swimmers who did not rank within the top 100 at young ages across adolescent ages?

Hypothesis 2b: The magnitude of the improvement in 45.7Fr is smaller in the U.S. top 100 nine-year-old swimmers through adolescence when compared with the improvement rates of the total U.S. swimming population.

Question 3: What is the percentage of the U.S. top 100 nine-year-old swimmers continuing in USA Swimming through adolescent ages and into adulthood?

Hypothesis 3: The dropout rate of the top 100 nine-year-old swimmers increases with age and is more than all swimmers in USA swimming.

Question 4a: Is there a significant sex-related difference in performance progression (45.7Fr time) in the U.S. top 100 nine-year-old swimmers throughout adolescence and into adulthood?

Hypothesis 4a: The improvements in swim times in 45.7Fr are greater in boys.

Question 4b: Is there a significant sex-related difference in the retention rates in participation (dropout) and the top 100 status in the U.S. top 100 nine-year-old swimmers throughout adolescence and into adulthood?

Hypothesis 4b: The participation retention rate of the top 100 nine-year-old swimmers and the percentage of maintaining the top 100 status are greater in boys, while the tendency of retention rate across adolescent ages will differ between sexes.

Question 5: Are there identifiable factors contributing to the levels of future athletic success in the U.S. top 100 nine-year-old swimmers?

Hypothesis 5: There will be identifiable factors contributing to future (late-adolescent- and college-level) athletic success and achievements, *such as late specialization and intensification in competitive swimming and multi-sports participation.* The parameters in youth sports participation and training biography in the top 100 nine-year-old swimmers would be different from those in later-successful, senior elites previously reported.

Study 2: Interpopulation variations in height growth and swim performance progression between the U.S. and Japan

Question 6: Are there significant relationships between age-related height growth and swim performance progression for girls and boys (in the U.S. and Japan)?

Hypothesis 6: Age-related height growth will be significantly correlated to age-related swim performance progression in both sexes (in the U.S. and Japan).

Question 7: Is there a significant interpopulation difference in age-related height growth?

Hypothesis 7: The pattern of age-related height growth will be significantly different between the U.S. and Japan.

Question 8: Is there a significant interpopulation difference in age-related swim performance progression?

Hypothesis 8: The pattern of age-related swim performance progression will be significantly different between the U.S. and Japan (US swimmers are faster than Japanese swimmers at later ages).

Question 9: Is there a significant relationship between interpopulation differences (ratio of Japan to U.S.) in age-related height growth and swim performance progression?

Hypothesis 9: There is a significant relationship between interpopulation differences (ratio of Japan to U.S.) in age-related height growth and swim performance progression.

Definitions

Adolescence -- is defined relative to chronological age, across the approximate age range of 10 to 18 years old (defined by the WHO: http://www.who.int/en/). Malina et al. (2004), however, propose that the age ranges from 8 to 19 years in girls and 10 to 22 years in boys are more appropriate when considering the degree of variation inherent in maturation. Preadolescence is the period at the end of childhood and before children clearly become adolescent, around age 8 to 10 in girls and 10 to 12 in boys. Peri-adolescence is a relatively new term describing the time spent within (or surrounding) the adolescent period. The term 'peri-adolescence' is less specific and includes the pre- and post-adolescent periods. Post-adolescence would be referred later period of adolescence when secondary sexual characteristics are, in essence, mature (Figure 1.5). Adolescence is often used synonymously with puberty. While puberty is associated with a child's physical and sexual characteristics and maturation, adolescence also refers to the psychological (also social and behavioral) changes (Marshall & Tanner, 1986).

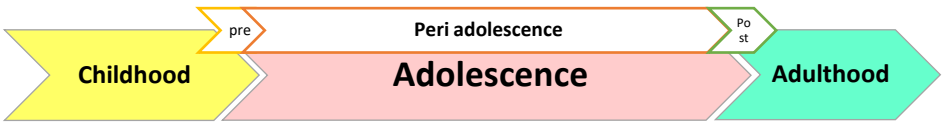


Figure 1.5. Schematic time frame of developmental ages based on the definition of Malina, Bouchard, & Bar-Or (2004).

Childhood -- is the period from the 1st birthday (day 365) to the start of adolescence (Malina et al., 2004). According to Malina et al. (2004), childhood is often divided into the following categories: early childhood (the preschool years, 1 to 4.99 years of age), and middle childhood (elementary school years, into 5th and 6th grades; 5 years to the beginning of adolescence). On the other hand, Gallahue (1989)

defines childhood as the period between approximately age 2 and 10 years. It can be divided into three stages: toddler (age 2-3 yrs.), early childhood (age 3-5 yrs.), and middle/late childhood (age 6-10 yrs.).

Deliberate practice – refers to extensive, specialized forms of practice aimed at building expertise (Mayer, 2003). Deliberate practice is also considered to be effortful and engaged in with the purpose of improving performance in a specific domain (Erickson et al., 1993; Hodges et al., 2004), which requires specialization and intensification of practice and training.

Development -- is in biological contexts, the differentiation of cells along specialized lines leading to the function and functional refinement of body systems, and in behavioral contexts, the development of competence in a variety of interrelated domains as a child adjusts to his or her cultural milieu (Malina et al., 2004).

Experience -- one's interactions with the environment (Mayer, 2003)

Expertise – refers to a high degree of competence that results from the interplay between genetic and environmental effects (Ceci et al., 2003)

Elite -- a select part of a group that is superior to the rest in terms of ability or qualities (http://oxforddictionaries.com).

Growth -- is a process involving hyperplasia (increase in cell number), hypertrophy (increase in cell size), and an increase in intracellular materials (Beunen, 1989). That is, growth refers to measurable changes in size, physique, and body composition of the various systems of the body. The processes of growth

and physical maturation are intimately linked because differential growth creates form (Falkner & Tanner, 1978).

(Adolescent) Growth spurt -- is an acceleration followed by a deceleration of growth in most skeletal dimensions and in many internal organs (Marshall & Tanner, 1986). The rates of growth in both stature and weight increase or accelerate (Malina et al., 2004). The growth spurt is commonly assessed by using height velocity (height growth or gain plotted against age) and the shape of the velocity curve of height growth (Figure 1.6). The peak value on this curve is called peak height velocity (PHV: maximum gain or growth rate in height). Age at PHV is used as an indicator of somatic maturity in children and adolescents, and on average, 12 years old in girls and 14 years old in boys (Malina et al., 2004).

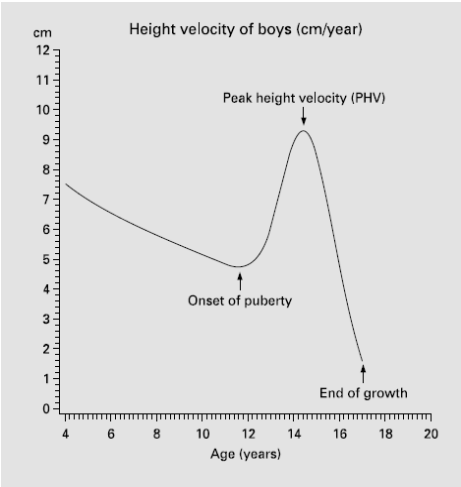


Figure 1.6. Height velocity curve of a typical boy with commonly used milestones on the adolescent height velocity curve (Karlberg, 2002, p. 21).

Intensification -- early involvement in focused, high intensity training (Baker et al. 2009).

Japanese Swimming Federation -- a major governing body of swimming in Japan

Maturation -- is the successive tissue changes that take place until a final form is achieved. Maturation implies specialization and differentiation of cells and systems (Acheon, 1966) and represents progress toward maturity (Malina et al., 2004). Maturation is a *process* and maturity is a *state*. The level of maturity *in timing* refers to when maturational events occur, and level of maturity *in tempo* refers to the rate at which maturation progresses. Maturity status is defined by comparing biological age (BA) with chronological age (CA), and children and adolescents are classified into three maturity statuses (Malina et al., 2004). When BA is more than 1 year older than CA, maturity status is advanced or she/he is early maturating (an early maturer); when BA = CA within ± 1 year, maturity status is average, also called 'on time'; and when BA is younger than CA by more than 1 year, maturity status is slower or she/he is late maturating (a late maturer). BA through assessment of morphology, skeletal maturation, dentition, and sexual maturation can be used to assess the progress of individuals toward maturity (Gallahue, 1989). By contrast, biological maturation must satisfy the following conditions: it must reflect changes in biological characteristics, reach the same final stage in every individual, show a continuous smooth increase although most often discrete stages on this continuum can be identified, be applicable throughout the maturation process, and be independent of size (Beunen, 1989).

Puberty -- refers collectively to the morphological and physiological changes that occur in the growing girl or boy as the reproductive organs change from the infantile to the adult state (Marshall & Tanner, 1986). It is a transitional period between childhood and adulthood. This includes the appearance of secondary sex characteristics, maturation of the reproductive system, and the adolescent growth spurt in addition to psychological behavioral changes (Malina et al., 2004). Prepuberty simply means that the children show no overt manifestations of maturational indicators, being in the 1st stage of secondary sex characteristics (Marshall & Tanner, 1986). Menarche, the age at which the first menstrual cycle occurs, is often used to reflect the pace towards maturation for girls.

Specialization -- In sports, it is defined as limiting participation to or focusing on a single sport trained for and competed in on a year-round basis with deliberate focus on training and development in that sport (Hill, 1987), while diversification is the participation in a variety of sports and activities through which an athlete develops multilateral physical, social, and psychological skills (Wiersma, 2000).

USA Swimming -- a major governing body of swimming in the United States

USA Swimming times database -- a database available to the public that has performance times for all

CHAPTER 2: REVIEW OF LITERATURE

The relevant literature pertaining to this project were divided into three categories under two studies: 1) administrative structure of sports participation and elite sporting success, 2) factors that influence sports performance and developmental pathways during adolescence, and 3) questions concerning early TID programs and long-term athlete development within and between populations.

1. Administrative structures of sports participation and elite sporting success

Sports are becoming a reflection of our cultural system. Global escalation of youth sports competitiveness and pressure toward developing future elite athletes has demanded more investment by youth sports stakeholders. Youth sports coaches and programmers strive to produce future elite athletes by providing participants with appropriate support and training to translate their high-level performance over adolescence into adulthood. This process requires systematic, logistical, and administrative support by sports organizations. Generic theories and recommendations have been established and are available in literature; however, coherent evidence to connect theory and practice may be deficient. Below, conventional strategies of sports organizations to promote elite sporting success are introduced.

Nine pillars of sports policy factors influencing international success

A country's sporting success at international-level competitions is administratively, and often politically, evaluated by the numbers of medals won at major competition (e.g., at the Olympic Games) in relation to those won by other countries. It appears that the international and elite sporting success depends substantially on the performance capacity of the national federations and their systems and the high-level investments in the system (De Bosscher et al., 2006; Hogan & Norton, 2000; Seiler, 2013; Shibli, 2003). Shibli (2003) even suggests that as competition for success increases the cost of such

success rises. However, it is difficult to determine the exact effects of targeted resource allocation and the sports systems by a sporting organization on elite sporting success and/or overall performance outcomes. Nevertheless, a conceptual model of nine pillars of sports policy factors leading to international sporting success has been proposed by De Bosscher et al. (2006 & 2010, Figure 2.1). This model focuses on what is best for the athletes' development (pillars 3, 4, and 5) and emphasizes how elite athletes can train and perform in ideal/optimal circumstances with access to sufficient training facilities, high quality coaches, and medical and paramedical supports (pillars 6 to 9) within a given sport.

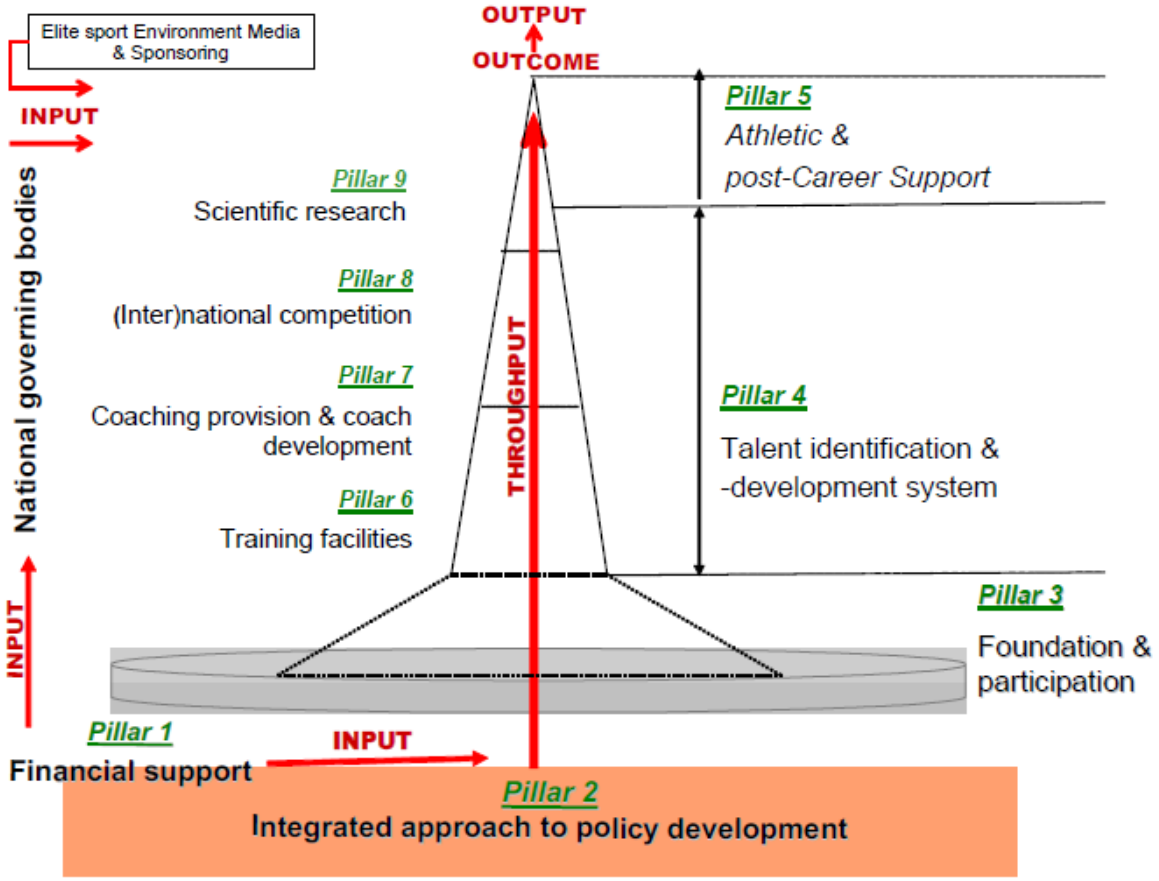


Figure 2.1. Nine pillars of sports policy factors influencing international sporting success (DeBosscher et al., 2006).

Once again, while this model does not guarantee success in international sport, the conceptual systems provide athletes (especially for those at elite levels) with ideal circumstances for success. For example, better training facilities (pillar 6), development of coaches (pillar 7), high-level international competition experiences and structures (pillar 8), and scientific supports (pillar 9) expose athletes to higher motive, expertise, and identifying them as being talented. In order for a sports federation to optimize the nine-pillar model and consequently maximize elite sporting success, there is a need for vast financial resources. Therefore, sports federations and authorities must manage financial and human resources (pillar 1), budget and integrate according to seasonal, yearly, or quadrennial plans reflected in policy development (pillar 2), and operationalize the sports policy model (pillars 2-9).

Top-down and bottom-up approaches to enhance elite sporting success

Once again, an increase in financial resources results in an increased chance of elite sporting success (De Bosscher et al., 2006; Hogan & Norton, 2000). A simple means of generating additional financial support and resources is to increase sport participation. Following the pyramidal structure model of sports participation (Bloomfield, 1973) shown in Figure 1.1, increasing participation can be achieved by directing the budget towards the grass-root levels, increasing regional facilities and sporting opportunities for a wide cross-section of community. This 'bottom-up' approach (Hogan & Norton, 2000) anticipates not only an increase in financial resources from mass participation (i.e., annual registration fees), but also that an increase in participation will increase the chance of producing potential future elite athletes ultimately enhancing elite sporting success (Charness & Gerchak, 1996; Cornett & Stager, 2015). However, due to globalization of sports competition and high social attention toward professional and Olympic sports, elite athletes and their success at international events have been frequently emphasized and prioritized, and consequently the federal budget has been directed towards elite athletes. Hogan & Norton (2000), in the case of the Australian Sports Commission in the

late ‘90s, report that approximately 80% of the federal funds was directed to elite sports and a 10% fund for improving participation in sports. The premises behind prioritizing elites and the disproportionate financial supports are that as a result of success of elite competitions giving inspiration and impetus to the citizens of the nation, an increase in a broad base of sports participation to generate a pool of talented athletes occurs. These holistic, logical, and proactive approaches to eventually obtain more resources for elite sporting success are referred to ‘trickle-down’, ‘demonstration’, or ‘Boris Becker’ effect and ‘top-down’ approach (Feddersen et al., 2009; Horgan & Norton, 2000). In addition, hosting international/elite sporting events is assumed to cause the same positive outcomes on mass participation and eventually lead to the enhancement in elite sporting success. However, a key question is whether or not there is such an effect of ‘trickle-down’ on sports participation. If there is no trickle-down effect, a high investment in an elite sports by sports federations may not be justified in terms of increasing participation in a sport.

Trickle-down effect and relevant findings for top-down and bottom-up approaches

Several research studies using correlational or regression analyses have been conducted to report the implication of trickle-down effects and to examine whether or not performances of elite athletes at international competitions (e.g., at Olympic Games) inspire others to become active and partake in sports in successful sports nations (De Bosscher et al., 2013; Feddersen et al., 2009; Frick & Wicker, 2016; Hindson et al., 1994; Hogan & Norton, 2000; Misener et al., 2015; Sipway, 2012; Weimar et al., 2014; Veal et al., 2012; Wicker & Sotiriadou, 2013). The limit of these studies is, however, that we can only observe if success correlated with membership figures. Previous studies have indicated either inconclusive or a lack of systematic (trickle-down) association between elite sporting success or hosting international sporting events and an increase in sports participation.

Hogan & Norton (2000) profiled the sports funding policy of the Australian Sports Commission (ASC) from 1980 to 1996 toward 2000 Sydney Olympics. The cost/benefit effects of a trickle-down model on Australia were examined by looking at two aspects of ASC's approach: 1) elite sporting success in international/Olympic events and 2) participation rates in sports and sports activities by Australians. Australia increased the number of medals won and placed higher in the medal count ranking at the Olympic Games during the late 20th century, indicating international/elite sporting success. As mentioned earlier, Australia is ranked in the second after the U.S. in the Olympic medal counts in the sports of competitive swimming (up to 2012). The authors emphasize that this is in large part due to increased federal funding pattern to elite sports program. They also estimated that a 5% increase in participation and doubling the participation rate would result in an $881 million and $17.5 billion rise in funding, respectively. However, *no* evidence suggests that a positive trickle-down effect on sports participation was revealed in this study as an increase in the sedentary population in Australia was demonstrated over the study duration in the study ($r = 0.66$, $p < 0.05$). The authors also state, by referencing a previous study, that major influences regarding children's participation in sports in Australia result from school activities and peers but not from elite athletes (their role model (Stevenson, 1995). Australia had a 1.30% growth rate in population during the study duration according to the website of Australian Bureau of Statistics (http://www.abs.gov.au), while that in sedentary population in adults was estimated as a 3.71%. These data may imply a conclusion for no positive trickle-down effect of elite sporting success on sports participation. Hindson et al. (1994) have also shown null trickle-down effect of elite sporting success in the case of New Zealand. The authors argue that more success in Olympics may not be a simple marketing strategy for promoting grass-root sports participation but may negatively contribute to such administrative challenges.

De Bosscher et al. (2013) explored the relationship between membership data and athlete success in 20 sports in Flanders from 1992 to 2007. In six out of 20 sports (badminton, basketball,

handball, fencing, football, and volleyball), there were no or very limited successes at international competitions, and three sports (swimming, kayaking, and table tennis) showed negative relationships (improved elite performance but decreased memberships). Only four sports (athletics, gymnastics, judo, and tennis) achieved a consistent trend in success over 15 years. In the successful Flemish sports (equestrian events, sailing, rowing, and archery), no correlations were found. Thus, the authors could not identify consistent relationship between membership levels and elite sporting success across 20 sports or provide adequate evidence to support a trickle-down effect.

Frick & Wicker (2016) addressed the effect of international sporting success on participation in German Football Association: how title wins of the German football teams (both sexes at World Cups and European Championships) affect the number of and the percentage changes in individual club memberships, clubs, and teams from 1950 to 2014. Men's team had won the title seven times and women's team had it ten times. The regression analysis, controlling monthly income and weekly working hours per employee, suggests that only a men's World Cup title had a positive effect on football membership (a 2.9% increase in amateur memberships, a 4.7% increase in clubs, and 7.3% increase in teams at the post World Cup years).

Feddersen et al. (2009) examined international sporting success in tennis and the growth rate in participation from 1974 to 2007 in Germany by accounting for general developments in participation in other sports. The authors specified three tennis heroes: Boris Becker (professional career, 1984-1999), Stefanie Graf (1982-1999), and Michael Stich (1980-1997). A difference-in-difference method with fixed-effect regression models was implemented to compare the yearly or periodically differences in the membership of the German Tennis Association to those of all other 25 sports federations in Germany. The overall increase in sports participation in Germany during study period (34 years) was 92.5%: the lowest in rowing (6.7%) and extreme growth rates in golf (1830%), badminton (530%), and volleyball (435%). In tennis, the numbers increased by 300% from 1974 to the mid-1990s, and a decline in the

numbers began in the mid-to-late 1990s. Annual growth rates in tennis increased, on average, by 11.8% from 1974 to 1985 before the three heroes appeared, and 2.9% from 1986 to 1994 during their prime period, but decreased by 3.1% from 1995 to 2007 (during their prime period and after their retirement). The results show similar figures between overall and youth membership numbers. The authors admitted no positive but relatively negative effect of the German tennis heroes on tennis membership numbers in Germany, thus no trickle-down effect. Similar, no connection between elite sporting successes and increases in sports participation in Olympic sports in Germany has also been demonstrated by Weimar et al. (2014).

In addition to the effect of sporting success by actual elite athletes and their performance on participation, hosting international or elite sports events as a means to increase mass participation is common. The results of empirical analyses, however, are null (Misener et al., 2015; Veal et al., 2012), positive (Sipway, 2012), or limited to certain groups of people (Weimar et al., 2014; Wicker & Sotiriadou, 2013). Like elite sporting success, there appear to be no differences in membership rates between adult (senior) and youth athletes. Sipway (2012) examined benefits of the London 2012 Olympic and Paralympic Games on the aspects of social, cultural, economic, and environmental legacies. Although positive relationships were identified, the author arguably states that "priority should be placed to support grass-roots participants and community, and not only elite-level sporting development, especially through more access to sporting opportunities."

The results of the previous studies regarding the trickle-down effect on sports participation contradict the sports policies and the administrative approach of many national sports federations. Identifying the relationship between the elite sporting success and mass participation is not straightforward, and true impact of the trickle-down effect is difficult to determine in empirical studies due to other confounding factors. These confounders include social, environmental, financial, and economical factors, such as availability of sports infrastructure, friendship and networks with peers,

school, accessibility to sports for all ages, and income. As such, these study outcomes do not answer questions about why and how the relationship between mass participation and elite performance exist, nor do they provide insights into the mechanisms of changes associated with any variable. Nonetheless, the above studies have highlighted shortcomings of the trickle-down effect and acknowledged possible factors influencing mass participation more than elite sporting success.

Even if the trickle-down effect exists, it is a short-term effect followed by an increased dropout rate and may only work for certain groups of people. For example, the effect may only happen in the post-Olympic years in major, popular sports for successful sports nations. This suggests that media-coverage of athletes and sports events is inherently and substantially associated to the trickle-down effect. Regarding media-coverage, sponsorship and organization's participation structure to sports or sports events impact the trickle-down effect. For example, in the study of Frick & Wicker (2016) regarding success in men's and women's German soccer teams, a link between Word Cup and European championship titles and mass participation was only evident in men's side. Although the women's team has won more titles, it is apparent that men's soccer obtains more attention (popularity, sponsorship, and media-coverage, etc.). Network effects and peer-friendships also influence mass participation, especially in youth sports. It has also reported that trickle-down effect may impact only already-active people, and such populations may be inspired by elite athletes and peers to start other sports (Misener et al., 2015). It is also argued that the trickle-down effect results in a significant increase in dropout rates the year following an international event. To depict examples of these shortcomings and possible influence of trickle-down effects, the following figures and data using USA Swimming (USAS) membership rate and success at international competitions are shown.

USAS has publicized the number of registered swimmers (Membership statistics report, USA Swimming)) every year for the past three decades. Figure 2.2 shows the USAS membership history for absolute numbers (total, women and men combined) and yearly change (%, [a year – previous year]/

previous year x 100). Membership has been increasing consistently over the past 28 years of USAS history, except for some years (1988, 2002, 2004, 2014, and 2015). It has approximately doubled since 1988 (2.2 times and 120.4% more in 2015 as compared with 1988), despite the US population increasing only 1.3 times (31.3%) over that same time period. It is recognizable that competitive swimming has gained popularity in the U.S. and is one of the more popular Olympic sports, earning the most medals for the U.S. at every Olympic Games. The trickle-down effect appears to exist as abrupt increases in the membership, and is evident in the post-Olympic years (Figure 2.2). As stated in the literature, however, this is a short-term effect followed by an increased dropout rate, especially in recent years (2014 and 2015). To date, competitive swimming in the U.S. has gained mainstream media-coverage as the U.S. sports media influence the system of competitive swimming at Olympic Games (event schedule). This would highlight the media-coverage effect on mass participation in USAS (at Olympic Games) most recently, conceivably independent of USAS's success at international competition (Figure 2.3).

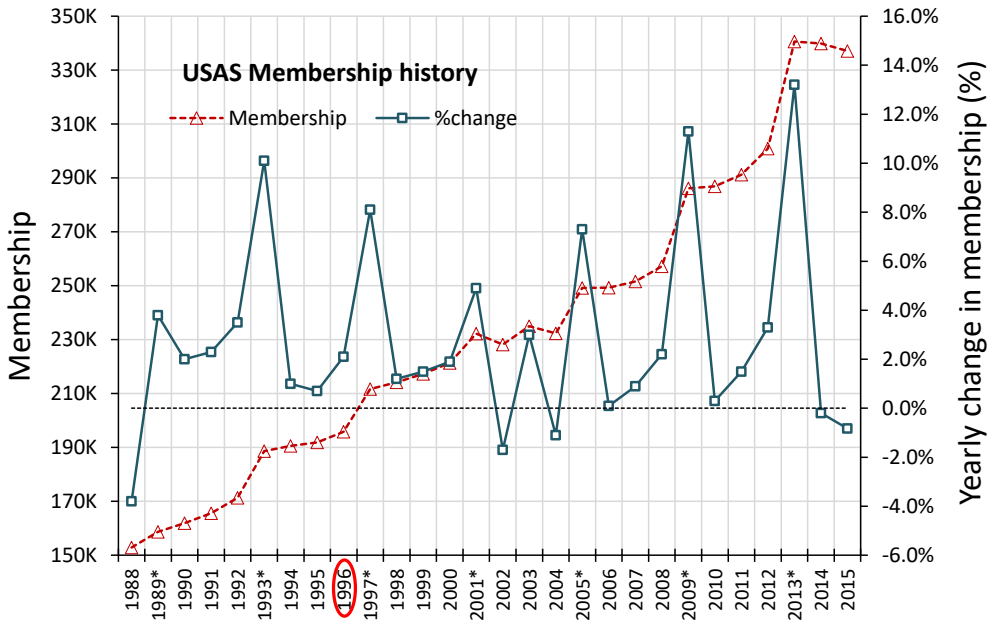


Figure 2.2. USA Swimming (USAS) membership statistics over the past 28 years.
* denotes the post-Olympic years; a circle denotes the year of Atlanta Olympics only when the U.S. hosted a major international swimming event; a dash-line across Figure 2.2 shows no (0%) yearly change in the number of swimmers, and plots below the line indicate that the membership decreased compared with the previous year.

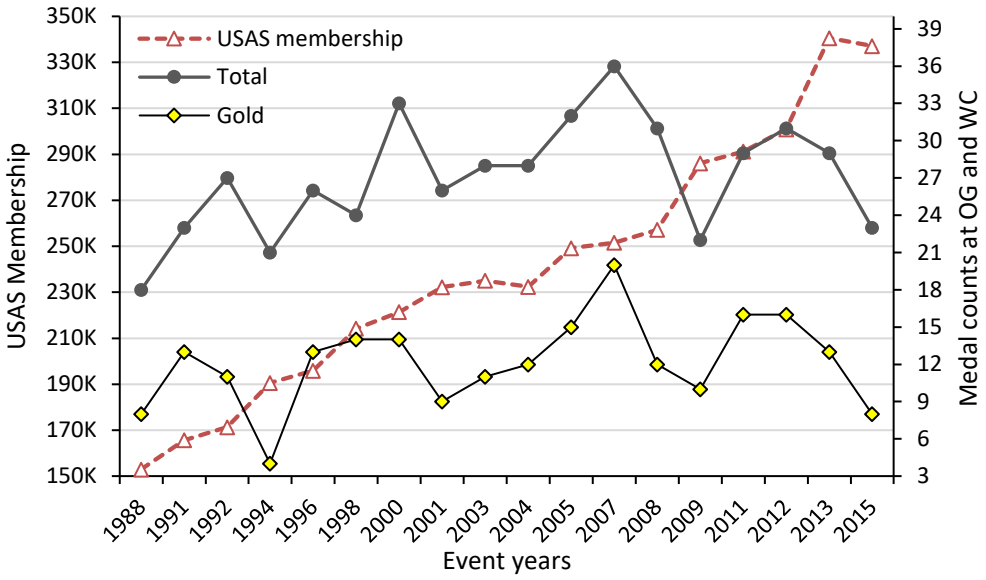


Figure 2.3. Membership and international competition success (total and gold medal counts at Olympic Games and World Championships of USA Swimming (USAS) for the past 28 years.
OG, Olympic Games (1988, 1992, 1996, 2000, 2004, 2008, and 2012); WC, World Championships (1991, 1994, 1998, 2001, 2003, 2005, 2007, 2009, 2011, 2013, and 2015).
Note: USAS membership from 1988 to 2015 was correlated to US population ($r = 0.970$, $p < 0.01$) but not with total medal counts (black-filled circles; $r = 0.349$, $p > 0.05$) or gold medal counts (yellow-filled diamonds; $r = 0.239$, $p > 0.05$).

In fact, an increase in membership over the 28 years simply has a higher link with an increase in US population per se ($r = 0.970$) as compared with international success ($r = 0.24$-0.35). In addition, the U.S. has hosted a world-class swimming competition only once (1996 Atlanta Olympics) in the past three decades. The relative change in membership in 1997 is not as high as some others post-Olympic years. Although the sample size is very small, this result combined with previous studies suggests that elite sporting success and/or the hosting of elite sports events may not be an essential factor for, or a direct contributor to, mass participation.

Again, correlation analyses and visual inspection of international swimming success and membership rates does not draw a causative mechanism of the relationship (e.g., whether or not an association between elite sporting performance and participation rate attributes more success to a top-

down or bottom-up approach). It may be anticipated that an elite sporting (USAS') success at international competition would affect membership differently across ages. For the top-down approach, we must see some lagged correlations between Olympic years and membership rate to illustrate an implication of the trickle-down effect as shown in Figure 2.2, while the inference of the effectiveness of the bottom-up approach may not see the same trend. In fact, the short-term effects of elite-sporting success are also seen in participation rates at each age category.

Figure 2.4 illustrates an increasing trend in USAS membership in boys and men swimmers aged nine to 19 years old, as well as improvements in the best performance in 45.7-merter freestyle speed (45.7Fr, $m \cdot s^{-1}$) for corresponding ages over the past 11 years. Dash lines (red color) present membership rates, and substantial increments or steep slopes are present at the post-Olympic years, though only for ages 15 and younger. As compared with the total sample (the bottom right figure in Figure 2.4), the curves of the membership rate across years in ages 14 & younger are similar to that of total sample. However, a consistent trend in best time progression across years for these adolescent ages does not seem to exist. In addition, statistical significance for the correlation between the two variables (membership and best performance in each age category over the 11 years) were only detected for ages 11, 14, and 17 years ($r = 0.71\text{-}0.77$, $p < 0.05$), shown at the right column of the top three figures. For older ages (age 19 and total sample), marked improvements in the best performance seen around years of 2008 to 2010 may be associated with an effect of 'technical suits'. Peaks of best performances seen between ages 10 (in 2010) and 15 (in 2014) are presumed to be achieved by the same individual. Therefore, a relatively right-upward (positive) curve in the best performance across the past decade in each category appears to be independent of 'Olympic- or media-effects' or USAS' international success (Figure 2.4).

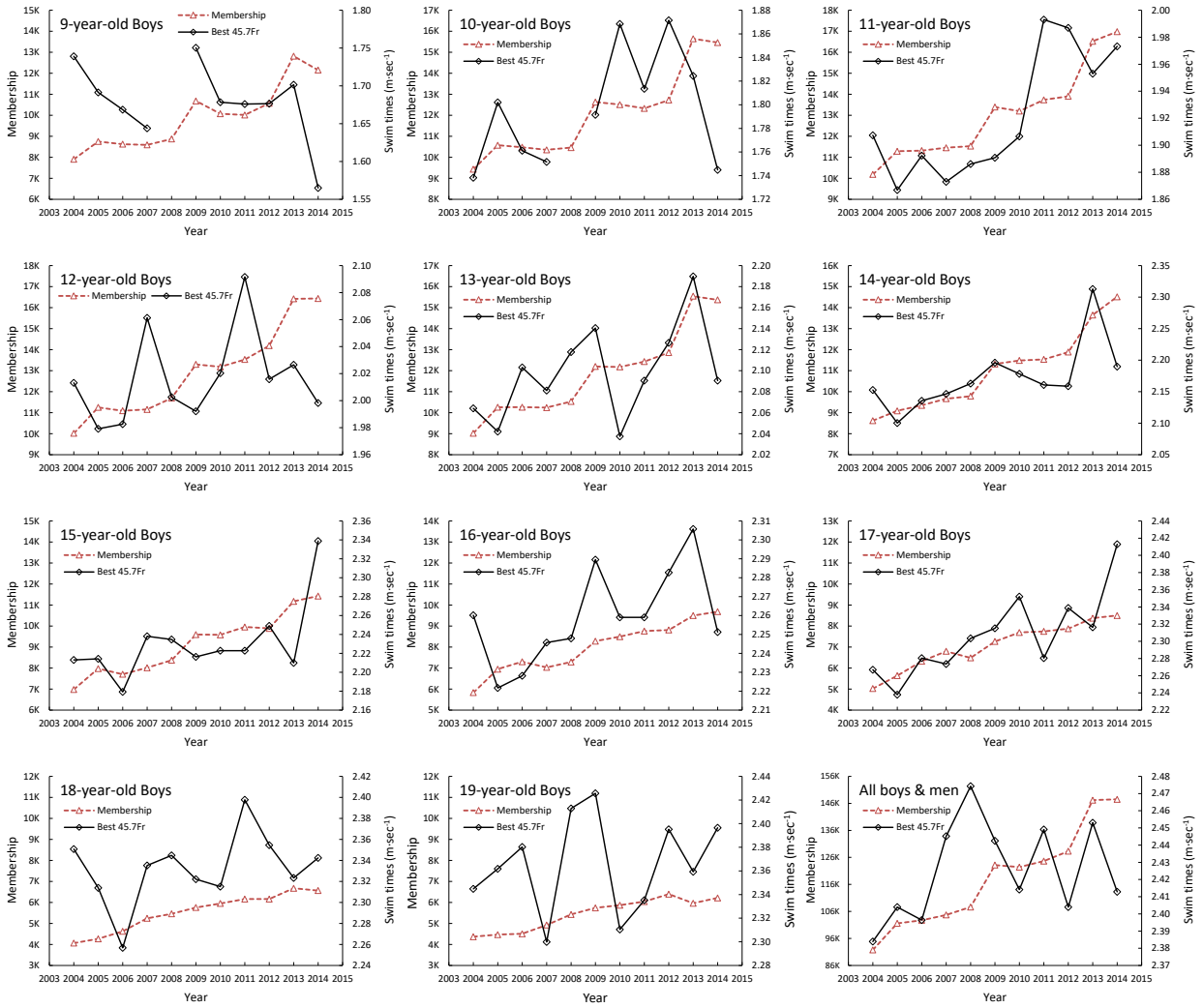


Figure 2.4. Changes in the best performance in 45.7-meter freestyle (45.7Fr, $m \cdot s^{-1}$) and membership in US boy and men swimmers as a function of year (2004 to 2014) for 11 age categories and total sample. Note: See APPEDIX I for figures with scale-matched Y axes.

As opposed to the inconclusive scientific reports analyzing the top-down approach, the bottom-up approach (efforts on increasing sports participation to promote elite sporting success) appears to have been collected good analytical rationale and empirical promise (Charness & Gerchak, 1996; Cornett & Stager, 2015). The bottom-up approach presumes that an increase in membership will result in an increase in the best performance of a group, which is clearly seen in sport domains such as chess for Russia, soccer for Brazil, ice hockey for Canada, basketball for the U.S., etc. Group size would ultimately

be a vital factor for producing high performance of the group. Accordingly, the relatively upward-right (positive) sloping curve in performance across the past decade (Figure 2.4) may be more influenced by increasing membership numbers. It is noted, however, as Australian Sports Commission states (1994, page 9), that 'participation levels can be only one factor to determine elite success as other factors such as social, economic, geographic, political, and quality of development opportunities have an influence'.

Early talent identification and development (TID) programs

Excelling at senior elite levels conceivably provides inspiration to spectators, potential rationale for maintained or increased funding, and increased participation in the sport. Currently, data support the bottom-up approach as a most effective means of enhancing elite performance. Increasing the number of participants contributes to increasing likelihood of producing elite performance of a given group (Charness & Gerchak, 1996; Cornett & Stager, 2015). Accordingly, developing appropriate and effective training paradigms for pre- and peri-adolescent athletes, ultimately contributing to their future high-level performance, is a challenging subject for coaches and scientists alike.

In conjunction with the top-down and bottom-up approaches, sports authorities conventionally conduct and deploy a proactive and extensive strategy to promote elite sporting success. This strategy is known as a talent identification and development (TID) program, which is also affiliated with the sports policy framework proposed by DeBosscher et al. (2006; the pillar 4 in Figure 2.1). Previously, TID had been initiated and utilized in Soviet Union and Eastern bloc in the 1960s. The rationale behind this enormous investment was that performance outcomes would be enhanced if the preparation began at earlier ages. If the right children were oriented to the sports where they best fit, the amount of training under appropriate supervision would push human performance to new heights. Training within these programs was 'scientifically' organized and monitored by experts (Gonçalves et al., 2012). 'Talented,' 'gifted,' or outstanding young athletes are selected into TID programs at given ages typically on a basis

of: 1) ranking within age-group or -category, 2) certain standards and times, 3) subjective judgement by stakeholders, or 4) physical or physiological performance tests and tasks assigned to athletes. This approach has been accentuated with impressive performances of (young) athletes at international competitions in such countries, and led other countries advocate for similar systems favoring early specialization.

In addition, as repeatedly discussed in the literature in the past decades through a 10-year rule (Simon & Chase, 1973), the power law of practice (Newell & Rosenbloom, 1981), and deliberate practice (Erickson et al., 1993), it is clear that a large volume (quantity) and a high level or intensity (quality) of practice and training are required for attaining proficient performance, ultimately allowing athletes to achieve elite levels. Deci & Ryan (2000) have suggested that "it is crucial to build a solid foundation of intrinsic motivation at early stage to be a highly motivated, self-determined, and committed senior athlete." These concepts have led to awareness of early specialization and draw attentions of sports organizations and coaches into TID programs. A key argument here, and the assumption behind TID programs, is that 'experts are always made but not born' (Erickson et al., 2007). Furthermore, the theories behind TID program have been supported by extensive results of positive relationships between practice hours and accomplishment levels in triathlon and swimming (Baker et al., 2005; Helsen et al., 2000; Hodges et al., 2004). Deliberate practice is considered to be effortful and engaged in with the purpose of improving performance in a specific domain (Erickson et al., 1993; Hodges et al., 2004), requiring specialization and intensification of practice and training. However, if one considers that the logic behind TID programs is fatally flawed, the approach for maximizing youth potential much be reevaluated.

Youth sports coaches generally implement structured training programs and early specialization with less diverse extracurricular activities at early adolescent ages (Fraser-Thomas et al., 2008a & 2008b, Malina, 2009a; Vaeyens, et al., 2008 & 2009). Such training paradigms are typically employed in older

adult athletes to attain high performance levels; however, their effectiveness on young athletes is unknown. In addition to lack of science-based knowledge for appropriate training paradigms for children and adolescents, coaches focus on short-term performance outcomes and immediate success of their athletes, creating unnecessary and sometime detrimental stress. This approached can lead towards a general trend of (too) early specialization and intensification (Barreiros et al., 2014; Faigenbaum, 2009; Fraser-Thomas et al., 2008a & 2008b; Gould et al., 1996; Hecimovich, 2004; Malina, 2009a & 2010; Martens, 1996; Martindale et al, 2005 & 2007; Petlichkoff, 1996; Vaeyens, et al., 2008; Wiersma, 2000). Early specialization in sports has been shown to cause risks (Malina, 2010), such as: social isolation, overdependence, burnout, manipulation, injury, etc. These concerning risks associated with early specialization overwhelm the potential future stars and result in their burnout and/or dropout from youth sports participation. It has been stated that "a relatively large participation in a sports quickly narrows as dropouts accelerate, often in concert with TID programs (Hogan and Norton, 2000)." TID programs turn many potential participants away from sport and discourage the masses from becoming a part of the broad participation base (Bloomfiled, 1973; Hindson et al., 1994). Furthermore, habitually facilities, coaching, and sports science expertise focus on the development of 'talented' athletes in the continuum of elite athlete production. The fact that youth sports stakeholders favor outstanding children at given young ages demotivates new participants in the sports. As a downside of the short-term trickle-down effect, an increase in membership at the post-Olympic year has turned out an increased dropout rate two years after Olympic Games (Figure 2.2). The majority of these new participants are most likely new to the sport (a few may be returning athletes), and many times do not have the same level of expertise as their engrained peers. As mentioned earlier, with the current TID program paradigm, sport authorities and stakeholders must deal with the dropout issue.

In the field of sports, it is also recognized that very few among the large groups of athletes engaged can attain the highest level and aspire to be recognized as outstanding athletes. For example,

in USAS, out of 340,000 memberships, only roughly 50 swimmers for both sexes can qualify for the US Olympic team: the probability to be an Olympic swimmer in the U.S. is 0.015%. Early TID programs are deployed to facilitate elite sporting success and its process from youth to senior levels. If too much focus is placed on a few, top-level youth athletes, and results in a heightened dropout rate, TID programs, which should be derived from the bottom-up approach (increasing participants for promoting elite success), may be more detrimental to elite performance than helpful. However, the factual question remains as to whether early TID programs worth the investment. Though TID programs appear to be conventionally conducted in several countries, early talent selection based only upon performance at younger adolescent ages may result not only in disregarding and omitting a large pool of (other) athletes, but might also be carried out according to flawed premises in regards to predicting future performance.

Effectiveness of TID programs for senior elite sporting success

To illuminate the necessity or effectiveness of TID programs or specialized practice in children and adolescents in sports, many studies have retrospectively examined youth sports participation, success levels, and training biographies of senior elite athletes to detect predictors differentiating levels of senior success and attainments (Barreiros et al., 2014; Baker et al., 2003 & 2005; Bridge & Toms, 2013; Figueiredo et al., 2009; Güllich & Emrich, 2014; Hodges et al., 2004; Julio et al., 2011; Moesch et al., 2011; Ostojic et al., 2014; Schumacher et al., 2006; Vaeyens et al., 2009). The assumption is that top junior athletes selected into TID programs would maintain their top levels if TID programs are effective. In addition, successful senior athletes would have early specialized, and engaged in intense practice if the concepts concerning TID programs are correct. These studies, however, have consistently revealed that an earlier onset of discipline-specific training and competition (early specialization and

intensification) appear not to be associated with greater success in senior international or elite-level performance.

In predicting senior-level success (elites) from youth-level success, previous studies have retrospectively investigated competitive athletic careers of senior elite cyclists (Schumacher et al., 2006) and national squads in multiple Olympic sports (Barreiros et al., 2014) to report an association between early and late international athletic success. Both studies conclude that approximately *one third* of senior elite athletes examined appeared as top juniors. Schumacher et al. (2006) examined 4432 athletes from 77 countries in all road and track cycling events, and early success (top junior level) was determined by participation in major junior international competitions for age 18 & under cyclists. The conclusion of Barreiros et al. (2014) were derived from the average of three sports in girls (volleyball, swimming, and judo) and four sports in boys (soccer, volleyball, swimming, and judo), resulting in 395 pre-junior top athletes aged 14-16 or younger (depending on sports) in girls and 16 and younger in boys. In swimming events, the minimum age for top juniors were set at 14 years old for girls and 16 years old for boys (Barreiros et al., 2014). The top-level retention rates were examined at age 17 years for girls and age 19 years for boys and similar between sexes (33% in girls and 30% in boys). One third may be a small proportion or can be a relatively large number although it would depend on some criteria of retrospective analyses used in the studies.

Careful attention must be paid to study population (age) within the investigated sports. Using older age criteria for early success (baseline) and a short study period (2-4 years) presumably yield a larger proportion of top junior athletes attaining elite levels in senior competitions as compared with a longer study period (> 5 years). Combining multiple sports events to establish the relationship between early and late success can be problematic. This is especially important as sports-specific ages at the onset of training have been demonstrated (Vaeyens et al., 2009), meaning that children tend to start their training earlier in certain sports than others. Patterns of sports participation across adolescence

and lifetime have been reported to be different among sports (e.g., team sports vs. individual sports) (Lunn, 2010). Many sports are not well-organized or provide an opportunity to compete as young children. This would also be associated with development or availability of youth sports programs or junior national teams. Therefore, simply combining the results of multiple sports in terms of assessing top-level retention may compromise the study outcomes or 'sport-specific' results. These previous studies refer to relatively late adolescent ages as the baseline of 'early' success (junior national team members), and the results are drawn from the average of combined multiple sports. In fact, Barreiros et al. (2014) show various rates of top-level retention in junior and senior competitions among sports they examined (20-56%). To evaluate whether early athletic success can be a good predictor of senior success (more importantly possible effectiveness of TID program), one needs to consider sports-specific, long-term analysis of individual athletes (tracking performance prospectively or retrospectively) covering possibly entire playing periods.

Julio et al. (2011) retrospectively analyzed one sport for ten years. State-level competitive success in the sport of Judo (top four athletes or medalists in eight or nine weight-categories for six age-groups: ages 9-10, 11-12, 13-14, 15-16, 17-19, and 20 & over) from 2000 to 2009 were longitudinally investigated. The first three age-groups had nine weight-categories (n = 36 per age-group), while the other three had eight weight-categories (n = 32 per age-group). These groups were followed for their achievements (top four in the state competition/tournament). Their results show that on average, 5% in women (N = 202) and 7% in men (N = 204) attained medal winning status (the top four) for 10 consecutive years. The authors do not describe any change in weight-categories of the athletes during the 10-year period, which is assumed to have occurred, nor information regarding dropout rate during the study period. In addition, it was concluded from the study outcomes that early success (i.e., being the top four athletes) in age 9-10 category) does not predict senior success (i.e., top four again in 20 & over age-category). However, the same tendency toward a 10-year decline in the number of medal

winners was observed across all six age-categories. The top-level retention rate for the 10&U athletes in 2000 to 2009 for 10 years (ages 10 to 20 years) was the same as that for 20 & over athletes who had competed from 2000 to 2009. Thus, this finding suggests that a success today does not predict a success in 10 years. Not only for early successful young athletes but also for any given age, a current performance status (success) does not predict or guarantee anyone's future performance success. Exponential dropout observed in the study of Julio et al. (2011) may simply be the nature of "selection" in successful athletics or depict a general nature of long-term success in an athletic event: fade-out or regression phenomenon. For example, it is hypothesized that retention rate of the medal winners in older age categories (e.g., age 17-19 and 20 & over categories) would be higher as compared with that of younger categories. However, this was not true in the study by Julio et al. (2011). Although it is expected that socio-economic status (amateur or professional athletes) and other factors would influence athletes' continuation (participation and training) in older ages, further analysis of this matter (a similar trend in long-term sustainability in athletic success among different ages) is difficult to ascertain.

Similar results have been shown in a critical review of the efficacy of early TID and promotion programs (Vaeyens et al., 2009). The authors note unpromising outcomes of early TID programs (i.e., early specialization) as such attempt does not appear to be an indispensable precondition for future athletic success. Mainly, a very low proportion of children selected in TID programs at young ages appeared to attain senior international athletic success. In the worst case scenarios, few of those selected continue playing the same sport at the late adolescence. For instance, German research groups found that 0.3% of young athletes selected for an early TID program for Olympic preparation (N = 4972 in seven Olympic sports) became the top 10 world athletes at senior level in seven years later from the early TID program (Güllich et al., 2001). The same group reported that Olympians who were recruited to youth TID programs or elite sports school (up to the age of 12 years old) did not attain a medal.

However, 18% of the medalists were recruited to TID programs at 13-15 years, and 56% were selected at even older ages (Vaeyens et al., 2009). These findings indicate that early TID programs do not seem to produce future elite senior-level athletes. Therefore, it was suggested that short-term effects of target-oriented, purposeful youth sports training programs and competition can produce adverse effects on long-term development.

Ostojic et al. (2014) conducted a prospective cohort study tracking 55 youth soccer players at age 14 years in Serbia and again in eight years later (at age 22). The authors examined 1) senior-level elite competence (being a national team member or playing one or more seasons for clubs in the top five European soccer leagues), and 2) whether maturity-level at age 14 would distinguish the senior-level elite competence. Biological age of the youth soccer players was measured using skeletal age (TW3 method, Tanner et al., 2001). The authors reported that 16 players out of 55 (29.1%) achieved the top professional level, and 32 (58.2%) players played for sub-elite-level club (national or other international leagues). There was no information regarding the seven (12.7%) players not included in these groups, although they are presumably classified as dropouts. Out of the 16 elite-level soccer players, majority (60.1%) were late maturing children at age 14, and 38.1% and 11.8% were normal and early maturers, respectively. Therefore, the authors supported previous studies critiquing the ineffectiveness of maturity-based early TID programs and maturity-related disparity in success in youth soccer. The later finding regarding early talent selection and maturational status (timing and pace) has been well documented in literature, and in fact, this has been advocated for the main confounding but causative factor for ineffectiveness of TID programs.

Figure 2.5 shows the summary of relative distributions of boy youth sports participants by maturity status: top, an American football team in central Michigan (Malina et al., 2005); bottom, combined results of six studies. Maturity status was estimated on a basis of predicted mature (adult) height using Khamis-Roche protocol (Khamis & Roche, 1994) or skeletal age (Malina et al., 2004) and

classified into three groups (early, average, or late based on his z-score for percentage of mature height or the difference between his skeletal and chronological age). These data suggest that late maturers may not be selected for the members of a sport team or simply not on teams over early maturing peers during early to mid-adolescence. In fact, early talent selection typically favors youth athletes with advanced maturity status, and late maturing children have less chance to be selected over early maturers (Figueiredo et al., 2009; Malina, 2009a & 2011; Malina et al., 2005). In other words, early maturers are typically successful youth sports athletes. Early maturing children dominate a youth sports competition and account for the majority of those in TID during adolescence (Figueiredo et al., 2009; Kanitz & Bar-Or., 1974; Helsen et al., 2000; le Gall et al., 2010; Malina et al., 2005; Malina, 2009a & 2011; Ostojic et al., 2014; Till et al., 2014; Torres-Unda et al., 2013). However, late-maturing children tend to catch up to their counterparts at late or post adolescence and appear to dominate senior-elite/professional levels. Therefore, maturity-related disparity and superiority in sport performances are suggested to be transient. Data of le Gall et al. (2010) indicate that youth soccer players in a top youth academy who became professional or international players were more likely to be late maturing individuals when compared with those who ended up as amateur soccer players. A greater potential for development and improvement in physical capacity and function, and consequently sports performance, has been documented in late maturers, while their precocious counterparts gain very little or no growth- and maturational-related advantages at the time (Lefevre et al., 1990; Till et al., 2014). These support the data shown in the study from Ostojic et al. (2014).

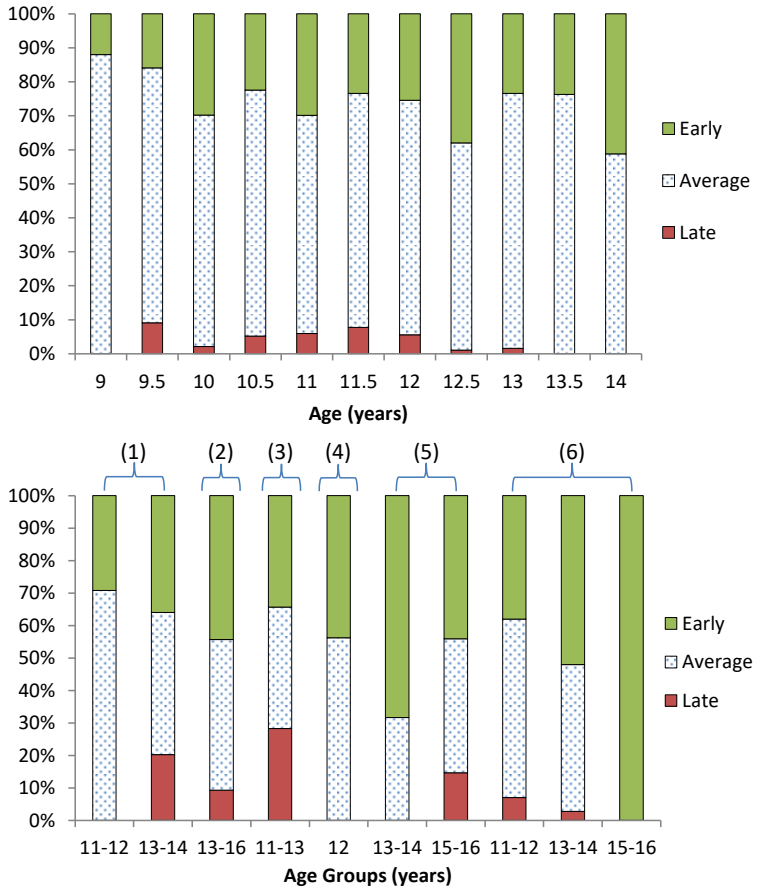


Figure 2.5. Relative distribution (%) of estimated maturity status in boy youth sports players for respective age-groups and sports.

Note: top figure, Malina et al. (2005: football, N = 582); bottom figure, (1) Malina et al. (2005: football, n = 298 for age 11-12 and n = 83 for age 13-14), (2) Rochelle et al. (1961: baseball, N = 62), (3) Krogman (1959: Ice hockey, N = 55), (4) Bouchard et al. (1969: Pee Wee hockey, N = 205), (5) Lariviere & Latfond (1997: soccer, n = 68 for age 13-14 and n = 85 for age 15-16), and (6) Malina et al. (2000: soccer, n = 63, 29, and 43 for age 11-12, 13-14, and 15-16, respectively).

One limitation concerning the data in Figure 2.5, however, is that no study has examined the distribution of maturational status in late adolescent age categories, such as 17- and 18-year-old. Given that later maturers must catch up to early or average maturing children during late adolescent ages in terms of their sports performance, it is required to investigate the distribution of maturational status up to post adolescent ages. Nevertheless, a late maturing status is disadvantageous for playing time in team or contact sports. It may also be difficult for late maturing children to join a team at late

adolescent ages despite a child's interest. It is assumed that children who enroll in a sport at an early age learn more technique and have a better fitness regardless of maturity status, while late enrollments put the children behind experienced peers in terms of getting opportunities to practice, train, and play in a game. Late maturers may have difficulty acquiring the same skills as compared with early or average maturers and may withdraw from a sport before they become mature. In addition, coaches may not accept late enrollment to facilitate immediate success of their team. Despite these data, the questions remain: is the trend within a team shown in Figure 2.5 seen in individual sports, such as swimming, tennis, and track & field, and is the proportion of later maturers also low in such individual sports?

An inevitable consequence would be that the documented consistent research findings regarding a high potential in late maturing children for senior athletic success make a considerable impression on coaches and their guidance of early maturers (e.g., see the conclusion of Lefevre et al., 1990), resulting in discounting early successful athletes and their presumed lesser athletic potential. Timing and pace of maturational events and sport success are not within the control of a child, and as a result, a long-term athlete development programs must be organized accordingly by stakeholders for youth athletes. It is suggested in most of the above-mentioned literature that appropriate training programs considering long-term developments for youth athletes must be prioritized for long-term participation and success in sports. Diverse domains and a large number of memberships would ultimately be vital for producing high performance of a given group leading to or conceptualized by the bottom-up approach, or at least for increasing the probability of expertise or elite performance within that group. Disregarding a youth athlete at any point during their adolescent development period would negatively affect the potential prosperity of competitive sports (elite sporting success). It is conceivable that a success in organized youth sports programs can be, in part, defined as a situation where youth athletes continue and pursue their career in the same sport for a long period of time

without withdrawing (bottom-up approach). Therefore, dealing with participant retention along with long-term developing of performance of young athletes needs to be urgent goals of coaches and youth sports organizations for their ultimate success.

Issues regarding dropout also arise from other facets of youth sports systems, such as age-groupings, in addition to talent selection criteria. Once again, considerable inter-individual differences in maturity status and maturation-related disparities in sports performance among adolescents have been well documented within a population (Baxter-Jones, 1995; Kojima et al., 2012; Lätt et al., 2009a, 2009b, 2010; Malina et al., 2004; Moreira et al., 2014; Pelayo et al., 1997; Saavedra, Escalante, & Rodriguez, 2010). Age-group classifications combining multiple ages into a single competitive group or talent selection based on performance at any given young adolescent age-group only work to emphasize targeting of those older-aged children, both chronologically and biologically, with superior performance within that group. Therefore, maturational consideration for youth sports athletes and performance is very important in an attempt to increase the likelihood of participation retention. It is also important for evaluating appropriateness and effectiveness of training paradigms prescribed to the young athletes, providing effective transfer from a training to actual sporting/competition performance, and more importantly deeming long-term athlete development. In order to provide insights into these topics, next sections discuss factors that influence athletic performance and progression of adolescents with specific reference to swimming from 1) anthropometric and maturational points of view; 2) developmental youth sports training patterns for senior-level success; and 3) ethnic and/or geographical variations in timing of growth and maturation.

2. Factors that influence sports performance and developmental pathways during adolescence

Anthropometric and maturational factors

Growth, development, and maturation occur during the first two decades of human life. Its timing and pace (rate) are considerably different among children because dynamic control of adolescent growth is endowed by age- and sex-dependent interactions among key genetic, environmental, dietary, socioeconomic, developmental, behavioral, nutritional, metabolic, biochemical, and hormonal factors (Veldhuis et al., 2005). Hence, the developmental transitions of physical, cognitive, and psycho-socio systems from childhood to adulthood occur sequentially during adolescence but not necessarily at the same time. For example, a boy at a chronological age of 12 years old may not display the 'average' physical, mental, cognitive, and/or social development for someone of his age. Therefore, adolescence often confuses or compromises decisions (or intuition) of adults, such as youth sports coaches and scientists, working toward training and improving future athletic success of young individuals. Inter- and intra-individual differences associated with adolescent growth entail a challenge for youth sports coaches and organizations in the evaluation of future success.

Maturity status is often and commonly estimated by a somatic (height) growth, and used to ascertain the age at peak height velocity (PHV). A longitudinal approach is required for determining the age at maximum rate of growth in height during the growth spurt (Malina et al., 2004). Spanning from age 9 to 18 years old, this approach also serves as a landmark against other body dimensions and physical performance. For example, the ages at peak weight velocity and peak strength development in both sexes and menarche in girls have been revealed to occur after PHV (Iuliano-Burns, Mirwald, & Bailey, 2001). Allowing for variation among samples and in methods of estimating age at peak height velocity (PHV), the mean ages at PHV in girls vary between 10.9 and 12.2 years old, while those in boys are between 12.9 and 14.4 years old on the basis of the data of numerous previous studies (Berkey, Wang, Dockery, & Ferris, 1994; Beunen & Malina, 1988; Bielicki, 1975; Bielicki, Koniarek, & Malina, 1984; Bock & Thissen, 1980; Guo, Siervogel, Roche, & Chumlea, 1992; Hauspie et al., 1980; Lago et al., 1978; Ledford & Cole, 1998; Lindgren, 1978; Malina, 1988, Malina et al., 1997; Malina & Beunen, 1996; Malina

et al., 2004; Mirwald et al., 1981; Preece & Baines, 1978; Tanner, Whitehouse, & Takahashi, 1966; Tanner et al., 1976; Taranger et al., 1976; Thissen et al., 1976; Wafelbakker, 1970; Zacharias & Rand, 1983). Reported standard deviations (SD) for the mean ages at PHV range from 0.7 to 1.3 years old in both sexes. It has been estimated that PHV occurs, on average (mean ± SD), 12.0 ± 1.0 years old in girls and 14.0 ± 1.0 years old in boys in North America or Caucasians (Malina et al., 2004), and these values are commonly referenced today. Based on the estimated mean age at PHV reported in previous studies, girls and boys who attain PHV before 11.0 and 13.0 years of age, respectively, would be classified as early maturing, whereas attaining PHV after 13.0 and 15.0 years of age, respectively, would be classified as late maturing. In addition, children attaining PHV 'on time' would be average maturing. At the age of PHV, children grow, on average, 12 to 15 cm per year in stature (Lindgren, 1978), while peak weight velocity has been reported as about 10 kg per year (Malina et al., 2004).

The age at peak velocities (gains) of weight, fat-free mass (FFM), fat mass (FM), and bone mineral content (BMC) in both sexes and menarche in girls have been reported to occur after PHV (Iuliano-Burns, Mirwald, & Bailey, 2001). Using anthropometry and dual-Xray absorptiometry, the authors measured annually 54 girls and 60 boys over six years. In their population sample, PHV occurred at age 11.8 ± 0.9 in girls and 13.4 ± 1.0 in boys. Peak velocities of weight, FFM, FM and BMC were found at ages 12.3 ± 1.2, 12.1 ± 1.0, 12.6 ± 2.0, and 12.5 ± 0.9, respectively, in girls, and at ages 13.8 ± 1.1, 13.7 ± 0.9, 14.0 ± 1.3, and 14.0 ± 1.0 in boys. Age of menarche was 12.7 ± 1.0. The trend in the sequence of peak velocities of the different tissues appeared to be consistent between sexes. Among other limited previous studies, ages at peak velocities of other body tissues appeared to be simultaneous with or within one year after age at PHV (Bailey 1997; Jackowski et al., 2009; Malina & Bouchard, 1991; Philippaerts et al., 2006; Rauch et al., 2004).

Athletic potential of an individual appears to be determined largely by the size and contractile characteristics of his/her muscles (Jones, & Round, 2008). Velocities of muscle growth are reported to

be closely associated with PHV (Borer, 2003). However, it is difficult to quantify true skeletal muscle size and mass. As a result, indirect anthropometric, physiological, chemical, or imaging analyses have been used for muscle mass measurements. The most common means to estimate whole body muscle mass is to measure FFM since skeletal muscle mass is the major component of FFM. Muscle mass explains somewhere between 30-40% and 40-50% of body mass and FFM, respectively, and they are highly correlated each other (Abe et al. 2003; Wang et al. 2001). Therefore, it is expected that as children increase their skeletal muscle mass during adolescence proportionally to body mass and FFM, and the peak values of adolescent muscle growth are also identified sometime after the age at PHV in both sexes. In fact, the cross-sectional data showing anthropometrically or chemically estimated muscle size or mass in children and adolescents closely follow growth in other body tissues during adolescence. This mass increases considerably with age, especially during the adolescent growth spurt (Malina et al. 2004; Tanner, Hughes, & Whitehouse, 1981). Sex-related differences in muscle size assessed by muscle cross-sectional area using magnetic resonance imaging do not appear until one year after boys' age at PHV (Deighan et al. 2006). Figure 2.6 shows changes in FFM in girls and boys during adolescence and the sex-related difference in FFM as a function of chronological age (top left figure) and the age at PHV (top right and bottom figures). In this sample, the average age of PHV in boys was 13.5 years and a marked increase in FFM in boys and greater sex-related difference are observed approximately one year after the age of boys' PHV, while girls are similar muscularity (FFM level) to boys until one year after the age of girls' PHV (top left figure). However, when expressing an increase in FFM relative to the age at PHV (right and bottom figures), standardizing somatic (biological/maturational) ages, boys are always bigger (more muscular) than girls, especially one year after the age at boys' PHV. The FFM velocity (annual gain in FMM) is always greater in boys during the growth spurt.

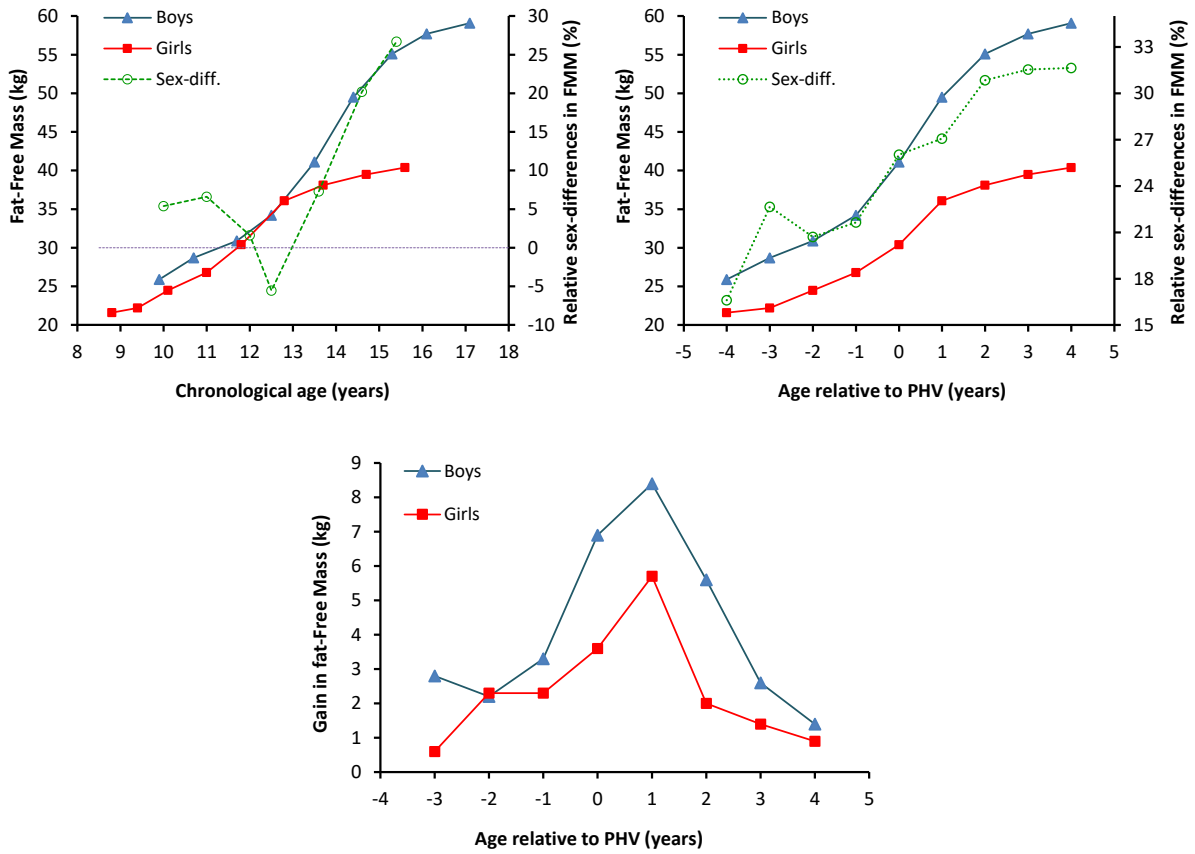


Figure 2.6. Changes in fat-free mass (FFM) in girls and boys and its sex-related differences plotted against chronological age (top left) and age in relation to peak height velocity (PHV: top right and bottom).

Data are derived from Malina et al. (2004) and recreated.
Note: the positive values in sex-differences (Sex-diff.) denote that FFM in boys is greater than girls.

These suggest that the age at PHV is an important indicator as a means of evaluating a child's maturational status and improvements in physical performance. It would seem logical to utilize the age at PHV as a long-term athlete development marker, to appropriate training methodology and timing of specialization in adolescent athletes. Karlberg (2002) emphasizes the importance of adolescence (growth spurt) and its timing in performance progression. Adolescent growth and development have been well documented to have a major influence on physical and psycho-socio aspects of day-to-day life

such as school performance and relationships with peers, and these factors are expected to have an impact on sports performance.

Height growth and swim performance

The development of physiological traits necessary for sports performance such as muscular strength and endurance, motor performance, and aerobic and anaerobic power in children is proportional to the timing of the adolescent growth spurt (height growth) and chronological age (Beunen & Malina, 1988; Heras Yague & de la Fuente, 1998; Malina et al. 2004; Roemmich & Rogol, 1995). The peak development of most physical performance tasks occurs around the age of PHV (Philippaerts et al., 2006). Motor development is the sequential, continuous age-related process whereby movement behavior changes (Haywood & Getchell, 2005). Although it appears improvements in neuromuscular performance in boys are subsequent events of height and muscle mass growth, improvements in girls appear to show variability (Malina et al., 2004). The improvement in swim performance during adolescence is also in response to and highly associated to the changes in physical size. The evolution of swim performance (50-meter freestyle) in non-skilled adolescent students aged 11 to 17 (961 girls and 1097 boys) has been reported in relation to age and anthropometric characteristics, such as height, weight, and arm span (Pelayo et al., 1997). The results show that swim velocity increased significantly with age for both sexes, ranging from 0.72 to 0.89 $m \cdot sec^{-1}$ in girls and from 0.77 to 1.09 $m \cdot sec^{-1}$ in boys. The authors also reported that swim velocity was significantly higher in boys than girls for all age categories with the exception of 12 year olds. To explain this result, anthropometric characteristics of the girls and boys at age 12 were compared and showed that the girls were significantly taller and heavier than the boys. In addition to height and weight, arm span in the girls aged 12 years was significantly longer than in boys of the same age category, which are similar results to FFM data in Figure 2.6. Therefore, the sex-differences in swim velocity were largely associated

with sex-differences in physical size. A more precocious status in girls in comparison to boys at age 12 presumably elucidated the sex-difference in swim velocity. After the age 12, the swim velocity in boys was consistently and significantly faster than the girls, and so were anthropometric values in boys. Stroke length was also shown to be one of the important factors for improving swim performance in non-skills adolescents as well as top-level swimmers (Lätt et al., 2010; Pelayo et al., 1994; Pelayo et al., 1997). Concerning this point, biomechanical factors that are critical to improved adolescent swim performance have been reported to be largely attributed to physical growth, i.e., increases in height and limb length (Moreira et al., 2014).

Kojima et al. (2012) have supported the findings of above studies. The age-related changes in swim performance using the US top 100 swimmers in each age between seven and 20 years during the years of 2005 to 2007 were reported. The authors showed that when age-related improvements (%) in swim performance are plotted (estimated annual improvement or gain in swim speed) along with the age-related height gain using US reference data, similar curves are observed. Further, it has been well documented that successful adolescent athletes including swimmers are often early maturers (Åstrand et al., 1963; Kanitz & Bar-Or, 1974; Malina et al., 2004). Given that the top 100 performing swimmers in the U.S. during the early adolescent ages were included in their analysis, it is likely that these top-level swimmers are early maturing children and the age at PHV occurred earlier than average. As a result, the peak improvements may have been displayed at age 10 and 12 in girls and boys, respectively (shown in arrows on Figure 2.7), instead of age 13 and 15 years as the peak gain in athletic performance have been reported to occur within a year from the age of PHV (on average, 12 and 14 in girls and boys, respectively). Thus, the swim performance analysis of Kojima et al. (2012) reflected a link between ages at PHV and peak improvements in swim performance. The data of Kojima et al. (2012) have also demonstrated that sex-differences in swim performance attenuate around the age of girls' PHV but are augmented after the age of boys' PHV (Figure 2.8), which is coincident to the physical size data (e.g.,

FFM shown in Figure 2.6) and support findings of Pelayo et al. (1997). Therefore, these data advocate that an improvement in swim performance occurs in a similar manner to an increase in physical size, and growth and maturational factors can be important predictors of swim performance progression during adolescence.

It is well documented that children with advanced biological maturity (early matures) are better performers in physical tasks, especially in boys (Malina et al., 2004), and it is understandable that early matures are typically taller, heavier, and more muscular than their chronologically age-matched, average or late maturing peers. Competitive swimming can be classified as sprint (or anaerobic) events as most of events last (much) less than two minutes in duration for proficient swimmers. As such, the ability to generate power and efficiently apply force against the resistance imposed by the water are seen as important limiting parameters, and considerable coaching effort may be focused on improving the muscular strength and power of swimmers. Consequently, it is presumable that advanced physical-size and maturity status of early maturing children clearly provide them with advantages in sprint swim performance (such as 50-meter freestyle) over late-maturing peers.

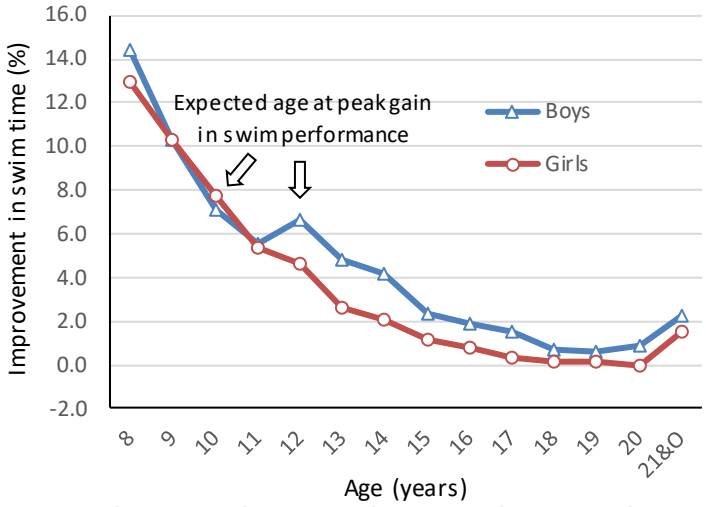


Figure 2.7. Age-related differences (relative improvements) in 50-yard freestyle time in the U.S. top 100 swimmers in each adolescent age (age 8 to 20) and the elite category (age 21 years and older; cross-sectional data).
Data were compiled from USA Swimming database (www.usaswimming.org).

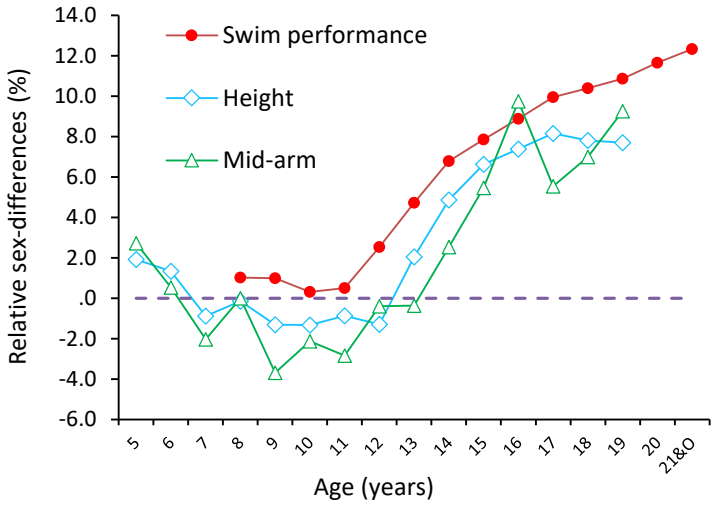


Figure 2.8. Relative sex-difference in swim performance and anthropometric measures as a functions of age (Kojima et al., 2012).
Positive numbers indicate boys are faster, taller, or larger than girls.
Growth reference data (cross-sectional) were obtained from McDowell et al. (2008).

Lastly, awareness of the importance of training to develop all fitness components throughout childhood and adolescence is imperative. It is principally because of variation in individual growth and maturational rates and because all components in children and adolescents associated with sports performance are trainable to some extent. Youth sports teams are always composed of early, average, and late maturing children whose responses to training stimuli are different or vary considerably. As shown in Figure 1.6 (rate of height increase and height velocity), height growth peaks after a few month of the birth, and its rate decreases and plateaus before the onset of growth spurt. During the plateau growth phase, a less development and improvement in motor performance has also been observed as compared with before or after the plateau (Malina et al., 2004). It has been reported that early maturers have a shorter duration of this plateau growth but a shorter total adolescent growth period (Malina et al., 2004). Late maturing individuals have a longer plateau growth period, which may leave them behind early and average maturing children in terms of athletic development, but a longer adolescent growth spurt period. These facts typically result in different adult stature (taller people are

reportedly late maturers) and are believed to cause a high potential in senior athletic performance (Karlberg, 2002; Malina et al., 2004). It is also noted that children may experience 'adolescent awkwardness' which is defined as a temporary disruption to motor coordination, especially developments of coordination and speed tasks, resulting from rapid growth of the limbs (Beunen & Malina, 1988; Lloyd & Oliver, 2013). This phenomenon is suggested to be associated with disproportionate growth in body dimensions. Growth in the lower-body length (i.e., legs) occurs, on average, before PHV, while the upper-body dimensions increase after PHV (Iuliano-Burns et al., 2001; Malina et al., 2004). It has been also reported that the impairments in motor performance occur within the 12 months prior to PHV (Philippaerts et al., 2006). Performance in motor tasks decline during the time of adolescent awkwardness' in some but not all boys, although boys who declined in performance were reported to be generally good performers at the onset of growth spurt (Beunen & Malina, 1988). It is assumed that adolescent awkwardness and such an impaired symptom may occur to a lesser extent in early matures, which may also contribute to their superior athletic performance over late maturing peers during adolescence. Therefore, it is important for youth sports coaches to keep in mind that carefully monitoring physical growth and performance progression in their athletes over a long period of time allows the coaches to make informed and appropriate judgements regarding individual improvements and progression. In addition, these ideas would substantially help coaches avoid issues regarding early specialization and burnout, provide the stakeholders with the appropriate design of effective training and sports programs, and consequently optimize and prolong athletic development of adolescents.

Developmental youth sports training patterns for senior-level success

Researchers have challenged the above-mentioned questions of young developing athletes by characterizing factors, such as adolescent sports participation and training biographies of senior

athletes, with different athletic competence or elite-level achievements (non- or sub-elite, elite, professional, national or international athletes etc.). Characteristics of developmental training patterns during adolescence, which presumably lead to senior athletic success are introduced in the following section. The previous literature has typically concentrated on three items of empirical supports for adolescent developmental athletic regimes: 1) early specialization (and intensification), 2) multi-sport involvement (early diversification), and 3) developmental career path (timing of specialization and intensification). To date, many studies have investigated early specialization and its contrasting model, early diversification, alternatively at the same time. Since both models interact with each other during the time course of the adolescent development, for the purpose of conciseness, these two models are concurrently discussed first. Subsequently, interesting and important research findings regarding the connection among the stakeholders (coaches, parents, and sports organizations) and coherence among their perception toward developing youth athletes (e.g., ideas on TID programs and its effectiveness) are reviewed.

Early diversification and late specialization

Specialization in sports is defined as limiting participation to a single sport, training for and competing in on a year-round basis with deliberate focus on training and development in that sport (Hill, 1987). On the other hand, diversification is the participation in a variety of sports and activities through which an athlete develops multilateral physical, social, and psychological skills (Wiersma, 2000). Early specialization is characterized by and include four specific features: 1) an early onset of a sport; 2) early involvement in one sport; 3) early involvement in focused, high intensity training; and 4) early involvement in competition (Baker et al. 2009). The first, second, and forth features would be casually conceptualized as early 'specialization,' and the third feature would be 'intensification.' The catalysts of early specialization and intensification would be associated with multifaceted factors: social trend,

parents, coaches, sports-specific peak performance, weather/geography, socioeconomics, recruitment and scholarship, business interest and so on (Hill, 1987; Malina, 2010).

There has been, however, lack of evidence showing that early onset or specialization and intensification leads to the development of expertise in sports. Alternatively, most literature supports early diversification and late specialization in the development of highly successful senior athletic careers (Côté et al., 2007; Güllich & Emrich, 2014; Moesch et al., 2011; Vaeyens et al., 2009). Retrospective investigations have been conducted by several research groups in European countries, attempting to characterize various factors of youth sports training and competition career path (age of milestones) influential to senior athletic achievements. Güllich & Emrich (2014) examined the results of adolescent sports training and competition biographies of senior elite national athletes in Olympic sports in Germany, and reported to what extent youth athletic biographies lead to different levels of junior and senior elite athletic success (i.e., world class vs national level). World class athletes (WC) were defined as the top 10 athletes (places) at Olympic Games or senior world championships, while national level athletes (NL) were as national top 10 rankers with no international top 10 achievement (WC and NC athletes in the study did not differ significantly in the distribution of sex or sport categories). Results were categorized by the types of sports: 1) CGS sports whose performances are measured in centimeters, grams, or seconds, 2) artistic competition sports, 3) martial arts sports, and 4) game sports. The CGS sports examined were alpine skiing, track & field, biathlon, bobsledding, cycling, ice speed skating, kayak/canoe, luge, long-distance (cross country) skiing, rowing, skeleton, swimming, triathlon, and weightlifting. This sample of German senior national athletes in CGS sports (N = 305; 208 WC athletes; 97 NL athletes) demonstrated no correlation in attributes between the two athletic success groups at youth levels nor youth sports training biographies. NL had earlier ages of onset of intensive training (mean age 12.3 vs 11.0 years in WC vs NL, respectively; $p < 0.05$, Cohen's $d = 0.31$) and competition (mean age 13.8 vs 12.6 years; $p < 0.05$, Cohen's $d = 0.31$) in the domain sport. The mean

age of the involvement in the domain sport (complete specialization) was not significantly different (mean age 14.3 vs 13.0 years; $p > 0.05$, Cohen's $d = 0.23$). The authors suggest that early onset and specialization in the domain sport appear to contribute to early adolescent development and performance success (e.g., being junior national team members) but not necessarily to senior international success. In addition, higher international success in senior levels appeared to be associated with a greater and longer involvement in a variety of sports before specialization in their domain sports: multi sports experience (67% of WC vs 52% of NL, $p < 0.01$, Cohen's $d = 0.15$), training (4.7 vs 3.1 years in WC vs NL, respectively, $p < 0.05$, Cohen's $d = 0.32$), and competing (4.1 vs 2.0 years in WC vs NL, respectively, $p < 0.01$, Cohen's $d = 0.46$). These results indicate that early diversification and late specialization are the important factors for higher senior athletic success. However, interestingly, when comparing senior WC and NL athletes, the total amount of training sessions per week or year in their domain sport was not significantly different between groups at any adolescence ages. Although the number of hours these athletes practiced/trained each sport they engaged during adolescent ages are not clear, the results of Güllich & Emrich (2014) indicate that WC had not only more time in non-domain sports for a longer period of times than NL, but the same number of practice sessions in domain sports as NL during adolescence. Therefore, in a manner of speaking contributing factors for higher senior success, WC showed a tendency of early diversification and late specialization. On the other hand, when comparing above junior national-level (n = 220) and below junior national-level (n = 337) athletes (at age 14 years), characteristics of the training and competition biographies are not similar to what we saw for WC vs NL in senior athletes. As it may be expected, above national-level (highly successful junior athletes) had significantly less involvement and time in other sports (less diversification) and early onset of training and competition in their domain sports (early specialization) during adolescence. These results are in line with previous reports and would make sense from a practical point of view: more training at earlier ages (early specialization and intensification) leads to

earlier success during youth athletic career within a sport as compared with less training. For the sustainability of athletic success at late adolescent and into senior level and to achieve above national levels, certain levels of quality and quantity training and practice must be required for athletes as nature of competitive sports. However, it is noted that the criteria for grouping levels of athletic success (elite vs none-elite, super elite vs elite, and so on) needs careful consideration to draw a conclusion regarding the extent to which youth sports training and experiences differences in senior-level athletic successes.

Vaeyens et al. (2009) supported early diversification and reinforce the concept that 'involvement or experience in other sports at early ages may make the difference in senior success in the domain sport.' Côté et al. (2007 and 2009) have also proposed the upsides of early diversification (also interchangeably called as deliberate play) to promote the development of intrinsic motivation, increase self-involvement, and transform cognitive and physical skills across sports. It is also suggested that in the sports where peak performance is reached in adulthood, early diversification does not hinder performance of those future elite athletes (Côté et al., 2009). In addition, early diversification may fit the concept of varied practice within a practice session, scientifically called as "contextual interference" effects (Shea & Morgan, 1979). The authors explain that interference results from practicing various skills within the same session of practice: switching from one skill to another or changing the context in which a task is practiced from a trial to the next trial. High contextual interference is reported to lead to a poor performance during acquisition stages but enhances learning (e.g., better performance at competitions). Therefore, it applies more to long-term development and maintenance. It is conceivable that years of multi-sports participation and deliberate play at early ages facilitate children's development of a basic movement pattern, fundamental motor skills, and enhance their adaptability of movement production through adolescence. Consequently, with a combination of physical/biological maturation, those children who had exposed to multiple sports experience for a longer period of adolescent time are expected to have an increased chance to succeed at senior level athletics. It must

be noted that the link between early diversification and contextual interference is one of speculation and must be confirmed by further investigation. The results of Güllich & Emrich (2014) and Vaeyens et al. (2009) strongly advocate the importance of early diversification and multi-sports involvement; however, they fail to reveal what type of sports or sport combinations at adolescent ages make positive differences in future senior-level careers. Moreover, these studies do not show how many sports children should play during adolescence. Clearly, the more sports children participate in, the more time, energy, and support are required. However, those resources are limited, and the balance with academics and school-related activities (non-sport activities in daily life) is another important consideration.

Regarding the optimal number of youth sports enrollments needed to promote higher future/senior athletic success, Bridge & Toms (2013) have reported the influence of early diversification and late specialization on late adolescent athletic achievements in a UK context. The authors concentrated on the number of sports at early adolescent ages and how these were associated with later adolescent performance. Their finding shows an increased likelihood of being national or representative level athletes at late adolescence (age 16-18 years) with participation in three or more sports at early- to mid-adolescence (age 11-15). The results, however, showed that this may only be true of team sports, and not of individual sports. This was in agreement with Güllich & Emrich (2014) demonstrating that deliberate play at early ages was a significant predictor of senior success in game sports.

Moesch et al. (2011), whose results also support late specialization, examined the number of youth sports that Danish elite or near-elite athletes played and its association with levels of senior athletic attainment. Unlike the other studies, their results showed that an involvement in multi-sports during adolescence is not an important predictor of higher senior-level athletic success in a Danish context. The elite and near-elite groups had, on average, an involvement in 1.57 and 1.42 youth sports,

respectively, in addition to their domain sport ($p > 0.05$, Cohen's $d = 0.09$). The duration (years) of multi-sports participation during adolescence was not also different between groups. To explain the null contribution of multi-sports experience, the authors assert that the heterogeneous distribution of elite and near-elite athletes within Olympic sports in the study. However, it is once again expected that the contradicting findings between studies may be associated with criteria for grouping elite and near-elite athletes within Danish national athletes (top 10 in the world or below: Moesch et al., 2011), while the grouping criteria was based on international or national levels in the study of Güllich & Emrich (2014). Moreover, in terms of study limitation, both studies investigated and combined multiple Olympic sports to make a conclusion. The availability of and opportunity to join organized youth sports programs is different among sports. For example, training environments and programs for adolescents have been well developed and organized in the major Olympic sports, such as competitive swimming, track & field, soccer, and ice hockey. However, it would be difficult to find competitive youth programs in canoeing, kayak, or rowing, which are included in the above studies. Vaeyens et al. (2009) showed that children tend to start their training earlier in certain sports than others: e.g., ages at onset of training in swimming (8.1 ± 3.1, n =226) and hockey (8.9 ± 3.5, n =167) vs rowing (15.4 ± 3.1 n =283), shooting (15.3 ± 5.3 n =250), and volleyball (13.8 ± 4.3 n =125). Furthermore, sports participation pattern throughout adolescence and into adulthood have been reported to be different among sports (e.g., team sports vs individual sports) and between sexes (Lunn, 2010). Individual sports athletes, such as swimming, cycling, running etc., tend to have a longer participation sustainability than team sports (soccer basketball etc.) due presumably to socio-economic factor and playing time/opportunities. Therefore, these limitations make it difficult to apply the broad conclusions to a single sport, and have led to mixed results in the literature.

In regards to the late specialization concept, USA Swimming has tried to deal with the issue of early specialization using a program called IMX (individual medley extreme challenges), which promotes

young (age-group) swimmers to compete in all four swimming styles. Swimmers receive points based on their time in each stroke and event and are ranked nationally, and the top several performers are awarded annually. However, this effort by USA Swimming is not in line with research findings concerning early diversification, since all challenges with the IMX still happen within the sport of swimming. This idea may help coaches and swimmers to not focus on one specialized event and provide them with more chance to success in swimming. However, it creates a challenge with 'highly awarded systems' that can result in coaches' and swimmers' focusing on short-term success and early adolescent achievement. Therefore, any investigation or further research would be required to evaluate the program to see how diverse competition opportunities (late specialization in swimming event) influence longer-term performance progression of age-group swimmers in the U.S. as well as overall performance of USA Swimming (e.g., membership ratio and performance outcomes, esp., individual medley, etc.).

A question regarding appropriate developmental training pattern during adolescence for senior athletic success is whether or not these findings are also true for top pre-adolescent athletes and their achievements during adolescence into senior levels. The previous studies focus commonly on senior elite athletes, and what they did as youth athletes. Therefore, limited data have been available for top pre-adolescent athletes and their future, and to date, causative factors influencing the success-level retention and developmental careers in early successful (youth) athletes has not been proposed. From a stand point of maturation-related advantage in youth sports performance, if a child has superior ability in a sport, he/she is presumably better at many other athletic tasks in other sports than same-aged and/or late-maturing peers. Consequently, such top pre-adolescent athletes may play multiple sports successfully although once again, this is purely speculative as no such informative, empirical data are available. Conversely, a conventional trend appears to be that top pre-adolescent athletes are pushed to focus on a particular sport to fulfill their potential. This is in line with traditional beliefs as people presume 'talent' is stable (see Introduction, the bottom paragraph in page 2).

Developmental career path: timing of specialization and intensification

Timing of specialization and intensification of training during adolescence are also vitally important when considering successful development of senior athletic performance. Erickson et al. (1993) have contended that "the accumulation of practice hours need to match sensitive stages of biological and cognitive development during adolescence." To excel at and/or beyond an elite-level further deliberate, strategic process in timing of specialization and intensification are critical during late adolescence. A risk of dropout/burnout becomes heightened when specialization and intensification are conducted without a careful consideration of physical, physiological, psychological, and social maturation of a young athlete. As reviewed earlier, children can perform similar training regimens to what matured, adult athletes conduct. The key question, however, is whether or not such intense training is necessary for the youngsters' performance improvements, and what potential risks arise from implementing said training.

In regard to this point, Côté (1999) and Côté et al. (2007) have proposed to encompass adolescent ages with three time periods for the purpose of youth athlete development: 1) sampling years (ages 6-12), 2) specializing years (ages 13-15), and 3) investment years (age 16 and older). The sampling years involve a wide range of deliberate play activities. During years of sport specialization, there is an equal balance of deliberate play and deliberate practice in fewer sports, and individuals hope to excel in one of the sports later in their lives. The investment years are characterized by individuals that have extensive deliberate practice in the domain or primary sport with little deliberate play in other sports. Again, early specialization is a choice where individuals participate in their main sport at young ages with more hours of deliberate practice (continual year-round training) but little or no play in other sports. This idea would be important in the sports where peak performance is achieved relatively early during adolescence such as gymnastics (Bridge & Toms, 2013; Helsen et al., 2000; Moesch et al., 2011;

Wylleman & Lavalee, 2004). Otherwise, careless early specialization is well documented to result in burnout and dropout issues of young athletes.

Wylleman & Lavalee (2004) have also suggested three-transition stages of adolescent athletic career development: 1) initiation stage (transition to organized sport), 2) developmental stage (transition into a more intense training and competition), and 3) perfection stage (transition into an elite level). These three stages presumably correspond to the three time periods by Côté' (1999). The results of Bridge & Toms (2013) also suggest that deliberate play during the sampling years is important, but they oppose early specialization before or during the sampling period due to the positive association of late specialization in the main sport with consequent higher athletic success at late and post adolescence. In addition, based on the results of Moesch et al. (2011) using three transitions stages proposed by Wylleman & Lavalee (2004), ages at the entrance to each stage were younger for near-elite (less successful) athletes as compared with elite (more successful) athletes at senior level, supporting the late specialization. The near-elite group had the average age of 8.6, 12.9, and 16.3 years old and the elite group had that of 11.7, 15.1, and 18.4 years, entering into initiation, developmental, and perfection stages, respectively. It is interesting to observe that in both groups (senior elite and near-elite athletes), the average age of entering the developmental stage came after (follows) the age at the first national competition experience, and that of entering perfection stage came after the age at the first international competition experience. It is reasonable to think that the transition of one stage to another stage is associated with a maturity-dependent sequence, but there has been no study linking between the two factors to date.

Decisions on 'when transition to higher training regimes occur' (i.e., intensification and specialization) are typically led by the three stakeholders (coaches, parents, and sports organizations) of developing adolescent athletes (Pankhurst et al., 2013). Regarding the decisions of developmental training process (timing of specialization and intensification) of a youth athlete, the three stakeholders

play very important roles. Coaching is a crucial figure in developmental patterns of adolescent performance: they are responsible for the systemic choices that 'best meet' the developing athletes' needs (Pankhurst et al., 2013). Baker et al. (2003) also have stated that "an important ability of a coach is to devise an environment that fosters optimal learning for the development of (elite) athletes." Additionally, coaches need to make efforts to associate between knowledge and practice and bridge the gap between science of sports and coaching sports. Parents play as important influences on young athletes as well (Côté, 1999). Parents can play a leadership role during sampling years by providing various sports and encouraging participation in sports with no emphasis on the choice of sport. During specializing years, parents can play a facilitative role by making financial and time commitments to their child's sport and supporting access to better coaching and needs for child's training. In advisory and supportive roles, parents can maintain a high interest in their child's sport and provide emotional support to help their child overcome any setbacks during the investment years. As youth athletes age and advance their athletic levels, parents' roles appear to be indirect or secondary as to actual training programs, but their role and contribution are essential to in-depth psychological support of athletes. Finally, the main role of sports organizations is as a 'system controller.' Questions for this group become what "appropriate" coaching for an adolescent athlete is, and how we can make achieve optimal individual athletes?

To fully fulfill athletic potential of an athlete, opportunities to be exposed to high-level competitive environment may also be a necessity. Financial supports extend many opportunities to an athlete. For example, in the U.S., college athletic careers provide athletes with a platform to pursue their high-level athletic and academic/life goals, and eventually professional levels. However, increasing tuition expenses for colleges and universities put an incredible burden on athletes and his/her families to pursue this avenue. Consequently, with an athletic success during late adolescent ages, colleges can offer athletes college scholarships (financial supports), opening up a window of opportunity for a further

college athletic career as well as academic success. Applicants who excel at a top level in sports receive athletic-related financial support as well as a potential edge in obtaining admission to many universities in the U.S. Available data (www.scholarshipstats.com) show that the cost to attend four-year universities in the U.S. appears to reach or exceed $60,000 per year, which could be more than an average annual salary of a parent. During the 2014-2015 school year, there were 633 universities and colleges (628 schools for women and 500 for men) sponsoring varsity level swimming & diving teams in the U.S., although the availability of athletic scholarship depends on schools. Therefore, achieving top-level athletic success at late adolescence can be life altering in terms of future athletic and academic opportunity. Nevertheless, a dilemma exists between financial pressure to pursue more athletic opportunities and long-term athletic development. Youth sports stakeholders will need careful considerations in appropriate training regimens and timing of specialization and intensification for developing adolescent athletes.

The followings depict the summary of empirical-research-based important factors for developmental career path of youth athletes leading to senior-level athletic success (using retrospective analyses of top- or elite-level senior athletes and their youth sports and training biography):

1) Early diversification (deliberate play at early ages)
    - Multi-sports participation and experience
        - Possibly three or more sports at early adolescent ages or through adolescence (even during late adolescence in some sports where peak performance is achieved after maturity).
        - Sports-specific: multi-sports experience may be more effective to 'open-skilled' and team sports athletes but may be less to individual (artistic and CGS sports) athletes.
2) Late specialization and intensification
        - Less training hours at early- to mid-adolescence in the domain sport (or a sport)

(Data suggest that practice frequency, i.e., sessions per week, in domain sport can be as many as it is available).

- Late complete-involvement in domain sport (specialization) and intense training (intensification)
- More training hours during late- and post-adolescence (ages 18 and above – deliberate practice)
- No need of early talent identification program
- Sports-specific: some acrobatic and highly kinesthetic sports may require early specialization, particularly sports whose peak performance is frequently achieved during adolescence such as gymnastics (swimming may also be included in high 'kinesthetic' sports).

3) Developmental athletic career path
   - Consideration on timing of specialization and intensification based on three time phases
     - Sampling years/ initiation stage (ages 6-12) = deliberate play
     - Specializing years/ developmental stage (ages 13-15)
     - Investment years/ perfection stage (age 16 and older) = deliberate practice
   - Contributions of youth sports stakeholders
     - Coherence of perceptions in regard to long-term youth athlete development among the stakeholders in youth sports programs is important to increase a chance of senior success.
     - Coherence between research and practice by stakeholders needs to be pursued to provide youth athletes with appropriate guidance for long-term development.

Administrative rationale behind early TID programs for elite sporting success is reviewed up to this point. A lack of scientific information supporting the effectiveness of early TID programs, especially

those centering on early successful athletes at young ages, is seen despite their wide use. Variations in growth and maturation leading to the maturation-based disparity in sports performance among adolescents have largely resulted in the negative outcomes of early TID programs. Adolescents with advanced maturity status appear to be overrepresented in youth sports, despite research suggesting success at early youth levels is a poor predictor of future potential/success at senior levels. Previous studies retrospectively examining senior elite athletes and their youth sports biography suggest that athletic success and superiority during adolescence is transient in most of cases. Growth and maturation and sport performance progression occur sequentially, while a decision for the talent selection is made on the basis of temporal, short-term performance results at a moment during adolescence (a competitive sport season). Therefore, the assumptions of facilitating development of senior elite athletes from youth sports talent pools and approaches of sports federations for elite sporting success at international scales have been exceedingly inflated but need more careful considerations and rational evaluations.

It is not true to say that early successful or early maturing youth athletes cannot become senior elites. Coaches and federations are responsible for retaining successful top young athletes and developing future elites at senior-level competition. In addition, it is the responsibility of scientists to profile and demonstrate all matters pertaining to adolescent growth and sport performance progression toward adulthood. For all those making decisions regarding youth athlete development, the link between timing of adolescent growth and maturational events and progression in athletic performance matters not only within a population (country), but among populations (countries or different ethnic/geographic groups). However, to date, there is no informative, empirical, and relevant results demonstrating an association of ethnic- or geographic-related variations in growth and maturation with those in sports performance progression. This is an important topic to examine due to the growing

globalization of youth sports competition and high social (political) attention toward international athletic success over the world.

Ethnic and/or geographical variations in timing of growth and maturation

During the past several decades, an advancement of timing of growth and maturation, and an increase in average adult height, have been reported worldwide. These trends are seen to be accentuated in countries with high socioeconomic status, such as the United States and Japan. The variability of the onset of puberty (growth spurt or when maturational events occur) estimated by maturational markers have been debated to be affected by genetic, social, and environmental factors (Euling et al, 2007; Eveleth & Tanner, 1990; Haas & Campirano, 2006; Malina, 2009; Parent et al., 2003).

While the factors driving a secular trend would be multifactorial, the secular increase in physical size and advancement in menarcheal age have been evident since the mid-19th century. However, changes have slowed in the late 20th century and appear to be approaching a plateau in many populations such as Northern Europe, the U.S., and some Asian counties (Cole, 2003; Euling et al, 2007; Parent et al., 2003). For example, Figure 2.11 demonstrates changes in height in Japanese children in respective ages over the past seven decades (MEXT, 2015). Increases in height are apparent after World War II but have leveled since the 1990s. The squares on the figure denote the peak values, and this tendency is observed in all other ages in Japanese children and in many countries, especially in the U.S. (Malina et al., 2004). Concerning the plateau of this secular trend in height in the late 20th century, Carling et al (2012) analyzed physical size, functional characteristics, and skeletal maturation of youth soccer players in the 13-14 age-group at the entry into an elite academy. They reported a lack of change in all measures except for $\dot{V}O_{2max}$ over a decade from 1992 to 2003. Additionally, most of the highly successful players were of advanced maturity status (maturational-advantage) or born at the first (49%) and second (29%) quarters of the selection year (relative age effect). The secular trend in average adult

height has been observed to be similar in children and adolescents. Available data suggest that average height has increased from 165 cm in 1860 to 181 cm in 1990 and 184 cm in 1994 in Dutch men (Cole, 2003), and similar trend has been shown in many European countries, the USA, and east Asia. Japanese data indicate (Figure 2.11) that in the past 70 years, adult height (data at age 17 years) increased from 160.6 cm to 170.7 cm, and most of the increase occurred within 30 years after World War II. This trend is observed in other ages in Japanese population with an exceptional height gain in 14-year-old boys (146.0 cm to 165.1 cm) and a moderate gain in 17-year-old girls (152.1 cm to 157.9 cm). The different degrees of secular height changes for 14-year-old boys and 17-year-old girls in Japan were also reflected to the data in Figure 2.12. Height at each age increased over 40 years but different tempo (rate or velocity) is evident across ages with larger gains at puberty in both sexes.

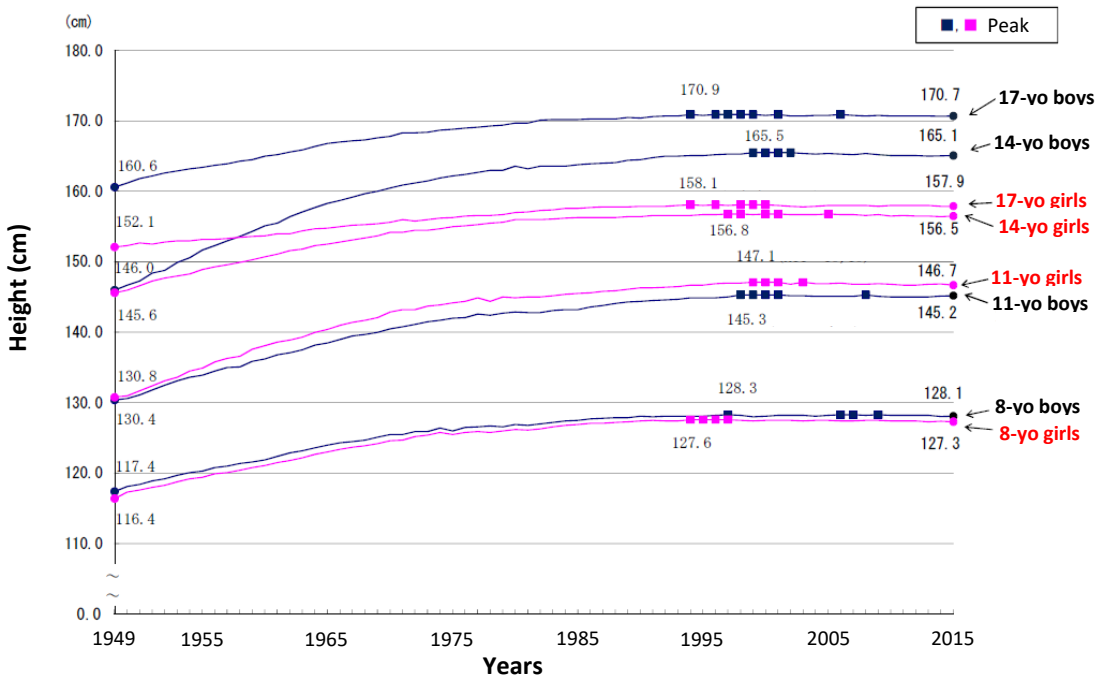


Figure 2.11. Changes in the median height in Japanese girls and boys in respective ages during the past seven decades (MEXT, 2015).

Note: 1) Data are derived from Japanese reference data (Ministry of Education, Culture, Sports, Science & Technology in Japan; MEXT, 2015); 2) Squares denote years when the peak height was reached (Japanese children today are slightly shorter than 10-20 years ago).

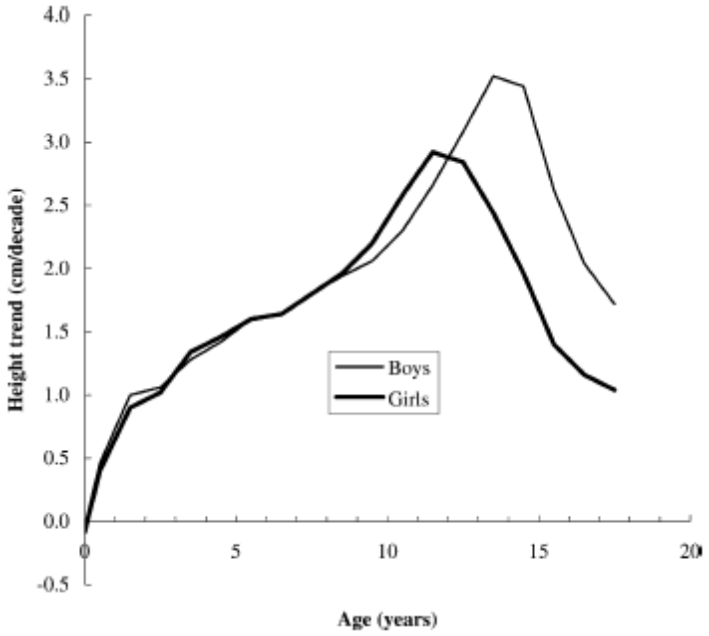


Figure 2.12. The mean increases in height in Japanese girls and boys from 1950 to 1990 (Cole, 2013. page 163).

Along with increases in height and changes in tempo (rate or velocity), the timing in maturational and biological markers (somatic, skeletal, and sexual ages) are also evident in many populations (Cole, 2003; Euling et al., 2007; Eveleth & Tanner, 1990; Haas & Campirano, 2006; Malina, 2009; Parent et al., 2003). The Japanese height growth data (Figure 2.12; Cole, 2013 and Takaishi, 1994) may imply that 14-year-old Japanese boy in 1990 are approximately 3.5 cm taller than the same age peers in 1950 due to an earlier age at PHV in 1990. Comprehensive height data across decades are available for Japanese but not for other countries. However, Parent et al. (2003) have shown evidence of a three-year decline in the age at menarche in girls from the mid-19th to mid-20th century in the U.S. and Western Europe. Euling et al. (2007) have demonstrated that an earlier onset of breast and pubic hair development and an earlier age at menarche have been evident, especially in US girls, while data for US boys is inconclusive (although a secular trend in maturational events are toward earlier ages). Figure 2.13 reveals a decline in the mean or median menarcheal age in girls in the U.S. Age at menarche

declined approximately two and half to six months in the U.S. during the mid to late 20th century. Similar secular trends have been observed in countries with relatively well-off conditions over the world (Parent et al., 2003). More studies relating to this subject are typically more available for girls than boys in the fields of epidemiology and physical anthropology due to less cultural awareness of male pubertal development (more physical markers in girls). Now, the imperative questions with global secular trend are whether or not 1) there are variations in timing and tempo (velocity) of growth and maturation among populations, and 2) such variations have influenced sports performance outcomes and progression among ethnic and geographic groups.

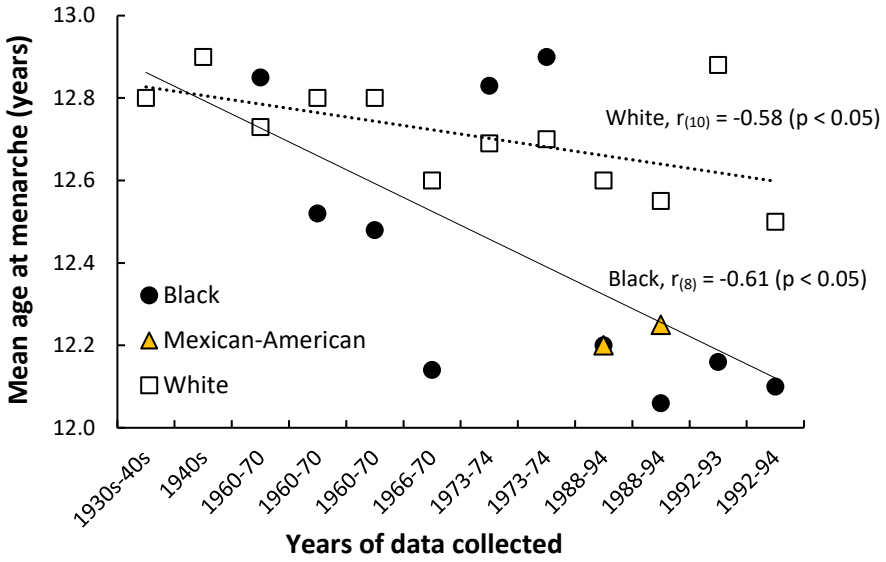


Figure 2.13. Secular trend in mean or median ages at menarche of girls in the U.S. over the past six decades.

Note: Data are derived and adapted from Euling et al. (2007) and nine studies and eight different reference data listed in Table 2.1.
Trend lines, a dash line for White population and a solid line for Black population.

Table 2.1. Description of studies examining the age at menarche in US girls in the 20th century.

Author (year)	Studied data	Data collected (years)	Ethinic or racial status investigated
Nicolson & Hanley (1953)	Guidance Study	1930s-40s	White
Reynolds & Wines (1948)	Fels Study	1940s	white
MacMahon (1972)	NHES I	1960-70	white & black
MacMahon (1972)	NHES II & III	1960-70	white & black
Anderson et al (2003)	NHES II & III	1960-70	white & black
Anderson et al (2003)	NHANES III	1966-70	white & black
Foster et al (1977)	Bogalusa Heart study	1973-74	white & black
Freedman et al (2004)	Bogalusa Heart study	1973-74	white & black
Wu et al (2002)	NHANES III	1988-94	white, black, Mexican-American
Chumlea et al (2003)	NHANES III	1988-94	white, black, Mexican-American
Herman-Giddens et al (1997)	PROS	1992-93	white & black
Freedman et al (2004)	Bogalusa Heart study	1992-94	white & black

Data are derived and adapted from Euling et al. (2007).
NHES, National Health Examination Survey; NHANES, National Health and Nutrition Examination Survey; PROS, Pediatric Research in Office Setting.

Differences in timing and development of maturational events among ethnic/racial or geographic groups are evident from the data shown above. In addition, ethnic/racial variations have often been debated due to a concern in a field of Public Health: whether or not a single set of reference data (e.g., by WHO) can be used internationally. However, most studies suggest that countries, or broad regions, should generate their own standards, meaning that ethnic/racial- or geographic-related variations in physical growth exist (Beunen et al., 2006; Cole, 2003; Eveleth & Tanner, 1990; Haas & Campirano, 2006; Malina, 2009). Skeletal/bone age (Cole et al., 2015; Dvorak et al., 2007; Ontell et al., 1996) as well as maturational/sexual and somatic ages (Beunen et al., 2006; Eveleth & Tanner, 1990; Karlberg, 2002; Malina et al., 2015) have been demonstrated to differ among populations. Asian and Black-Amercian children are commonly older in biological ages (advanced maturity status) as compared with same-chronological aged white children. Using menarcheal age, US Black children appear to be early maturers than other ethnicity or race (White and Mexican-American children) shown in Figure 2.13

(Euling et al., 2007). This is not necessarily the case in the South African Black and White children (Cole et al., 2015), where differences in socioeconomic status between the countries influence development.

More commonly, somatic age has frequently used due to decrease variation in methodology. It is determined 1) by longitudinally measuring height over adolescence to identify age at PHV or 2) on a basis of cross-sectional data analyses to define maximum increment age (MIA) in height (more detailed methodology are described earlier). In addition, the age at PHV or MIA also appears to be earlier in Asian, Hispanic (Latino), and Black (African & Black-American) children when compared with Caucasian and White-American children (European ancestry). Based on the data of Eveleth & Tanner (1990), girls are observed to reach MIA at age 11.7 ± 0.6 in White, 10.5 ± 0.6 in Hispanic/Latino, 10.5 ± 0.9 in Black, and 11.3 ± 1.0 in Asian (Table 2.2ab). In boys, MIA is at 14.2 ± 0.6 in White, 12.9 ± 0.8 in Hispanic/Latino, 14.0 ± 1.7 in Black, and 13.3 ± 0.8 in Asian (Table 2.2ab). Similar evidence has been reported in Beunen et al. (2006) and Haas & Campirano (2006). Data of Malina et al. (2015) have shown the estimated mean age at PHV of youth athletes aged 10 to 18 years in different sports in European and Asian countries in the same time frame, and the similar variations between ethnically- and/or geographically-distinct populations were also seen: European girl (12.6 ± 0.6) and boy (13.8 ± 0.8) athletes vs. Asian girl (11.1 ± 0.2) and boy (12.8 ± 0.7) athletes. In addition, Kojima & Stager (2010) have reported that the mean age of Asian swimmers participating in the 2nd FINA Youth Swimming Championships was different from that of European, US, and Canadian swimmers at: on average, 0.5 and 0.7 years younger ($p < 0.05$) in Asian youth swimmers in both girls and boys, respectively. This may suggest a maturation-related competitive advantages in early maturers (Asian swimmers) over late and/or average maturers (Caucasian swimmers).

Table 2.2a. Cross sectional data of the mean or median height in girls over the world in the late 20th century.

[Girls]

Country	City of Data collected	Authors	Ethnic/geographic groups	Age (years)																	
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Belgium	Brussels	Vercauteren, 1984	White				101	109	115	121	127	132.3	138	144	150	155.8	159.8	162	163	163	163.5
Ddenmark	National	Anderson et al., 1982	White	78	87.1	96.5	103.5	111	117.2	123.4	128.1	132.9	138.4	144.1	150.4	156.5	160.6	163.1	164.9	165.6	166.6
France	Paris	Sempe, 1987	White	72.2	84	92.3	98.9	105.6	111.3	118.4	124	130	135.2	143	149.5	155.5	159	161	162	162.5	163
Hungary	National	Eiben & Panto, 1986	White			97.2	102	109.2	116	121.4	127	132.4	138.3	144.7	150.7	156	159.3	161.2	161.9	162.1	162.3
Ireland	Dublin	Hoey et al., 1987	White					106.8	113	118.9	124.5	129.9	135.3	141.1	147.3	153.7	158.6	161.3	162.6	163	163
Netherlands	National	Roede & van Weiringen, 1985	White	74.8	87.7	97	104.8	119	118.3	124.4	130.4	135.8	141.4	147.2	154.4	160.6	164	166.4	167.7	168	168.2
Netherlands	Oosterwolde	Gerver, 1988	White	77.2	89.7	98.6	106.5	113.6	120.2	126.2	132	137.7	143.4	149.4	155.7	161.7	165.4	167.5	168.8	169.8	
Norway	Bergen	Waaler, 1983	White			97.3	104.3	110.6	117.3	123.2	128.5	133.9	139.1	145	151.4	157.5	162.1	164.5	165.9	165.9	
Poland	Warsaw	Kurniewicz-Witczakowa et al., 1983	White	75.5	85.2	94.9	103	109.8	116.1	121.5	127.1	132.1	137.7	145	152	157.8	160.5	162.5	163	163.1	163.1
Spain	Bibao	Hernandez et al., 1985, 1988	White	73.3	85.4	94.1	101.5	108.9	114	120	129.6	131.4	136.6	142.5	148.4	153.7	156.8	158.3	159.9	160.8	161.3
USA (white)	National	NCHS	White	73.7	85	93.6	100.7	107.5	114.4	120.6	126.1	132	136.9	144.5	150.2	157.1	160.4	161.7	163.5	162.8	163.8
Argentina (W)	National	Lejarraga, 1986	White	74	85	93	100	106	112	118	124	129	134	140	147	153	157	159	160	160	160
Brazil (white)	Santo Andre	Marques et al., 1982	White	75.1	88	97	104.1	110.4	116.3	122.1	127.8	133.2	138.4	143.7	149.2	154.7	157.1	159.4	159.8	159.9	159.9
			Mean ± S.D.										**11.7 ± 0.6**								
Venezuela	Caracas	Mendez-Castellano et al., 1986	Hispanic/Latino	74.9	86.2	95	103.2	109.7	115.8	121.8	127.5	132.2	138.4	144.5	149.9	155.4	158.4	159.3	159.4	160.5	161.2
Ecuador	Chdchi	Stinson, 1989	Hispanic/Latino			84.1	89.7	93.6	102.9	105.5	109.1	116.2	120.7	127.1	130.4	136	140.3	143.2	142.9	147.3	148.3
USA	Mexican	Malina et al., 1987	Hispanic/Latino							119	124	129	135	142	148.5	152	154	156.5	156.5		
USA	Mexican	Martorell et al., 1987	Hispanic/Latino			93	100	107	115	120	125	131	137	144.5	150	155	157	158	159	159	
			Mean ± S.D.										**10.5 ± 0.6**								
Kenya	Machakos	Stephenson et al., 1983	Black		77.2	85.4	93.5	99.9	107	112.6	116.6	120	127	130	135	140.5	145.5	149	150.5	151.5	151.3
Somalia	Mogadish	Gallo & Mestriner., 1980	Black	69	79	88	97	107	114	119	123	129	135	140	145	151	156	159	159	159	160
USA (Black)	National	NCHS	Black	75	84.7	93.8	103.2	109.1	115.8	123.2	127.7	133.1	140.3	147.6	154.1	156.2	159.8	162.2	165.1	164.2	
			Mean ± S.D.									**10.5 ± 0.9**									
China	urban	Zhang & Huang, 1988	Asian	75.1	86.6	94.2	101.2	107.6	113.9	119.3	124.6	129.5	134.8	140.6	146.6	150.7	153.7	155.5	156.8	157.4	
Japan	National	Kikuta & Takahashi, 1987	Asian		85	92	97	105	112	114	125	130	136	143	149	153	155	156	157	157	
Korea	n/a	Kim, 1982	Asian							118.5	124	130	137	144	149	152.5	155	156.5	157.5	158.5	
Thailand	Bangkok	Lai & Yaung, 1987	Asian	72.8	85	94.6	101.3	107.4	112.7	118.4	122.8	128.4	133.7	139.6	146.2	150.8	153.9	153.9	156.2	156.1	156.6
			Mean ± S.D.										**11.3 ± 1.0**								

Highlighted ages indicate the maximum increment age (MIA, an indication of age at peak height velocity).

Note: there are more than one MIA in some population samples due to cross-sectional data (e.g., the data in Belgium, Spain, Brazil, Somalia, and Korea).

Data are derived and adapted from Eveleth & Tanner (1990).

Table 2.2b. Cross sectional data of the mean or median height in boys over the world in the late 20th century.

[Boys]

Country	City of Data collected	Authors	Ethnic/geographic groups	Age (years)																	
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Belgium	Brussels	Vercauteren, 1984	White				102.5	109.5	116.1	122.1	127.5	132.5	137.3	142.2	147.8	153.9	160.5	166.9	171.5	174.1	175.3
Denmark	National	Anderson et al., 1982	White	78	88.5	97.2	104.7	111.2	118.8	124.1	129	134	139.1	143.8	148.8	154.8	161.7	168.2	173.8	177	179
France	Paris	Sempe, 1987	White	73	85	93.7	100.5	107	113.5	119.5	125	131	136	141	147	154.5	162	168.5	172.5	174	175
Hungary	National	Eiben & Panto, 1986	White			97.5	103	109.3	116.2	122.3	127.6	133.2	138.6	143.3	149	155.6	162.7	168.8	172.4	174.2	175.3
Ireland	Dublin	Hoey et al., 1987	White					108.1	114.2	120	125.6	131	136.2	141.3	146.4	151.9	158.7	166.1	171.5	175	175.5
Netherlands	National	Roede & van Weiringen, 1985	White	76.4	88.6	98.2	105.7	112.4	118.8	125	131	136.6	142.2	147.3	152.1	157.5	165.8	173.2	177.4	179.6	180.9
Netherlands	Oosterwolde	Gerver, 1988	White	77.9	89.9	99	107	114.1	120.6	126.5	132.1	137.6	142.9	147.9	153.1	159.1	166.5	174.2	178.8	181.2	
Norway	Bergen	Waaler, 1983	White			99.4	105.8	112.4	118.7	124.3	130	135.4	139.7	145.4	150.4	156.4	163.8	169.9	174.9	176.6	
Poland	Warsaw	Kurniewicz-Witczakowa et al., 1983	White	77.2	86.5	95.5	103.8	111	117.8	123	128.4	134.2	139	144.3	149.2	156	162.8	170	173.7	176.8	176.8
Spain	Bibao	Hernandez et al., 1985, 1988	White	75	86.7	95.2	102.5	108.7	114.1	120.2	126.1	131.7	136.5	141.5	146.7	152.8	160	165.5	170.9	173.7	175.6
USA (white)	National	NCHS	White	76.1	86.5	95	101.6	108.5	115.4	121.5	126.9	133.2	137.7	143.4	148.4	157	162.4	169.2	172.6	175.3	176.8
Argentina (W)	National	Lejarraga, 1986	White	76	87	96	102	108.5	114.5	120.5	126	131	136	140	145	151	158	164	168	172	172
Brazil (white)	Santo Andre	Marques et al., 1982	White	76.6	88.8	96.9	103.5	109.2	115.6	122.5	128.4	133.6	138	142	146.2	153.1	160.8	166.9	170.6	172.3	172.9
			Mean ± S.D.													**14.2 ± 0.6**					
Venezuela	Caracas	Mendez-Castellano et al., 1986	Hispanic/Latino	76.6	87	95	101.2	109.6	116.1	122	127.8	132.2	139.1	142.8	149.2	156.2	162.4	168.4	171.6	171.5	173.4
Ecuador	Chdchi	Stinson, 1989	Hispanic/Latino			83	93.8	99.2	102.8	110.7	112.5	114	118.3	124.5	128.9	129.3	139.3	143.7	146.9	151.8	155
USA	Mexican	Malina et al., 1987	Hispanic/Latino							121	127	131.5	135.5	140.5	147	153	158	162	164.5	168	
USA	Mexican	Martorell et al., 1987	Hispanic/Latino			95	101	108	115	120	126	132	136	143	149	156	163	166	169	170	
			Mean ± S.D.												**12.9 ± 0.8**						
Kenya	Machakos	Stephenson et al., 1983	Black		78.6	85.9	93.8	100.3	106	110.6	116.8	120	124.2	128.2	134.2	138	140.8	145	151	156.5	
Somalia	Mogadish	Gallo & Mestriner., 1980	Black	71	80	89	99	107.5	112.5	118	154	128	132.5	137	140	146	152.5	160	166	170	171
USA (Black)	National	NCHS	Black	76.1	85.7	94.6	103.1	111.6	116.2	120.8	127.7	134.4	138.6	145.1	147.6	153.7	159.4	171.2	171.2	174.7	175.1
			Mean ± S.D.													**14.0 ± 1.7**					
China	urban	Zhang & Huang, 1988	Asian	76.5	87.9	95.1	102.1	108.6	114.7	120.6	125.3	130.6	134.4	139.2	144.2	149.8	156.5	162	165.6	167.7	
Japan	National	Kikuta & Takahashi, 1987	Asian		85	92	99	106	113	119	125	130	135	140	147	154	161	166	169	170	
Korea	n/a	Kim, 1982	Asian								119	125	130.5	135.5	140	147	155	162	166	168	169
Thailand	Bangkok	Lai & Yaung, 1987	Asian	74.9	86.3	95.6	102.8	108	113.8	120	124.3	130.4	135.5	139.2	142.5	152.3	157.5	161.5	167.4	168.1	168.3
Bahrain	Bahrain	Musaiger et al., 1989	Asian							118	121	126	132	136	140	146	152.5	157.5	163	167	168
India	National	Ind. Coun. Med. Res., 1972	Asian	70.5	77.5	85.5	92.5	99	105.2	111.2	116.8	121.6	124	129	136	141.5	147	153	157.8	160.8	162.5
			Mean ± S.D.												**13.3 ± 0.8**						

Highlighted ages indicate the maximum increment age (MIA, an indication of age at peak height velocity).

Note: there are more than one MIA in some population samples due to cross-sectional data (e.g., the data in France, US-Mexican, and Japan).

Data are derived and adapted from Eveleth & Tanner (1990).

3. Questions concerning early TID programs and long-term athlete development within and between populations

Study 1: *Performance progression, participation retention, and developmental career path in the U.S. top 100 nine-year-old swimmers*

To date, how early successful, young athletes mature into successful senior elites, with an exploration spanning throughout pre- to late-adolescent ages, remains contentious. A question is whether or not early, highly successful young athletes (e.g., the top 100 in an age-category in the nation or national youth team members) maintain their performance levels across adolescence or their success is transient. What would be the probability that a pre-adolescent top athlete maintains his/her successful, top athletic achievement throughout and after adolescence (10+ years)? It may be simply predicted that the ten tallest nine-year-old children may not become the ten tallest human beings, but more chance of this in competitive sports performance would be presumed. Particularly, in the sport of competitive swimming, there are more than 13 competitive swimming events, and swimmers tend to pursue and change their specialization (primary stroke styles and events) during their mid-to-late adolescent career, leading to an increased chance to be successful throughout adolescence when compared with 'open-skilled' sports or team sports. Competitive swimming is one of a few sports which the performances are measurable, and such data are accessible through national federations' database. For example, in the U.S., all swim performance data across the country of the United States are publicly accessible and well organized by USA Swimming since the early 21st century.

Furthermore, factors influencing senior athletic successes have been investigated retrospectively for senior-level athletes and their youth sports careers, but not for top young athletes and their future attainments (the latter analysis is possible using swim performance data). Understanding tendencies in training history and biography of top youth athletes can be an important information for youth sports stakeholders. For example, it is hypothesized that top young athletes could

not participate in multiple sports due to early specialization to fulfill their potential OR they participated in several sports and excelled over their same-aged peers due to maturity-related sport performance advantages given that they were advanced in maturity status. In competitive swimming, training workout are well structured and organized by coaches, and consequently it is not difficult to track training biographies retrospectively.

Longitudinally tracking performance progression in top young swimmers enables us to underline the probability of future senior success from early success. Traditionally, early TID programs are deployed around ages eight to 12 years, and swimming is one of the few sports in which the onset of participation is generally seen at a fairly young age (Figure 1.4, Vaeyens et al., 2009). Therefore, the prospective analysis of performance in top preadolescent swimmers can provide us with valuable information regarding a long-term developmental athletic career path of top young individuals. In addition, previous studies reporting the contribution of early athletic success to late or senior athletic achievements only concentrate on performance, but do not incorporate causative factors differentiating late adolescent or senior athletic achievements. Simply asking the swimmers, who are used to be the top preadolescent swimmers, about their youth sports participation and training biography could provide important, valuable insights into long-term athlete development and evaluating the work and performance of coaches and sports federations, as well as recruitment strategies for college coaches. An important focus of this study, in addition to an argument about the effectiveness of early TID programs, is how early successful young athletes develop and retain their athletic level into adulthood. This is an important topic from a stand point of physiological and psychological perspectives as well as administrative and financial strategies for coaches and sports authorities. Empirically derived, detailed descriptions of the development of top young swimmers and their progression, participation retention, and interrelationships with youth sports participation need to be addressed. This study endeavors to

illustrate the effectiveness of TID systems and to contribute to our understanding of long-term athlete development with specific reference to the sport of competitive swimming.

Study 2: *Interpopulation variations in height growth and swim performance progression between the U.S. and Japan*

Given that ethnic- and geographic-related variations in timing of growth and maturation exist, the documented transient contribution of adolescent growth and maturational factors to youth sports performance should presumably exist among populations and dictate international competitive sports outcomes. In addition, age and height have been reported to be two important factors for physical tasks and sports performance in adolescents (Kojima et al., 2012; Lätt et al., 2009a, 2009b, 2010; Malina et al., 2004; Moreira et al., 2014; Pelayo et al., 1997; Saavedra, Escalante, & Rodriguez, 2010).

Anecdotal evidence concerning this point has been observed through international youth and senior sports scenes. As depicted in Chapter 1 (Figures 1.2 and 1.3), the proportion of successful countries (populations) at international sports events appear to be different between youth- and senior-level competitions. East Asians and Africans have outperformed Whites and European ancestry at youth and junior levels, which may not be necessarily the case in its senior-level international sports events. Figures 1.2 and 1.3 propose a tendency in the superior performance of early maturers (i.e., Asians) at youth/junior levels and catch-up growth and related performance progression of late maturers (whites) in the field of competitive sports. It is also indicated that early maturers have a shorter duration of a plateau growth period prior to growth spurt as compared with late maturers (Beunen et al., 2006; Haas & Campirano, 2006; Karlberg, 2002; Malina et al., 2004). Therefore, it is assumed that children in East Asian countries undergo earlier maturation and experience less adolescent awkwardness due to an earlier maturation with a shorter growth period. Subsequently, this may result in advanced athletic performance relative to children of the same chronological age in European and Caucasian countries. It

is hypothesized that there would be a link between interpopulation variations in height growth patterns and youth athletic performance development. However, to date, no empirical data suggesting the extent which differences in timing in adolescent height growth are associated with those in adolescent sports performance progression among ethnically- or geographically-disparate populations has been available.

Once again, competitive swimming is the sport where performances are easily accessible, as swim time data are publicly available and well organized in some countries. Additionally, adolescent swim performance has been reported to be, to a large extent, influenced by physical size and maturity status (Lätt et al., 2009a, 2009b, 2010; Moreira et al., 2014; Pelayo et al., 1997; Saavedra, Escalante, & Rodriguez, 2010). The United States of America (US) and Japan are identified as distinct ethnic and geographic background populations, comparable high socioeconomic status, and representatives of swimming countries in the world that have well-organized swim performance database. Therefore, it is possible to provide informative evidence for differences in the patterns of the age-related height growth and adolescent swim performance progression between the U.S. and Japan, and describe a relationship between adolescent height growth and swim performance for the two populations. Tracking and demonstrating trends in the timing of adolescent physical growth and sports performance progression within and among populations would identify concerns and initiatives of Public Health, Anthropology, and Kinesiology majors.

CHAPTER 3: METHODS

Introduction

This study consisted of two projects. The first project was concerned with variations in performance progressions and participation retention of US top 100 girl and boy swimmers, *within a population,* throughout adolescence and into adulthood (college career). Emphasis was placed on 1) whether or not early successful athletes maintained top athletic levels (top 100 in each age category in the U.S.) and 2) continued participation in the sport up until college (i.e., dropout rate from the sport of competitive swimming). In addition, factors influential to or distinguishing future athletic success in senior levels of the top young swimmers were addressed in order to provide insights into long-term athletic development of early successful young children. The information from the first portion (variations in performance progressions and participation retention in the U.S. top 100 young girl and boy swimmers) was valuable when conducting the second portion, as it helped draw a causative mechanism in the relationship between performance outcomes and youth sports and training experience (sports participation and training biographies).

The second project (interpopulation or ethnic/geographic variations) was conducted in order to demonstrate the relationship between age-related height growth and swim performance progression for two ethnically and geographically disparate populations (American and Japanese). In essence to examine whether or not age-related differences in height growth pattern *between populations* can be shown to be related to swim performance progression, the ratios of Japanese to US people in age-related height and swim performance were compared.

Data collection and set-up

Study 1: Performance progression, participation retention, and developmental career path in the U.S. top 100 nine-year-old swimmers

Data (age, competition swim time, and corresponding national rankings) were acquired from the public-domain website of USA Swimming (USAS; http://www.usaswimming.org). As well, USAS's swim performance database (provided upon our request to USAS) was used. In the USAS database, a selection year begins on September 1st and ends on August 31st, consisting of two sub-seasons (short course yard, fall-winter season; and long course, summer season). Consequently, the database in the 2004 season, for example, comprises swims from September 1, 2003, through August 31, 2004.

The US top 100 nine-year-old girls and boys in the 45.7-meter (50-yard) freestyle (45.7Fr) in the year of 2004 were identified herein as being 'successful, top pre-adolescent swimmers.' Their annual best swim times and corresponding rankings in all swimming events of the swimmers were compiled and tracked for each of the subsequent nine years over their adolescent ages (i.e., 2004 to 2013). Additionally, the National Collegiate Athletic Association (NCAA) rankings (years 2013-2015) of the US top 200 swimmers were obtained. Dropout was determined when neither ranking nor competition time of a swimmer was found for a given year on the USAS and NCAA database.

The 45.7Fr was used as a baseline event because it is a common (or the only available) competitive swimming event throughout all ages and the swimming event that the performance outcome is, presumably, largely determined by physical growth and maturation status of swimmers (Kojima et al., 2009). There are 14 competitive swimming events which were investigated for swim times and rankings of the top 100 girl and boy swimmers in the present study: 45.7-, 91.4-, 182.8-, 457.0-, 914.0-, and 1508.1-meter freestyle, 91.4- and 182.8-meter backstroke, breaststroke, and butterfly, and 182.8- and 365.6-meter individual medley. An event with the highest national ranking among the 14 events was referred to the best stroke/event of a swimmer at any given age.

An online questionnaire (Appendix A) used to collect information regarding participation in multiple sports, adolescent training biographies in swimming and other sports, and ages at maturational milestones was sent to swimmers identified as the US top nine-year-old swimmers for Study 1. First,

locations, college, club swim teams, and/or coaches of the 200 swimmers were searched through the USA Swimming and NCAA database, and upon identification, an initial contact letter (Appendix B) was sent to coaches or directly to the swimmers in order to request their cooperation in the study. Prior to initiation, this study received ethical approval from the University Institutional Review Board. The use of the data allows all results to remain anonymous and all data were collected exclusively for scientific purposes.

Study 2: Interpopulation variations in height growth and swim performance progression between the U.S. and Japan

Height growth reference data from age seven to 17 and swim performance data (50-meter long course competitive freestyle time, 50Fr) from ages seven to 22 years and 23 years and older (23&O) were compiled from publicly accessible websites for the U.S. and Japan. Japanese growth reference data were collected from the statistical report of the school health survey by Ministry of Education, Culture, Sports, Science & Technology in Japan (MEXT, 2000), and swim performance data were from the swim time database of Japan Swimming Federation (www.swim-record.com). The U.S. growth reference data were compiled from 2000 CDC Growth Charts (Kuczmarski et al., 2002), and swim times were acquired from the database of USAS. Since the most recent, complete swim performance data across ages in Japan and US growth reference data were only available in 2008 and 2000, respectively, data for corresponding years for both countries were used in the present analyses: i.e., height reference data in 2000 and 50Fr in 2008 for both countries. There was no change in height between 2000 and 2008 based on the Japanese data (MEXT, 2000 and 2008; also shown in Figure 2.11): girls, $r = 0.99$; boys, $r = 0.99$ ($p < 0.01$). No data were available for the US growth reference in 2008 although the secular increase in height in US appears to have been plateau in the past two decades (Euling et al., 2007;

Parent et al., 2003). Once again, 50Fr was used because it is presumably the least sensitive swimming event to training and highly influenced by physical size and maturation.

Statistical analyses

The statistical analyses used to answer each of the research questions are listed below.

Study 1: Performance progression, participation retention, and developmental career path in the U.S. top 100 nine-year-old swimmers

Descriptive statistics (mean ± standard deviation) were used to characterize performances (time and ranking) of the U.S. top 100 nine-year-old girl and boys and to illustrate sample size (the number of swimmers competing) in 45.7Fr and any of 14 swim events at each age in both sexes. Paired and independent sample t-tests with the Welch-Satterthwaite method for normality of the variables and the Levene's test for equality of variances were performed for comparisons in the dependent variables (annual USAS memberships from 2004 to 2013 and sample size in 45.7Fr and any swim event by age) within sex (paired t-test) and between sexes (independent sample t-test), respectively. When Levene's test indicated unequal variances, an adjustment to the degree of freedom was made using the Welch-Satterthwaite method. Cohen's d was used to estimate effect sizes for the comparison between means of two variables (Cohen, 1988). Boundaries of 0.20-0.49 was considered a 'small' effect, 0.50-0.79 a 'medium' effect, and 0.80 to infinity a 'large' effect.

A linear mixed-effect model with restricted maximum likelihood estimation was conducted to detect effects of age and sex on performance progression (swim times and national rankings in 45.7Fr and best event, and retention rate: to test hypotheses 2 and 4) as follows:

Eq. 1: $Y_{ij} = \pi_{0i} + \pi_{1i}AGE_{ij} + \pi_{2i}SEX_{ij} + \varepsilon_{ij}$

$\pi_{0i} = \gamma_{00} + \zeta_{0i}$

$$\pi_{1i} = \gamma_{10} + \zeta_{1i}$$

$$\pi_{2i} = \gamma_{20}$$

where,

Y_{ij}, a swimmer i's performance variable (swim time or ranking in 45.7Fr or best event) at time j, is a linear function of his or her age on that occasion (AGE_{ij}).

π_{0i} is intercept (initial status) of the true change trajectory for swimmer i.

π_{1i} is slope (growth rate) of the true change trajectory for swimmer i.

ε_{ij} is random measurement error.

γ_{00} is the parameter estimate for initial status.

γ_{10} is the slope parameter (the estimated growth rate)

ζ is residual.

Note that the third equation in Eq., 1 (π_{2i}), the parameter for SEX, includes no level-2 residual due to a time-invariant predictor.

(Singer & Willett, 2003)

Omega-squared (ω^2) was reported for the measure of the strength of association as $0.010 \leq \omega^2 < 0.059$ was a small association, $0.059 \leq \omega^2 < 0.138$ was medium, and $\omega^2 \geq 0.138$ was large (Cohen, 1988). For the purpose of this study, nine comparisons between two subsequent ages were made for the post hoc tests (i.e., ages 9-10, 10-11, 11-12, 12-13, 14-15, 15-16, 16-17, and 17-18) with a Sidak correction.

A mixed-effect logistic regression (also called generalized estimating equation) was used to test the hypotheses and to illustrate the odds of whether or not the top 100 young swimmers had 1) ranked within the top 100 (hypothesis 1) and 2) dropped out from competitive swimming (hypothesis 3) at any time during adolescent ages. If the swimmers ranked within the top 100 in any event at any age, they were coded as 1, and 0 otherwise for examining the top 100 performance retention. In addition, if the

swimmers dropped out from competitive swimming at any age, they were coded as 1, and 0 otherwise for exploring dropout rate given by the following equation:

Eq. 2: $log\left\{\frac{\mathrm{P}}{1-\mathrm{P}}\right\} = \beta_0 + \beta_9 z_9 + \beta_{10} z_{10} + \cdots + \beta_r z_r$

where,

log odds are a linear function of the covariates.

P is the probability of success at covariate level z (z_9, US top 100 or dropout at age 9; z_{10}, U.S. top 100 or dropout at age 10; …… z_r, US top 100 or dropout at age r).

β is the parameter estimate.

β_0 represents the log odds of the response.

β = 0 → the probability of success is the same at each level of predictor (x).

β > 0 → the probability of success increases as x increases.

β < 0 → the probability of success decreases as x increases.

(Hosmer & Lemeshow, 2000; Johnson & Wichern, 2012)

R-squared (R^2) was calculated for a measure of relationship between age and binary code (Cox & Snell, 1989). Repeated subsequent level contrasts with sequential Sidak correction were conducted for the nine comparisons to detect changes in chance to rank within the top 100 or dropout from one age to next. Odds ratio (OR) was computed as an exponential function of a contrast estimate between a pair of the subsequent-level contrasts for a measure of effect size: 1.50-2.49 (small), 2.50-4.29 (medium), and 4.30 (large) (Cohen, 1988).

A mixed-effect logistic regression was also performed in order to investigate whether or not there were any factors (independent variables: swim and youth sports training biographies, involvement in multiple sports, and variables of maturational timing) contributing to differential status of athletic success at late adolescence and in college/senior levels (dependent variables) by retrospectively examining the case of the 200 young swimmers (for testing hypothesis 5). In other words, the test was

performed to model the determinants of having achieved the top 100 in each age during adolescence. Dependent variables (success levels) were also listed in Table 5.14. A dependent variable took the value '1' if the swimmers achieved the top 100, '0' if not by given the following equation:

Eq. 3: $$log\left\{\frac{\mathrm{P}}{1-\mathrm{P}}\right\} = \beta_0 + \beta_1 AGE_1 + \beta_2 SEX_2 + \beta_3 MULTI_SPORTS_3 + \cdots + \beta_r z_r$$

where,

log odds are a linear function of the covariates.

P is the probability of success at covariate level z.

β is the parameter estimate.

β_0 represents the log odds of the response.

β = 0 → the probability of success is the same at each level of predictor (z).

β > 0 → the probability of success increases as x increases.

β < 0 → the probability of success decreases as x increases.

(Hosmer & Lemeshow, 2000; Johnson & Wichern, 2012)

OR was used for the measure of effect size. For all statistical analyses, a significance level was set at $p < 0.05$. All calculations and analyses were performed using IBM SPSS Statistics 22 for Windows (Armonk, NY: IBM Corp.).

Study 2: Interpopulation variations in height growth and swim performance progression between the U.S. and Japan

Data were presented as mean ± standard deviations (SD). A 2 x 17 (country x age) ANOVA for each sex was performed to compare 50Fr between countries (to test hypothesis 8), and subsequently, planned comparisons of 50Fr between the two countries at each age were performed. Effect sizes were computed based on the omega-squared (ω^2) for ANOVA and Cohen's d (d) for planned comparisons. Independent sample t-tests were used to compare height reference data (median for ages seven to 17

years old) between countries for each sex (to test hypothesis 7). Cohen's d was also used to estimate effect sizes (Cohen, 1988).

For determining the relationships between variables in Study 2, it was hypothesized that the patterns of age-related height growth and 50Fr progression curves between US and JPN are similar, except that the timing of the peak improvement in 50Fr may be delayed, or lagged, relative to that the peak height growth based on previous findings between height growth and physical tasks or physiological capacities (one-year lag in performance; Malina et al., 2004). Thus, it was expected that the correlation between height growth and 50Fr progression curves as well as the ratio of US to JPN in age-related height growth and 50Fr progression would be better when it is allowed a linear shift in time between the two curves in order to line up their peak points, and cross-correlation analysis was conducted.

Cross-correlation analysis was used to determine 1) the relationship between age-related height growth and 50Fr progression for each sex and country (hypothesis 6) and 2) the relationship of interpopulational differences between age-related height growth and 50Fr progression for each sex (hypothesis 9). The following questions corresponded above relationships (cross-correlation analyses): 1) whether or not age-related height growth was correlated with age-related improvement in 50Fr during adolescent ages for each sex and each country, and 2) whether or not differences in height between the two countries were correlated with those in 50Fr between countries for each sex. A measure of the strength of the correlation was provided by the correlation coefficient ($r \pm$ standard error). For all statistical analyses, a significance level was set at $p < 0.05$. All calculations and statistical procedures were performed using IBM SPSS Statistics 22 for Windows (Armonk, NY: IBM Corp.).

CHAPTER 4: RESULTS

The two projects in this study were: (1) performance progression, participation retention, and developmental career path in the U.S. top 100 nine-year-old swimmers and (2) interpopulation variations in height growth and swim performance progression between the U.S. and Japan. The results for both projects are shown below. For clarity, each research question (RQ) is restated prior to the results pertaining to that question.

Study 1: Performance progression, participation retention, and developmental career path in the U.S. top 100 nine-year-old swimmers

Population and sample size

Table 4.1 shows descriptive statistics: sample size (the number of the top 100 nine-year-old swimmers competing 45.7Fr each year and annual USAS memberships from 2004 to 2013 in corresponding ages) as well as their performance data and progression (swim times and national rankings). There was a tendency in the USAS memberships to increase the numbers of swimmers until age 12 and markedly decrease from age 15 to age 18 in both sexes. The number of girl swimmers was greater than boy swimmers at every age, with the exception of age 18, and a significant difference in memberships between girls and boys was revealed, $t_{(12.26)} = 2.68$, $p = 0.02$, $d = 1.20$. The differences in annual membership between sexes were approximately 1.5 times more in girls up to age 14, and the difference became smaller and smaller by age 17 years. The number of the top 100 nine-year-old swimmers who competed in 45.7Fr from age nine to age 18 was not statistically different between sexes (on a 10-year average, 80.1 ± 16.2 girls and 78.0 ± 15.5 boys), $t_{(18)} = 0.30$, $p = 0.77$, $d = 0.13$. All top 100 girl and boy swimmers (at age nine years), however, did not compete in 45.7Fr for ten consecutive years (Table 4.1). Roughly half (48 girls and 48 boys) continuously competed in 45.7Fr during their adolescent

ages (ten years in a row), either in an individual event or as the first leg (swimmer) of 182.8-meter (200 yards) freestyle relay members.

Table 4.1. Annual USAS memberships and available swims and performance in 45.7-m freestyle in the U.S. top 100 nine-year-old swimmers during the ten years of their adolescent swimming careers.

Girls	USAS^		45.7Fr (sec)				45.7Fr (ranking)			
year (age)	membership	n	mean ± SD	median	fastest	slowest	mean ± SD	median	highest	lowest
2004 (9)	12,054	100	29.76 ± 0.72	29.93	27.84	30.62	50.3 ± 28.9	50.5	1	99
2005 (10)	15,850	96	28.23 ± 0.96*	28.25	25.53	31.86	166.3 ± 263.4	98.0	1	1957
2006 (11)	17,160	95	27.22 ± 0.90*	27.19	25.30	29.27	263.7 ± 288.5	147.0	4	1444
2007 (12)	17,392	94	26.25 ± 0.90*	26.23	23.75	28.73	406.6 ± 493.6	253.0	1	2845
2008 (13)	15,890	82	25.86 ± 0.93*	25.85	23.65	28.70	571.4 ± 712.6	353.0	1	4322
2009 (14)	15,546	75	25.41 ± 1.07*	25.58	23.18	28.00	738.9 ± 757.2*	576.0	2	3892
2010 (15)	12,484	74	25.24 ± 1.11	25.31	22.74	28.45	824.9 ± 919.2	584.0	1	4835
2011 (16)	10,281	69	25.09 ± 1.16	25.00	23.16	28.60	900.6 ± 997.4	551.0	9	4789
2012 (17)	8,448	66	25.04 ± 1.16	24.79	22.92	27.57	885.7 ± 890.5	479.5	7	3138
2013 (18)	6,224	50	24.79 ± 1.28	24.64	22.64	30.40	488.6 ± 444.1*	329.0	8	2269
Boys	USAS^		45.7Fr (sec)				45.7Fr (ranking)			
year (age)	membership	n	mean ± SD	median	fastest	slowest	mean ± SD	median	highest	lowest
2004 (9)	7,909	100	29.53 ± 0.69	29.72	26.28	30.32	50.3 ± 28.9	50.0	1	100
2005 (10)	10,574	96	28.12 ± 0.97*	28.11	25.36	32.01	153.1 ± 219.0	94.5	1	1637
2006 (11)	11,319	92	27.02 ± 1.11*	27.09	24.15	30.72	250.5 ± 314.4	168.5	1	2121
2007 (12)	11,154	87	25.87 ± 1.59*	25.96	22.66	34.09	569.3 ± 942.5*	363.0	1	6984
2008 (13)	10,533	82	24.90 ± 1.57*	24.89	22.08	30.96	857.8 ± 1144.1*	499.0	2	6434
2009 (14)	11,314	71	23.57 ± 1.19*	23.44	21.17	27.4	751.3 ± 929.4	375.0	4	5046
2010 (15)	9,582	65	22.85 ± 1.03*	22.80	20.92	25.84	656.4 ± 873.8	364.0	4	4204
2011 (16)	8,760	67	22.37 ± 1.02*	22.38	20.25	24.98	770.1 ± 880.7	481.0	2	3966
2012 (17)	7,874	66	22.02 ± 1.04*	21.92	20.22	25.2	812.7 ± 979.1	437.0	5	4428
2013 (18)	6,673	54	21.65 ± 0.87	21.52	19.83	23.94	451.2 ± 416.8*	328.0	3	1614

(age), the age of the swimmers studied in each year; USAS, USA Swimming; n, available swims out of the 100 girls and boys in the database (sample size); * Different from one-year younger age ($p < 0.001$).
Note: ^ the numbers of USAS membership show only the swimmers registered for USAS in given years for the corresponding age and each sex but not the total membership of USAS.

Table 4.2 illustrates results of the top 100 nine-year-old swimmers' participation in competitive swimming (membership retention) and the highest rankings among all swimming events that the swimmers achieved during adolescent ages. As expected, there were more swimmers whose times and

rankings are available on the USAS database in both sexes when investigating all 14 events (i.e., highest rankings; on a 10-year average, 88.9 ± 9.1 girls and 85.3 ± 10.1 boys) as compared with 45.7Fr only, $t_{(9)}$ = 3.86, p = 0.004, d = 0.67 in girls and $t_{(9)}$ = 3.98, p = 0.003, d = 0.56 in boys. There were 67 girls and 61 boys among the top 100 nine-year-old swimmers who competed for ten consecutive years.

Table 4.2. Participation and performance progression (best rankings) in the best swimming event for the US top 100 nine-year-old swimmers during the ten-year of their adolescent swimming careers.

year (age)	Girls					Boys				
	n	mean ± SD	median	highest	lowest	n	mean ± SD	median	highest	lowest
2004 (9)	100	35.5 ± 28.4	27.5	1	99	100	31.4 ± 28.1	23.0	1	99
2005 (10)	97	79.6 ± 157.5	33.0	1	1403	98	88.1 ± 268.4	27.0	1	2367
2006 (11)	97	96.8 ± 134.7	44.5	1	785	95	179.8 ± 800.3	38.5	1	7439
2007 (12)	96	151.0 ± 274.9	57.0	1	2136	91	203.8 ± 593.7	51.5	1	3906
2008 (13)	91	227.4 ± 503.8	64.0	1	3739	85	266.4 ± 629.2	87.0	1	4639
2009 (14)	88	292.4 ± 584.0	68.0	1	3892	78	192.7 ± 338.4	97.0	1	2248
2010 (15)	85	217.9 ± 344.4	54.5	1	1987	78	162.9 ± 241.1	72.5	1	1183
2011 (16)	83	257.5 ± 401.2	72.0	1	2136	78	200.2 ± 283.4	80.0	1	1501
2012 (17)	81	235.7 ± 341.9	71.5	1	1550	79	261.6 ± 474.9	116.5	1	3207
2013 (18)	71	128.1 ± 154.3	77.0	1	805	71	127.9 ± 135.0	88.0	1	698

(age), the age of the swimmers studied in each year; USAS, USA Swimming; n, available swims out of the 100 girls and boys in the database (sample size).

Note 1: ^ the numbers of USAS membership show only the swimmers registered for USAS in given years for the corresponding age and each sex but not the total membership of USAS.

Note 2: the lowest rankings in boys at age 10 and 11 years (2005 and 2006, respectively) were greater than those in 45.7Fr data (see Table 3). It was because one of the swimmers in respective years did not compete in 45.7Fr (or data in 45.7Fr were not available in the database) but both competed in other events.

RQ_1: What is the percentage of the U.S. top 100 nine-year-old swimmers maintaining the top 100 status through adolescent ages and beyond?

Changes in rankings of the swimmers in 45.7Fr

A linear mixed-effect model revealed an effect of age on 45.7Fr ranking in both sexes (Table 4.1): $F_{(9, 614.9)}$ = 15.59, p < 0.001, ω^2 = 0.18 (girls) and $F_{(9, 604.9)}$ = 13.87, *p* < 0.001, ω^2 = 0.16 (boys). Post

hoc tests detected significant differences in 45.7Fr rankings between ages 13 and 14 years (d = 0.23) and between ages 17 and 18 years (d = -0.54) in girls. In boys, there were significant differences between ages 11 and 12 years (d = 0.46), ages 12 and 13 years (d = 0.28), and ages 17 and 18 years (d = -0.46).

Changes in the highest rankings of the swimmers among all 14 competitive events

A linear mixed-effect model revealed an effect of age on the highest ranking in both sexes (Table 4.2): $F_{(9, 660.6)} = 5.95$, $p < 0.001$, $\omega^2 = 0.06$ (girls) and $F_{(9, 623.2)} = 3.61$, $p < 0.001$, $\omega^2 = 0.04$ (boys). Post hoc test (repeated comparisons) with Sidak corrections, however, did not find any significant difference in the highest rankings of the top 100 nine-year-old swimmers between two subsequent ages during adolescence in either sex.

The odds of maintaining top 100 status over adolescence

Figure 4.1 demonstrates the number of the nine-year-old girl and boy swimmers who ranked within the U.S. top 100 in 45.7Fr and in their best swimming events (at age nine in 2004 and during subsequent nine years). A mixed-effects logistic regression demonstrated an effect of age on the odds that the top nine-year-old swimmers ranked within the top 100 in 45.7Fr in both sexes: [girls] $\chi^2_{(1, N = 1000)} = 72.93$, $p < 0.001$, ($\beta = -0.534$, SE = 0.063, OR = 0.59, 95%CI = [0.52, 0.66]); [boys] $\chi^2_{(1, N = 1000)} = 63.45$, $p < 0.001$, ($\beta = -0.496$, SE = 0.062, OR = 0.61, 95%CI = [0.54, 0.69]). β (beta estimate, i.e., slope) indicates that the odds of being ranked within the top 100 in the U.S. between ages nine and 18 years significantly decreases by 0.53 in girls and 0.50 in boys with an increase in age. When setting age as a categorical variable, significance was also revealed for both sexes: $\chi^2_{(9, N = 1000)} = 25220.6$, $p < 0.001$, $R^2 = 0.22$ (girls) and $\chi^2_{(9, N = 1000)} = 24535.8$, $p < 0.001$, $R^2 = 0.19$ (boys). Post hoc tests revealed that the odds changed from age nine to 10 years ($\chi^2_{(1)} = 108.3$, $p < 0.001$, OR = 0.59) in girls OR suggests that the girls at age 10 years were 0.59 times as likely as at age nine years to rank within the top 100 in this cohort. In boys, the

odds changed from age nine to 10 years ($\chi^2_{(1)}$ = 104.1, p < 0.001, OR = 0.60) and 10 to 11 years ($\chi^2_{(1)}$ = 14.2, p = 0.001, OR = 0.83).

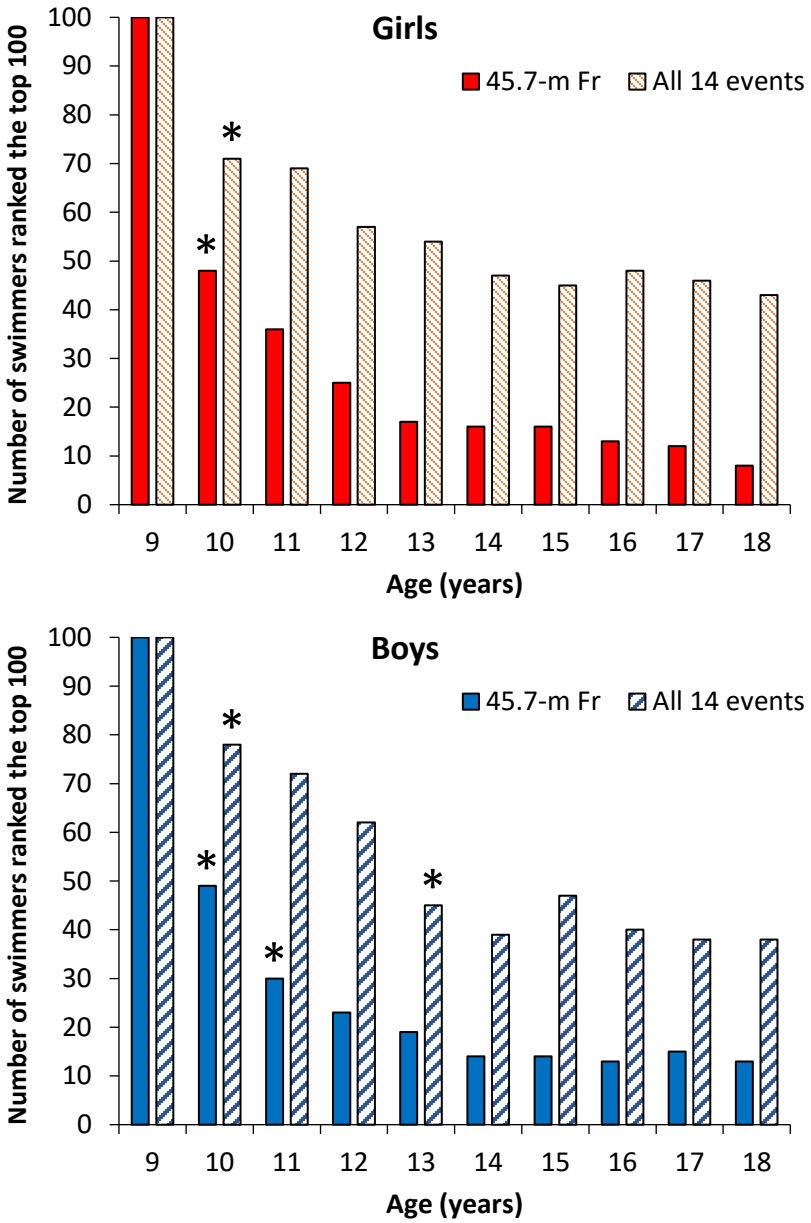


Figure 4.1. Retention rate of ranking within the U.S. top 100 for the top 100 nine-year-old swimmers during adolescence.
45.7-m Fr, top 100 status retention rate for investigating only 45.7-meter freestyle; All 14 events, investigating all 14 events (to determine the best/highest ranking of each swimmer).
* Changed odds of ranking within the U.S. top 100 as compared with the one-year younger age (p < 0.005).

For the best ranking (all 14 events in Figure 4.1), age was also associated with the odds that the top 100 nine-year-old swimmers ranked within the top 100 during adolescence in both sexes: [girls] $\chi^2_{(1, N = 1000)} = 115.47$, $p < 0.001$, ($\beta = -0.257$, SE = 0.024, OR = 0.77, 95%CI = [0.74, 0.81]); [boys] $\chi^2_{(1, N = 1000)} = 117.66$, $p < 0.001$, ($\beta = -0.301$, SE = 0.028, OR = 0.74, 95%CI = [0.70, 0.78]). With age set a categorical variable, a significant effect was also revealed for both sexes: $\chi^2_{(9, N = 1000)} = 23671.2$, $p < 0.001$, $R^2 = 0.09$ (girls) and $\chi^2_{(9, N = 1000)} = 21611.2$, $p < 0.001$, $R^2 = 0.13$ (boys). Post hoc tests revealed that the odds changed from age nine to 10 ($\chi^2_{(1)} = 40.9$, $p < 0.001$, OR = 0.75). A significant tendency in changing the odds was found from age 11 to 12 ($\chi^2_{(1)} = 8.7$, $p = 0.025$, n.s., OR = 0.89) in girls. In boys, the odds changed from age nine to 10 ($\chi^2_{(1)} = 28.2$, $p < 0.001$, OR = 0.80) and 12 to 13 ($\chi^2_{(1)} = 16.0$, $p = 0.001$, OR = 0.84).

Approximately 10% of the top 100 nine-year-old swimmers (8% in girls and 13% boys) achieved the top 100 in 45.7Fr and 40% of them (43% in girls and 38% in boys) in at least one swimming event at age 18 in both sexes (Figure 4.1). As a chance to make the top 100 may have increased with competing in more events, there were more swimmers achieving the top 100 when tracking 14 events throughout nine years of adolescence (on average, 58.0 ± 17.7 girls and 55.9 ± 21.4 boys) as compared with only 45.7Fr (29.1 ± 27.8 girls and 29.0 ± 27.4 boys), $t_{(9)} = 8.39$, $p < 0.001$, d = 1.24 (girls) and $t_{(9)} = 7.48$, $p < 0.001$, d = 1.10 (boys). In either case (examining one event or all events), these findings support the hypothesis that the proportion of the nine-year-old swimmers maintaining the top 100 status decreases with age.

Additionally, the top 100 nine-year-old swimmers ranked within the top 100 in an average of 2.5 ± 2.2 events in girls and 2.5 ± 2.3 events in boys during adolescence (Figure 4.2). Out of the 100 swimmers in each sex, there were only seven girls and six boys whose highest ranking was achieved in 45.7Fr at age 18, suggesting that their best event or specialization would be the 45.7Fr although none of the seven girl swimmers but four boys ranked within the top 100 in 45.7Fr at age 18: average ranking,

329.7 ± 230.2 (155th, 168th, 204th, 253th, 285th, 438th, and 805th) for the seven girls; and 83.3 ± 132.0 (3rd, 8th, 13th, 25th, 111th, and 340th) for the six boys. There were 26 girls and 22 boys who achieved the top 100 in at least one swimming event for ten consecutive years from ages nine to 18 years. On average, those swimmers ranked within the top 100 in 5.0 ± 2.1 events in girls and 5.7 ± 2.2 events in boys. When examining eight or more years achieving the top 100 in any event, but not necessarily consecutively, there were 41 girls and 35 boys out of the 100 swimmers in each sex.

From the 200 top 100 nine-year-old swimmers studied, 12 girls and four boys were selected for the U.S. Junior National team, and three girls and one boy for the U.S. Senior National team members by and or at age 18. The Senior National members (four swimmers) represented the country for the World championships, London Olympics, and/or other senior international competitions.

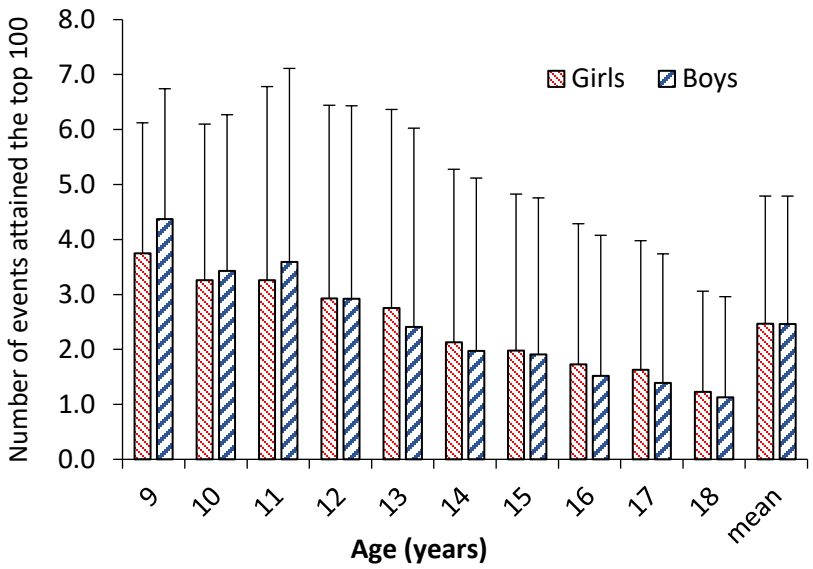


Figure 4.2. The number of swimming events that the U.S. top 100 nine-year-old swimmers attained the top 100 during adolescent ages.
Data are shown as means ± standard deviations (error bars).

RQ_{2a}: Do the U.S. top 100 nine-year-old swimmers improve their performance times (45.7-meter freestyle: 45.7Fr) across adolescent ages?

Overall, 45.7Fr in the top 100 girl and boy swimmers improved from age nine to 18 years (Table 4.1). A linear mixed-effect model revealed an effect of age on 45.7Fr in both sexes: $F_{(9, 623.0)} = 173.27$, $p < 0.001$, $\omega^2 = 0.71$ (girls) and $F_{(9, 624.0)} = 283.58$, $p < 0.001$, $\omega^2 = 0.80$ (boys). Post hoc tests detected significant differences ($p < 0.001$) in 45.7Fr time between two subsequent ages up to age 14 ($d = -0.43$ to -1.80) in girls and age 17 ($d = -0.34$ to -1.68) in boys (Table 4.1). The fact that an effect of age on 45.7Fr was evident for both sexes support the hypothesis that the U.S. top 100 nine-year-old swimmers will improve their performance in 45.7Fr across adolescence, especially in boys, while this may not be the case in girls who did not constantly improve 45.7Fr across ages nine to 18 years.

Table 4.3 shows the annual improvements in 45.7Fr (actual time improvements in sec) for the top 100 swimmers at ages 10 to 18 years. Data were compiled (calculated using) from the swimmers who competed in 45.7Fr in two or more consecutive years (see Table 5 for the sample size). A linear mixed-effect model indicated an effect of age on the annual improvements in the swimmers across adolescent ages for both sexes: $F_{(8, 414.9)} = 81.53$, $p < 0.001$, $\omega^2 = 0.61$ (girls) and $F_{(8, 500.6)} = 30.87$, $p < 0.001$, $\omega^2 = 0.32$ (boys). Post hoc test with Sidak corrections detected the significant decreases in the annual improvements in 45.7Fr at age 11 (-3.6% vs. -5.1% at age 10; $p < 0.001$, $d = -0.82$) and age 13 (-1.5% vs. -3.6% at age 12; $p < 0.001$, $d = -0.97$) in girls. In boys, there was a significant decrease in the annual improvement detected from age 14 to 15 years (-5.4% to -3.0%, respectively; $p < 0.001$, $d = -0.81$). In addition, three and four homogenous subsets in girls and boys, respectively, from Tukey's HSD on the annual improvements in 45.7Fr for nine ages (age 10 to 18) were shown (Table 4.4). The subsets (groups) in the annual improvement levels appear to be corresponded to ages before, during (around), and after the reported average age of PHV for both sexes.

Table 4.3. Comparisons in 45.7Fr progression between the US top 100 nine-year olds and all-time observations/swims (2004 to 2013).

GIRLS	US top 100 45.7Fr 9-year-old swimmers							All-time 45.7Fr observations (2004-2013)								Group-diff. in annual improv.	
	45.7Fr time (sec)			Annual improvment (sec)				45.7Fr time (sec)				Annual improvment (sec)					
Age	n	Mean ± SD	*MED*	n[a]	Mean ± SD		*MED*	N	Mean ± SD	*MED*	*US rank* [2015-16]	n[a]	Mean ± SD	*MED*		Sig. (p)	d
9	100	29.76 ± 0.72	*29.93*					156182	42.27 ± 12.09	*40.62*	^ *>7000 (38.93)*	77686	-5.54 ± 5.01	*-4.63*			
10	96	28.23 ± 0.96	*28.25*	95	-1.60 ± 0.74		*-1.54*	177748	38.21 ± 7.05	*36.81*	^ *>7000 (34.32)*	105107	-4.37 ± 4.00	*-3.67*	^	0.000	2.80
11	95	27.22 ± 0.90	*27.19*	94	-1.04 ± 0.64	*	*-1.02*	176266	35.02 ± 5.78	*33.81*	^ *>7000 (31.51)*	117715	-3.11 ± 3.20	*-2.52*	^	0.000	2.31
12	94	26.25 ± 0.90	*26.23*	93	-0.95 ± 0.58	†	*-0.96*	163420	32.33 ± 4.79	*31.35*	^ *>7000 (29.58)*	114783	-2.35 ± 2.54	*-1.93*	^	0.000	1.68
13	82	25.86 ± 0.93	*25.85*	82	-0.38 ± 0.58	*†	*-0.40*	141958	30.65 ± 5.80	*29.85*	^ *>7000 (28.72)*	106019	-1.30 ± 5.20	*-1.03*	^	0.000	1.11
14	75	25.41 ± 1.07	*25.58*	72	-0.36 ± 0.59	†	*-0.40*	111200	29.43 ± 7.53	*28.78*	^ *>7000 (28.39)*	86519	-0.80 ± 1.46	*-0.65*	^	0.000	0.50
15	74	25.24 ± 1.11	*25.31*	69	-0.14 ± 0.71	†	*0.00*	86075	28.61 ± 3.37	*28.11*	^ *6034*	65532	-0.40 ± 1.56	*-0.33*		0.027	0.27
16	69	25.09 ± 1.16	*25.00*	65	-0.15 ± 0.65	†	*-0.19*	68239	28.04 ± 3.04	*27.62*	^ *4741*	51001	-0.24 ± 1.55	*-0.20*		0.553	0.07
17	66	25.04 ± 1.16	*24.79*	61	-0.01 ± 0.53	†	*-0.05*	50677	27.58 ± 2.92	*27.19*	^ *3500*	38379	-0.11 ± 1.53	*-0.10*		0.198	0.17
18	50	24.79 ± 1.28	*24.64*	46	-0.16 ± 0.53		*-0.01*	21233	26.87 ± 3.16	*26.37*	^ *1315*	16435	-0.04 ± 1.59	*-0.06*		0.192	-0.20

BOYS	US top 100 45.7Fr 9-year-old swimmers							All-time 45.7Fr observations (2004-2013)								Group-diff. in annual improv.	
	45.7Fr time (sec)			Annual improvment (sec)				45.7Fr time (sec)				Annual improvment (sec)					
Age	n	Mean ± SD	*MED*	n[a]	Mean ± SD		*MED*	N	Mean ± SD	*MED*	*US rank* [2015-16]	n[a]	Mean ± SD	*MED*		Sig. (p)	d
9	100	29.53 ± 0.69	*29.72*					100736	41.83 ± 8.77	*39.99*	^ *6167*	50984	-5.43 ± 5.37	*-4.45*			
10	96	28.12 ± 0.97	*28.11*	96	-1.40 ± 0.82		*-1.52*	113200	38.10 ± 7.48	*36.49*	^ *>7000 (36.06)*	66938	-4.17 ± 4.58	*-3.38*	^	0.000	2.41
11	92	27.02 ± 1.11	*27.09*	91	-1.10 ± 0.62		*-1.04*	110891	35.15 ± 6.36	*33.77*	^ *>7000 (33.16)*	73389	-2.97 ± 3.52	*-2.31*	^	0.000	1.95
12	87	25.87 ± 1.59	*25.96*	86	-1.24 ± 0.70		*-1.25*	105016	32.03 ± 5.36	*30.88*	^ *>7000 (30.48)*	71402	-2.87 ± 2.90	*-2.38*	^	0.000	1.64
13	82	24.90 ± 1.57	*24.89*	79	-0.91 ± 0.69		*-1.04*	94732	29.38 ± 4.30	*28.48*	^ *6778*	68091	-2.24 ± 2.29	*-1.86*	^	0.000	1.37
14	71	23.57 ± 1.19	*23.44*	69	-1.09 ± 0.67		*-1.08*	79862	27.19 ± 3.52	*26.50*	^ *5849*	59442	-1.73 ± 1.82	*-1.48*	^	0.000	0.58
15	65	22.85 ± 1.03	*22.80*	62	-0.58 ± 0.59	*	*-0.57*	66019	25.80 ± 2.74	*25.34*	^ *4878*	48047	-1.02 ± 1.46	*-0.84*	^	0.001	0.44
16	67	22.37 ± 1.02	*22.38*	59	-0.49 ± 0.59		*-0.41*	59575	24.87 ± 2.48	*24.52*	^ *4156*	41708	-0.73 ± 1.38	*-0.63*		0.064	0.25
17	66	22.02 ± 1.04	*21.92*	60	-0.34 ± 0.50		*-0.29*	46649	24.21 ± 2.38	*23.91*	^ *3385*	33289	-0.46 ± 1.49	*-0.42*		0.228	0.16
18	54	21.65 ± 0.87	*21.52*	53	-0.28 ± 0.54		*-0.29*	25445	23.61 ± 2.60	*23.26*	^ *1464*	18990	-0.25 ± 1.29	*-0.25*		0.663	-0.06

US rank[2015-16], demonstrating the levels (rankings) of the all-time median in each age in 45.7Fr relative to the latest 2015-16 season in the US (ranks available only up to 7000th); Sig (p); significance (p-value) of the differences in annual improvements (sec) between the top 100 swimmers and all-time median time (one-sample t-test); d, Cohen' s d; * Age-differences in annual improvements (between a given age and one-year younger age, $p < 0.005$); † Sex-differences in annual improvements ($p < 0.001$); ^ Group-differences in annual improvements ($p < 0.005$). Note (n[a]): the numbers (observations) of the annual improvements are less than numbers (sample size) of the swimmers. This is because an annual improvement in 45.7Fr time in a swimmer was not calculated unless the swimmer had times in a given year and its previous year (one-year younger age; i.e., two consecutive years)

Table 4.4. Homogenous subsets from Tukey's HSD on the annual improvements in 45.7Fr of the US top 100 girl and boy swimmers during adolescent ages (ages 10-18).

Girls		Subsets			**Boys**		Subsets			
Age	N	1	2	3	Age	N	1	2	3	4
10	95	-1.60			10	96	-1.40			
11	94		-1.04		12	86	-1.24	-1.24		
12	93		-0.95		11	91	-1.10	-1.10		
13	82			-0.38	14	69	-1.09	-1.09		
14	72			-0.36	13	79		-0.91	-0.91	
18	46			-0.16	15	62			-0.58	-0.58
16	65			-0.15	16	59				-0.49
15	69			-0.14	17	60				-0.34
17	61			-0.01	18	53				-0.28
Sig.		1.000	0.995	0.014	Sig.		0.125	0.084	0.066	0.173

Subset for alpha = 0.0056 with Bonferroni correction.
The value in each age indicate the annual mean improvement from one-year younger age.

RQ_{2b}: Do the U.S. top 100 nine-year-old swimmers improve their performance times (45.7Fr) more than swimmers who did not rank within the top 100 at young ages across adolescent ages?

Table 4.3 and Figure 4.3 illustrate 45.7Fr performances of the top 100 nine-year-old swimmers from ages nine to 18 (2004 to 2013) along with all-time 45.7Fr performances (2004-2013) for ages nine to 18 years. All-time performances were used as representing USAS' general or average performances in order to compare with the performances in the top 100 nine-year-old swimmers at every age category. As seen in Figure 4.3 and Table 4.3, mean times in 45.7Fr in the top 100 swimmers were significantly faster than median times of all-time performance for all ages ($p < 0.0001$, $d = -1.24$ to -15.00 in girls and $d = -1.81$ to -15.13 in boys). These results are not unexpected since the median times in all-time performances, in fact, commensurate with lower rankings in the US, especially during early- to mid-adolescence (US top 5000th or above; mostly above 7000th) (see US rank in Table 4.3).

In contrast, when using annual improvements in 45.7Fr for all-time observations/swimmers between 2004 and 2013 and comparing its median values with the annual 45.7Fr improvements in the top 100 nine-year-old swimmers, one-sample t-tests detected significant differences ($p < 0.01$) up to age 14 years in girls and age 15 years in boys (Table 4.3 and Figure 4.4). As it is expected that slower (lower-

ranked) or younger swimmers tend to improve more than higher-ranked or older (senior-level) swimmers, the top 100 nine-year-old swimmers improved significantly less than the national's median performers in both sexes during early- to mid-adolescence (Table 4.3 and Figures 4.4-5). However, smaller improvements in the top 100 nine-year-old swimmers as compared with the US' median performances do not mean that the top 100 nine-year-old were slower than US median performance. The top 100 nine-year-old swimmers maintained approximately the top 500-level (median ranking; on average, below top 900) in the US during adolescence (Table 4.1). It is also noted that there were no differences in the annual improvements in 45.7Fr beyond (after) age 15 in girls and age 16 in boys.

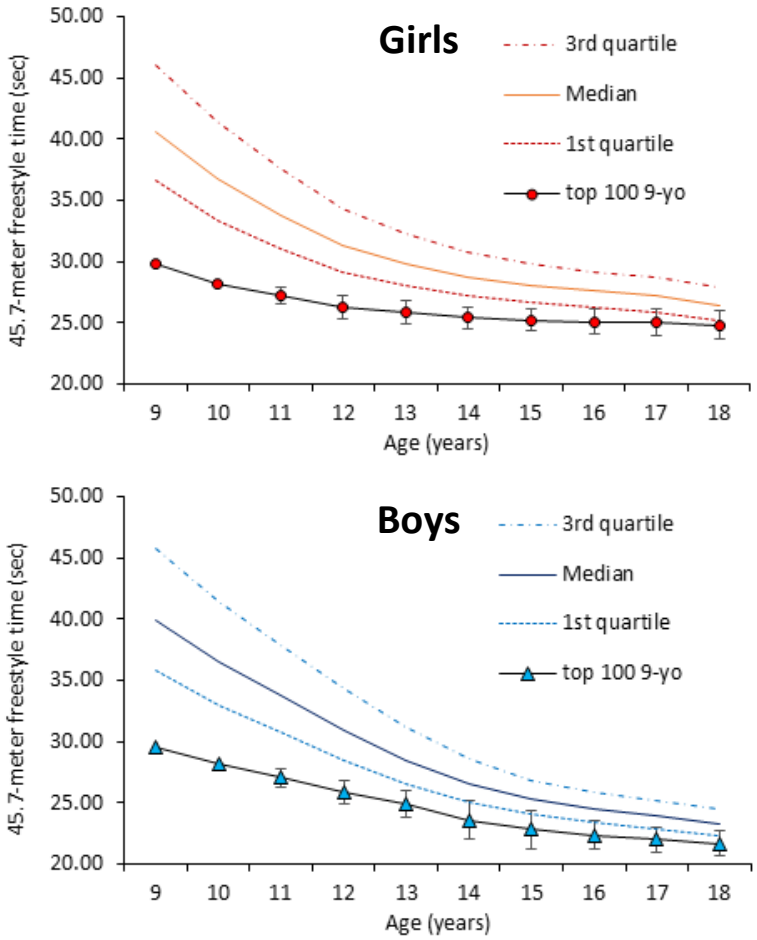


Figure 4.3. 45.7-meter freestyle times in the top 100 nine-year-old (9-yo) swimmers plotted along all-time 45.7-meter across (median and 1st and 3rd quartiles) adolescent ages (2004-2013).
Data for the top 100 swimmers are shown as means ± standard deviations (error bars).

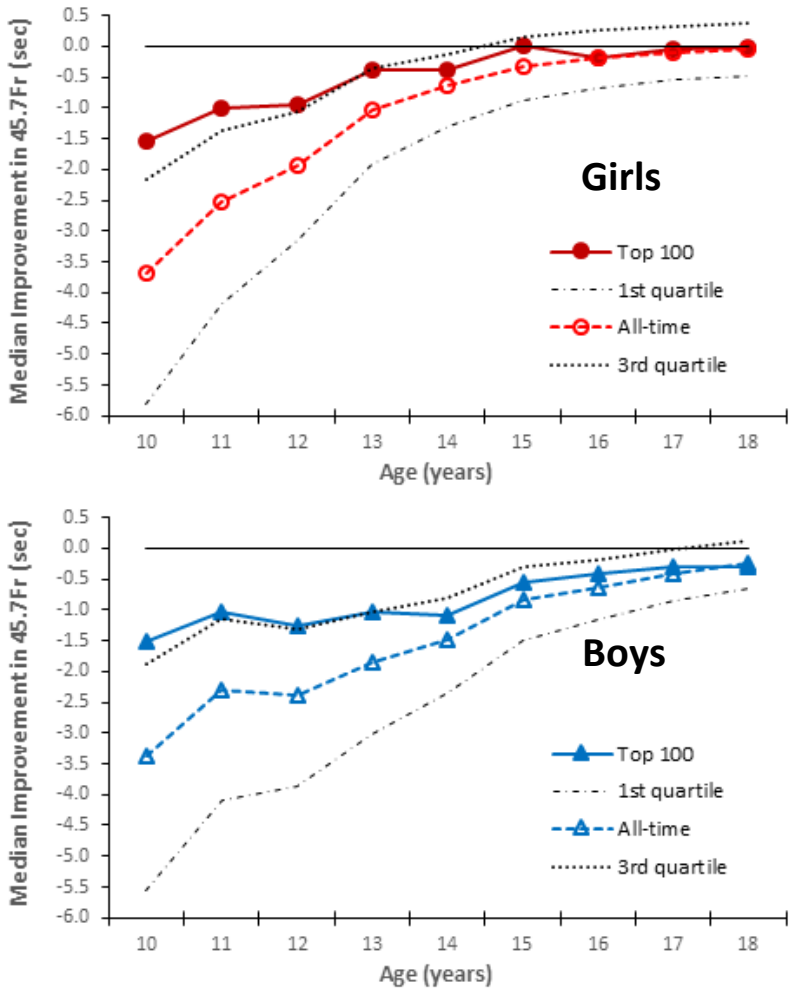


Figure 4.4. Median improvements in 45.7Fr (sec) in the top 100 nine-year-old swimmers plotted along all-time observations across adolescent ages (2004-2013).
45.7Fr, 45.7 meters (50 yards) freestyle

Note 1: Each data point (an annual improvement in 45.7Fr of a swimmer) was calculated by the subtraction of the swimmer's 45.7Fr time in a given age (year) from the subsequent age (year). Values correspond to Table 4.3.

Note 2: A bold straight line on the figure denotes no time improvement (0 sec) between a given age and the subsequent age (any plot/value above this line indicates a deterioration in the 45.7Fr time).

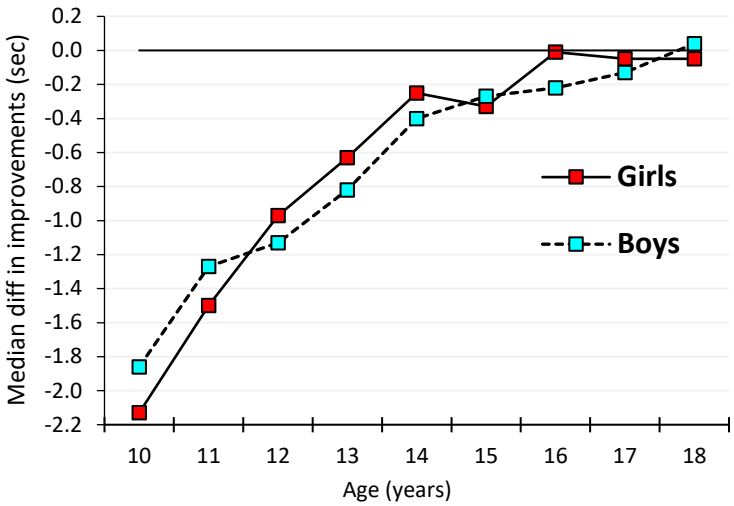


Figure 4.5. Differences in annual improvements in 45.7Fr (sec, median values) between the top 100 nine-year-old swimmers and all-time observations across adolescent ages (2004-2013).
Diff, difference.

Note: A bold straight line on the figure denotes no difference in 45.7Fr improvement between groups (0 sec). Any plot/value below and above the bold straight line indicates more improvements in all-time observations and top young swimmers, respectively.

These data support the hypothesis that the magnitude of the improvement in 45.7Fr is smaller in the top 100 nine-year-old swimmers through adolescence when compared with the improvement rates of the total U.S. swimming population as expressed by median performances and progressions in all-time US swimmers. However, due to the apparent disparity in the performance levels (US rankings) between the top 100 swimmers and all-time median performances across ages, the following analyses were conducted for a more concrete, practical evaluation of performance progressions in the top nine-year-old swimmers. For the different standard performance measures in USAS, all-time US top 50th, 100th, 500th, and 1000th swims in 45.7Fr for each age between nine and 18 years old were tracked for the past 12 years (2004 to 2015) to demonstrate whether the U.S. top 100 nine-year-old swimmers improve their performance times (45.7Fr) more or less than different levels of swimmers (Figure 4.6 and Table

4.5). It is noted that the median performance (ranking) of the US top 100 swimmers in this study corresponded to top 50th (Table 4.1).

Based on these cross-sectional data using the four designated rankings for 10 ages across past 12 years and using log-transformed times and further calculated improvements, a linear mixed-effect model revealed a significant interaction between the effects of rank and age on 45.7Fr improvements (log-transformed) for both sexes (Figure 4.6 and Table 4.5-6): $F_{(38, 574.6)} = 6.67$, $p < 0.001$, $\omega^2 = 0.27$ (girls) and $F_{(38, 567.19)} = 5.58$, $p < 0.001$, $\omega^2 = 0.23$ (boys). Post hoc tests with Bonferroni corrections (alpha set at 0.0125) detected significant differences in the 45.7Fr improvements between top 100 nine-year-old swimmers and the 500th rank at age 10 ($p < 0.01$, $d = 1.08$) and the 1000th rank at age 10 ($p < 0.01$, $d = 1.31$), age 11 ($p < 0.01$, $d = 0.97$), and age 18 ($p < 0.01$, $d = -1.61$) in girls. In boys, there were significant differences at age 10 for 500th ($p < 0.01$, $d = 1.08$) and 1000th ($p < 0.01$, $d = 1.31$) ranks and age 12 for all ranks ($p < 0.01$; 50th, $d = 0.90$; 100th, $d = 0.94$; 500th, $d = 0.97$; and 1000th, $d = 0.97$). Therefore, the progressions in 45.7Fr in the top 100 nine-year-old swimmers were the smallest but not significantly different from the four rankings in most ages ($p > 0.01$), with the exception of lower ranks (US 1000th) in both sexes and age 12 years in boys (Figure 4.6 and Table 4.5). Similar results were evident using raw time data in seconds (Table 4.6). Once again, the median improvements in all-time swims were significantly greater than those of the top 100 nine-year-old swimmers at every age between 10 and 18 years ($p < 0.01$, $d = 1.46$-2.09 in girls and $d = 0.42$-1.61 in boys, Table 4.5).

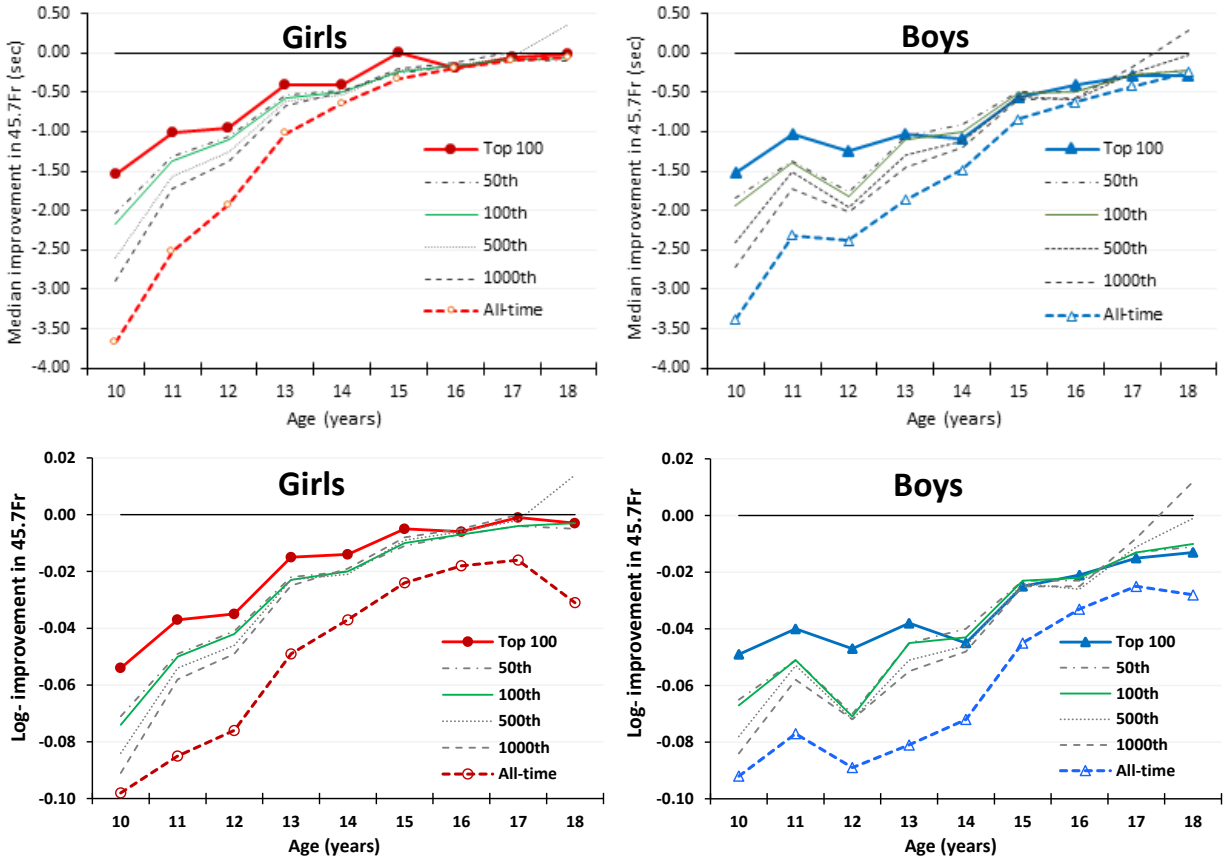


Figure 4.6. Median improvements in 45.7Fr in the US top 100 nine-year-old swimmers plotted along all-time observations and respective rankings (50, 100, 500, and 1000th, age-related improvements) in adolescent ages (2004-2015).

Top figures, absolute values (sec); bottom, log-transformed values.

Note: A bold straight lines on the figure denotes no time improvement (0 sec or 0 %) from a given age to the subsequent age, and any plot/value above the line indicates a deterioration in the 45.7Fr time; Data (median improvements) of the top 100-nine-year-old swimmers and all-time swims were based on longitudinal analyses, while age-related improvements (median values) of four selected rankings over 12 years consisted of cross-sectional analysis.

Table 4.5. Log-transformed (age-related) improvements in 45.7-meter freestyle in the US top 100 nine-year-old swimmers and US top 50th, 100th, 500th, 1000th, and all-time times for 10 age categories during the past 12 years from 2004 to 2015 (n = 12 per each age for each sex).

GIRLS	Log-transformed improvments (Δ) in all-time US 45.7Fr (2004-2015)					
	Top 100	50th	100th	500th	1000th	All-time
Age	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Median
9	±	-0.081 ± 0.0077	-0.086 ± 0.0062	-0.099 ± 0.0045	-0.108 ± 0.0042	
10	-0.054 ± 0.0296	-0.071 ± 0.0056	-0.074 ± 0.0039	-0.084 ± 0.0026 ^	-0.091 ± 0.0033 ^	-0.098 ^
11	-0.037 ± 0.0229	-0.049 ± 0.0042	-0.050 ± 0.0035	-0.054 ± 0.0027	-0.058 ± 0.0030 ^	-0.085 ^
12	-0.035 ± 0.0220	-0.041 ± 0.0039	-0.042 ± 0.0035	-0.046 ± 0.0009	-0.049 ± 0.0019	-0.076 ^
13	-0.015 ± 0.0223	-0.022 ± 0.0038	-0.023 ± 0.0044	-0.023 ± 0.0022	-0.025 ± 0.0014	-0.049 ^
14	-0.014 ± 0.0230	-0.020 ± 0.0042	-0.020 ± 0.0034	-0.021 ± 0.0029	-0.019 ± 0.0025	-0.037 ^
15	-0.005 ± 0.0279	-0.011 ± 0.0030	-0.010 ± 0.0023	-0.009 ± 0.0028	-0.008 ± 0.0024	-0.024 ^
16	-0.006 ± 0.0255	-0.007 ± 0.0043	-0.007 ± 0.0037	-0.006 ± 0.0024	-0.005 ± 0.0029	-0.018 ^
17	-0.001 ± 0.0206	-0.004 ± 0.0038	-0.004 ± 0.0031	-0.002 ± 0.0035	0.000 ± 0.0040	-0.016 ^
18	-0.003 ± 0.0310	-0.005 ± 0.0030	-0.003 ± 0.0044	0.014 ± 0.0113	0.050 ± 0.0389 ^	-0.031 ^

BOYS	Log-transformed improvments (Δ) in all-time US 45.7Fr (2004-2015)					
	Top 100	50th	100th	500th	1000th	All-time
Age	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Median
9	±	-0.077 ± 0.0064	-0.081 ± 0.0047	-0.098 ± 0.0040	-0.109 ± 0.0045	
10	-0.049 ± 0.0286	-0.065 ± 0.0038	-0.067 ± 0.0026	-0.078 ± 0.0043 ^	-0.084 ± 0.0035 ^	-0.092 ^
11	-0.040 ± 0.0229	-0.051 ± 0.0057	-0.051 ± 0.0050	-0.053 ± 0.0028	-0.058 ± 0.0021	-0.077 ^
12	-0.047 ± 0.0268	-0.070 ± 0.0057 ^	-0.071 ± 0.0057 ^	-0.072 ± 0.0018 ^	-0.072 ± 0.0024 ^	-0.089 ^
13	-0.038 ± 0.0287	-0.045 ± 0.0036	-0.045 ± 0.0045	-0.051 ± 0.0027	-0.055 ± 0.0023	-0.081 ^
14	-0.045 ± 0.0269	-0.040 ± 0.0049	-0.043 ± 0.0029	-0.046 ± 0.0023	-0.048 ± 0.0026	-0.072 ^
15	-0.025 ± 0.0253	-0.023 ± 0.0049	-0.023 ± 0.0038	-0.024 ± 0.0028	-0.025 ± 0.0029	-0.045 ^
16	-0.021 ± 0.0255	-0.023 ± 0.0033	-0.022 ± 0.0024	-0.026 ± 0.0025	-0.025 ± 0.0025	-0.033 ^
17	-0.015 ± 0.0224	-0.013 ± 0.0084	-0.013 ± 0.0096	-0.011 ± 0.0187	-0.008 ± 0.0313	-0.025 ^
18	-0.013 ± 0.0236	-0.011 ± 0.0091	-0.010 ± 0.0103	-0.001 ± 0.0215	0.012 ± 0.0393	-0.028 ^

45.7Fr, 45.7-meter freestyle

^ Group-difference, different from the annual improvements in the US top 100 nine-year-old swimmers ($p < 0.01$).

See Appendix D for the log-transformed times in 45.7Fr for the different (designated) rankings.

Table 4.6. US top 50th, 100th, 500th, and 1000th times in 45.7-meter freestyle for 10 age categories during the past 12 years from 2004 to 2015 (n = 12 per each age for each sex).

GIRLS	All-time US 45.7Fr times (2004-2015)														
	50th				100th				500th				1000th		
Age	Mean ± SD		Δ	%Δ	Mean ± SD		Δ	%Δ	Mean ± SD		Δ	%Δ	Mean ± SD		Δ	%Δ
9	29.65 ± 0.21		-2.49	-7.7	30.24 ± 0.24		-2.72	-8.3	32.11 ± 0.32		-3.32	-9.4	33.33 ± 0.39		-3.78	-10.2
10	27.61 ± 0.23	*	-2.04	-6.9	28.08 ± 0.23	*	-2.17	-7.2	29.52 ± 0.29	*	-2.60 ^	-8.1	30.44 ± 0.35	*	-2.89 ^	-8.7
11	26.29 ± 0.22	*	-1.32	-4.8	26.71 ± 0.23	*	-1.37	-4.9	27.95 ± 0.26	*	-1.56	-5.3	28.72 ± 0.31	*	-1.72 ^	-5.7
12	25.24 ± 0.23	*	-1.05	-4.0	25.61 ± 0.21	*	-1.10	-4.1	26.69 ± 0.25	*	-1.26	-4.5	27.35 ± 0.28	*	-1.37	-4.8
13	24.70 ± 0.24	*	-0.54	-2.1	25.03 ± 0.24		-0.57	-2.3	26.07 ± 0.25		-0.62	-2.3	26.68 ± 0.29		-0.67	-2.4
14	24.22 ± 0.26	*	-0.48	-2.0	24.54 ± 0.26		-0.49	-2.0	25.53 ± 0.28		-0.54	-2.1	26.18 ± 0.32		-0.50	-1.9
15	23.96 ± 0.23		-0.26	-1.1	24.29 ± 0.23		-0.25	-1.0	25.31 ± 0.29		-0.22	-0.9	25.97 ± 0.34		-0.20	-0.8
16	23.80 ± 0.25		-0.16	-0.7	24.13 ± 0.28		-0.16	-0.7	25.15 ± 0.30		-0.16	-0.6	25.85 ± 0.38		-0.12	-0.5
17	23.71 ± 0.25		-0.09	-0.4	24.04 ± 0.26		-0.09	-0.4	25.10 ± 0.35		-0.05	-0.2	25.86 ± 0.43		0.01	0.0
18	23.60 ± 0.28		-0.11	-0.5	23.97 ± 0.32		-0.07	-0.3	25.46 ± 0.63		0.37	1.5	27.21 ± 1.52	*	1.35 ^	5.1

BOYS	All-time US 45.7Fr times (2004-2015)														
	50th				100th				500th				1000th		
Age	Mean ± SD		Δ	%Δ	Mean ± SD		Δ	%Δ	Mean ± SD		Δ	%Δ	Mean ± SD		Δ	%Δ
9	29.33 ± 0.27		-2.36	-7.5	29.93 ± 0.29		-2.54	-7.8	32.02 ± 0.46		-3.30	-9.3	33.47 ± 0.58		-3.84	-10.3
10	27.49 ± 0.26	*	-1.84	-6.3	28.00 ± 0.26	*	-1.93	-6.5	29.61 ± 0.33	*	-2.40 ^	-7.5	30.77 ± 0.47	*	-2.71 ^	-8.1
11	26.11 ± 0.29	*	-1.38	-5.0	26.60 ± 0.28	*	-1.39	-5.0	28.10 ± 0.35	*	-1.52	-5.1	29.04 ± 0.43	*	-1.72 ^	-5.6
12	24.35 ± 0.29	*	-1.77	-6.8	24.78 ± 0.29	*	-1.82 ^	-6.9	26.15 ± 0.35	*	-1.95 ^	-6.9	27.03 ± 0.41	*	-2.01 ^	-6.9
13	23.28 ± 0.29	*	-1.07	-4.4	23.68 ± 0.27	*	-1.10	-4.4	24.85 ± 0.31	*	-1.30	-5.0	25.59 ± 0.38	*	-1.44	-5.3
14	22.37 ± 0.24	*	-0.91	-3.9	22.67 ± 0.25	*	-1.01	-4.3	23.73 ± 0.28	*	-1.12	-4.5	24.40 ± 0.33	*	-1.19	-4.6
15	21.86 ± 0.25	*	-0.50	-2.3	22.15 ± 0.27		-0.52	-2.3	23.17 ± 0.29		-0.56	-2.4	23.81 ± 0.35		-0.60	-2.5
16	21.37 ± 0.25		-0.49	-2.3	21.66 ± 0.24		-0.49	-2.2	22.57 ± 0.30		-0.59	-2.6	23.23 ± 0.38		-0.58	-2.5
17	21.10 ± 0.23		-0.28	0.8	21.38 ± 0.25		-0.28	-1.3	22.32 ± 0.39		-0.25	-1.1	23.05 ± 0.67		-0.17	-0.7
18	20.86 ± 0.27		-0.23	-1.1	21.16 ± 0.28		-0.22	-1.0	22.30 ± 0.43		-0.02	-0.1	23.34 ± 0.76		0.28	1.3

45.7Fr, 45.7-meter freestyle; Δ, age-related improvements; %Δ, age-related relative improvements.
* Age-related difference, different from one-year younger age ($p < 0.005$); ^ Group-difference, different from the annual improvements in the US top 100 nine-year-old swimmers (Table 4.3; $p < 0.01$).

RQ_3: What is the percentage of the U.S. top 100 nine-year-old swimmers continuing in USA Swimming through adolescent ages and into adulthood?

Dropout rate across adolescent ages of the top 100 nine-year-old girl and boy swimmers are demonstrated in Figure 4.7. A mixed-effects logistic regression revealed an effect of age on the odds that the top 100 nine-year-old swimmers dropout from competitive swimming in both sexes: girls, $\chi^2_{(9, N = 1000)} = 59.02$, $p < 0.001$ ($\beta = 0.338$, SE = 0.044, OR = 1.40, 95%CI = [1.29, 1.53]); and boys, $\chi^2_{(9, N = 1000)} = 90.52$, $p < 0.001$ ($\beta = 0.286$, SE = 0.03, OR = 1.33, 95%CI = [1.25, 1.41]). When setting age as a categorical

variable, a significant effect was also revealed for both sexes: $\chi^2_{(9, N = 1000)} = 7324.5$, $p < 0.001$, $R^2 = 0.08$ (girls) and $\chi^2_{(9, N = 1000)} = 2816.2$, $p < 0.001$, $R^2 = 0.07$ (boys). Post hoc tests detected a change in the odds of dropout rate only from age 17 to 18 years in both sexes: $\chi^2_{(1)} = 9.1$, $p = 0.02$, OR = 1.11 (girls); $\chi^2_{(1)} = 9.1$, $p = 0.02$, OR = 1.11 (boys). Twenty-nine swimmers dropped out from competitive swimming by age 18 in both sexes, and ten girls and eight boys withdrew from competitive swimming at age 18 (the highest dropout rate across adolescent ages).

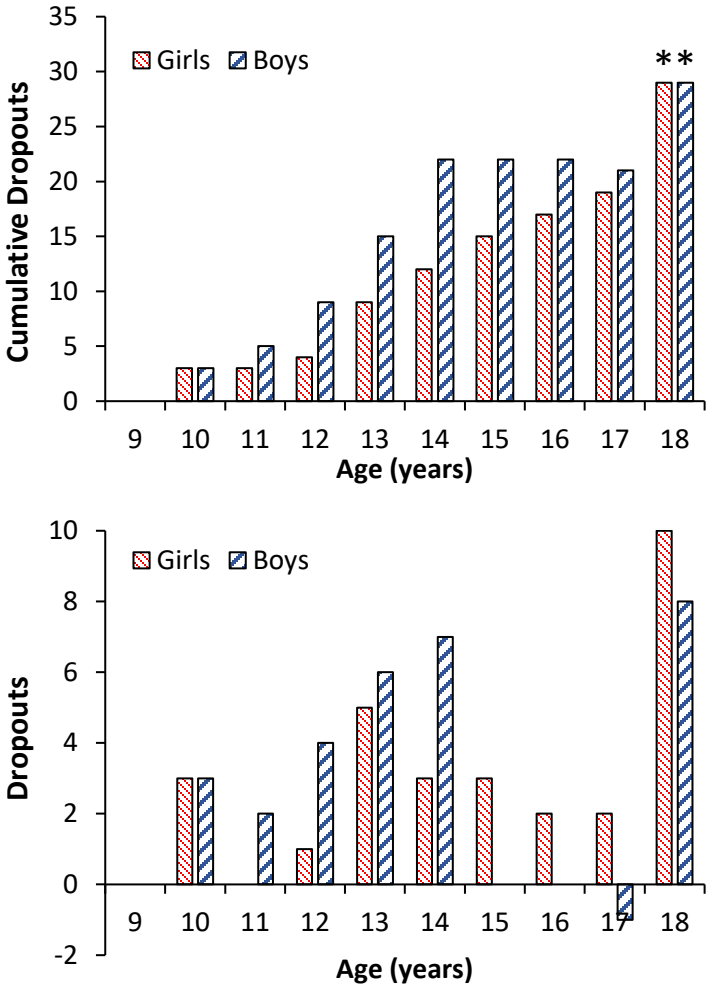


Figure 4.7. Dropout (rate) and its timing of the top 100 nine-year-old girl and boy swimmers during adolescent ages.
Top, cumulative dropouts across adolescence; bottom, annual dropouts (dropout rate).
* Changed odds of the dropout rate from the one-year younger age ($p < 0.05$).
Note: the negative number for boys at age 17 indicates that a boy swimmer resumed competitive swimming (swimming competition) at age 17 although he had previously dropped out completely from competition or competitive swimming at age 14 years.

RQ_{4a}: Is there a significant sex-related difference in performance progression (45.7Fr time) in the U.S. top 100 nine-year-old swimmers throughout adolescence and into adulthood?

[Sex-related differences in 45.7Fr time across adolescence]

A linear mixed-effect model examined the effects of sex and age on 45.7Fr and revealed a significant interaction between the effects of sex and age on 45.7Fr (Figure 4.8 and Table 4.1): $F_{(9, 1250.4)} = 27.19$, $p < 0.001$, $\omega^2 = 0.16$. Post hoc tests (pairwise comparison with Sidak corrections, alpha set at 0.005) detected significant differences in 45.7Fr between sexes after the age of 12 years: age 9, $p < 0.02$ (not significant, n.s.), $d = 0.16$; age 10, $p = 0.43$, $d = 0.06$; age 11, $p = 0.18$, $d = 0.10$; age 12, $p = 0.05$ (n.s.), $d = 0.17$; age 13, $p < 0.001$, $d = 0.41$; age 14, $p < 0.001$, $d = 0.82$; age 15, $p < 0.001$, $d = 1.12$; age 16, $p < 0.001$, $d = 1.25$; age 17, $p < 0.001$, $d = 1.37$; and age 18, $p < 0.001$, $d = 1.45$. The corresponding results were obtained with log-transformed 45.7Fr times: $F_{(9,1259.7)} = 33.29$, $p < 0.001$, $\omega^2 = 0.19$ (data in Appendix D). Therefore, boys become significantly faster than girls after the age of 12 years in this cohort.

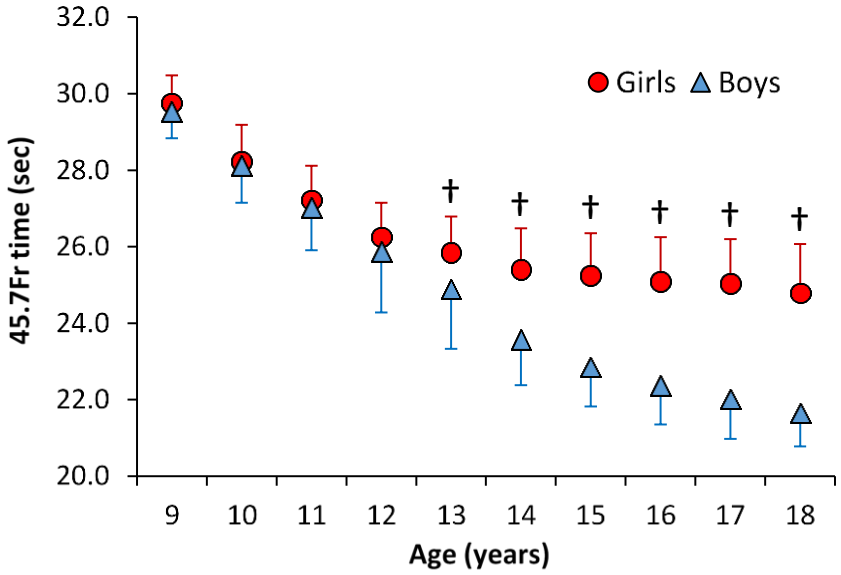


Figure 4.8. Performance progression in 45.7-meter freestyle (45.7Fr) for the top 100 nine-year-old girl and boy swimmers across adolescent ages.
†, Sex-differences in 45.7-meter freestyle (45.7Fr) times ($p < 0.005$), within each age group.
Data are shown as means ± standard deviations (error bars).

[Sex-related differences in annual improvements in 45.7Fr across adolescence]

A linear mixed-effect model also examined the effects of sex and age on annual improvements in 45.7Fr and revealed a significant interaction between the effects of sex and age on the annual improvements (Table 4.3 and Figures 4.9-10): $F_{(8, 883.2)} = 8.90$, $p < 0.001$, $\omega^2 = 0.07$. Post hoc tests (pairwise comparison with Sidak corrections, alpha set at 0.005) detected significant differences in annual improvements between sexes from age 12 to 17 years: age 10, $p = 0.23$, $d = -0.09$; age 11, $p = 0.41$, $d = 0.06$; age 12, $p = 0.001$, $d = 0.24$; age 13, $p < 0.001$, $d = 0.45$; age 14, $p < 0.001$, $d = 0.62$; age 15, $p < 0.001$, $d = 0.37$; age 16, $p = 0.001$, $d = 0.30$; age 17, $p < 0.001$, $d = 0.35$; and age 18, $p = 0.08$, $d = 0.18$. The equivalent results were obtained with log-transformed 45.7Fr improvements: $F_{(8, 922.6)} = 9.60$, $p < 0.001$, $\omega^2 = 0.07$ (data in Table 4.5). Thus, while the top 100 nine-year-old boy swimmers continued to improve, the magnitude of the improvement in the girls became smaller after age 11 years compared with the boys. These results support the hypothesis that the improvements in times in 45.7Fr are greater in boys.

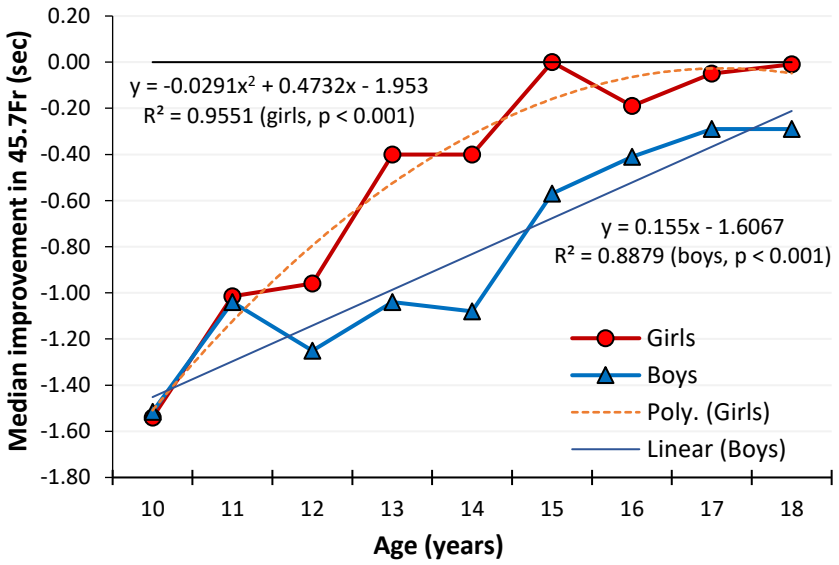


Figure 4.9. Median annual improvements in 45.7-meter freestyle (45.7Fr) for the top 100 nine-year-old girl and boy swimmers across adolescent ages (2004-2013).
Note: A bold straight line across the figure denotes no time improvement (0 sec) from a given age to the subsequent age.

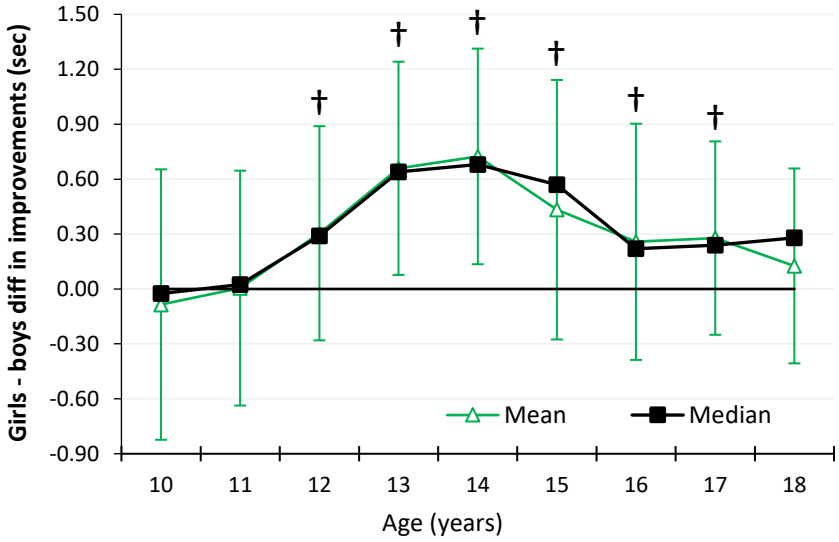


Figure 4.10. Differences in median annual improvements in 45.7-meter freestyle (45.7Fr) between the top 100 nine-year-old girls and boys across adolescent ages.
Diff, difference; each value was calculated as the subtraction of a boy's value from a girl's value.
†, Sex-differences in annual improvements in 45.7Fr ($p < 0.005$).

Note: A bold straight line across the figure denotes no sex-difference in annual 45.7Fr improvements (0 sec), and positive values at given ages indicate greater improvements in 45.7Fr in boy swimmers as compared with girl swimmers. For means, data are shown as means ± standard deviations (error bars).

RQ_{4b}: Is there a significant sex-related difference in the retention rates in participation (dropout) and the top 100 status in the U.S. top 100 nine-year-old swimmers throughout adolescence and into adulthood?

[Dropouts]

A mixed-effects logistic regression examined effects of sex and age on the odds that the US top 100 nine-year-old swimmers drop out from the sport of competitive swimming across adolescence and demonstrated no effect of sex or sex × age interaction (Figure 4.7): an effect of sex, $\chi^2_{(1, N = 2000)} = 1.38$, $p = 0.24$, $R^2 = 0.08$, OR = 2.91 (95% CI, 0.49-17.46); sex × age interaction, $\chi^2_{(1, N = 2000)} = 1.16$, $p = 0.28$, $R^2 = 0.08$, OR = 0.95 (95% CI, 0.85-1.05).

[US top 100 status in 45.7Fr]

A mixed-effects logistic regression did not demonstrate an effect of sex or a sex × age interaction on the odds that the US top 100 nine-year-old swimmers rank within the top 100 in 45.7Fr across adolescence (Figure 4.1): an effect of sex, $\chi^2_{(1, N = 2000)} = 0.47$, $p = 0.49$, $R^2 = 0.20$, OR = 0.54 (95% CI, 0.09-3.14); sex × age interaction, $\chi^2_{(1, N = 2000)} = 0.38$, $p = 0.54$, $R^2 = 0.20$, OR = 1.06 (95% CI, 0.89-1.26).

[US top 100 status in the best event]

A mixed-effects logistic regression also did not reveal an effect of sex or a sex × age interaction on the odds that the US top 100 nine-year-old swimmers rank within the top 100 in any (best) event across adolescence (Figure 4.1): an effect of sex, $\chi^2_{(1, N = 2000)} = 1.21$, $p = 0.27$, $R^2 = 0.11$, OR = 1.64 (95% CI, 0.68-3.94); sex × age interaction, $\chi^2_{(1, N = 2000)} = 1.44$, $p = 0.23$, $R^2 = 0.11$, OR = 0.96 (95% CI, 0.89-1.03). These results rejected the hypothesis that the participation retention rate of the top 100 nine-year-old swimmers and the probability of maintaining the top 100 status are greater in boys, while the tendency of the retention rate across adolescent ages will differ between sexes.

RQ_5: Are there identifiable factors contributing to the levels of future athletic success in the U.S. top 100 nine-year-old swimmers?

[Sample size]

Out of 200 potential subjects (100 girl and boy top 100 swimmers in 45.7Fr at age nine in 2004), swim teams or affiliated club teams of 100 swimmers (51 girls and 49 boys) were identified, and an online survey regarding youth sports and training biography was sent to them directly or through their coaches. Other 100 swimmers (49 girls and 51 boys) had dropped out from the sport of competitive swimming and/or their contact information could not be identified at the time of the investigations (December 2015 to August 2016). Among the hundred swimmers sent the online survey, 40 swimmers

(19 girls and 21 boys) responded the survey. The response rate was 40% from a group of subjects receiving the online survey (n = 100) and 20% of the total sample size (N = 200) in Study 1.

Tables 4.7-9 and Figures 11-13 demonstrate the performance data (45.7Fr times and rankings and best rankings) of the 40 survey responders and the plots along with the top 100 swimmers, respectively, across adolescent ages. For a comparison between the top 100 performance and the 40 survey responders (19 girls and 21 boys from the top 100 girls and boys, respectively), a linear mixed-effect model (post hoc tests with Sidak corrections, alpha set at 0.005) examined an effect of group and a group × age interaction on 45.7Fr times in the swimmers across adolescent ages for both sexes. For girls, an effect of group was revealed but no (group × age) interaction: (an effect of group) $F_{(1, 134.6)}$ = 10.30, p = 0.002, ω^2 = 0.06; (group × age) $F_{(9, 743.1)}$ = 0.56, *p* = 0.83, ω^2 = 0.0. For boys, there was no effect of group or group × age interaction on 45.7Fr times (p > 0.05, ω^2 = 0.0). For ranking data (45.7Fr and best events), an effect of group was revealed but not group × age interaction in girls: (45.7Fr) $F_{(1, 140.3)}$ = 6.10, p = 0.015, ω^2 = 0.03; (best events) $F_{(1, 135.65)}$ = 8.01, p = 0.005, ω^2 = 0.05. For boys, neither an effect of group nor a group × age interaction was found for boys (p > 0.05).

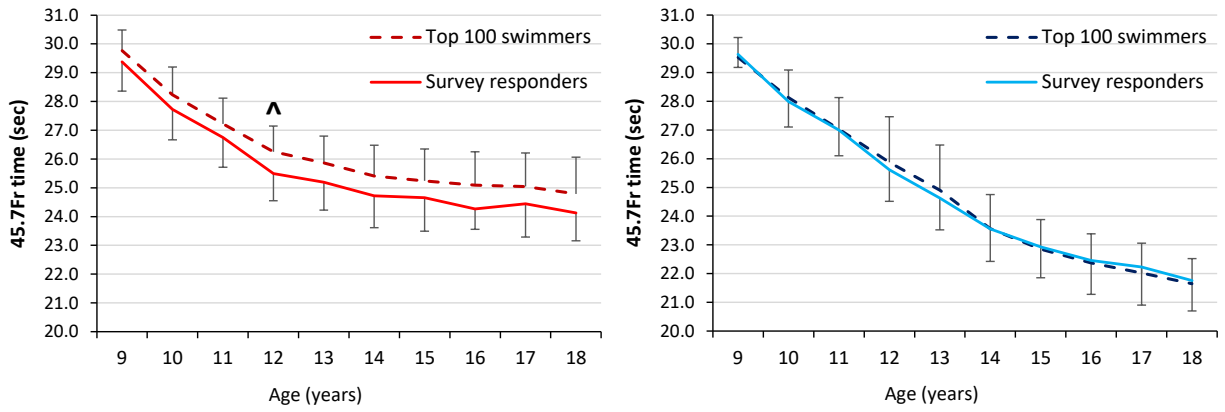


Figure 4.11. Comparison of 45.7-meter freestyle times (means ± standard deviations) across adolescent ages between the US top 100 nine-year-old swimmers in 45.7Fr in 2004 and the 19 girls (left) or 21 boys (right) who responded the online youth sports biography survey among the top 100 girl and boy swimmers.
^ Significant difference between groups (p < 0.005).

Table 4.7. Sample size and performance in 45.7-meter freestyle of swimmers, who ranked within the US top 100 at age nine and responded age-group swimming biography survey, across adolescent ages.

45.7Fr time (sec)										
	Girls					Boys				
Age	N	Mean ± SD	Med	Min	Max	N	Mean ± SD	Med	Min	Max
9	19	29.37 ± 1.01	29.70	27.84	30.62	21	29.64 ± 0.46	29.77	28.55	30.25
10	18	27.73 ± 1.07	27.93	25.53	30.11	21	27.99 ± 0.89	28.04	25.36	29.38
11	18	26.75 ± 1.04	26.66	25.30	29.27	20	27.00 ± 0.90	27.10	25.07	28.23
12	19	25.49 ± 0.94 ^	25.34	23.75	27.88	20	25.61 ± 1.09	25.95	23.49	27.21
13	15	25.19 ± 0.96	25.23	23.92	27.70	21	24.63 ± 1.11	24.59	22.56	26.41
14	17	24.72 ± 1.11	24.50	23.21	27.00	20	23.55 ± 1.13	23.57	21.17	25.34
15	18	24.65 ± 1.16	24.53	22.74	27.36	19	22.93 ± 1.07	22.91	20.92	25.84
16	14	24.27 ± 0.71	24.29	23.16	25.51	18	22.46 ± 1.18	22.45	20.54	24.98
17	15	24.44 ± 1.15	24.24	22.92	27.21	19	22.23 ± 1.32	21.95	20.22	25.20
18	12	24.12 ± 0.96	24.10	22.64	26.29	17	21.75 ± 1.06	21.69	19.83	23.94

N, the number of swimmers who competed in 45.7-meter freestyle (45.7Fr); SD, standard deviation; Med, median; Min, minimum (the fastest time); Max, maximum (the slowest time).

^ Faster than the top 100 swimmers demonstrated in Table 4.1 ($p < 0.005$); age 12, $p = 0.001$, $\omega^2 = 0.08$.

Table 4.8. Sample size and the US rankings in 45.7-m freestyle (45.7Fr) of swimmers, who ranked within the US top at age nine and responded age-group swimming biography survey, across adolescent ages.

45.7Fr ranking										
	Girls					Boys				
Age	N	Mean ± SD	Med	Min	Max	N	Mean ± SD	Med	Min	Max
9	19	40.4 ± 32.6	39.0	1	99	21	51.7 ± 23.4	56.0	9	92
10	18	99.9 ± 158.0	62.5	1	683	21	123.1 ± 105.9	83.0	1	388
11	18	189.9 ± 339.8	63.0	4	1444	20	203.3 ± 135.1	171.0	7	520
12	19	177.3 ± 354.8	42.0	1	1561	20	372.4 ± 300.6	358.0	8	1050
13	15	283.9 ± 595.1	128.0	4	2380	21	594.4 ± 548.4	348.0	12	1755
14	17	381.1 ± 569.6	104.0	3	2157	20	709.0 ± 658.8	449.0	4	2283
15	18	499.1 ± 774.0	187.0	1	3123	19	704.2 ± 957.9	428.0	4	4204
16	14	277.7 ± 325.6	179.5	9	1004	18	904.1 ± 1102.1	535.0	7	3966
17	15	519.4 ± 802.7	200.0	7	2790	19	1100.5 ± 1287.3	459.0	5	4428
18	12	246.6 ± 271.1	177.5	8	972	17	494.4 ± 479.1	339.0	3	1614

N, the number of swimmers who competed in 45.7-meter freestyle (45.7Fr); SD, standard deviation; Med, median; Min, minimum (the highest ranking); Max, maximum (the lowest ranking).

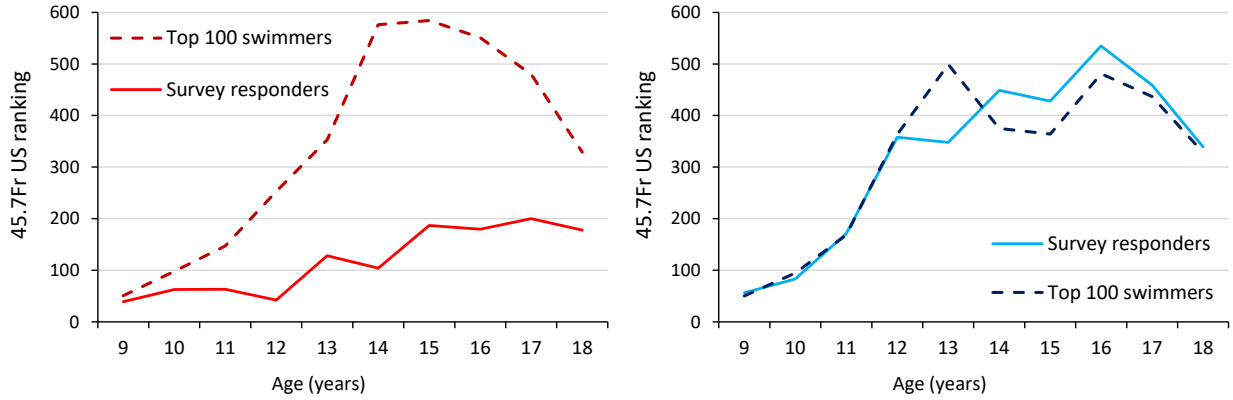


Figure 4.12. Comparison of median rankings in 45.7-meter freestyle across adolescent ages between the US top 100 nine-year-old swimmers in 45.7Fr in 2004 and the 19 girls (left) or 21 boys (right) who responded the online youth sports biography survey among the top 100 girl and boy swimmers.

Table 4.9. Sample size and the best US rankings of swimmers, who ranked within the US top at age nine and responded age-group swimming biography survey, across adolescent ages.

	Best ranking									
	Girls					Boys				
Age	N	Mean ± SD	Med	Min	Max	N	Mean ± SD	Med	Min	Max
9	19	25.4 ± 29.5	9.0	1	99	21	33.7 ± 24.1	31.0	2	82
10	19	29.8 ± 41.9	16.0	1	163	21	55.6 ± 73.7	21.0	1	256
11	19	48.8 ± 102.0	8.0	1	441	21	59.5 ± 61.1	31.0	2	208
12	19	34.8 ± 58.7	4.0	1	225	21	96.6 ± 106.6	37.0	1	343
13	19	35.3 ± 52.9	9.0	1	176	21	123.0 ± 153.3	57.0	5	508
14	19	36.7 ± 49.8	12.0	1	152	21	135.3 ± 210.0	65.0	1	874
15	19	33.7 ± 39.2	15.0	1	122	21	131.1 ± 240.9	58.0	2	1073
16	19	67.0 ± 183.0	24.0	1	815	21	91.4 ± 107.9	63.0	7	433
17	18	34.4 ± 41.0	24.5	1	155	21	87.5 ± 89.1	52.0	5	281
18	18	39.9 ± 47.2	21.0	1	168	21	113.9 ± 118.8	81.0	2	405

N, the number of swimmers who competed in 45.7-meter freestyle (45.7Fr); SD, standard deviation; Med, median; Min, minimum (the highest ranking); Max, maximum (the lowest ranking).

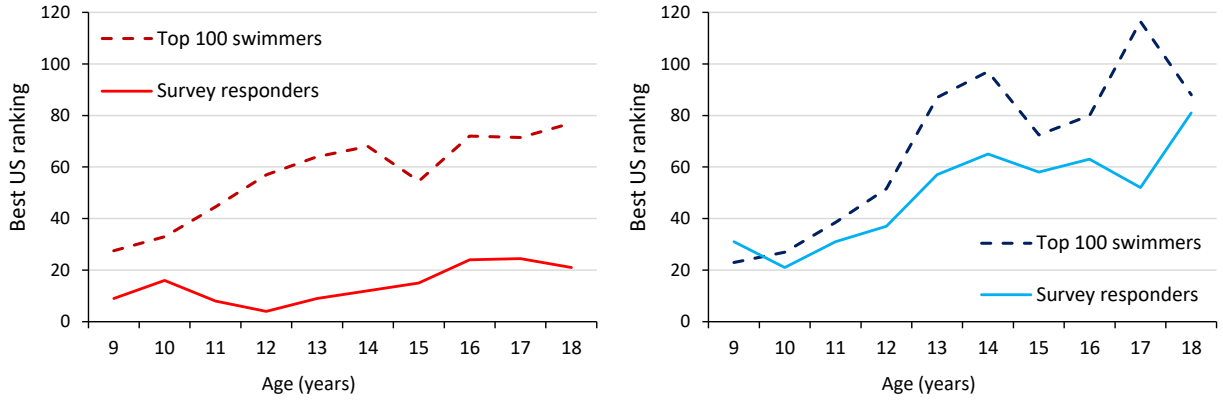


Figure 4.13. Comparison of median rankings in best events across adolescent ages between the US top 100 nine-year-old swimmers in 45.7Fr in 2004 and the 19 girls or 21 boys who responded the online youth sports biography survey among the top 100 girl and boy swimmers.

When examining a difference in the odds that (whether or not) the swimmers ranked within the top 100 in any event across adolescent ages between the top 100 swimmers (n = 100 per sex) and the survey respondents (19 girls and 21 boys), a mixed-effects logistic regression did not demonstrate an effect of group or a group × age interaction on the odds ($p > 0.05$) (Figure 4.14). This indicates that the rate of changes in the odds (decline in the slope across ages) was not significantly different between groups although there appeared to be relatively larger differences in the odds of ranking within the top 100 at mid- to late-adolescence in girls. In fact, pairwise comparisons (means of the odds across ages) appeared to be significant in girls ($p < 0.001$) and boys ($p < 0.05$). Survey responders seem to consist of a relatively better group of the swimmers among the top 100 nine-year-old swimmers in this study, especially the 19 girl survey responders (Figure 4.14). However, the results suggest that the 40 responders (19 girls and 21 boys) would represent of the top 100 young swimmers in both sexes.

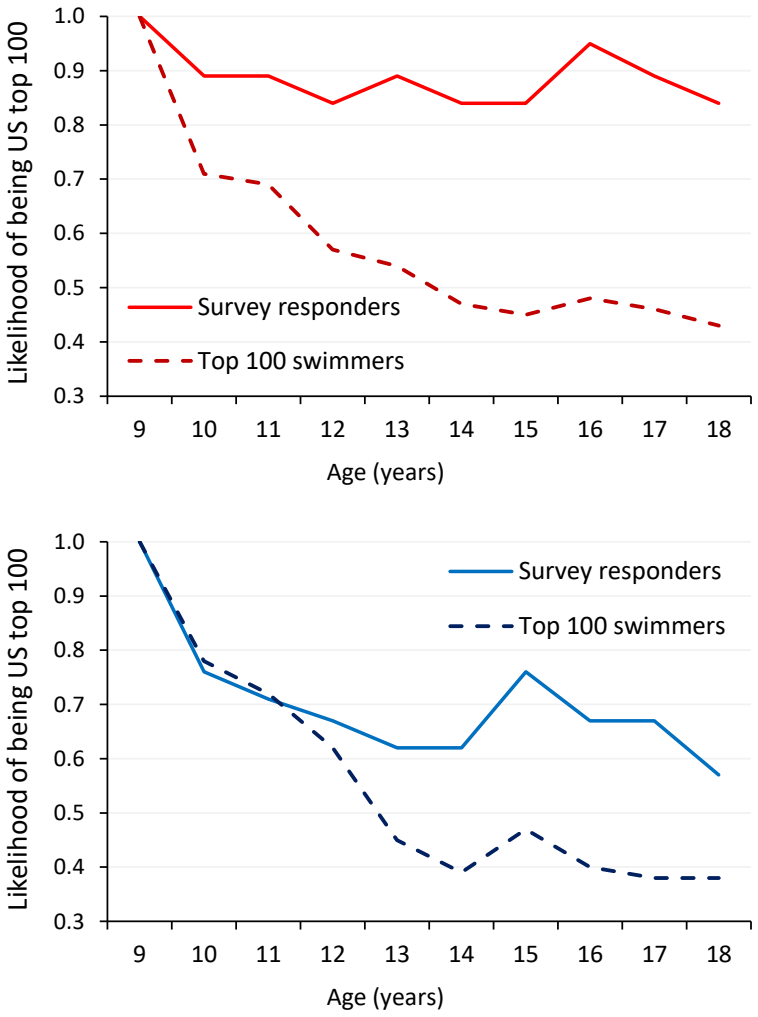


Figure 4.14. Comparison of the odds of ranking the top 100 in best events across adolescent ages between the US top 100 nine-year-old swimmers in 45.7Fr in 2004 and the 19 girls or 21 boys who responded the online youth sports biography survey among the top 100 girl and boy swimmers. Top figure, girls; bottom figure, boys.

[Data of the survey responses]

Descriptive data regarding responses of the 40 survey responders are reported in Figures 4.15-18 and Table 4.10. 'Reliability' (self-confidence level) of memory in the milestones of the responders toward developmental youth sports biographies throughout pre to late adolescent ages were expressed by 0 to 100 percentage (0% as being not sure at all and 100% as being definite, Figure 4.15). A generalized linear model indicated the effects of age and sex and a sex × age interaction on the self-

confidence levels across ages: effect of age, $\chi^2_{(1, N = 567)} = 190.93$, $p < 0.01$, OR = 1.55 (95% CI, 1.43-1.67); effect of sex, $\chi^2_{(1, N = 567)} = 6.61$, $p = 0.01$, OR = 4.32 (95% CI, 1.42-13.15); and sex × age interaction, $\chi^2_{(1, N = 567)} = 5.12$, $p = 0.024$, OR = 0.89 (95% CI, 0.81-0.99). However, post hoc tests detected no difference in self-confidence levels between two subsequent ages for either sex ($p > 0.003$) except for between ages seven and eight years in girls ($p = 0.002$) or no sex-related difference at any age ($p > 0.003$).

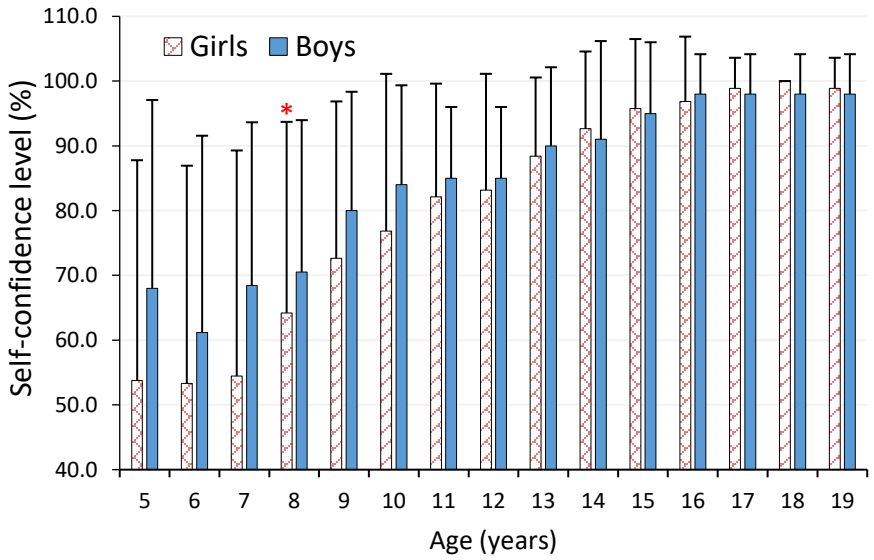


Figure 4.15. Self-confidence level (five levels; 0, 20, 40, 60, 80, and 100%) in the memory of age-related milestones in the 40 responders.
* Different from one-year younger age ($p < 0.003$).
Data are shown as means ± standard deviations (error bars).

Table 4.10. Characteristics of developmental youth sports and swim training, post-adolescent swim performance, and maturational data of the 40 survey responders (19 girls and 21 boys out of the US top 100 nine-year-old girl and boy swimmers in 45.7-meter freestyle in 2004).

	Girls (n = 19)					**Boys** (n = 21)					**Total** (n = 40)				
Variables	N	Mean ± SD	Med	Min	Max	N	Mean ± SD	Med	Min	Max	N	Mean ± SD	Med	Min	Max
Swimming biography															
Age at enrollment in swimming (yr)	19	5.6 ± 1.5	5.3	4	8	21	5.9 ± 1.3	5.5	4	9	40	5.8 ± 1.4	5.5	4	9
Swim training befoe age 9 yr (%)	18	94.7 %				20	95.2 %				38	95.0 %			
Dryland exercise before age 9 yr (%)	5	26.3 %				6	28.6 %				11	27.5 %			
Age at focusing on/prioritizing swimming (yr)	19	9.7 ± 3.0	10.0	5	14	21	10.7 ± 3.3	10.8	4	15	40	10.2 ± 3.2	10.5	4	15
Age at specializing swimming events (yr)	19	12.9 ± 3.1	13.6	6	18	20	14.2 ± 2.8	14.4	6	18	39	13.6 ± 2.9	14.0	6	18
Age at starting 2 or more training a day (yr)	19	13.3 ± 2.1	13.3	10	18	21	14.0 ± 2.6	13.6	9	19	40	13.7 ± 2.4	13.4	9	19
Age at peak improvement in siwmming (yr)	19	14.5 ± 1.6	14.5	12	18	21	15.2 ± 1.7	15.3	12	19	40	14.9 ± 1.6	14.9	12	19
US top 100 status at age 18 yr (%)	16	84.2 %				12	57.1 %				28	40.0 %			
USAS overall ranking at age 19 yr	18	255.3 ± 461.6 †	71.5	1	2002	20	538.3 ± 684.8	302.0	6	2637					
age 20 yr	17	349.6 ± 975.5	60.0	2	4105	19	491.0 ± 472.8	272.0	2	1523					
age 21 yr	15	150.2 ± 182.9 †	74.0	1	496	17	452.1 ± 652.3	155.0	5	2185					
2016 Olympic trial results (places)	5	34.6 ± 20.4	23.0	18	64	5	40.0 ± 35.6	30.0	4	99	10	25.0 %			
Dropout from swimming by age 18 yr (%)	1	5.3 %				0	0 %				1	2.5 %			
Multi- and non-sport activity biography															
Multi-sports participation before age 9 yr (%)	8	42.1 % †				16	76.2 %				24	60.0 %			
Multi-sports participation at ages 9-18 yr (%)	14	73.7 %				20	95.2 %				34	85.0 %			
Number of sports experience①	14	2.4 ± 1.3	2.0	1	5	20	2.3 ± 1.3	2.0	1	5	34	2.3 ± 1.2	2.0	1	5
Continuation of multi-sports participation (yr)	12	6.3 ± 3.2	7.0	1	11	20	7.4 ± 3.8	8.5	1	14	32	6.9 ± 3.6	8.0	1	14
Non-sports activity participation (%)	6	31.6 %				11	52.4 %				17	42.5 %			
Number of non-sport activities	6	1.5 ± 0.5	1.5	1	2	11	1.4 ± 0.5	1.0	1	2	17	1.4 ± 0.5	1.0	1	2
Continuation of non-sport activities (yr)	6	4.6 ± 3.8	3.0	1	6	11	5.1 ± 3.5	3.0	1	11	17	4.9 ± 3.50	3.5	1	11
Maturational biography															
Age at menarche (yr)	18	13.0 ± 1.5	12.5	11	16										
Recalled age at peak gain in height (yr)②	19	12.7 ± 2.0 †	13.0	10	16	21	14.2 ± 1.6	14.0	11	17					
Maturity status (early, %)	3	15.8 %				4	19.0 %				7	17.5 %			
Maturity status (average, %)	5	26.3 %				8	38.1 %				13	32.5 %			
Maturity status (late, %)	11	57.9 %				9	42.9 %				20	50.0 %			

N, numbers of subjects responding to or concerned with the listed item (variable); USAS, USA Swimming; ① excluding competitive swimming; ② based on the swimmers' recall/memory; †, Different from boys ($p < 0.05$).

Developmental training biographies

All of the 40 swimmers started swimming at ages between four and nine years (5.8 ± 1.4 years): age four, n = 7 (17.5% of the 40 swimmers) (Table 4.10); age five, n = 14 (35.0%); age six, n = 9 (22.5%); age seven, n = 3 (7.5%); age eight, n = 6 (15.0%); and age nine, n = 1 (2.5%). Thirty-eight (95%) of the swimmers enrolled in an organized swimming club/team and started structured swim practice/training before age nine years old, and the two started at age nine years, all became the top 100 in 45.7Fr in age nine-year-old category in 2004 in the U.S. Less than 30% of the 40 swimmers had dryland exercise programs as a portion of swim practice by the age nine years. At relatively early ages (on average, 10.2 years old), the swimmers started considering swimming as their main sport while many were still enrolled in some other sports. Complete specialization of their swimming events (with training programs focusing on the specialized events) occurred, on average, by the age of 13.6 years. Among the 40 swimmers, 22.5% (n = 9) specialized their events by age 12 years, 57.5% by age 14 years (n = 4 at ages 13-14 years), and 40% (n = 16) during high school ages (age 15 and older). One swimmer specialized his event during his collegiate swimming career. The swimmers started having multiple swim training sessions (more than once a day) as follows: under age 12, 32.5%; age 13-14, 40%; age 15-18, 22.5%; and during collegiate career, 5.0%. Reported age at peak improvements in swim performance was, on average, similar between girls (14.5 years) and boys (15.2 years), and the majority of them peaked at ages 14-16 years (72.5%): age 14 (20%); age 15 (22.5%); and age 16 (30%).

Swim performance data during college ages (ages 19-21)

At age 18 years, 84.2% of the girls among the 40 responders ranked within the top 100, which was more than the boys (57.1%), and during collegiate swimming careers five girl swimmers ranked in the top 10 in the overall USAS ranking, while 1 boy ranked within the US top 10 (Table 4.10). Regarding NCAA Championship results, in women, seven swimmers made the top 16 (five for the top 8, including

two NCAA championships winners). In men, three swimmers made the top 16 (two for the top 8). Ten swimmers among the survey responders (25.0%) competed at the 2016 Olympic Team Trials, and the highest place was the fourth.

One of the 19 girls dropped out from the sport of competitive swimming at age 16 years due to attenuated improvements in swimming and increased interest in other sports. Three boy swimmers had temporary cessations of competitive swimming during adolescence, and did not training or compete during one of two seasons in a year. During collegiate careers, one woman stopped training due shoulder surgery, and two men dropped out from competitive swimming due to conflict with their team and/or coaches.

In-water and dryland training biography

Duration and frequency of in-water and dryland training of the 40 swimmers were depicted in Figures 4.16-17. Dryland training was typically conducted before or after the in-water (swim) practice/training at younger ages as a portion of 'daily swim training'. At the mid- to late adolescent ages, the swimmers performed resistance (weight) training which may had happened at a separate time from in-water training. Training duration and frequency progressively and linearly increased across pre to late adolescent ages for both in-water and dryland training. There was an effect of age on all developmental training biographies from pre to late adolescent ages, while no effect of sex or a sex × age interaction was indicated. However, no difference between two subsequent ages ($p > 0.003$) was found except for between ages nine and ten years for dryland practice frequency in girls (sessions per week, $p = 0.002$) (Figure 4.17).

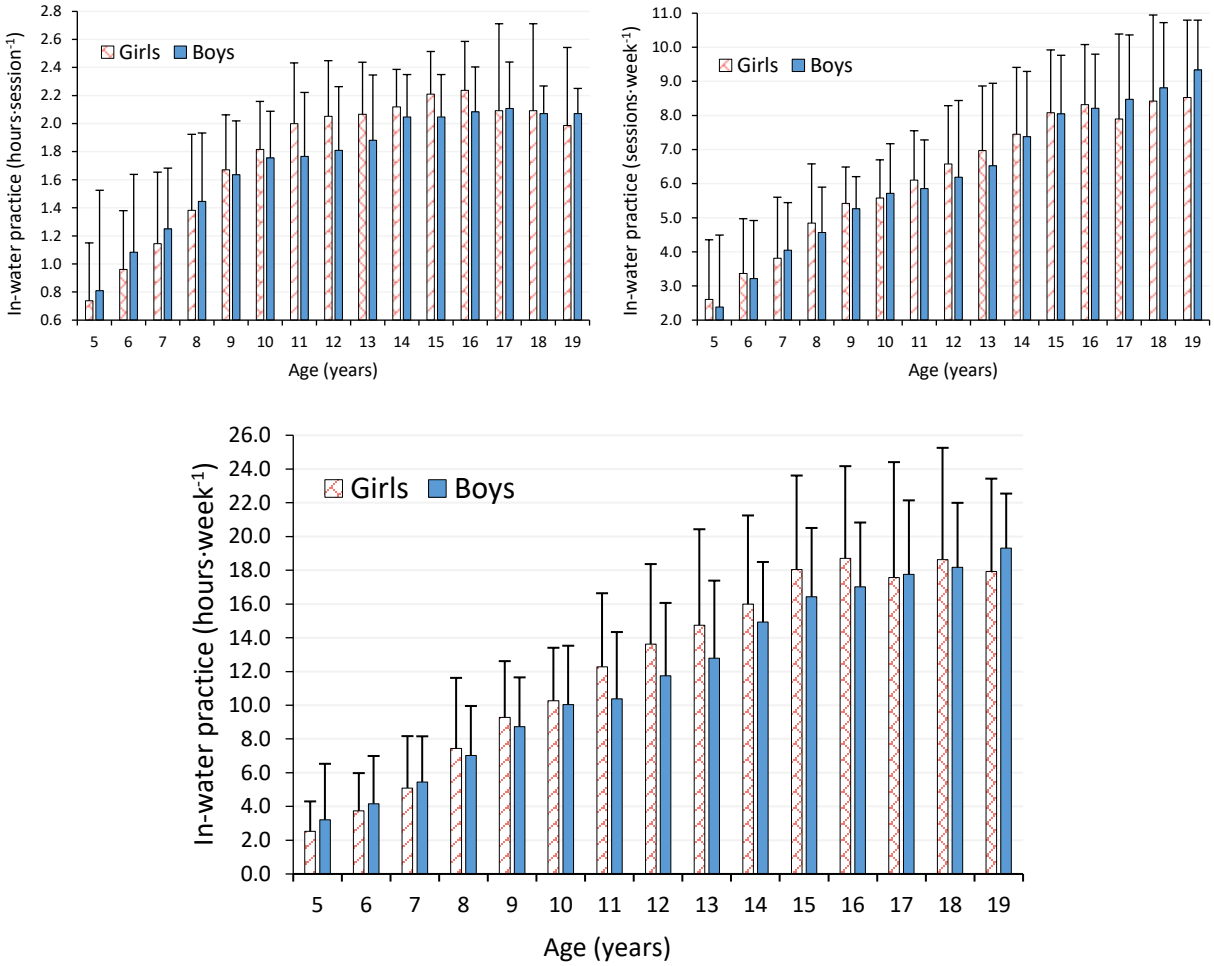


Figure 4.16. Duration and frequency (weekly) of in-water swim practice/training of the 40 survey responders across pre to late adolescent ages.
Top left, practice hours per session; top right, practice sessions per week; and bottom, practice hours per week.
Data are shown as means ± standard deviations (error bars).

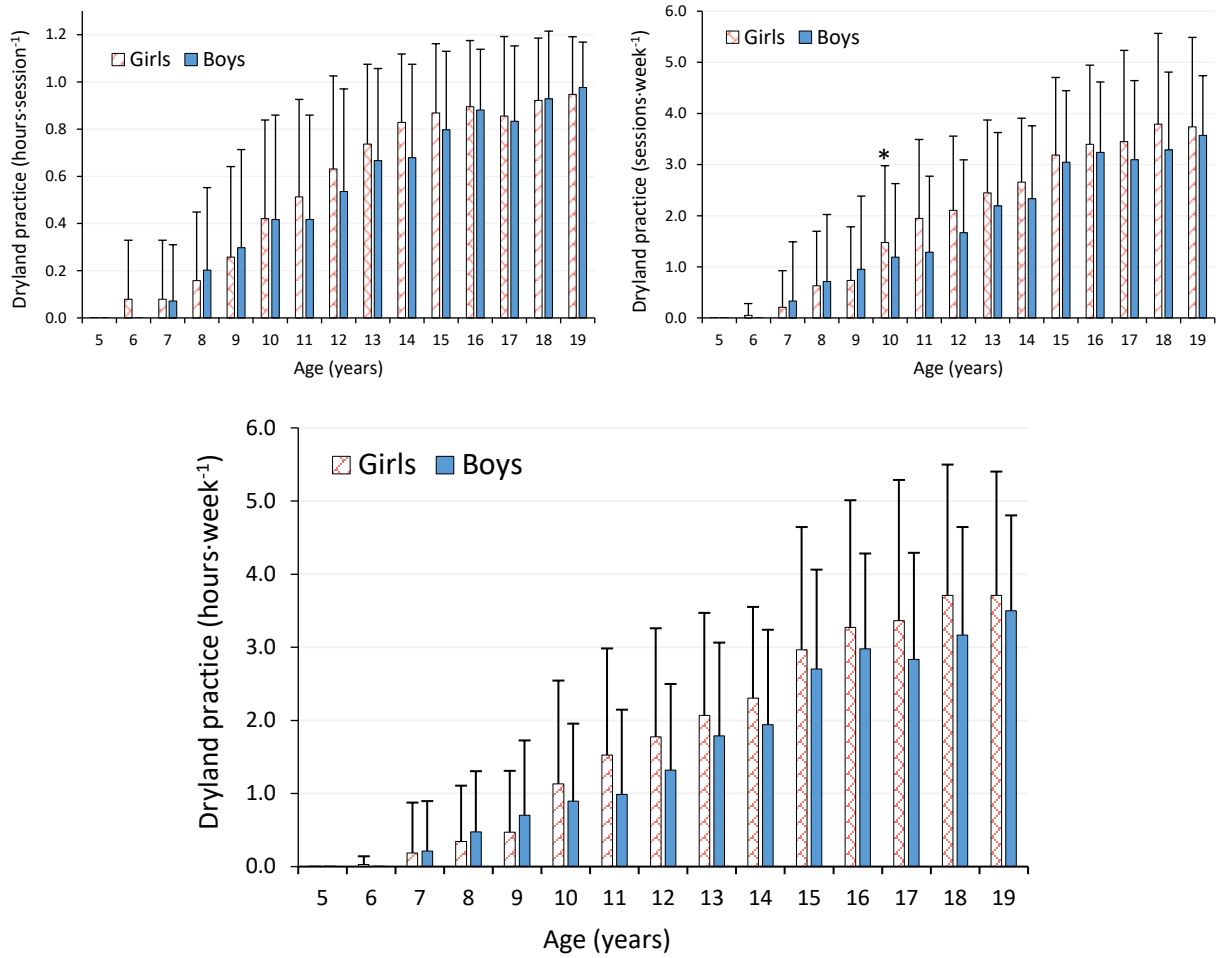


Figure 4.17. Duration and frequency (weekly) of dryland practice (exercise training) of the 40 survey responders across pre to late adolescent ages.
Top left, practice hours per session; top right, practice sessions per week; and bottom, practice hours per week.
* Different from one-year younger age ($p < 0.003$).
Data are shown as means ± standard deviations (error bars).

Multi-sport participation

Among the 40 survey responders, 73.7% of the girls and 95.2% of the boys (85.0% of the total) had multi-sport experience during adolescence and 42.1% of the girls and 76.2% of the boys (60.0% of the total) enrolled an or multiple organized sports practice before the age of nine. Proportions of the 40 swimmers who participated in multi-sport during pre to late adolescent ages for both sexes are shown in

Figure 4.18. A mixed-effects logistic regression revealed no effect of age or sex on the odds of participating in multi-sport ($p > 0.05$). All of the 40 swimmers stopped playing 'other' sports at the entrance of their colleges.

Multi-sport training biography (duration and frequency) is shown as a function age in Figure 4.19. No effect of age or sex on the multi-sports training duration and frequency was detected ($p > 0.05$). Corresponding to the Figure 4.18, many swimmers had multi-sport participation and had more various sports practice/training at ages between eight and twelve years, especially in boys. In addition, the amount (demand) of multi-sports training decreased in concert with an increasing demand from competitive swimming training and specialization in events around the ages of 13-14 years (Table 4.10 and Figures 4.16-17).

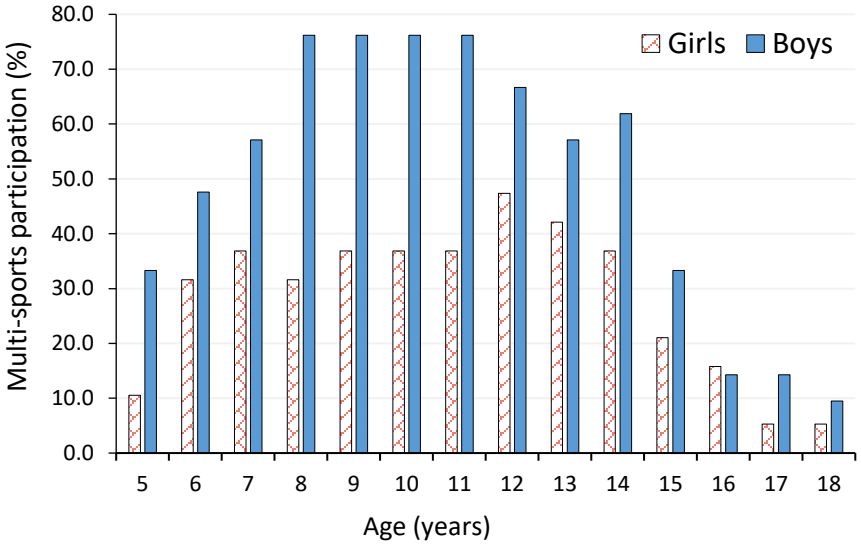


Figure 4.18. Proportion of the of the 40 survey responders enrolling multi-sports across pre to late adolescent ages.
Note: Multi-sports include all sports with the exception of competitive swimming.

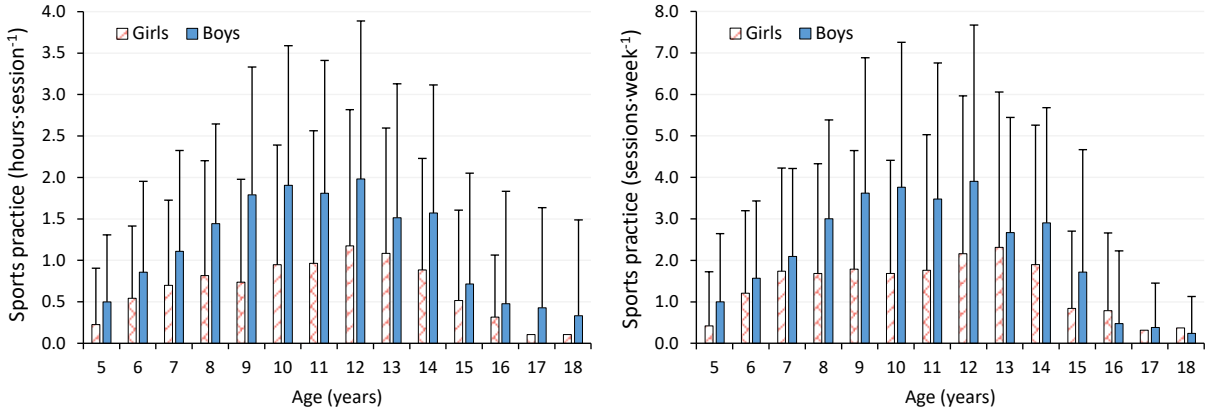


Figure 4.19. Duration and frequency (means ± standard deviations) of youth sports training (weekly, excluding swimming) of the 40 survey responders across pre to late adolescent ages.
Left, practice hours per session; Right, practice sessions per week.

Note: data indicate the summation of weekly training duration and frequency that may consist of multiple sports excluding swimming, which the swimmers participated, in a given age. Multiple sports practice may had overlapped at the same time of a season or happened at different times of a year.

Maturational milestones

Reported age at menarche (n = 18) was 13.0 ± 1.5 years, and reported ages at peak height gain (n = 40) were 12.7 ± 2.0 years in girls and 14.2 ± 1.6 years in boys, which indicated a sex-related difference: $F_{(1,38)} = 7.03$, $p = 0.012$, $\omega^2 = 0.13$. In addition to ages at maturational events (menarche and peak height gain), swimmers were asked to recall their height during adolescent ages. With available data (13 girls and 15 boys), Figure 4.20 depicts changes in reported height (in cm) and calculated annual height gains as a function of age. At age 18 years, girls were, on average, 172.6 ± 4.7 cm (n = 16) and boys were 184.0 ± 5.9 cm (n = 20). Their final height (at age 22-23 years) was, on average, 173.2 ± 4.7 cm in girls (n = 17) and 185.3 ± 6.3 cm in boys (n = 20). Calculated ages at PHV from the recalled height data were 10 years old for girls and 14 years old for boys. There was a large difference between the reported age at peak height gain and the calculated age at peak height velocity (PHV) in girls (12.7 vs. 10 years, respectively), while reported and calculated ages at peak height growth were similar in boys (14.2 vs. 14 years, respectively).

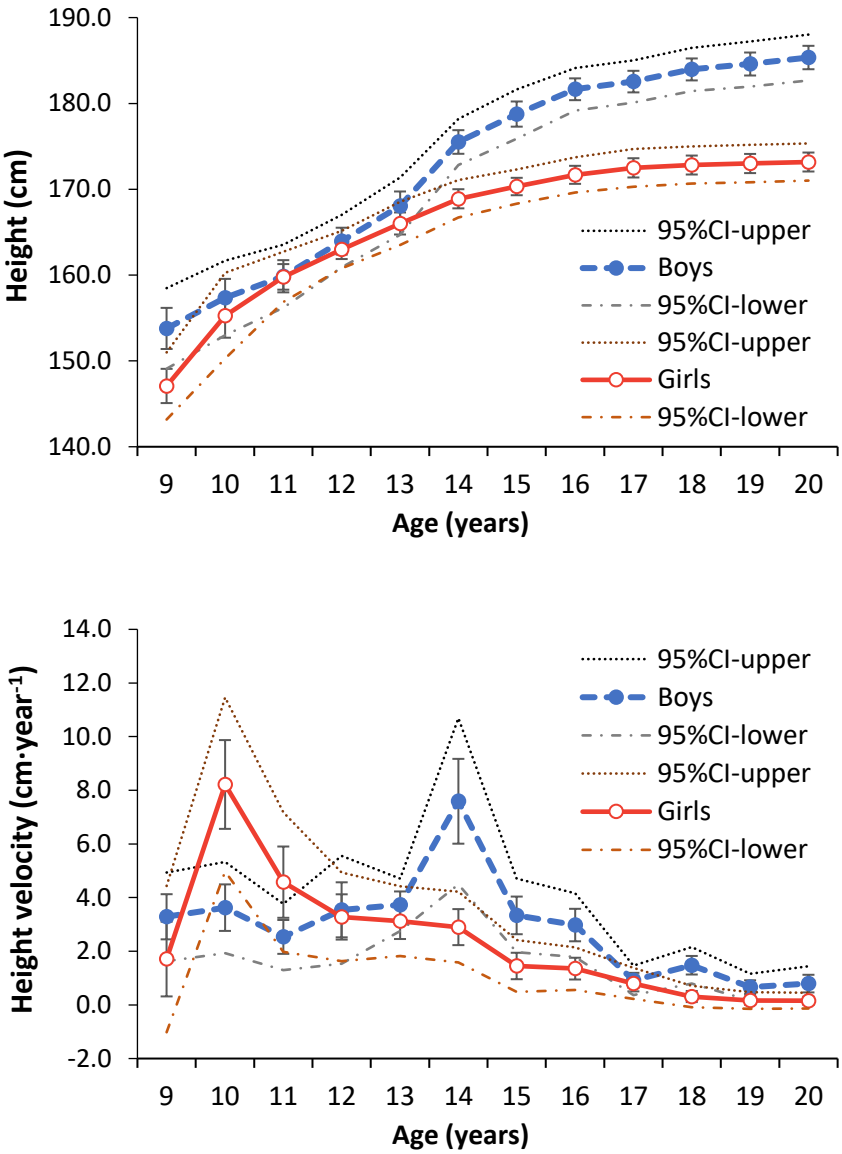


Figure 4.20. Estimated marginal means (± standard errors) and 95% confidence intervals (lower and upper bounds) of recalled height and calculated annual height velocity (cm•year^{-1}) of the survey responders as a function age.
Data were produced from a generalized linear model (generalized estimating equation).

Note: Due to incomplete/missing height data from swimmers (uncertainty of their memory about height) across adolescent ages, data at each age consist of the estimated marginal mean (±SE) of *available samples*: [girls] n = 4, 5, 7, 9, 14, 14, 15, 16, 16, 16, and 16 at ages 9 to 20 years old, respectively; [boys] n = 7, 8, 12, 11, 13, 16, 18, 18, 18, 19, 20, and 20 at each age, respectively.

Maturational status of the 40 responders was assessed by using their ages at menarche and/or PHV and referring to previously reported reference ages of menarche and PHV for US population (Malina et al., 2014; Malina et al., 2016). Seven (17.5% of total) swimmers were classified as early maturers, were 13 (32.5%) average maturers, and 20 (50.0%) late maturers in this cohort (Table 4.10). Mean (± SD) ages at menarche and PHV in the girls were 11.3 ± 0.6 and 10.0 ± 0.0 years old, respectively, in early maturing status, 12.2 ± 0.4 and 11.2 ± 0.4 years old in average maturing status, and 13.9 ± 1.3 and 14.2 ± 1.2 years old in late maturing status (Table 4.11). In boys, the mean ages at PHV were 11.8 ± 0.5 years old for early maturing status, 13.9 ± 0.4 years old for average maturing status, and 15.7 ± 0.7 years old for late maturing status. Table 4.11 also demonstrates descriptive data for maturational and performance characteristics of the 40 responders as a function of three maturity statuses (early, average, and late).

Identifiable factors contributing to the odds of ranking within the US top 100 during adolescence

Table 4.12 shows the key predictors and dummy variables used in the mixed-effects logistic regression analyses and for testing the hypothesis. Among a variety of predictors, seven significant predictors ($p < 0.05$) were revealed as increasing the odds that the swimmers ranked within the US top 100 across adolescence ages (Table 4.13). They are: 1) age ($\chi^2 = 10.1$, $p < 0.01$), 2) weekly dryland exercise hours during ages five to eight ($\chi^2 = 24.6$, $p < 0.01$), 3) sex ($\chi^2 = 27.0$, $p < 0.01$), 4) multi-sport experience ($\chi^2 = 6.3$, $p < 0.05$), 5) age at the enrollment in competitive swimming and practice ($\chi^2 = 49.3$, $p < 0.01$), 6) age at the peak improvement in swim performance ($\chi^2 = 13.1$, $p < 0.01$), and 7) weekly swim practice hours during preadolescent ages ($\chi^2 = 64.5$, $p < 0.01$). In addition, Table 4.14 shows six significant predictors including a categorical variable representing a sex × multi-sport interaction (but excluding sex and multi-sport predictors from the model).

Table 4.11. Maturational milestones, developmental youth sports and swim training biography, and swim performance of the survey responders.

	Early					Average					Late				
Variables	N	Mean ± SD	Med	Min	Max	N	Mean ± SD	Med	Min	Max	N	Mean ± SD	Med	Min	Max
GIRLS (n = 19)	3	15.8 %				5	26.3 %				11	57.9 %			
Age at menarche (yr)	3	11.3 ± 0.6	11.0	11	12	5	12.2 ± 0.5	12.0	12	13	10	13.9 ± 1.3 ^	14.0	12	16
Reported age at peak gain in height (yr)①	3	10.0 ± 0.0	10.0	10	10	5	11.2 ± 0.5	11.0	11	12	11	14.2 ± 1.2 ^	14.0	12	16
Calculated age at peak height velocity (yr)②	1	10.0				2	10.5 ± 0.7				6	13.0 ± 1.4			
Final height at age 22-23 yrs old (cm)	3	166.8 ± 2.9 ^				4	175.9 ± 5.6				10	174.0 ± 3.0			
Multi-sports participation at ages 9-18 yr (%)	3	100.0 %				3	60.0 %				8	72.7 %			
Age at peak improvement in siwmming (yr)	3	13.3 ± 1.5	13.0	12	15	5	13.6 ± 1.5	13.0	12	16	11	15.2 ± 1.3	15.0	13	18
Age at focusing on/prioritizing swimming (yr)	3	9.3 ± 1.5	9.0	8	11	5	10.2 ± 2.3	10.0	8	13	11	9.6 ± 3.7	11.0	5	14
Age at specializing swimming events (yr)	3	13.3 ± 2.1	14.0	11	15	5	11.6 ± 2.5	13.0	8	14	11	13.5 ± 3.5	14.0	6	18
US top 100 status at age 15 yr (%)	2	66.7 %				4	80.0 %				10	90.9 %			
age 16 yr (%)	2	66.7 %				5	100.0 %				11	100.0 %			
age 17 yr (%)	1	33.3 % ^				5	100.0 %				11	100.0 %			
age 18 yr (%)	2	66.7 %				4	80.0 %				10	90.9 %			
USAS overall ranking at age 19 yr	2	71.5 ± 10.6	71.5	64	79	5	237.6 ± 195.1	313.0	7	418	11	296.8 ± 581.5	56.0	1	2002
age 20 yr	2	113.0 ± 89.1	113.0	50	176	4	192.3 ± 214.3	173.5	2	420	11	449.9 ± 1214.8	60.0	2	4105
age 21 yr	2	50.5 ± 33.2	50.5	27	74	4	246.0 ± 280.7	243.5	1	496	9	129.8 ± 146.0	112.0	11	475
BOYS (n = 21)	4	19.0 %				8	38.1 %				9	42.9 %			
Reported age at peak gain in height (yr)①	4	11.8 ± 0.5	12.0	11	12	8	13.9 ± 0.4 ^	14.0	13	14	9	15.7 ± 0.7 ^	16.0	15	17
Calculated age at peak height velocity (yr)②	4	11.5 ± 1.0 ^				4	14.0 ± 0.0				5	15.4 ± 0.9			
Final height at age 22-23 yrs old (cm)	4	185.4 ± 6.9				7	186.3 ± 5.8				9	184.6 ± 7.0			
Multi-sports participation at ages 9-18 yr (%)	4	100.0 %				7	87.5 %				9	100.0 %			
Age at peak improvement in siwmming (yr)	4	14.0 ± 1.6	14.0	12	16	8	14.4 ± 1.2	14.5	12	16	9	16.4 ± 1.2 ^	16.0	15	19
Age at focusing on/prioritizing swimming (yr)	4	9.8 ± 3.1	9.0	7	14	8	10.6 ± 3.6	11.0	4	14	9	11.1 ± 3.5	13.0	6	15
Age at specializing swimming events (yr)	3	15.3 ± 1.5	15.0	14	17	8	14.8 ± 2.0	15.0	12	18	9	13.2 ± 3.5	14.0	6	18
US top 100 status at age 15 yr (%)	2	50.0 %				7	87.5 %				7	77.8 %			
age 16 yr (%)	2	50.0 %				6	75.0 %				6	66.7 %			
age 17 yr (%)	2	50.0 %				7	87.5 %				5	55.6 %			
age 18 yr (%)	2	50.0 %				5	62.5 %				5	55.6 %			
USAS overall ranking at age 19 yr	3	620.7 ± 994.1	79.0	15	1768	8	592.6 ± 833.4	317.5	142	2637	9	462.6 ± 497.0	271.0	6	1509
age 20 yr	2	768.5 ± 1067.0	768.5	14	1523	8	379.9 ± 304.0	255.0	81	951	9	528.1 ± 496.7	272.0	2	1451
age 21 yr	2	1106.0 ± 1525.9	1106.0	27	2185	6	224.2 ± 253.4	139.5	31	730	9	458.7 ± 611.5	192.0	5	1683

N, numbers of subjects responding to or concerned with the listed item (variable); USAS, USA Swimming; ① based on the swimmers' recall/memory; ② calculated from *available*, reported height data of swimmers across ages; ^ Different from other maturity groups ($p < 0.025$).

Additionally, statistical tables (with Wald qui-square, estimated coefficients, odds ratio etc.) and plots for each predictor examined as well as Pearson correlation coefficient matrix for all predictors investigated in this study are shown in APPENDIX E. Among predictors examined for testing the hypothesis, a few were revealed as significant when fewer variables were included into an analysis (APPENDIX F) but did not make it to the best fit model in Tables 4.13 and 4.14 (e.g., age at doubles and sex × multi-sport interaction). Those, however, were significantly correlated with dependent variable (top 100 status: see APPENDIX E), indicating potentially significant predictors for contributing to the odds of ranking within the US top 100 during adolescence. The followings describe each of eight predictors derived from the mixed-effects logistic regression analyses.

1) Age

Age negatively contributed to the odd of ranking within the top 100 in the early successful preadolescent swimmers. The odd of being ranked within the top 100 in the U.S. between ages nine and 18 years (during adolescence) significantly decreased with an increase in age, with a mean decrease = 0.276 per age: $p < 0.01$, OR = 0.76 (95% $CI_{(lower, upper)}$ = 0.64, 0.90).

2) Weekly dryland exercise hours during ages five to eight years (preadolescence)

Although Table 4.13 (the best-fit model) shows the B estimate for this factor is positive (B = 2.409, $p < 0.01$, OR = 11.12 [95% $CI_{(lower, upper)}$ = 4.29, 28.80]), this became and was treated as an negative factor when it was included into an analysis with only age and sex (APPENDIX F). Presumably, this was associated with a collinearity problem in multiple linear regression analysis. In fact, this factor was negatively associated with the dependent variable (US top 100 status at each age) ($r = -0.17$, $p < 0.01$; Table 4.12). Therefore, following APPENDIX F, preadolescent weekly dryland hours also negatively contributed to the odd of ranking within the top 100 in the early successful preadolescent swimmers.

For those who had dryland exercise before age eight years, the odd of being ranked within the top 100 in the U.S. during adolescence decreased with an increase in age, with a mean decrease = 0.152 per age: $p = 0.086$, OR = 0.86 (95% $CI_{(lower, upper)}$ = 0.72, 1.02).

3) Sex

The US top 100 nine-year-old boy swimmers were 0.06 times *less* likely to be ranked within the US top 100 than the girls: B = -2.743, $p < 0.01$, OR = 0.06 (95% $CI_{(lower, upper)}$ = 0.02, 0.18).

4) Multi-sport experience

The US top 100 nine-year-old swimmers with multi-sport experience were 0.35 times *less* likely to be ranked within the US top 100 across adolescence than those without multi-sport experience, indicating a negative influence of multi-sport experience: B = -1.050, $p < 0.05$, OR = 0.35 (95% $CI_{(lower, upper)}$ = 0.15, 0.79).

5) Age at the enrollment in competitive swimming and practice

For age at which the top preadolescent swimmers started swimming, the top preadolescent swimmers began swimming at age five, six, and seven and older (7&O) were 22.6, 6.7, and 12.5 times, respectively, *more* likely to be ranked in the top 100 during adolescence than those who began swimming at age four years: age five, B = 3.117, $p < 0.01$, OR = 22.57 (95% $CI_{(lower, upper)}$ = 9.39, 54.23); age six, B = 1.898, $p < 0.01$, OR = 6.67 (95% $CI_{(lower, upper)}$ = 2.77, 16.08); and age 7&O, B = 2.524, $p < 0.01$, OR = 12.48 (95% $CI_{(lower, upper)}$ = 2.76, 56.44).

6) Age at the peak improvement in swim performance

For age at which swim performance of the top preadolescent swimmers improved the most during adolescence, the top preadolescent swimmers with the peak improvement occurring at age 14, 15, and 16&O were 5.17, 6.18, and 3.01 times, respectively, *more* likely to be ranked in the top 100 during adolescence than those with the peak improvement at age 12-13 years: at age 14, B = 1.643, $p < 0.01$, OR = 5.17 (95% $CI_{(lower, upper)}$ = 1.61, 16.61); at age 15, B = 1.822, $p < 0.01$, OR = 6.18 (95% $CI_{(lower, upper)}$ = 2.11, 18.09); and age 16&O, B = 1.101, $p > 0.05$ (n.s.), OR = 3.01 (95% $CI_{(lower, upper)}$ = 0.92, 9.83).

7) Weekly swim practice hours during preadolescent ages

The US top nine-year-old swimmers who had weekly swim practice for 2.5-4.4, 4.5-5.9, and 6.0 or more hours were 0.12, 0.01, and 0.22 times, respectively, *less* likely to be ranked in the top 100 during adolescence than those with less than 2.4 hours: 2.5-4.4 hours, B = -2.087, $p > 0.05$ (n.s.), OR = 0.12 (95% $CI_{(lower, upper)}$ = 0.01, 1.27); 4.5-5.9 hours, B = -4.867, $p < 0.01$, OR = 0.01 (95% $CI_{(lower, upper)}$ = 0.00, 0.08); and 6 or more hours, B = -1.531, $p > 0.05$ (n.s.), OR = 0.22 (95% $CI_{(lower, upper)}$ = 0.02, 2.91).

8) Sex × multi-sport interaction

The US top nine-year-old girl swimmers with multi-sport participation (MP), boy swimmers without MP, and boys swimmers with MP were 0.37, 0.07, and 0.02 times less likely to be ranked in the top 100 during adolescence than girl swimmers without MP: girls with MP, B = -0.983, $p > 0.05$ (n.s.), OR = 0.37 (95% $CI_{(lower, upper)}$ = 0.12, 1.21); boys without MP, B = -2.718, $p < 0.01$, OR = 0.07 (95% $CI_{(lower, upper)}$ = 0.02, 0.20); and boys with MP, B = -3.795, $p < 0.01$, OR = 0.02 (95% $CI_{(lower, upper)}$ = 0.01, 0.08).

These results support the hypothesis that there will be identifiable factors contributing to future athletic success and achievements in the top preadolescent, early successful swimmers.

Table 4.12. Predictors used for testing hypothesis 5.

Predictors	Description	Dummy variables (codes)	R (vs. DV)
Factors (categorical variables)			
Age at peak imp.	Age at peak improvement in siwmming (years)	1, at age 12-13; 2, at age 14; 3, age 15; 4, age 16 and older	-0.079
Age at start swimming	Age at enrollment in swimming (years)	1, at age 4; 2, at age 5; 3, age 6; 4, age 7 and older	0.139**
Age_doubles	Age at starting two or more training sessions a day	1, at age 12 and younger; 2, at age 13-14; 3, age 15 and older	0.198**
Maturity status	Maturity status (early, average, or late)	1, early; 2, average; 3, late	0.171**
Multi-sport	Multi-sport participation (MP) at ages 9-18 yr	0, not participating in MP; 1, participating in MP	-0.172**
Sex	Girls (women) or boys (men)	0, girls; 1, boys	-0.227**
Sex × multi-sport	Sex × multi-sport interaction	1, girls without multi-sport; 2 girls with multi-sport; 3, boys without multi-sport; 4, boys with multi-sport	-0.260**
DLT_age5-8	Dryland training during ages 5-8 yr	0, did not have DLT; 1, had DLT	-0.196**
ST_age5-8	Swim training during ages 5-8 yr	0, did not have ST; 1, had ST	-0.117*
ST hr_session_age5-8	Swim training hours per session during ages 5-8 yr	1, less than 0.99 hrs; 2, 1.0-1.49 hrs; 3, 1.50 and more hrs	-0.150**
ST hr_wk_age5-8	Swim training hours per week during ages 5-8 yr	1, 0-2.4 hrs; 2, 2.5-4.4 hrs; 3, 4.5-5.9 hrs; 4, 6 and more hrs	-0.181**
Covariates (continuous variables)			
Age	Chronological ages (years) of the subjects		-0.126*
Age at doubles	Age at starting two or more training sessions a day (yr)		0.159**
APHV	Recalled age at peak height velocity (yr)		0.047
Pre-ad DLT duration	Dryland training hours per session during ages 5-8 yr		-0.220**
Pre-ad DLT frequency	Dryland training sessions per week during ages 5-8 yr		-0.191**
Pre-ad DLT wk hours	Dryland training hours per week during ages 5-8 yr		-0.165**
Pre-ad ST duration	Swim training hours per session during ages 5-8 yr		-0.068
Pre-ad ST frequency	Swim training sessions per week during ages 5-8 yr		-0.129**
Pre-ad ST wk hours	Swim training hours per week during ages 5-8 yr		-0.021

R, Pearson correlation coefficient with dependent variable (DV, top 100 status binary); Imp., improvement; DLT, dryland training; ST, swim training; APHV, age at peak height velocity; Pre-ad, pre-adolescent (ages 5 to 8 years). * Significant correlation ($p < 0.05$); ** ($p < 0.01$).
Note: see APPENDIX E for Pearson correlation coefficient table.

Table 4.13. Significant predictors detected from a mixed-effects logistic regression analysis 1.

Effects	Wald χ^2	p value	β estimate	Std. E.	Odds Ratio	95% CI for OR	
[Continuous variables]							
Age	10.14	0.001	-0.276	0.087 ^^	0.76	0.64	0.90
Pre-ad DLT (hr• wk^{-1})	24.60	0.000	2.409	0.486 ^^	11.12	4.29	28.80
[Categorical variables]							
Sex	27.04	0.000					
Boys			-2.743	0.527 ^^	0.06	0.02	0.18
Girls			0		1		
Multi_sport	6.32	0.012					
with			-1.050	0.418 ^	0.35	0.15	0.79
without			0		1		
Age at start swimming	49.26	0.000					
Age 7&O			2.524	0.770 ^^	12.48	2.76	56.44
Age 6			1.898	0.449 ^^	6.67	2.77	16.08
Age 5			3.117	0.447 ^^	22.57	9.39	54.23
Age 4			0		1		
Age at peak imp.	13.10	0.004					
Age 16&O			1.101	0.605	3.01	0.92	9.83
Age 15			1.822	0.548 ^^	6.18	2.11	18.09
Age 14			1.643	0.595 ^^	5.17	1.61	16.61
Age 12-13			0		1		
ST hr_wk_age5-8	64.48	0.000					
6.0 and more hr• wk^{-1}			-1.531	1.326	0.22	0.02	2.91
4.5-5.9 hr• wk^{-1}			-4.867	1.188 ^^	0.01	0.00	0.08
2.5-4.4 hr• wk^{-1}			-2.087	1.185	0.12	0.01	1.27
0-2.4 hr• wk^{-1}			0		1		

χ^2, qui-squared; β estimate, regression slope; Std. E., standard error; 95% CI, 95% Wald confidence interval; OR, odds ratio; Pre-ad, pre-adolescent (ages 5 to 8 years); DLT, dryland training; Imp., improvement; ST, swim training.

Quasi-likelihood under independence model criterion (QIC) = 280.01, R^2 = 0.33.

^ and ^^, statistical significance from reference category ($p < 0.05$ and $p < 0.01$, respectively: see note)

Note 1: See Table 4.12 for more detailed descriptions of predictors.

Note 2: The reference categories for categorical variables was set at the bottom category for respective variables, and their β estimates were set to zero because these effects are redundant. Accordingly, significance (^ or ^^) indicates as compared with the reference category for each variable.

Table 4.14. Significant predictors detected from a mixed-effects logistic regression analysis 2.

Effects	Wald χ^2	p value	β estimate	Std. E.	Odds Ratio	95% CI for OR	
[Continuous variables]							
Age	10.14	0.001	-0.276	0.087 ^^	0.76	0.64	0.90
Pre-ad DLT wk hours	23.65	0.000	2.395	0.492 ^^	10.97	4.18	28.80
[Categorical variables]							
Sex × multi-sport	36.74	0.000					
Boys with MP			-3.795	0.644 ^^	0.02	0.01	0.08
Boys without MP			-2.718	0.558 ^^	0.07	0.02	0.20
Girls with MP			-0.983	0.600	0.37	0.12	1.21
Girls without MP			0		1		
Age at start swimming	44.45	0.000					
Age 7&O			2.542	0.775 ^^	12.70	2.78	57.99
Age 6			1.898	0.444 ^^	6.67	2.79	15.95
Age 5			3.133	0.483 ^^	22.94	8.90	59.11
Age 4			0		1		
Age at peak imp.	12.72	0.005					
Age 16&O			1.111	0.607	3.04	0.92	9.97
Age 15			1.831	0.570 ^^	6.24	2.04	19.08
Age 14			1.647	0.589 ^^	5.19	1.64	16.48
Age 12-13			0		1		
ST hr_wk_age5-8	63.76	0.000					
6.0 and more hr・wk^{-1}			-1.525	1.317	0.22	0.02	2.88
4.5-5.9 hr・wk^{-1}			-4.869	1.189 ^^	0.01	0.00	0.08
2.5-4.4 hr・wk^{-1}			-2.085	1.181	0.12	0.01	1.26
0-2.4 hr・wk^{-1}			0		1		

χ^2, qui-squared; β estimate, regression slope; Std. E., standard error; 95% CI, 95% Wald confidence interval; OR, odds ratio; Pre-ad, pre-adolescent (ages 5 to 8 years); DLT, dryland training; Imp., improvement; ST, swim training; MP, multi-sport participation.

Quasi-likelihood under independence model criterion (QIC) = 282.10, R^2 = 0.33.

^^, statistical significance from reference category ($p < 0.01$: see note 2 below)

Note 1: See Table 4.12 for more detailed descriptions of predictors.

Note 2: The reference categories for categorical variables was set at the bottom category for respective variables, and their β estimates were set to zero because these effects are redundant. Accordingly, significance (^^) indicates as compared with the reference category for each variable.

Study 2: Interpopulation variations in height growth and swim performance progression between the U.S. and Japan

RQ_6: Are there significant relationships between age-related height growth and swim performance progression for girls and boys (for the U.S. and Japan)?

First, it was expected that the timing of the peak improvement in 50Fr may be delayed (or lag) relative to peak height growth based on previous findings between height growth and physical tasks or physiological capacities (one-year lag in performance; Malina et al., 2004). The cross-correlation function indicates the point in time where the age-related height growth and 50Fr progression curves are best aligned. With such an analysis, the most dominant cross correlations between height and 50Fr times across adolescent ages occurred at lag 0 for all four analyses (2 countries x 2 sexes, Figure 4.21), and correlation coefficients at lag 0, which are the same results as normal Pearson's correlation, were applied here.

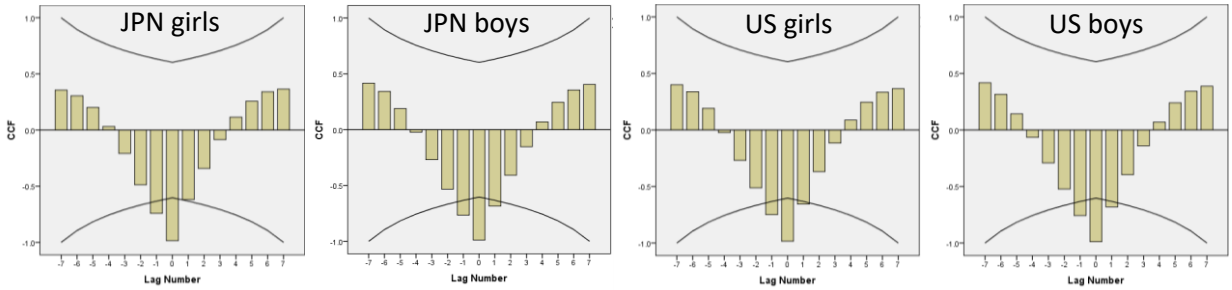


Figure 4.21. Cross-correlation functions (CCF) as a function of numbers of lags between age-related height growth and 50Fr progression in adolescents in US and JPN.
Lines in figures: top (curved) line, upper confidence limit; mid straight line, r = 0; bottom, lower line, confidence limit. Bars indicate coefficients.

Pearson's correlation demonstrated that there was a linear relationship between median height and median 50Fr across adolescent ages for both sexes and countries: US girls, $r_{(12)} = -0.968$, $p < 0.001$; JPN girls, $r_{(9)} = -0.968$, $p < 0.001$; US boys, $r_{(12)} = -0.967$, $p < 0.001$; and JPN boys, $r_{(9)} = -0.968$, $p < 0.001$. Highly significant curvilinear relationships ($p < 0.001$) between height and 50Fr times were also shown

for both sexes in both countries (Figure 4.22). Moreover, age-related height gains were highly correlated with age-related 50Fr progression in both sexes and both countries (Figure 4.23): linear relationships, JPN girls, $r_{(8)} = 0.78$, $p < 0.01$; US girls, $r_{(9)} = 0.81$, $p < 0.01$; JPN boys, $r_{(8)} = 0.69$, $p = 0.03$; US boys, $r_{(9)} = 0.77$, $p < 0.01$. The curvilinear functions between the two variables indicated higher relationships: JPN girls, $r_{(8)} = 0.83$, $p < 0.01$; US girls, $r_{(9)} = 0.89$, $p < 0.01$; JPN boys, $r_{(8)} = 0.84$, $p < 0.01$; US boys, $r_{(9)} = 0.88$, $p < 0.01$. These results support the hypothesis that age-related height growth will be significantly correlated to age-related swim performance progression in both sexes (in the US and JPN).

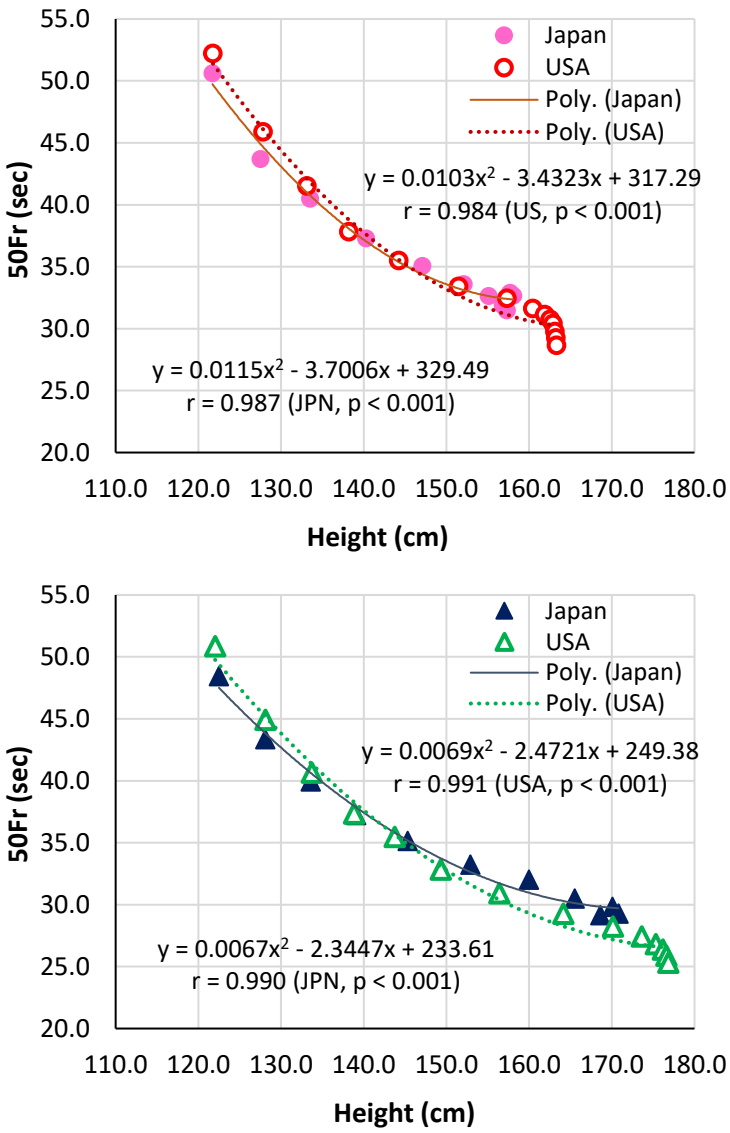


Figure. 4.22. Relationships between height and 50-meter long course freestyle time (50Fr) for US and Japan. Top, girls; bottom, boys

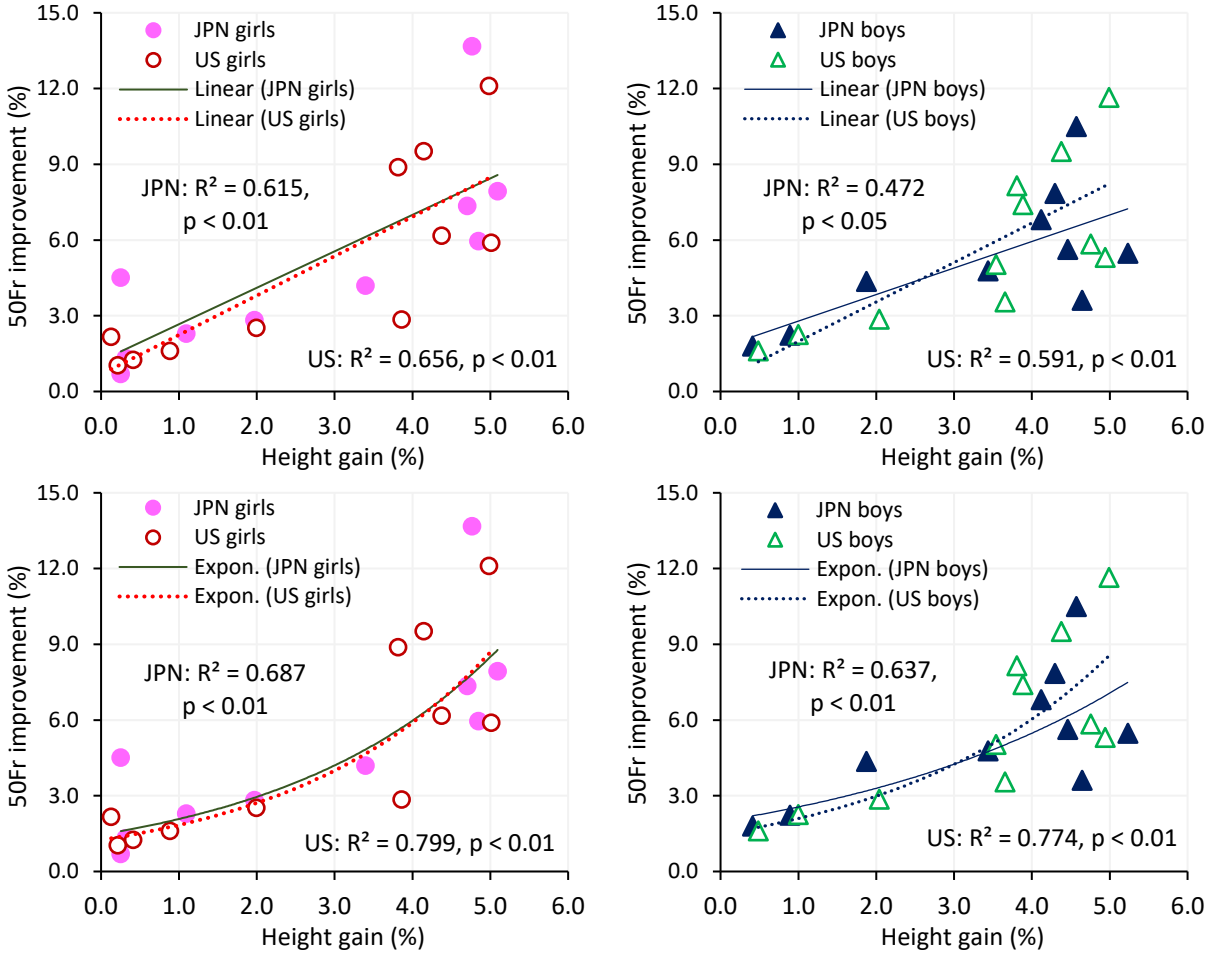


Figure 4.23. Relationships between age-related gains in height (%) and age-related improvements in 50-meter long course freestyle time (50Fr, %) for US and Japan.

Linear functions: JPN girls, $y = 1.4441x + 1.2193$; US girls, $y = 1.5605x + 0.6785$; JPN boys, $y = 1.0508x + 1.7379$; US boys, $y = 1.5633x + 0.4192$.
Exponential functions: JPN girls, $y = 1.4622e^{0.3519x}$; US girls, $y = 1.2495e^{0.3877x}$; JPN boys, $y = 1.984e^{0.2539x}$; US boys, $y = 1.4757e^{0.352x}$.

RQ_7: Is there a significant interpopulation difference in age-related height growth (between the U.S. and Japan)?

Figure 4.24 demonstrates growth reference data for US (Kuczmarski et al., 2002) along with those for JPN (MEXT, 2000) in the year of 2000. Overall age-related height growth curve (median values) in JPN children fits to that in US children (50th percentile) until age 14 years in girls and 16 years in boys). The growth curves between countries were highly correlated: $r_{(9)} = 0.989$, $p < 0.001$, $t_{(10)} = -$

1.57, $p = 0.148$, $d = -0.47$ (girls); $r_{(9)} = 0.992$, $p < 0.001$, $t_{(10)} = 0.17$, $p = 0.872$, $d = 0.05$ (boys). However, visual inspection of the height growth curves for US and JPN suggest some differences in the characteristics of the curves between countries. Median height in JPN children at age five years (110 cm and 111 cm, respectively) was taller than that in US children at age five (108.0 cm and 109.0 cm, respectively) (Figures 4.24 and 25). Thereafter until age 10 years in girls and age 11 years in boys, growth curves are very similar between two countries. Around age 11 years in girls and 12 to 13 years in boys, JPN adolescents become taller than US children. After age 12 years in girls and age 14 years in boys, US adolescents become taller than JPN adolescents, and the height differences between countries continues to diverge to the final adult height, most noticeably in boys (Figure 4.25). The reference data show at age 20 years that US women and men are taller than JPN counterparts by approximately 5.0 cm and 6.5 cm: US women, 163.3 cm; US men, 176.9 cm; JPN women, 158.2 cm; JPN men, 170.4 cm.

Visual inspection of age-related height gains (an alternative index of height velocity requiring longitudinal study or data collection) calculated as differences in height between a given age and its subsequent age also suggested noticeably different patterns of age-related height growth between countries (Figure 4.26). As compared with the respective US cohorts, age-related peak height gains (PHG) occur approximately two years earlier for JPN children (10 years vs. 12 years in girls; 12 years vs. 14 years in boys). Height growth spurt, which is an acceleration in most skeletal dimensions (Marshall & Tanner, 1986), also displays a similar manner to PHG in both sexes. Growth spurt in height is observed approximately two years before the age of PHG in both sexes and countries with JPN children being earlier (Figure 4.26). Unlike the data of the age-related height (Figure 4.24), the data of age-related height gains in JPN children during their growth spurt (from the onset to one-year after their PHG) diverge from those of US children (50h percentiles) in both sexes. During times of growth spurt for JPN children, height gains in JPN are located above the 97th percentiles of US children although no statistical differences were found but curves for both countries are significantly correlated: $t_{(9)} = -1.07$, $p = 0.31$, d

= -0.34, and $r_{(8)} = 0.858$, $p = 0.001$, (girls); $t_{(9)} = -1.01$, $p = 0.34$, $d = -0.32$, and $r_{(8)} = 0.735$, $p = 0.015$, (boys). These findings indicate that JPN children are early matures as compared with US children. Further, for the differences in height between US and JPN during adolescence appear to be determined by the age at PHG. Before the age at PHG of US children, JPN children are taller in both sexes, but after the average age of PHG of US children, US children become taller (Figures 4.24 & 26). The hypothesis that the pattern of age-related height growth will be significantly different between US and JPN was supported.

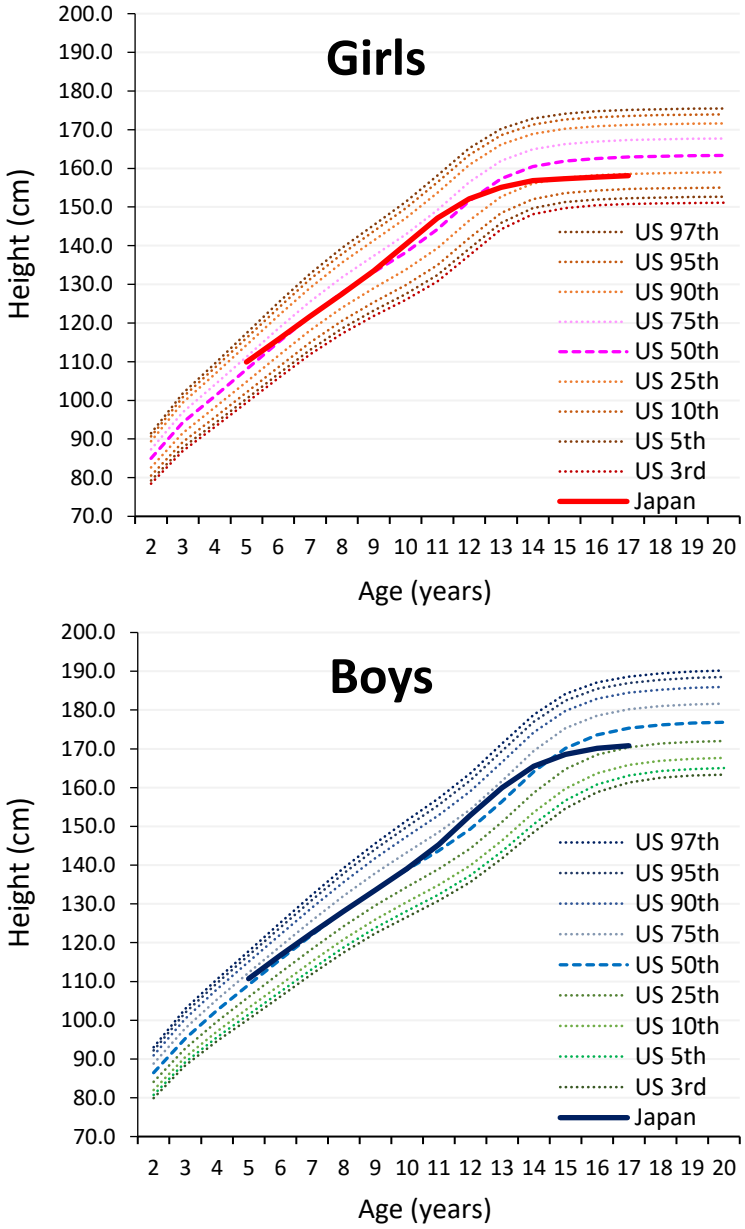


Figure 4.24. Height reference for US children along with for Japanese in 2000 as a function of age.

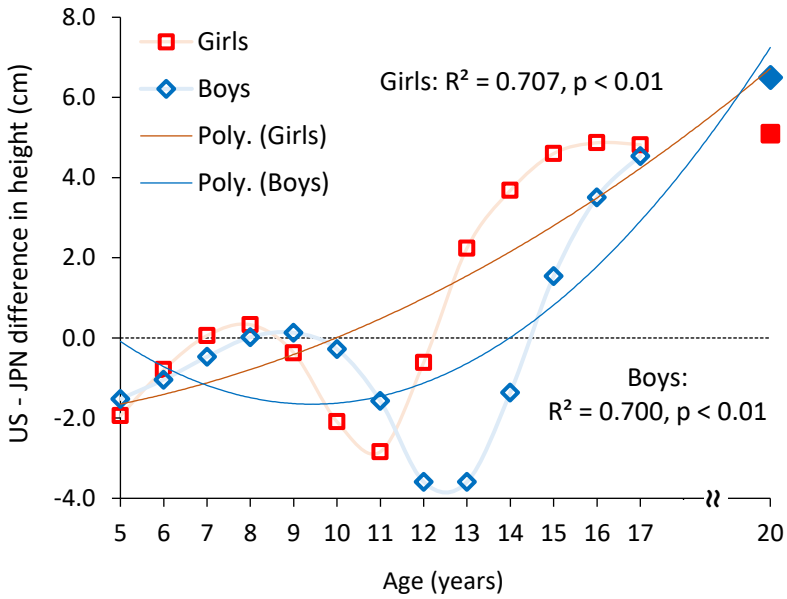
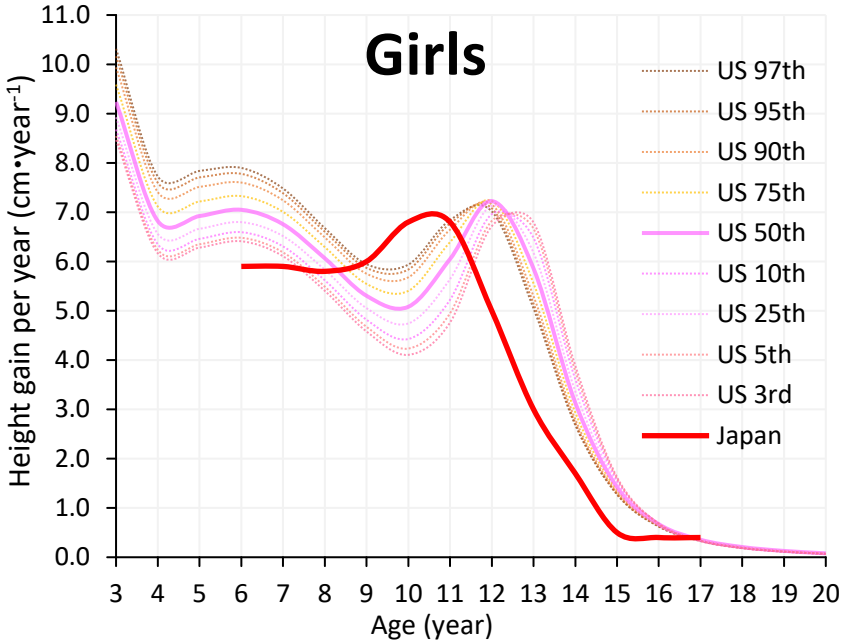


Figure 4.25. Differences in median height between US and JPN children across adolescent ages. Bold plots at age 20 indicate the difference in the average adult height between two countries. Positive values indicate US children are taller than JPN children.

Polynomial functions: Girls, $y = 0.0226x^2 - 0.0066x - 2.1801$; Boys, $y = 0.0796x^2 - 1.5011x + 5.4247$



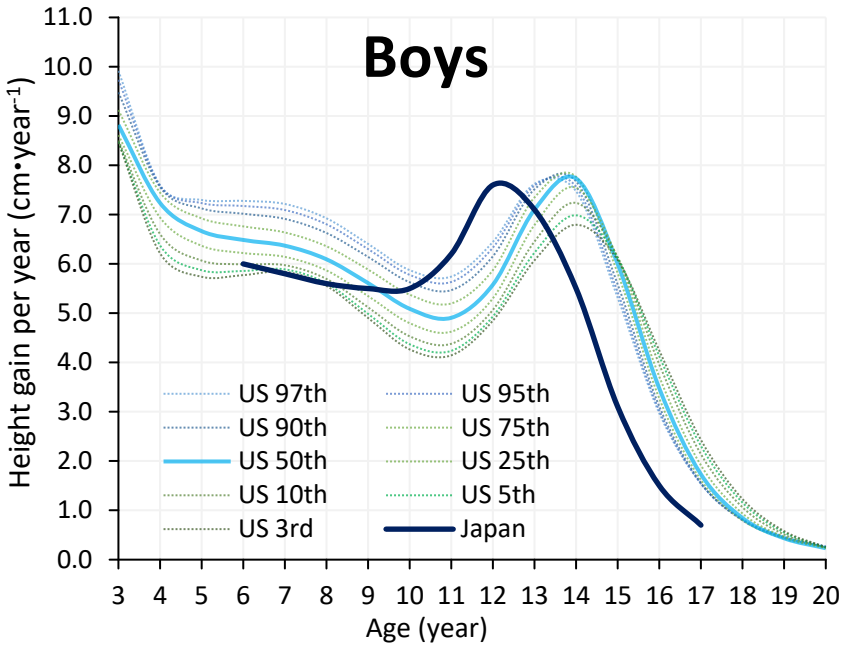


Figure 4.26. Age-related height gains in children in US and Japan based on reference data in 2000.

RQ_8: Is there a significant interpopulation difference in age-related swim performance progression? [All swims in 2008]

A two-way (age × country) ANOVA examined the effect of age and country on the 50Fr times using all swims in ages from seven to 22 and a group of 23 years and older (23&O) in 2008. There was a significant interaction between the effects of age and country on 50Fr times for both sexes (Figure 4.27): $F_{(16, 56818)} = 110.31$, $p < 0.001$, $\omega^2 = 0.03$ (girls) and $F_{(16, 50783)} = 100.64$, $p < 0.001$, $\omega^2 = 0.03$ (boys). Simple main effects analysis by an independent sample t-test with Bonferroni corrections (alpha set at 0.003) detected significant differences in 50Fr times between countries at many ages in both sexes (Figure 4.27). In girls/women, as compared with the respective US cohorts, the 50Fr was faster for JPN swimmers ($p < 0.001$) aged seven to 11 years (age 7, d = -0.25; age 8, d = -0.20; age 9, d = -0.13; age 10, d = -0.06; and age 11, d = -0.06), not different at age 12 years ($p < 0.075$, d = 0.02), and slower at ages 13 years and older for JPN swimmers ($p < 0.001$: age 13, d = 0.21; age 14 d = 0.15; age 15, d = 0.18; age 16,

d = 0.53; age 17, d = 0.53; age 18, d = 0.51; age 19, d = 0.74; age 20, d = 0.71; age 21, d = 0.81; and 23&O, d = 0.53), with the exception of age 22 years (p = 0.017, d = 0.21). Similarly, the 50Fr in JPN boys aged seven to nine years was faster (p < 0.001: age 7, d = -0.24; age 8, d = -0.14; and age 9, d = -0.05), not different at 10 (p = 0.01, d = -0.04) and 11 (p = 0.17, d = -0.02) years, and slower at ages 12 years and older (p < 0.001): age 12, d = 0.05; age 13, d = 0.26; age 14 d = 0.29; age 15, d = 0.28; age 16, d = 0.54; age 17, d = 0.49; age 18, d = 0.57; age 19, d = 0.71; age 20, d = 0.52; and age 21, d = 0.54; age 22, d = 0.68; and age 23&O, d = 0.79.

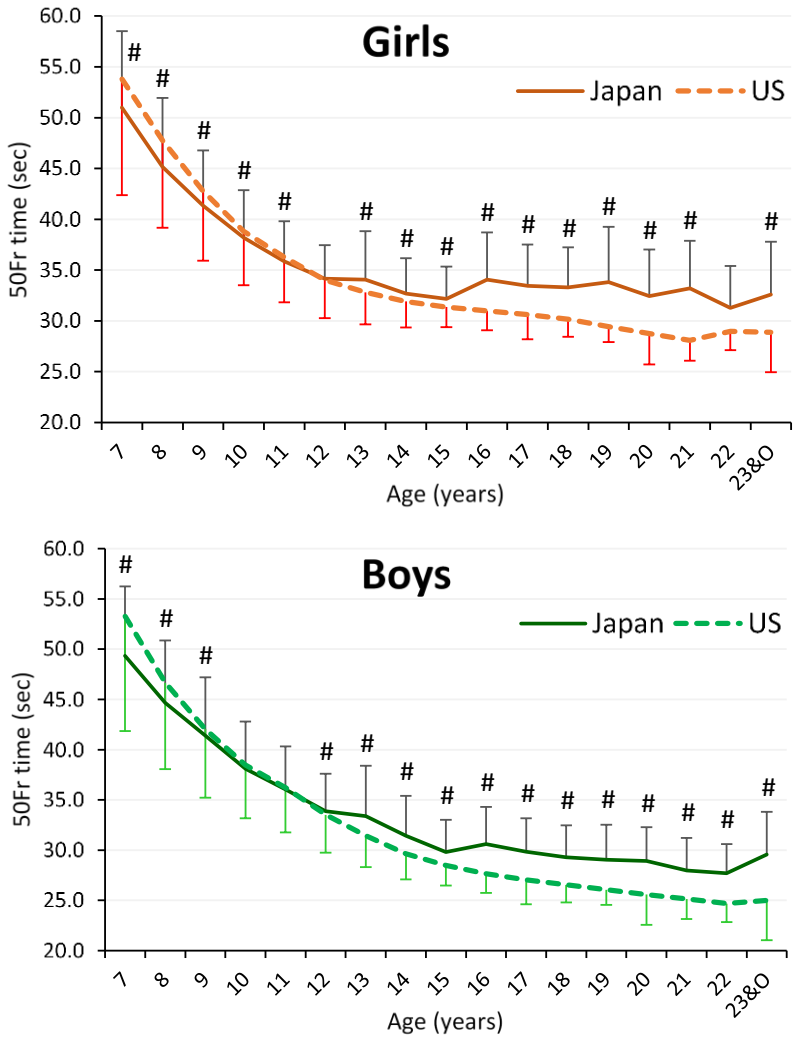


Figure. 4.27. Mean (± standard diviation) times in 50-meter freestyle (50Fr) of all swimmers in Japan and US in 2008 as a funciton of age (seven to 22 years old and an age-group of 23 years and older).
#, different between Japanese and US swimmers (p < 0.002).

[Top 100 US and JPN swimmers in 2008]

A two-way (age × country) ANOVA also revealed an interaction between age and country on 50Fr times using the top 100 swims for 17 age categories in 2008 for both sexes (Figure 4.28): $F_{(16, 3289)} = 24.14$, $p < 0.001$, $\omega^2 = 0.10$ (girls) and $F_{(16, 3344)} = 16.50$, $p < 0.001$, $\omega^2 = 0.07$ (boys). Independent sample t-tests also detected significant differences (alpha set at 0.003) in 50Fr times between US and JPN at most of age categories for both sexes. In girls/women, the 50Fr was faster for the US top 100 swimmers ($p < 0.001$) at all ages, with the exception of being no difference at ages nine, ten, 22, and 23&O: age 7 ($d = 0.76$), age 8 ($d = 0.26$), age 9 ($p = 0.46$ [n.s.], $d = 0.05$), age 10 ($p = 0.54$ [n.s.], $d = 0.04$), age 11 ($d = 0.31$), age 12 ($d = 0.50$), age 13 ($d = 0.38$), age 14 ($d = 0.39$), age 15 ($d = 0.57$), age 16 ($d = 1.01$), age 17 ($d = 0.82$), age 18 ($d = 0.80$), age 19 ($d = 1.29$), age 20 ($d = 1.03$), and age 21 ($d = 0.78$), age 22 ($p = 0.02$, $d = 0.21$), and age 23&O ($p = 0.89$, $d = 0.01$). Correspondingly, the 50Fr of the top US 100 swims was faster than the top JPN 100 swims at all ages, with the exception of ages 10 and 11: age 7 ($d = 0.47$), age 8 ($d = 0.24$), age 9 ($d = 0.22$), age 10 ($p = 0.10$ [n.s.], $d = 0.12$), age 11 ($p = 0.03$ [n.s.], $d = 0.17$), age 12 ($d = 0.33$), age 13 ($d = 0.59$), age 14 ($d = 0.69$), age 15 ($d = 0.25$), age 16 ($d = 0.75$), age 17 ($d = 0.71$), age 18 ($d = 0.81$), age 19 ($d = 0.91$), age 20 ($d = 1.04$), and age 21 ($d = 0.53$), age 22 ($d = 0.34$), and age 23&O ($d = 0.89$).

These results suggest that there are significant differences in 50Fr across ages between US and JPN. The 50Fr were faster in US than JPN in both sexes when examining nations' top 100 swimmers across all ages examined (Figure 4.28). However, the same trend or pattern (of interpopulation differences in 50Fr; i.e., US is better than JPN) was not evident when analyzing nations' all swims across ages (Figure 4.27). JPN swimmers were faster during pre- and early-adolescent ages than US swimmers in both sexes. Age-related 50Fr progression (curves) for US and JPN had an interaction at age 12 for both sexes. Therefore, these findings support the hypothesis that the pattern of age-related swim progression is significantly different between US and JPN.

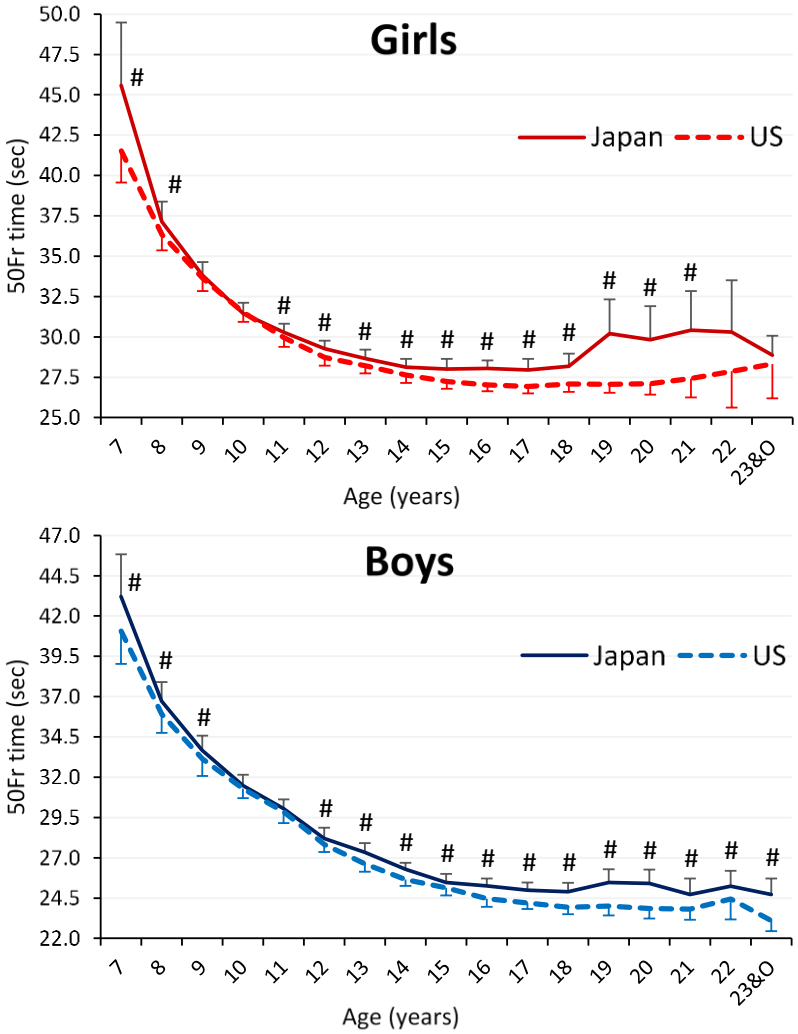


Figure 4.28. Mean (± standard diviation) times in 50-meter freestyle (50Fr) of the top 100 swimmers for 16 age categories (age seven to 22 years) and an age-group of 23 years and older in Japan and US in 2008.
#, different between Japanese and US swimmers ($p < 0.003$).

RQ_9: Is there a significant relationship between interpopulation differences (ratio of Japan to US) in age-related height growth and swim performance progression?

It has been demonstrated so far that height correlates with swim performance (50Fr) during adolescent ages, and there is a relationship between age-related height growth and 50Fr progression for both sexes in US and JPN. In addition, there appear to be differences in age-related height growth

patterns and in age-related 50Fr progression between US and JPN for both sexes. The question becomes whether the interpopulation differences in age-related 50Fr progression during adolescence can be attributed to those in age-related height growth. This was examined by using the ratios of JPN to US in the two variables (height and 50Fr times) and elaborating a comparative analysis of the two ratios. Once again, as it is also show in Figure 4.29, the magnitude of height growth and 50Fr improvements decreases as a function of age with a similar manner for both sexes in both countries. More importantly, height growth spurt and increased 50Fr progression and its respective peaks are depicted at a relatively similar timing within a population and sex. Such a tendency seems to be well highlighted in girls (age 10 in JPN and age 12 in US).

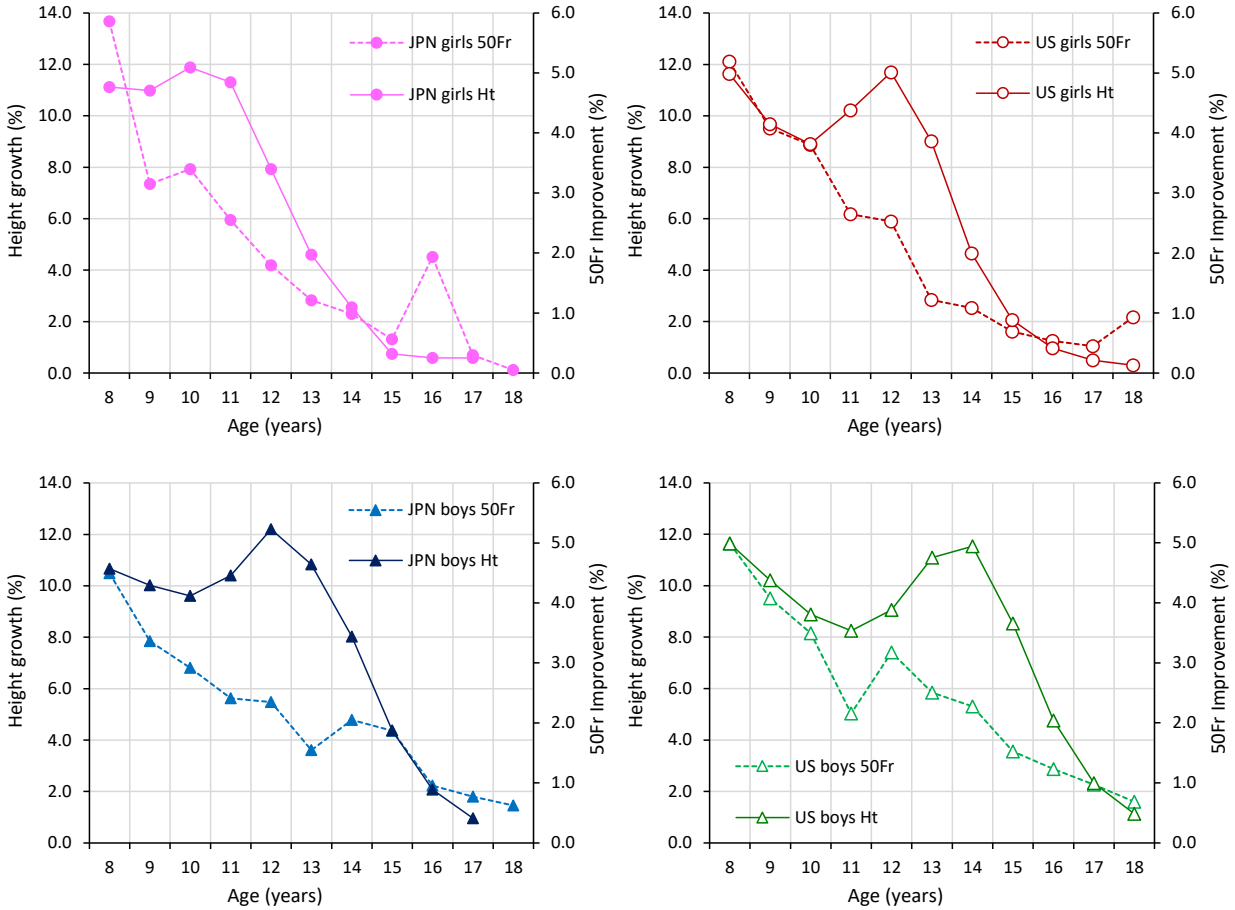


Figure 4.29. Age-related gains in height (Ht, %) plotted along with age-related improvements in mean speed in 50-meter freestyle (50Fr, %) for Japanese (JPN) and US children across adolescent ages. Top left, JPN girls; top right, US girls; bottom left, JPN boys; bottom right, US boys.

With cross-correlation analysis, the most dominant cross correlations between JPN-to-US ratios in height and 50Fr across adolescent ages occurred again at lag 0 for both sexes (Figure 4.30), although, a higher variance (dispersion) was found in boys' results (Figure 4.29). Pearson's correlation (due to highest cross correlations detected at lag 0) demonstrated that there was a linear relationship between JPN-to-US ratios (interpopulation differences) in height and 50Fr in girls ($r_{(9)} = 0.71$, $p = 0.015$), but not in boys ($r_{(9)} = 0.49$, $p = 0.12$). The quadratic term, however, revealed significant correlation between JPN-to-US ratios in height and 50Fr for both sexes: girls ($r_{(9)} = 0.85$, $p < 0.01$), but not in boys ($r_{(9)} = 0.82$, $p < 0.01$) (Figure 4.31). In fact, quadric functions must fit better for this relationship because of the observed curvilinear relationship between height and swim performance and an interaction of the regression lines between US and JPN for both sexes (Figure 4.32). These results support the hypothesis that there is a significant relationship between interpopulation differences (ratio of Japan to U.S.) in age-related height growth and swim performance progression.

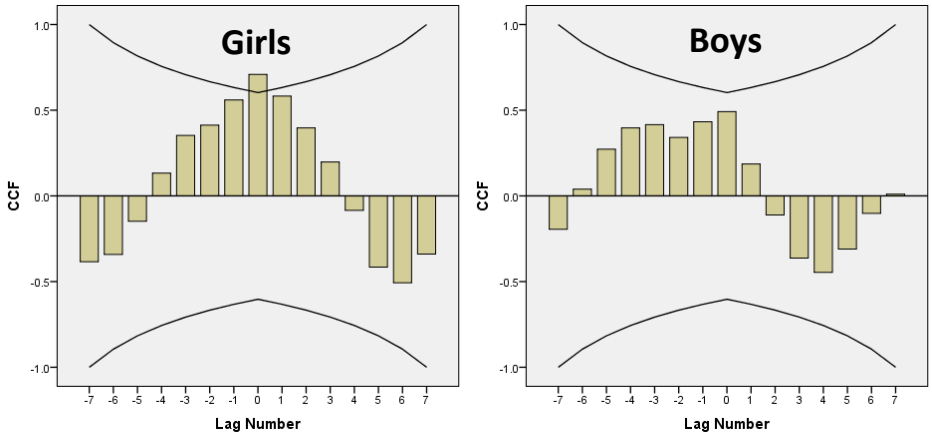


Figure 4.30. Cross-correlation functions (CCF) as a function of numbers of lags between JPN-to-US ratios in height and 50Fr in adolescents in US and JPN.
Top (curved) line, upper confidence limit; mid straight line, r = 0; bottom curved line, lower confidence limit. Bars indicate coefficients.

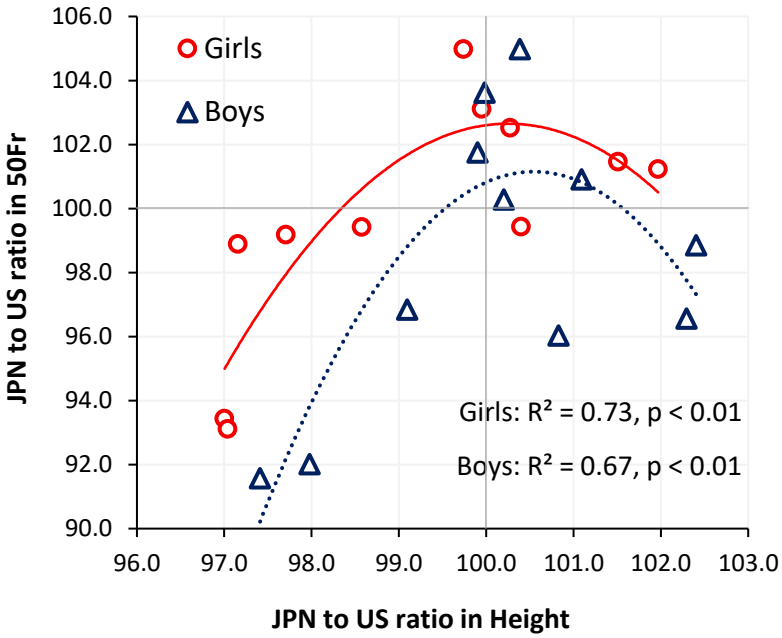


Figure 4.31. Relationships between interpopulation differences (ratio of JPN to US expressed as %) in median height and 50-meter freestyle performance (50Fr) during adolescence.

Note: bold trend lines for girls; dash trend lines for boys.
Linear functions: Girls, $y = 1.4367x - 42.837$ ($R^2 = 0.494$, $p = 0.015$); Boys, n.s.
Polynomial functions: Girls, $y = -0.7261x^2 + 145.57x - 7194.3$; Boys, $y = -1.1121x^2 + 223.63x – 11142$.

Figure 4.32 also depicts the changes in the ratios of JPN to US (interpopulation difference) in height and 50Fr as a function of age. The JPN-to-US ratio in height reaches above 100.0, indicating that JPN children are taller than US peers, during the growth spurt of JPN children, which are identifiable to Figure 4.25. The JPN-to-US ratio in 50Fr shows above 100.0 at preadolescent ages (JPN children are faster than US peers) but ratios become smaller and smaller with increasing age (US children catch up to and become faster than JPN counterparts).

One might expect that an association between height and swim performance would indicate JPN children are taller and consequently faster than US children at preadolescent ages, while US children catch up to and become taller and faster than JPN children around the time or after the age of PHV in US children in both sexes. Therefore, it was hypothesized that the age (timing) when the JPN-to-US ratios

in height and 50Fr reach below the value of 100.0 (US children become taller and faster than JPN peers) happens simultaneously, and corresponds to age 12 years in girls and 14 years in boys. This was, in fact, the case for girls and the hypothesis appeared to be supported for girls, but this was not true of boys in the cohort when using all swim performance data for both countries (Figure 4.32).

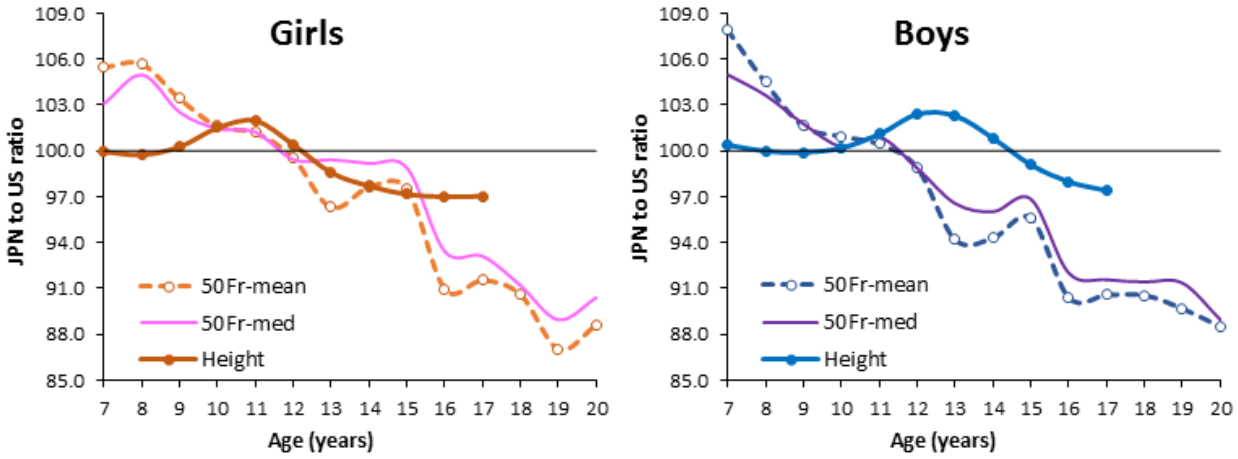


Figure. 4.32. Japan-to-US ratios (%) in height and 50-meter freestyle (50Fr) as a function of age.
JPN, Japan; 50Fr, 50-meter long course freestyle time (performance); med, median.

Note 1: A line at 100.0 (%) denotes that values (ratios) in JPN and US are the same.
Note 2: Values above the line (> 100.0) denote that JPN children are faster than taller than US children.

CHAPTER 5: DISCUSSION

The aim of this chapter is to discuss each of the nine research questions for both study projects outlined in the first chapter. For clarity, the research question and hypothesis are restated followed by discussion.

Study 1: Performance progression, participation retention, and developmental career path in U.S top 100 nine-year-old swimmers

Question 1: What is the percentage of the U.S. top 100 nine-year-old swimmers maintaining the top 100 status through adolescent ages and beyond?

Hypothesis 1: The proportion of the nine-year-old swimmers maintaining the top 100 status decreases with age.

DISCUSSION 1

A mixed-effects logistic regression provided statistical evidence that the odds of the US top young swimmers ranking within the US top 100 (at age nine years) in any swimming event during subsequent adolescent ages decreases (with an increase in age; $p < 0.01$; Figure 4.1). The results indicated that an increase in age leads to a 0.26- and 0.30-decrease in the odds in girls and boys, respectively. A greater magnitude of the decrease (an effect of age) in the odds was found when examining solely the 45.7Fr (a 0.53- and 0.50-decrease in girls and boys, respectively; Figure 4.1). The proportion of the US top 100 nine-year-old swimmers who maintained their success level (US top 100) at age 18, i.e., 10-year performance retention rate, was approximately 40% for both sexes (43% in girls and 38% in boys) in this cohort. These findings support the hypothesis that the proportion of the nine-year-old swimmers maintaining their top 100 status decreases with age.

The retention rate of the US top 100 status (sustainability of successful athletic attainment) obtained in this study (top young swimmers), however, appeared to be higher than that in previous

reports (approximately 10-30% of studied population; Barreiros et al., 2014; Julio et al., 2011; Schumacher et al., 2006), despite the longer study duration in the present analyses than previous studies. Julio et al. (2011) analyzed the relevant samples to the present study (design) and reported that on average, 5% in girls/women (N = 202) and 7% in boys/men (N = 204) at the state-level Judo competitions attained medal winning status (the top four) for 10 consecutive years during adolescence. It is common experience within the competitive swimming community, which have more than 13 competitive swimming events, that swimmers tend to pursue and change their specialization (primary stroke styles and events) during their mid-to-late adolescent career (in the present study, girls at age 12.9 ± 3.1 and boys at age 14.2 ± 2.8 years). This trend leads to an increased chance to be successful (US top 100) throughout adolescence when compared with 'open-skilled' sports or team sports. Alternatively, a lower dropout rate in the top young swimmers during the 10-year duration studied may have been associated to a potentially higher top-level sustainability. Research have suggested that up to 70 percent of youth sports athletes drop out from their sports by age 18 years old (Brady, 2004; Gould, 1987; Seefeldt et al., 1996). USA Swimming (USAS) data indicate that 60% of the girls and 53% of the boys dropped out from USA swimming for a similar duration (age nine to 17 years).

In addition, the retention rate in successful athletic attainment would be dependent on types of sports, age-span and duration studied, and/or the criteria determining the successful status (nation's top 100, national championships qualifiers or team members, medal winners at national and international championships, and percentage of total population etc.). The present analyses with US top nine-year olds centered on examination of the retention rate of top athletic status, competitive swimming, and its performance data in the U.S. This cohort was chosen because 1) competitive swimming is one of a few sports that performance is measurable, and children typically start at very young ages (Figure 1.4.); 2) performance data are available for all ages and past years in the database of

USAS; and 3) USAS has had the best performances in the world swimming scene. Questions remain as to the criteria determining successful athletic status used in the present analysis.

First, *what proportion of all swimmers in USAS in each age category does the 'US top 100' represent*? According to USAS membership data and the cohort examined in this study (Table 4.1), the US top 100 status accounted for less than top 1% of the total memberships in respective adolescent ages from age nine to 16 years (0.57-0.97%), and top 1.18% and 1.61% at age 17 and 18, respectively, in girls. In boys, the US top 100 represented top 1.3% of the swimmers at age nine in 2004, less than 1% of swimmers in respective ages from age 10 to 14 years, and little over 1% after age 15 years (1.04, 1.14, 1.27, and 1.50% at ages 15, 16, 17, and 18 years, respectively). As compared with world-leading swimming countries (based on Olympic medal counts), USAS has the largest swimming population around the world (FINA, 2013):

USA (331,189 swimmers out of 314,700,000 inhabitants – 0.11% swimmers to total population)

Japan (185,853 swimmers out of 127,200,000 – 0.15%)

Australia (76,406 swimmers out of 21,300,000 – 0.36%)

Hungary (5,562 swimmers out of 10,000,000 – 0.06%)

Great Britain (71,756 swimmers out of 58,000,000 – 0.12%)

Data based on early 2013.

These results would suggest that the US top 100 represents exceptional athletic status in the cohort of the best swimming country in the world due to the large number of participants in USAS.

The second question is, if the different levels of (higher) success of nine-year-old swimmers had been tracked for evaluating their adolescent swim performance and development, would the study outcomes the same? To answer to this question, the US top 10 nine-year-old swimmers in 45.7Fr in 2004 and their performances for following ten years were tracked, and the data were shown in Figure 5.1 and Table 5.1. First, the top 10 status accounted for a very high athletic success: below or around

0.1% of athletes within respective ages (Table 5.1). The results of the US top 10 nine-year olds demonstrated an analogous tendency of the retention rate to the US top 100 swimmers studied for study hypothesis 1. At age 18, two girls (20%) and four boys (40%) maintained the US top 10 levels. Four girls and five boys ranked within the US top 10 in consecutive 10 years, and three girls and one boy ranked nine years out of ten years. Moreover, as displayed in the left figures in Figure 5.1, a higher odds of ranking within the US top 100 status for this highly successful pre-adolescent swimmers were evident in both cases (investigating 45.7Fr and best events) and in both sexes.

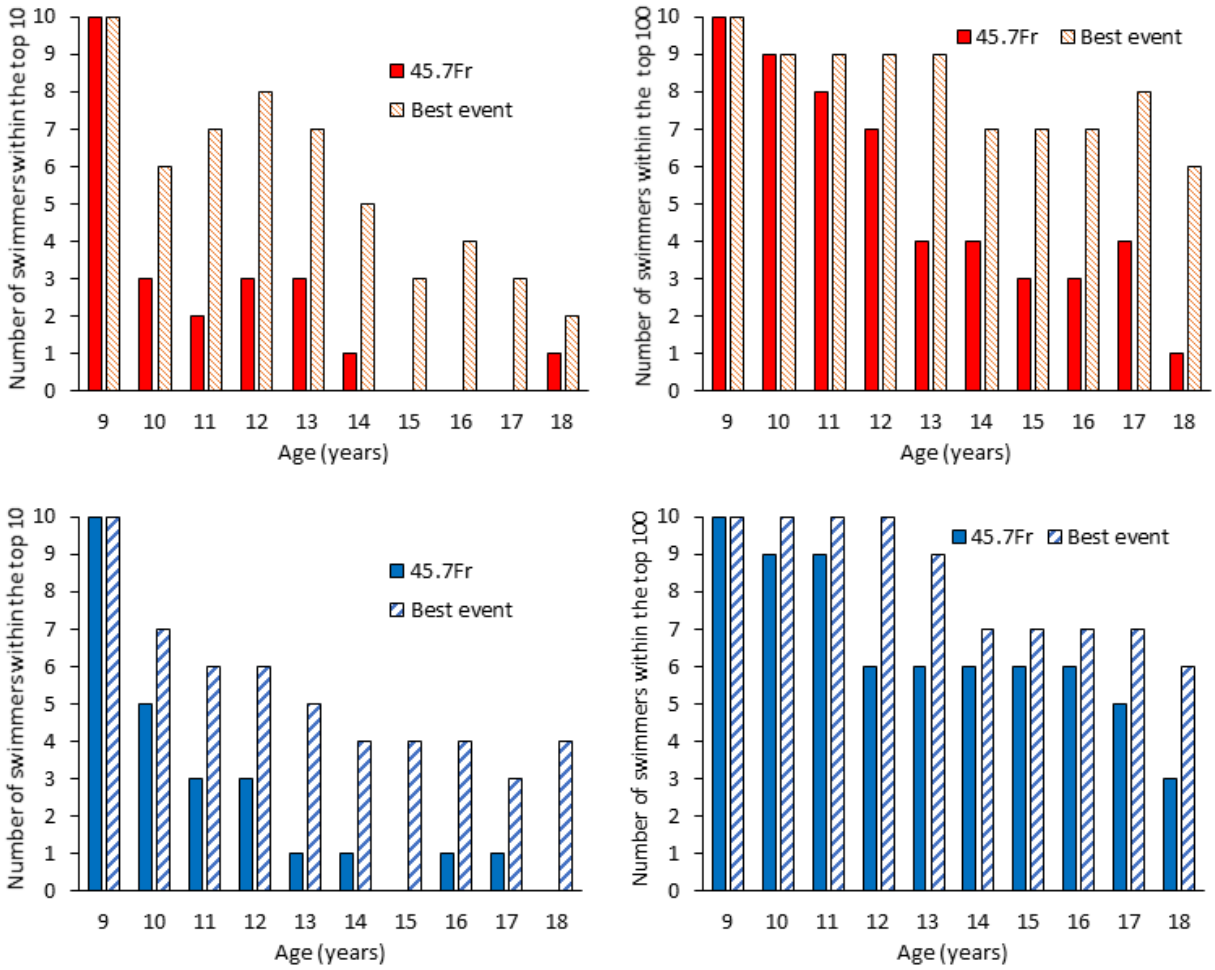


Figure 5.1. Retention rate of ranking within the US top 10 and top 100 in the US top 10 nine-year-old swimmers in 45.7-meter freestyle (45.7Fr) in 2004 during adolescence.

Top figures for girls' data; bottom figures for boys.
Left figures for the US top 10 status (retention rate); right figures for the US top 100 status

Table 5.1. Performance characteristics and the number of top 10 swimmers in any event in each adolescent age among the US top 10 nine-year-old swimmers in 45.7Fr in 2004.

Girls

Year (age)	%USAS	Top10	Mean	±	SD	Median	Highest	Lowest
2004 (9)	0.08	10	3.5	±	3.3	2.0	1	10
2005 (10)	0.06	6	10.2	±	14.9	2.0	1	43
2006 (11)	0.06	7	9.8	±	15.0	4.0	1	47
2007 (12)	0.06	8	7.6	±	16.7	2.0	1	52
2008 (13)	0.06	7	19.9	±	35.2	3.0	1	100
2009 (14)	0.06	5	88.1	±	201.3	9.0	1	613
2010 (15)	0.08	3	53.0	±	84.2	21.0	1	261
2011 (16)	0.10	4	120.8	±	263.3	31.0	3	815
2012 (17)	0.12	3	24.5	±	25.1	15.5	1	71
2013 (18)	0.16	2	65.0	±	58.9	53.0	1	168

Boys

Year (age)	%USAS	Top10	Mean	±	SD	Median	Highest	Lowest
2004 (9)	0.13	10	3.8	±	1.9	3.5	1	6
2005 (10)	0.09	7	8.6	±	8.9	4.5	1	30
2006 (11)	0.09	6	8.6	±	7.1	8.0	1	18
2007 (12)	0.09	6	9.9	±	9.8	8.0	1	31
2008 (13)	0.09	5	20.3	±	27.7	8.0	1	87
2009 (14)	0.09	4	59.2	±	110.0	12.0	1	331
2010 (15)	0.10	4	167.7	±	359.9	13.0	1	1073
2011 (16)	0.11	4	85.8	±	146.7	15.0	1	433
2012 (17)	0.13	3	72.9	±	96.6	35.0	1	270
2013 (18)	0.15	4	49.3	±	58.6	17.0	2	143

(age), the age of the swimmers studied in each year listed; %USAS, the percentage of the top 10 nine-year-old swimmers representing within the respective years and ages in USA Swimming; top 10, the number of top 10 swimmers ranked within the US top 10 in each age category; Median, highest, and Lowest rankings attained by the top 10 swimmers examined.

These data suggest that the US top 100 status evidently represent the top, highly outstanding athletic level in the US, and potentially even in the world. Once again, from the 200 top 100 nine-year-old swimmers studied, 12 girls and four boys were selected for the U.S. Junior National team, and three girls and one boy swimmers were U.S. Senior National team members by and/or at age 18. The Senior National members (four swimmers) represented the country for the World Championships, London

Olympics, and/or other senior international competitions. In addition, 71 girls and 68 boys within the studied cohort extended their swimming career into the collegiate levels, and 54 girls and 53 boys competed in Division 1 schools. The available reports indicate that the percentage of high school swimmers advancing their career into collegiate levels is 7.8% in girls and 7.5% in boys, and competing in Division 1 schools is 3.1% in girls and 2.7% in the data during 2015 (http://www.scholarshipstats.com/). These data suggest that the US top 100 pre-adolescent aged swimmers maintain successful athletic attainments throughout their adolescent careers into college/senior levels. Moreover, these data sustain the main finding of this study, revealing that higher retention rates (43% in girls and 38% in boys; Figure 4.1) in highly successful levels exist for the US top 100 young swimmers in the cohort studied and in the sport of competitive swimming. Therefore, early success at younger ages (US top 100 or top 1% in the nation) appears to predict future success (top 1% during late adolescent ages and into top collegiate levels) in competitive swimming.

***Question 2a*:** Do the U.S. top 100 nine-year-old swimmers improve their performance times (45.7-meter freestyle: 45.7Fr) across adolescent ages?

***Hypothesis 2a*:** The U.S. top 100 nine-year-old swimmers will improve their performance in 45.7Fr across adolescence.

DISCUSSION 2a:

A linear mixed-effect model revealed an effect of age on 45.7Fr in both sexes (Table 4.1). Post hoc test revealed that significant differences exist between two subsequent ages up to age 14 in girls and age 17 in boys, which were analogous findings to Kojima et al. (2012) using cross-sectional data analyses of age-related improvements in 45.7Fr in the US top 100 swimmers. In addition, annual improvements in 45.7Fr of the US top 100 swimmers also revealed a significant effect of age (Table 4.3). These results support the study hypothesis 2a.

One of the most influential factors for adolescent sport performances and its improvements is physical growth and development (Malina et al., 2004). The development of swim performance in non-skilled adolescent students aged 11 to 17 has been reported in relation to age and anthropometric characteristics such as height, weight, and arm span (Pelayo et al., 1997). The results of 961 girls and 1097 boys with minimum swimming sessions (Physical education class only; 6 ± 2 hours per year) in the cross-sectional study show that swim velocity in 50-meter freestyle performance in the cohort increased significantly with age for both sexes. The authors emphasized growth (height and arm span) is the one of important factors for improvements in sprint swim performance in non-swimmers. The age-related improvements in 50-meter freestyle were 23.6% in girls and 41.6% in boys between ages 11 and 17 years, which were much greater than the top young swimmers in the present study (8.0% in girls and 18.5% in boys from ages 11 to 17 years) as well as age-related improvements in the US top 100 swimmers in the same age-range (9.8% in girls and 18.7% in boys; Kojima et al., 2012). Biomechanical factors that are critical to (adolescent) swim performance, such as stroke length, have been also reported to be largely attributed to physical growth, i.e., increases in height and limb length (Moreira et al., 2014). A question with the results of the present study is whether this phenomenon is occurring in the early successful swimmers, who may not have as much room to improve their performance time as their average-level peers or non-swimming populations.

To answer to the above question, available height data across adolescent ages were compiled from the US top 100 swimmers used in research question 5, and plotted height data and progression in 45.7Fr (girls, n = 11; boys, n = 12) were shown in Figure 5.2. The height and 45.7Fr were highly correlated: girls, $r_{(8)} = -0.99$ ($p < 0.01$); and boys, $r_{(8)} = -0.98$ ($p < 0.01$). The same results were revealed between annual high gain and 45.7Fr improvement (Figure 5.3): girls, $r_{(7)} = 0.85$ ($p < 0.01$); and boys, $r_{(7)} = 0.78$ ($p < 0.05$). The data in Study 1 suggest that height growth is also closely related to (swim) performance improvements in early successful young athletes. Therefore, physical growth and

development appear to be one of the important predictors for success (winning and or game-playing time) in all adolescent sports performance.

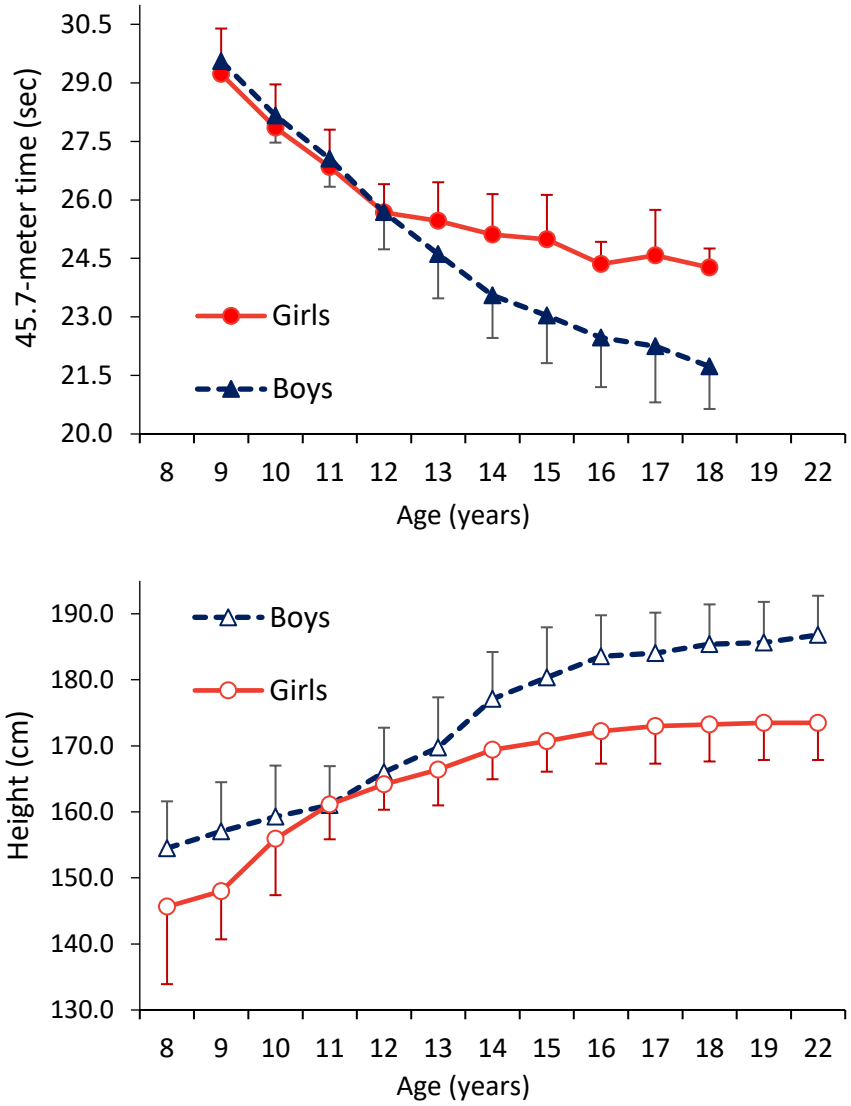


Figure 5.2. 45.7-meter freestyle performance (45.7Fr) and height in the US top 100 nine-year-old girls (n = 11) and boys (n = 12) as a function of age.
Top, 45.7Fr; bottom, height.
Data are shown as means ± standard deviations (error bars).

Note: relationship between 45.7Fr and height; Girls, $r_{(8)} = -0.99$ ($p < 0.001$); Boys, $r_{(8)} = -0.98$ ($p < 0.001$).

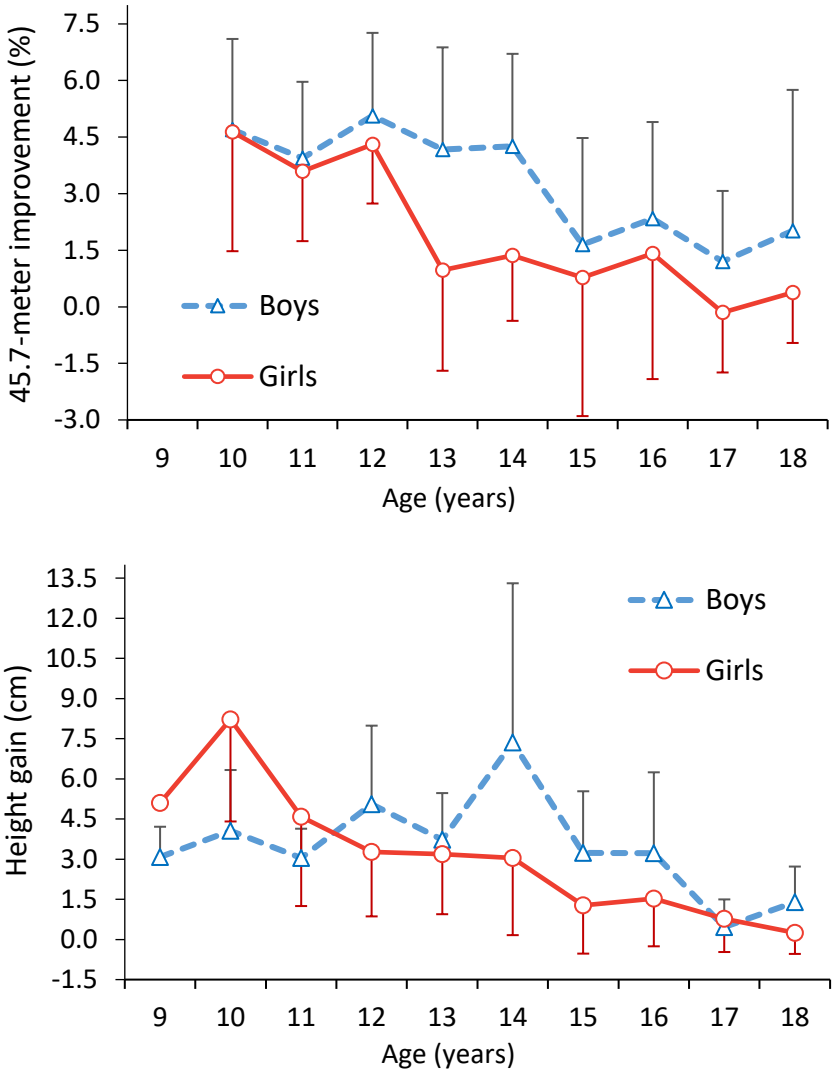


Figure 5.3. Changes in mean (± standard deviations) in annual improvements in 45.7-meter freestyle (45.7Fr) and annual gains in height in the US top 100 nine-year-old girls (n = 11) and boys (n = 12). Note: Relationship between relative improvements in 45.7Fr and relative gains in height; Girls, $r_{(7)} = 0.85$ ($p < 0.01$); Boys, $r_{(7)} = 0.78$ ($p = 0.013$).

Question 2b: Do the U.S. top 100 nine-year-old swimmers improve their performance times (45.7Fr) more than swimmers who did not rank within the top 100 at young ages across adolescent ages?

Hypothesis 2b: The magnitude of the improvement in 45.7Fr is smaller in the U.S. top 100 nine-year-old swimmers through adolescence when compared with the improvement rates of the total U.S. swimming population.

DISCUSSION 2b:

To test the hypothesis 2b, the following criteria were used for the comparison of the magnitude of the improvement in 45.7Fr with the US top 100 nine-year-old swimmers in this study: 1) all-time USAS median performances, 2) all-time USAS top 50th swims 3) all-time USAS top 100th swims, 4) all-time USAS top 500th swims, and 5) all-time USAS top 100th swims in 45.7Fr for each age between nine and 18 years old for the past 12 years (2004 to 2015).

The magnitude of the improvements in 45.7Fr across adolescent ages was smaller in the US top 100 nine-year-old swimmers ($p < 0.01$) as compared with all-time USAS median performance (the 1st criterion) up to age 14 years in girls and age 15 years in boys (Figures 4.3-5 and Table 4.3). However, in comparison to the designated rankings in USAS all-time swims, the magnitude of the improvements in the US top 100 nine-year-old swimmers was not significantly different in most of adolescent ages except for the 1000th swims (Figure 4.6 and Tables 4.5-6). This is presumably due to a reflection of performance levels for each criterion at young ages. The higher-level the performance at the beginning of studied duration (e.g., age nine years in this study), the less potential there is for improvement over time. Nevertheless, the US top nine-year-old swimmers demonstrated the lowest magnitude of improvements in 45.7Fr, on average, among designated ranking groups and during early- to mid-adolescent ages, especially in girls (Figure 4.6 and Table 4.5).

On the other hand, as shown earlier and as compared with previous data (Kojima et al., 2012; Pelayo et al., 1997), improvements in sprint freestyle performance in the top young swimmers in Study 1 (longitudinal- assessment) were analogous to data in the US top 100 swimmers (cross-sectional assessment; Kojima et al., 2012) and smaller than non-swimming population (Pelayo et al., 1997). It is reasonable to assume that early successful youth athletes are early or average maturing children as maturity-related advantage and disparity in youth sports performances have been well documented in literature (Malina et al., 2004). As compared with US growth reference data (Kuczmarski et al., 2002),

the US top nine-year-old swimmers in the present study whose height data are available across adolescent ages (11 girls and 12 boys) were, on average, a group of taller children and adolescents, especially at early adolescence (Figure 5.4). The predicted age at PHV from reported height data of the US top nine-year-old swimmers also suggest that, on average, these top young swimmers may have been relatively more advanced in maturity status and height growth, especially the top girl swimmers (right figures in Figure 5.4).

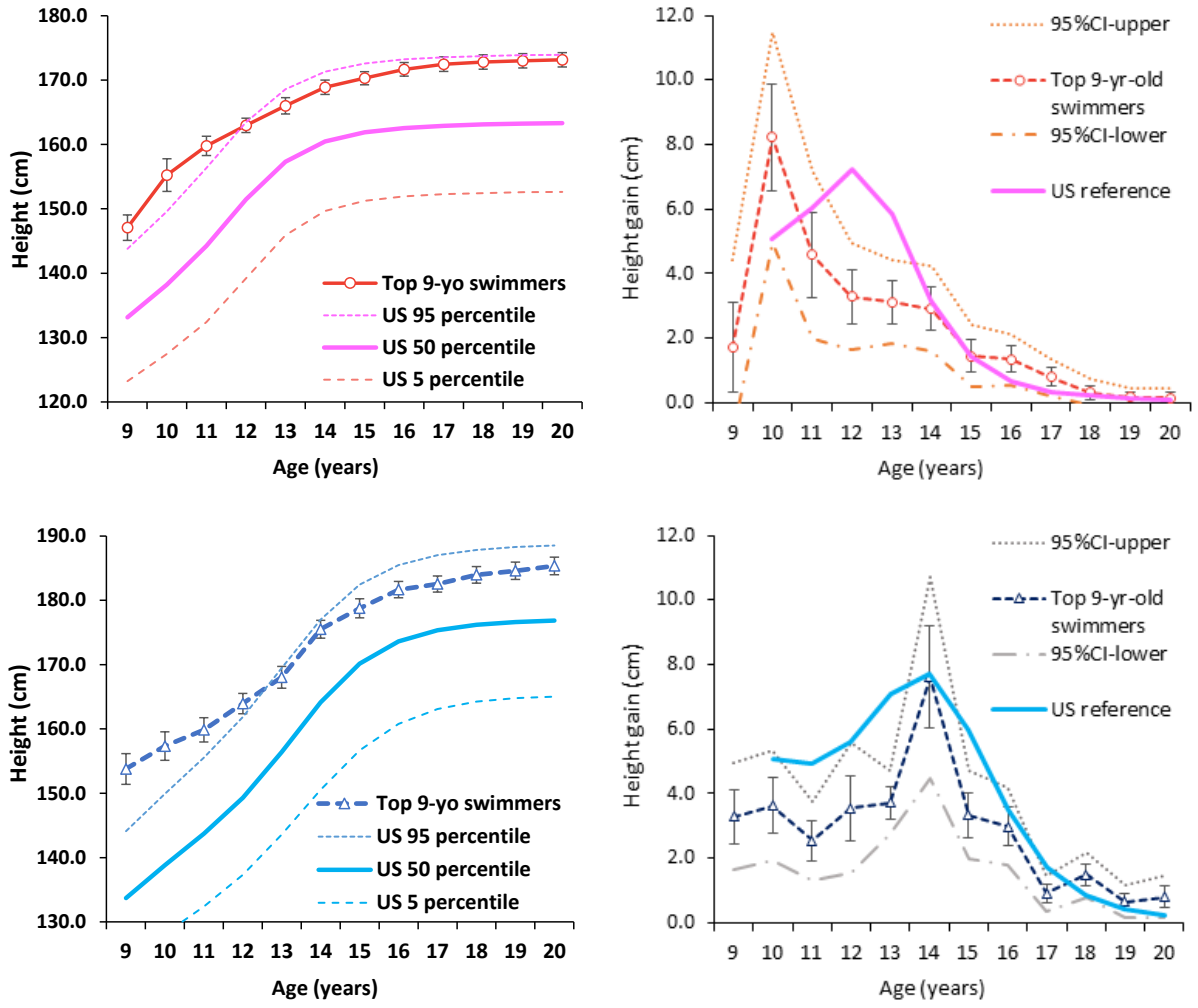


Figure 5.4. Means (±standard errors) of height and annual height gains in the US top 100 nine-year-old girls (n = 11) and boys (n = 12) and US growth reference data as a function of age

Left, girls; right, boys; top, height data; bottom, height gain; CI, confidential interval; yo, years old.

Up to this point, it is suggested that children with advanced maturity status potentially outperform same-aged, late maturing peers in youth sports due to maturity-related advantages in physical tasks and athletic performance, leading to early success in youth sports. It was also revealed in Study 1 that early successful preadolescent swimmers appeared to have smaller improvements in performance times than general populations across adolescence, although performance 'levels' are still higher in the early successful populations at any adolescent ages (Figures 4.3-6 and Table 4.5). One question concerning the magnitude of improvements in adolescent sports performance and being elusive in the literature due to the difficulty associated with measuring 'performance' in team-sports athletes such as soccer and ice hockey (le Gall et al., 2010; Malina et al., 2005) is how and when late successful youth athletes catch up to the early successful peers during adolescence.

To demonstrate and answer this question, the US top 100 swimmers in 45.7-meter freestyle at age nine years old (in 2004) and at age 18 years old (in 2013) were tracked retrospectively for their 10-year performance progression. The US top 100 18-year-old swimmers represent the late successful youth athletes. A generalized linear model (GLM, *as setting the US top 100 nine-year olds as reference category*) indicated an interaction (group × age) on performance (45.7Fr) and its absolute and relative improvements in 45.5Fr in both sexes as follows (Figure 5.5.):

45.7Fr time (sec)

[Girls] $\chi^2_{(1, N = 1682)} = 245.70$, $p < 0.001$, ($\beta = -0.453$, SE = 0.029, OR = 0.64, 95%CI = [0.60, 0.67]);

[Boys] $\chi^2_{(1, N = 1638)} = 172.97$, $p < 0.001$, ($\beta = -0.381$, SE = 0.029, OR = 0.68, 95%CI = [0.65, 0.72]).

In both sexes, 45.7Fr in the US top 100 18-year-old swimmers improved as compared with the US top 100 nine-year olds by 0.453 in girls and 0.381 in boys with an increase in age. OR suggests that the US top 100 18-year olds were 0.64 and 0.68 times in girls and boys, respectively, more likely to improve across 10 years of adolescent periods than the US top 100 nine-year olds. On average, the 10-year improvement in 45.7Fr was 5.0 sec (16.7%) and 10.6 sec (31.1%) in US top 100 nine-year-old and

18-year-old girls, respectively, and 7.9 sec (26.7%) and 12.3 sec (37.2%) in nine-year-old and 18-year-old boys, respectively. The US top 100 18-year olds became faster than the US top 100 9-year olds after age 13 years old in both sexes (Figure 5.5). Statistics generated from GLMs for the comparisons in absolute and relative improvements in 45.7Fr between early and late successful swimmers are also shown below:

Absolute improvements in 45.7Fr ($m \cdot sec^{-1}$)

[Girls] $\chi^2_{(1, N = 1437)} = 105.25$, $p < 0.001$, ($\beta = 0.197$, SE = 0.019, OR = 1.22, 95%CI = [1.17, 1.27]);

[Boys] $\chi^2_{(1, N = 1400)} = 80.56$, $p < 0.001$, ($\beta = 0.191$, SE = 0.021, OR = 1.21, 95%CI = [1.16, 1.26]).

Relative improvements in 45.7Fr (%)

[Girls] $\chi^2_{(1, N = 1437)} = 70.30$, $p < 0.001$, ($\beta = 0.498$, SE = 0.059, OR = 1.65, 95%CI = [1.46, 1.85]);

[Boys] $\chi^2_{(1, N = 1400)} = 58.39$, $p < 0.001$, ($\beta = 0.510$, SE = 0.067, OR = 1.67, 95%CI = [1.46, 1.90]).

These results also suggest that the US top 100 18-year-old swimmers improved more over the 10-year of adolescent ages as compared to the US top 100 nine-year-old swimmers. The magnitude of improvement between early and late successful swimmers was significantly different at ages up to age 14 year olds in both sexes ($p < 0.005$), while no statistical significance was revealed after ages 15 to 18 years old in both sexes (Figure 5.5).

In both sexes and groups of top youth swimmers, staggered slopes for the 45.7Fr improvements were evident over time (shown in mid and bottom figures in Figure 5.5). It was expected that there are 1) curvilinear declines in performance improvements as a function of age, and 2) peaks associated with the age at PHV (growth-spurt-related performance improvement at approximately age 12 and 14 years in girls and boys, respectively). First, age-related declines in improvements in 45.7Fr were revealed. However, several peaks in the improvements during adolescent ages, especially even ages (12, 14, 16, and 18 years) were also demonstrated in both sexes and groups of the top youth swimmers. Presumably, these peaks are associated with motivation and demotivation with the age-grouping systems or relative age effect (Delorme et al., 2011; Kojima et al., 2012).

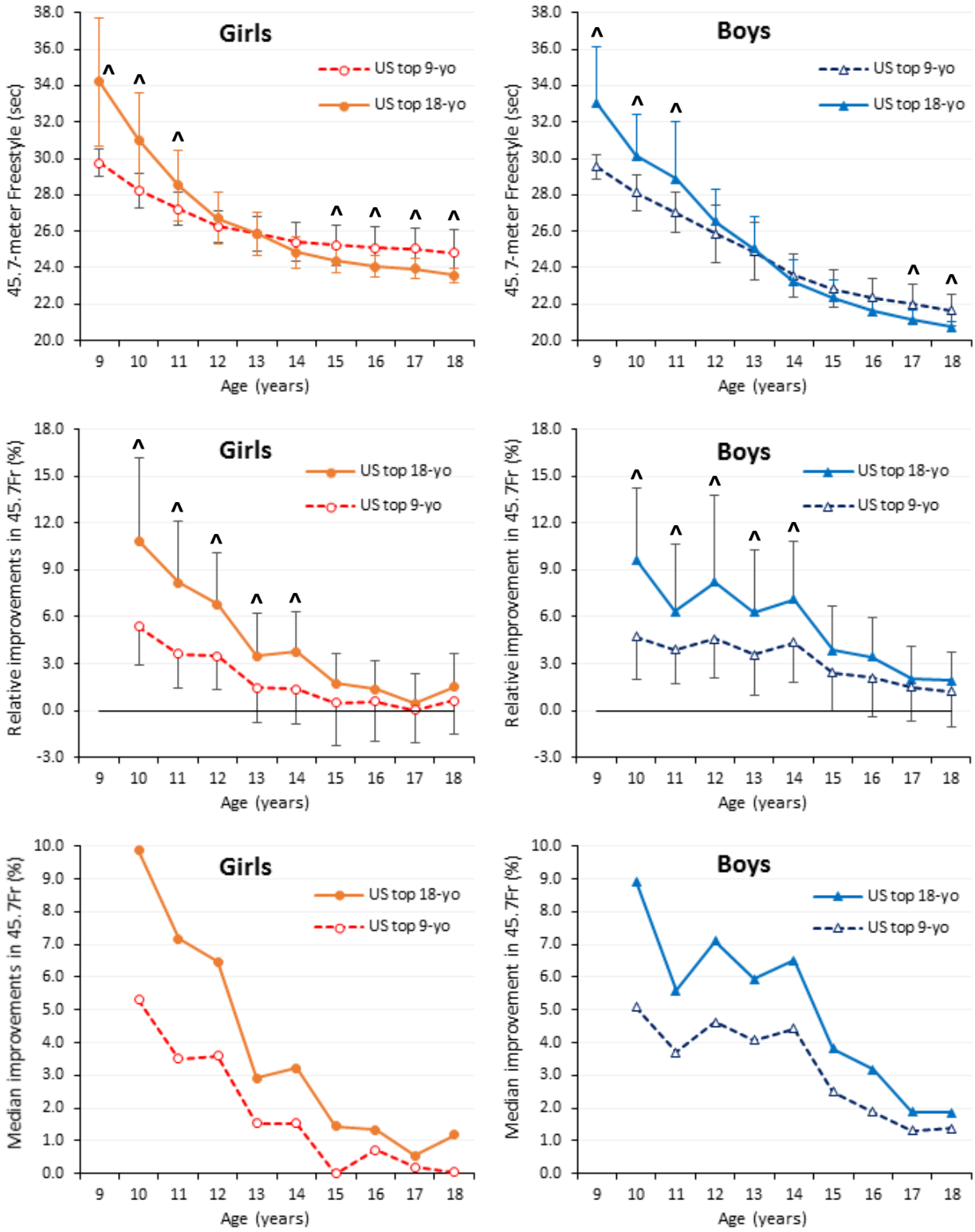


Figure 5.5. Progression in 45.7-meter freestyle (45.7Fr) time and improvements (in speed, m·sec^{-1}) of the swimmers ranked within the US top 100 at age nine and eighteen years old as a function of age.
^ Significant difference between groups ($p < 0.005$).

The age-grouping system (age 10 & under, 11-12, 13-14, and 15 & over or 15-16 and 17 & over) has been commonly used in USAS and around the world (Kojima et al., 2012; Kojima & Stager, 2010). It has been shown that younger swimmers within an age-group appear to be discouraged to compete and/or participate in the sport of swimming, and this is likely related to the maturity-based advantage in sport performance (disadvantage for the younger swimmers within an age-group). As well, because it is more difficult for an individual to compete and excel against the older-age counterparts within the age-group, dropout increases when aging up into an older group. Such a tendency has been shown as relative age effects in French youth basketball (Delorme et al., 2011) and USA Swimming data (Kojima, 2010). The effect is illustrated as performance and participation advantages in older athletes, over-representation of older athletes, and/or under-representation of younger athletes within an age-group (Delorme et al., 2010). It is speculative that the older athletes within an age-group are motivated to compete and practice/train harder due simply to more chances to be successful against younger-aged counterparts and within an age-group. These improvements in performance can also result in moving into a new, higher level training group within their swim teams. Additionally, it is reasonable to think that coaches may tend to pay more attention to older or more successful athletes as their positive performance outcomes yield benefits for the coach and team as a whole (Fraser-Thomas et al., 2008a; Fraser-Thomas et al., 2008b).

The staggered slope for the 45.7Fr improvements was also observed when tracking the 45.7Fr performance of the US top 100 18-year-old boy swimmers in 2012 (one-year older cohort from the subjects in the present study, Figure 5.6). In this cohort the maturity-related improvement at ages 11-15 years and the influence of age-grouping paradigms at even ages (relative age effect) were seen. As expected, the magnitude of improvement in US top 100 18-year olds (late successful swimmers) was greater than that in US top 100 nine-year-old boys (early successful swimmers) across adolescent ages. Furthermore, the relative age effect on performance improvements over adolescence were observed in

longer distance swimming events for both late and early successful US top girl swimmers (Figure 5.7). These observations may suggest that a possible link between relative age effects and the staggered slopes in improvements in 45.7Fr.

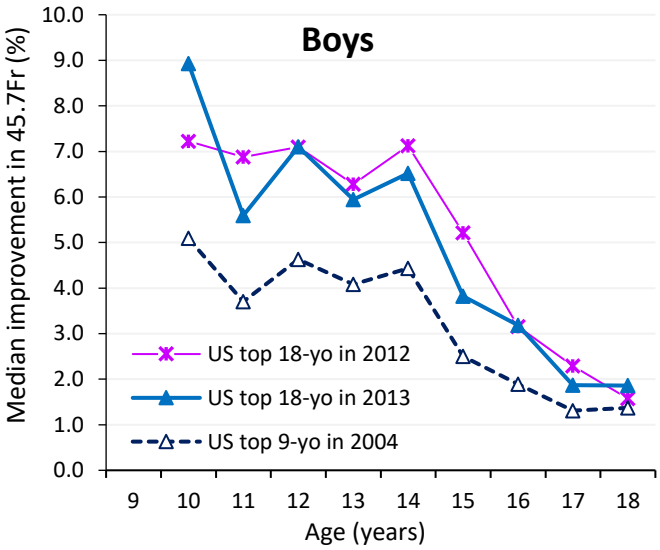


Figure 5.6. Median improvements (in speed, m·sec^{-1}) of the boy swimmers ranked within the US top 100 at age nine years old in 2004 and eighteen years old in 2012 and 2013 as a function of age.

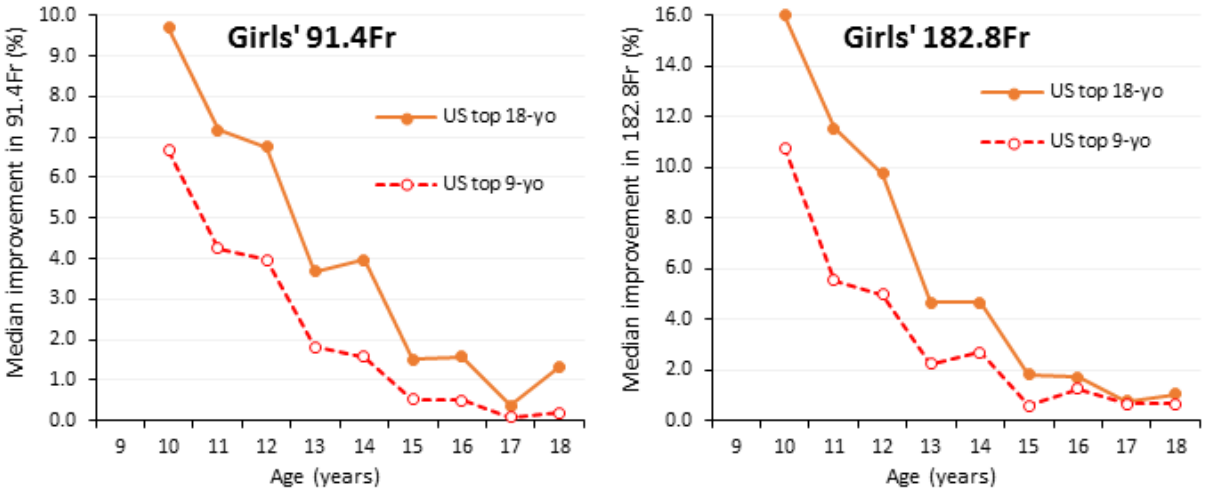


Figure 5.7. Median improvements (in speed, m·sec^{-1}) of the girl swimmers ranked within the US top 100 at age nine and eighteen years old in 91.4-meter and 182.8-meter freestyle as a function of age.

91.4Fr, 91.4-meter (100-yard) freestyle; 182.8Fr, 182.8-meter (200-yard) freestyle

Question 3: What is the percentage of the U.S. top 100 nine-year-old swimmers continuing in USA Swimming through adolescent ages and into adulthood?

Hypothesis 3: The dropout rate of the top 100 nine-year-old swimmers increases with age and is more than all swimmers in USA swimming.

DISCUSSION 3:

An effect of age on the odds that the top 100 nine-year-old swimmers dropout from competitive swimming in both sexes was found (Figure 4.7). However, when tracking yearly dropout rate of the top young swimmers by age, the tendency in dropout rate across adolescence was not consistent within sex or between sexes, possibly indicating sex-specific dropout rate.

One of the unique features of Study 1 was the systematic tracking of dropout rates along with the performance progression of successful preadolescent swimmers across ten years of adolescence. Although there are many participants at the novice levels in many sports, the social issue of discontinued participation (dropout) has been evident on the logistical side of youth sports. Previous studies have stated that approximately 35 percent of participants withdraw annually from organized youth sports programs, and up to 70 percent of participants drop out from youth sports by the age of 18 years (Brady, 2004; Gould, 1987; Seefeldt et al., 1996). Data concerning the number (percentage) of high school athletes (9th to 12th graders) playing in sports in collegiate sports are published (www.scholarshipstats.com). Based on the available data, the average among many sports are 7.6% (2.0% in archery to 29.7% in fencing) in boys and 7.9% (1.2% in badminton to 38.2% in fencing) in girls. In major sports such as basketball, baseball, football, soccer, and track & field, the percentages range somewhere between five and 11 percent in both sexes.

In competitive swimming, the average dropout rate of the total annual memberships (all ages included) from 2011 to 2014 is 27.8 ± 1.8% in girls and 28.1 ± 1.9% in boys (2011-2014 membership demographics: USA Swimming, 2011, 2012, 2013, and 2014). These four years were selected since

those are the most recent four-year Olympic cycle, and consider an influence of an Olympic cycle on fluctuation of USAS memberships (see also pages 29-33 in Chapter 2). When looking at the membership data by age, the average dropout rate of age nine to 18 categories in the past four years is 26.4 ± 3.2% (range 20.0-34.2) in girls and 25.0 ± 3.1% (range 17.5-30.1) in boys. The lowest dropout rates were commonly found from ages 13 to 14 (at age 14: about 3% below average), and lower dropout rates occur when swimmers enter the older echelon of an age-group. On the other hand, corresponding to present data (Figure 4.7), the highest dropout rate was observed always at age 18 years in both sexes. However, these reports are based on cross-sectional assessments which may differ from actual longitudinal assessment used in Study 1.

Consequently, the total numbers of nine-year-old swimmers in 2004 (7366 girls and 4434 boys) who represent the total population of the US top pre-adolescent swimmers in Study 1 as well as the total nine-year-old swimmers in 2005 (8097 girls and 5038 boys) were tracked and compared between early successful young swimmers and a general dropout trend in swimming. It is noted that these data are based on available numbers of competition performances (swims) for the selected year and population. Consequently, there may be some nine-year-olds who did not compete or have any competition swims, who are counted in the USAS membership reports but not shown here. With the available number of swims in nine-year olds in 2004 and 2005, the dropout rates during their adolescent ages are shown in Figure 5.8. The dropout rates of all nine-year-old swimmers in 2004 and 2005 are similar across adolescence. However, the data demonstrate greater annual dropout rates between ages ten and 18 years for all nine-year-old swimmers in 2004 (on average, 10% in both sexes) as compared with the top young swimmers (3.2%) in both sexes. For the total dropouts in all nine-year-old swimmers studied, 60.2% of all girls and 52.7% of all boys dropped out from USA swimming by the age 17 years (top 100 swimmers; 19% in girls and 21% in boys). At the age 18 years, the 10-year dropout rates were 92.5% and 91.0% in all nine-year-old girls and boys, respectively (top 100 swimmers, 29%).

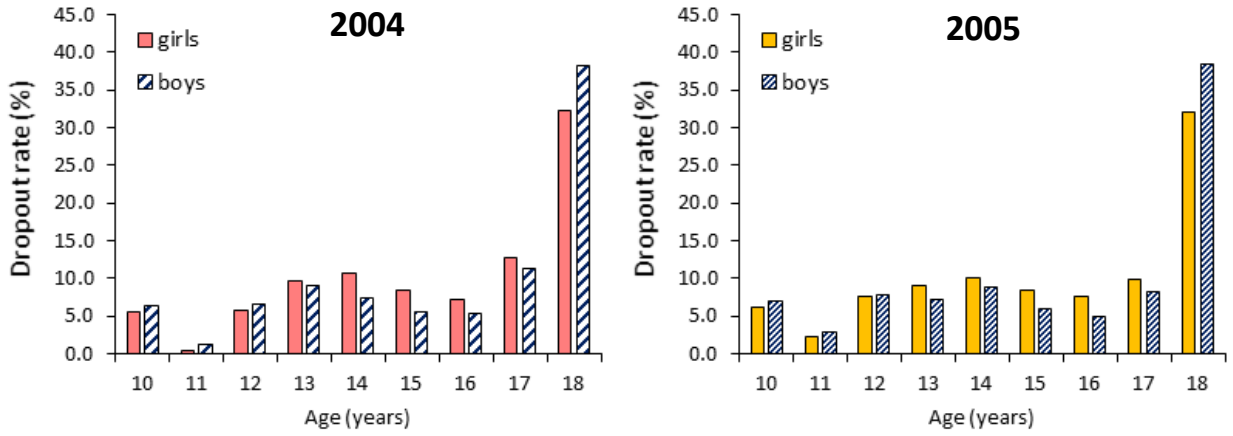


Figure 5.8. Yearly (year over year) dropout rates (%) of all nine-year-old swimmers in 2004 (left) and 2005 (right) during adolescence as a function of age.

The factors ascribed to dropouts in youth soccer (Figueiredo et al., 2009) and swimming (Salguero et al., 2003) have been reported to be training conditions, enjoyment in training, playing time in games, skill improvement, and recognition of effort. Moreover, changed interests, academic demand, socio-economic status, and the nature of competitive sports in that, as the level of skill and competition increases sports become more exclusive, contribute to youth sports dropout (Figueiredo et al., 2009; Salguero et al., 2003). Petlichkoff (1996), who examined reasons for youth sports dropouts, has also reported that adults' (coaches') excessive emphasis on winning discourages young athletes from competing, achieving, being successful, and continuing to choose the sport. Negative reinforcement and coaching manners and/or over-demand and -pressure from coaches and parents on children can be other reasons for dropout (Martens, 1996). Hardy (1986, p. 157) insists that

"there is nothing wrong with competition per se. What is wrong is the way in which children's competition is sometimes used by adults to achieve their own aims, regardless of whether these aims are coincident with those of the children."

The highest dropout rate observed at age 18 (i.e., from age 17 to 18) in the present study could be largely associated with the decision to pursue a collegiate swimming career (an increase in academic demand and the availability to get funding; www.scholarshipstats.com) in addition to the above

mentioned coaches' influence. Referring to USAS 2014 membership data, the total number of swimmers aged 19 & over (11,192; 4,977 women and 6,215 men; membership data for single age 19 is unavailable) is less than that of 18-year-old swimmers per se (12,897: Table 1). In addition, Lunn (2010) also reported a tendency of youth sports dropout at age 18 years, especially in girls, and the findings of Lunn (2010) are consistent to the present study 1.

In this cohort of US top young swimmers, 29 swimmers in each sex withdrew from competitive swimming (29% dropout) in 10 years, a much smaller percentage than the general trend (70%) in youth sports (Brady, 2004; Gould, 1987; Seefeldt et al., 1996). Once again, 71 girl swimmers and 68 boy swimmers who ranked in the top 100 in 45.7Fr at age nine years extended their competitive swimming careers to Division I, II, or III schools or junior colleges. Among the 29 dropouts by age 18, a few appeared to have changed their domain sport in a college level (rowing, water polo, golf, basketball, etc.). Therefore, these data indicate a very high participation rate in competitive swimming throughout adolescence into young adulthood as compared with the previously reported data in other sports (Brady, 2004; Gould, 1987; Seefeldt et al., 1996; www.scholarshipstats.com). Although the high participant retention within the early successful young swimmers may be due to their levels of success, a lower dropout rate in swimming may again be attributed to increased individual chances to participate in competition, as participation in competition does not require being a member of a team. As swimming is one of the sports with an early onset of participation (age seven and eight or late childhood; Figure 1.4), swimming can be a long-life sport. In addition, although a marked decrease in USA Swimming memberships from age 15 to age 18 in both sexes is observed in general, this was not the case for the early successful swimmers. The high continuation rate (low dropout rate) as compared with general population or other sports are apparent among early successful swimmers. Nevertheless, it needs to keep in mind that the dropout rate must have been higher at the lower success levels or greater rankings (not examined in the present study). In addition, it is evident within competitive

swimming that dropout rates vary year to year, and a higher dropout rate is observed commonly two to three years after an Olympic year (Figure 2.2). Thus, maintaining membership from post- to mid- and pre-Olympic years, especially for novice, non-elite level swimmers, is a logistical challenge of USAS as well as, presumably, many national youth sports federations and local sports club teams.

Lastly, using a Google search, three swimmers (two girls and one boy) out of the 200 swimmers tracked appeared to suffer from serious illness/injury (brain injury, thyroid cancer, or anorexia) and all passed away. Six swimmers played in other sports in college levels instead of swimming, either varsity or competitive club sports (Rowing, Soccer, golf, basketball or Water polo). Consequently, these are counted as dropouts in the current data set. Figure 5.9 display the proportion of the US top 100 nine-year-old swimmers who 1) ranked within the top 100, 2) ranked above top 100, and 3) had no swim performance data (presumably did not compete or completely dropped out from swimming). Figures 5.10-11 illustrate the proportion of designated US ranking status and dropout (no performance data) in the top 100 nine-year-old girl and boy swimmers across adolescent ages.

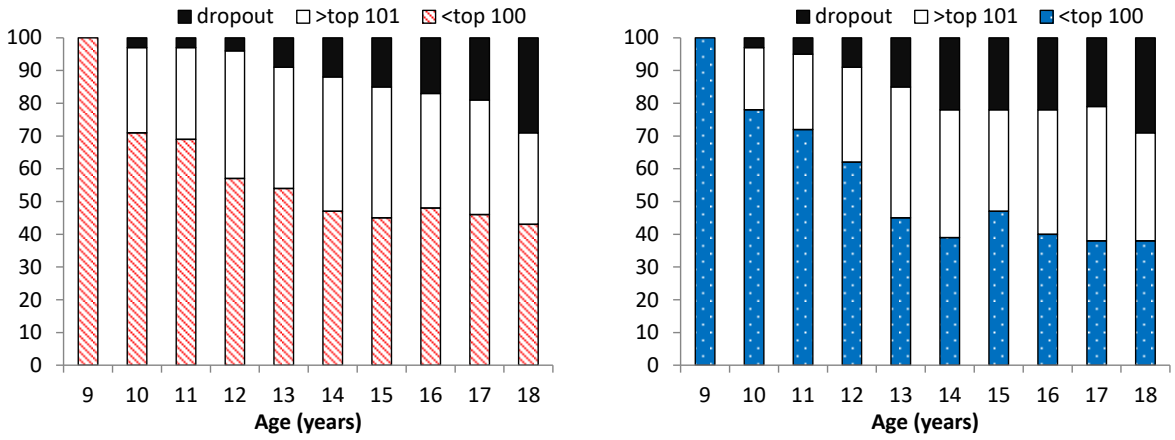


Figure 5.9. Proportion of the US top 100 nine-year-old girl (left) and boy (right) swimmers ranked (any event) within the top 100 (<top 100), ranked above the top 100 (>top 101), and did not compete in or dropped out from swimming (dropout).

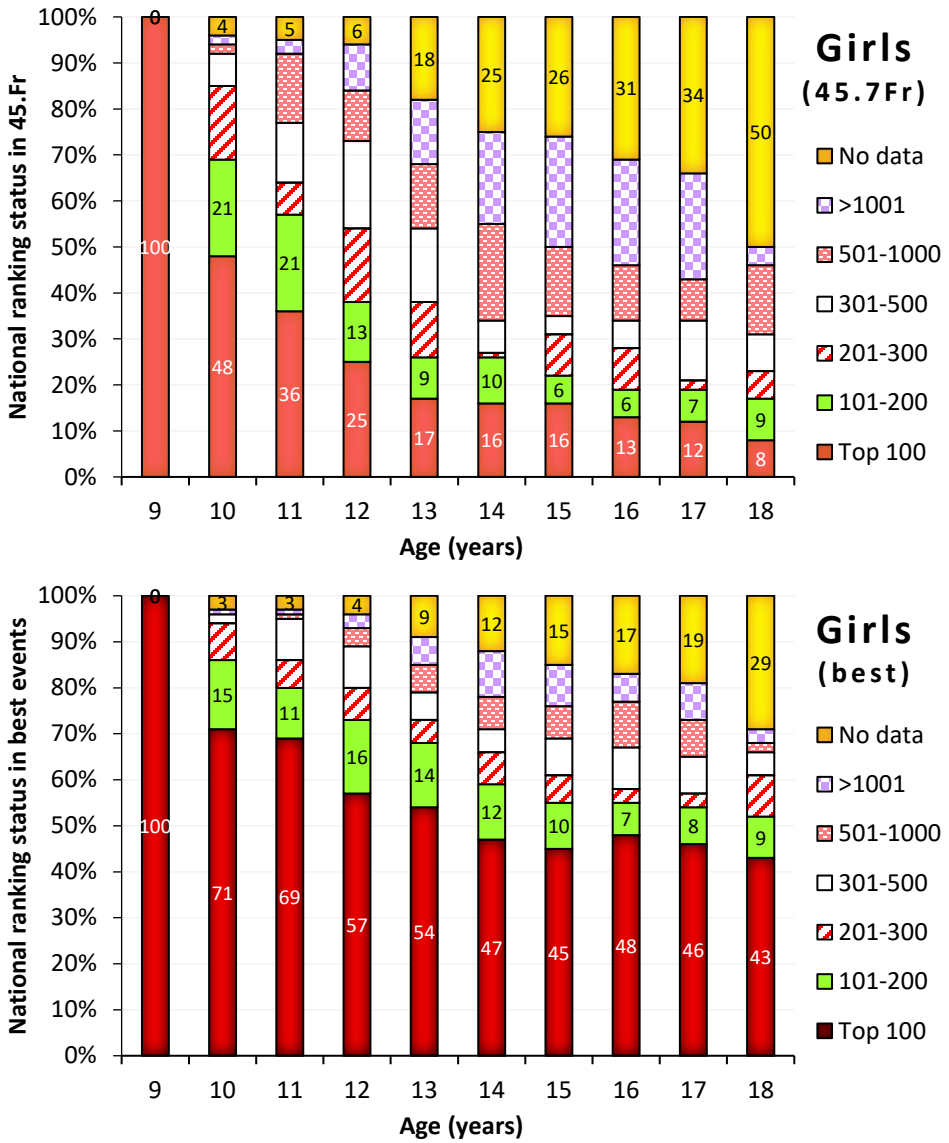


Figure 5.10. Proportion of the US top 100 nine-year-old girl swimmers ranked within the designated US rankings in 45.7Fr (top) and any event (bottom) or dropout as a function of age.

Note 1, The values in bar graphs denote the number (or %) of the top 100 nine-year-old swimmers ranking the categories in each age; Note 2, These figures correspond to Figure 4.1; Note 3, "No data" include dropouts and swimmers with no competition performance; and Note 4, see APPENDIX G1 for changes in rankings in the top 100 nine-year-old girl swimmers in all events across adolescence.

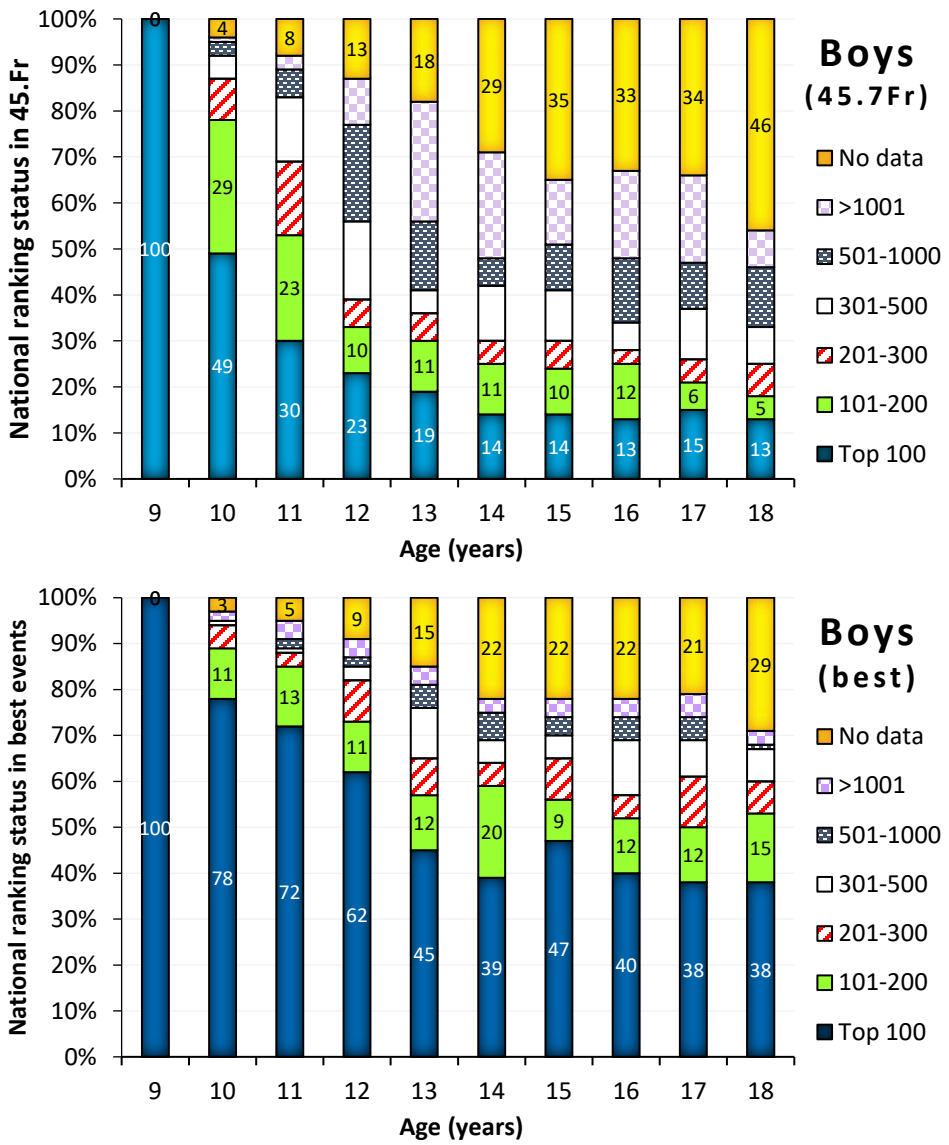


Figure 5.11. Proportion of the US top 100 nine-year-old boy swimmers ranked within the designated US rankings in 45.7Fr (top) and any event (bottom) or dropout as a function of age.

Note 1, The values in bar graphs denote the number (or %) of the top 100 nine-year-old swimmers ranking the categories in each age; Note 2, These figures correspond to Figure 4.1; Note 3, "No data" include dropouts and swimmers with no competition performance; and Note 4, see APPENDIX G2 for changes in rankings in the top 100 nine-year-old boy swimmers in all events across adolescence.

Based on these data, when counting the top 200 or top 300 swimmers as 'an outstanding performance status' (see Table 4.1), the majority continued to excel as outstanding youth athletes in competitive swimming (less than top 3% of the population at each age). This implies that the probability

of top young swimmers continuing to excel in their sport is high, and may suggest two considerations in terms of LTAD: 1) swimming is one of the very-early-start sports (Figure 1.4) and 2) the majority of or a greater number of dropouts potentially derives from the lower-ranked swimmers at each age, especially at younger ages. Concerning the 2nd consideration, when examining the annual changes in the USAS membership and median performance in 45.7Fr in boys aged 11 and 12 years for the past decade (Figure 5.12), an increase in memberships (e.g., post-Olympic year) has an adverse impact on the median performance for a given year (i.e., a slower median time) due mainly to increases in "new' members/ beginners. Conversely, a decrease in the annual membership results in a faster median performance for a given year (e.g., mid-Olympic years). A similar tendency is observed for the link between dropout rate and performance improvements in the top pre and late adolescent swimmers at late adolescence. In both 45.7Fr and best-event rankings for both sexes, if one is ranked above 500 or 1000 at age 17 years, the odds of dropout at age 18 or before a college career seems to be higher as compared with better/higher ranked 17-year-old swimmers (Figures 5.10-11). Accordingly, the increased dropouts by "plateaued" swimmers seem to reflect an acceleration in improvements or attenuated decline in improvements at age 18 years (Figures 5.3 and 5.5-7).

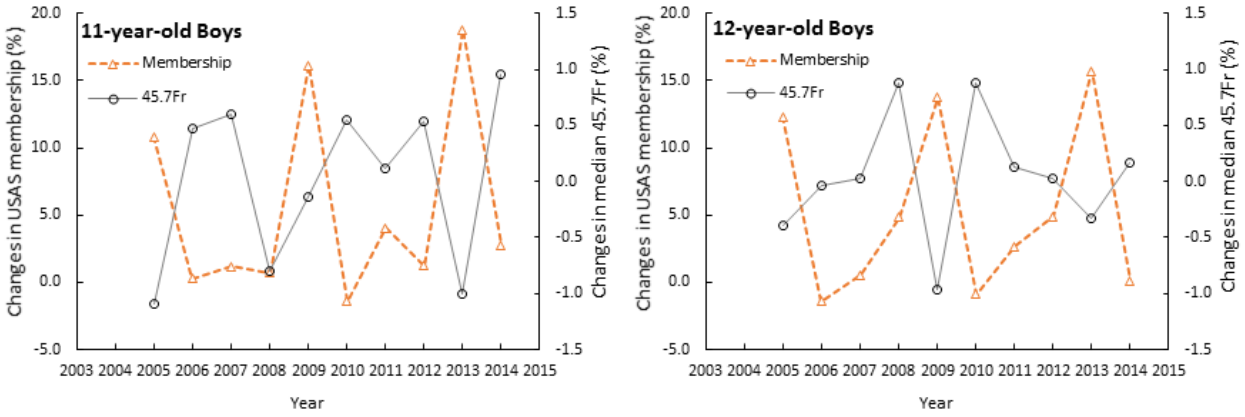


Figure 5.12. Relative changes in USAS annual memberships and median performance in 45.7-meter freestyle (45.7Fr) in 11- and 12-year-old boy swimmers for the past 12 years.
USAS, USA Swimming

***Question 4a*:** Is there a significant sex-related difference in performance progression (45.7Fr time) in the U.S. top 100 nine-year-old swimmers throughout adolescence and into adulthood?

***Hypothesis 4a*:** The improvements in swim times in 45.7Fr are greater in boys.

DISCUSSION 4:

A linear mixed-effect model revealed a sex × age interaction, and significant sex-related differences in 45.7Fr were found after the age of 12 years (Table 4.8). A significant sex × age interaction was also found for annual improvements (Table 4.3 and Figures 4.9-10), and sex-related differences in the annual improvements were detected ages 12 to 17 years.

Sports performance during adolescence has been well documented to be influenced by growth, development, and maturity status within a sex and between sexes (pages 41-54 in Chapter 2). Once again, Pelayo et al. (1997) and Kojima et al. (2012) have reported that no sex-differences or superiority in girls in in swim velocity at early adolescence (during the girls' growth spurt, age nine to 12 years) was, in part, due to more precocious status in girls relative to boys. After the age 12 years when boys' growth spurt occurs, the swim velocity of boys became consistently and significantly faster, and anthropometric values in boys were higher/greater than the girls. The present study 1 and the previous studies (Kojima et al., 2012; Pelayo et al., 1997) were consistent in terms of when sex-related differences in 45.7Fr are amplified (after the age 12 years).

Additionally, Vealey & Chase (2015) comment on the influence of "sex stereotyping" on the sex-related differences in sports as well as physical tasks. The authors insist that sex stereotyping is often formed in human society related to sports and physical activity and contributes to the sex-related differences observed in sports. Based on the authors, sex stereotyping is that (p. 283):

> "a process in which children's biological sex determines the activities they engage in (and not engage in), as well as the manner in which they are treated in these activities. Sports are generally considered a masculine domain, and this stereotype results in boys' perceiving greater ability and attaching greater importance to sport than girls."

Interestingly, the authors also mention that there is a tendency for girls to be taught and to engage less in fundamental motor skills during pre-adolescent periods. They state that this may contribute to the fact that boys are generally superior to girls on many fundamental motor skills, especially object control (throwing, catching, and kicking) and agility skills.

***Question 4b*:** Is there a significant sex-related difference in the retention rates in participation (dropout) and the top 100 status in the U.S. top 100 nine-year-old swimmers throughout adolescence and into adulthood?

***Hypothesis 4b*:** The participation retention rate of the top 100 nine-year-old swimmers and the probability of maintaining the top 100 status are greater in boys, while the tendency of retention rate across adolescent ages will differ between sexes.

DISCUSSION 4:

A mixed-effects logistic regression indicated no effect of sex on or sex × age interaction for the odds that the US top 100 nine-year-old swimmers drop out from the sport of competitive swimming and rank within the US top 100 across adolescence. Therefore, the present results of the studied cohort rejected the hypothesis that participation retention rate of the top 100 nine-year-old swimmers and the probability of maintaining the top 100 status are greater in boys.

Studies have examined reasons behind sex-related pattern and difference in dropout rate in youth sports frequently to date (Figueiredo et al., 2009; Fraser-Thomas et al., 2008a; Fraser-Thomas et al., 2008b; Petlichkoff, 1996; Salguero et al., 2003). However, there has been a lack of data for longitudinal, empirical data regarding sex-related patterns and difference (e.g., timing) in youth sports dropouts for early successful youth athletes. For example, in competitive swimming, annual dropout rates have been often reported, and reasons for the dropouts have been investigated (Fraser-Thomas et

al., 2008a; Fraser-Thomas et al., 2008b; Salguero et al., 2003), while the data were limited to either sex, general (total) population, or identifying reasons.

First, reasons for youth sports dropout are multifactorial. They are classified into two factors: physical factors (training patterns and level of maturation), and psychosocial factors (parents, coaches, peers, and siblings) (Fraser-Thomas et al., 2008a; Fraser-Thomas et al., 2008b; Salguero et al., 2003). As a determinant for sex-related difference in youth sports dropout, scientists and practitioners point out the sex-stereotype (Fredricks & Eccles, 2005) and maturity status between sexes (Sherar et al., 2007). Vincent & Glamser (2006) examined youth soccer players and contended social pressure for girls to conform to a socially constructed sex role: e.g., making early maturing girls less motivated to succeed in competitive sports as they perceive less value in athletic achievements by women as compared with men. Fredricks & Eccles (2005) analyzed questionnaires for parents of elementally-school-aged children and reported that parents may not encourage girls and women to be physically active and offer fewer athletic opportunities. Considering these views, it was hypothesized that early maturity status in girls may result in earlier plateauing performance improvement and more dropouts at younger ages in girls as compared with boys. Moreover, the top girl swimmers were thought not to be able to maintain their successful athletic status due to motivational issues in response to an early plateau in performance improvement.

However, the present data showed no statistical difference in dropout rate between sexes across adolescence, although the patterns across adolescence appears to be different between sexes. Work of Delorme et al. (2011) with French basketball youths may provide an explanation for the lack of a sex-difference in dropout. The authors suggest that the relative age effect on dropout is competition-level dependent. This is likely to occur at intermediate levels or below as such youth athletes are more susceptible to frustration due to their limited ability to compete with older counterparts within an age-group. Also, relative age effect can be more important for boys due to a higher variance in the degree of

maturity in boys (Baxter-Jones, 1995). Therefore, similarly, early successful youth athletes in the sport of competitive swimming may not have had as many negative experiences with their performance improvements in comparison to late developing youth athletes in other competitive sports. Nevertheless, there were 29 dropouts in each sex among the US top 100 preadolescent girl and boy swimmers. Some responses of the dropped-out top youth swimmers regarding the reasons for dropout (data compiled for the survey in RQ5) are available and introduced below:

Dropout A:

"I plateaued as most swimmers do at a point and just became very disillusioned with the sport. I wasn't happy and I wasn't getting any better, and I started to feel as though I had some to the end with my swimming career. It was hard to swallow at first but it was right. I also started playing water polo and really fell in love with that."

Dropout B:

"Most of my friends had quit swimming to play other sports, my mother was sick for a prolonged period of time, and I got bored with winning all the time. I wanted something challenging."

Dropout C:

"I feel like I was burnt out from the sport. I had started swimming when I was 5 years old and I really enjoyed other sports (football, basketball, and baseball). Those three sports, I still would say, are my three favorite sports. I also dropped out of competitive swimming because my friends in high school didn't swim, and I would be giving up a lot of social time with them because I had swim meets and practices."

Dropout D:

"I burnt out and wanted to focus on other sports for the time being and wanted a better attitude about the sport as I thought break was best way to accomplish that."

These anecdotal responses provide youth sports coaches with beneficial insights into performance and participation retention of their athletes. This especially applies to individuals who achieved national top rankings at an early age and/or for several years of adolescence and burnt out

shortly after but continued to participate in their sports despite their disinterest. It is also important to emphasize the paths of these young athletes: how they take in their careers and internalize each step. That being said, coaches need not only to improve their athletes' performance, but also help them pursue better challenges and motivation for long-term goals in the sports: i.e., how to win or achieve goals rather than what to win or achieve.

***Question 5*:** Are there identifiable factors contributing to the levels of future athletic success in the U.S. top 100 nine-year-old swimmers?

***Hypothesis 5*:** There will be identifiable factors contributing to future (late-adolescent- and college-level) athletic success and achievements, *such as late specialization and intensification in competitive swimming and multi-sports participation.* The trend in youth sports participation and training biography in the top 100 nine-year-old swimmers would be different from those in later-successful, senior elites previously reported.

DISCUSSION 5:

A mixed-effects logistic regression revealed seven significant factors contributing to the odds that the early successful swimmers ranked within the US top 100 across adolescence ages: 1) age, 2) weekly dryland exercise hours during ages five to eight, 3) sex, 4) multi-sport experience, 5) age at the enrollment in competitive swimming and practice, 6) age at the peak improvement in swim performance, and 7) weekly swim practice hours during ages five to eight (Table 4.13). In addition, a sex × multi-sport interaction (a categorical variable) was created to constitute both 'sex' and 'multi-sport experience' and revealed as a significant factor (Table 4.14). These results support the hypothesis that there are identifiable factors contributing to future athletic success and achievements in the top preadolescent, early successful swimmers. The followings discuss the details of contributing factors

(youth sports participation and training biography) for future athletic success and its potential differences between early- and late-successful athletes.

Most of the factors selected for testing the hypothesis 5, including the significant seven factors and a dummy variable for sex × multi-sport interaction, were significantly correlated with the dependent variable (US top 100 status at each age) ($p < 0.05$; Table 4.12 and APPENDIX E). Among the seven factors listed above, negative correlations with the dependent variable was found for *age* ($r = -0.13$, $p < 0.05$), *weekly dryland exercise hours during ages five to eight* ($r = -0.17$, $p < 0.01$), *sex* ($r = -0.23$, $p < 0.01$; dummy-coded girls as 0 and boys as 1), and *multi-sport experience* ($r = -0.17$, $p < 0.01$; 'without' as 0 and 'with' as 1). Positive relationship with the dependent variable was found for *age at start swimming* ($r = 0.14$, $p < 0.01$), while *age at the peak improvement in swim performance* ($r = -0.08$, $p = 0.11$) and *weekly swim practice hours during ages five to eight* ($r = 0.68$) were not.

One of issues with a multi-level regression analysis that must be addressed is collinearity. For example, in the present data among the seven factors, weekly hours of preadolescent dryland and swim practice (when to have begun and the amount of practice time) would be expected to be associated with the age when swimmers enrolled in competitive swimming. It was typically the case that the earlier age the swimmer enrolled, the more hours of practice may have done by the age of nine years. Table 5.2 shows the correlation coefficients among the seven predictors generated from the mixed-effects logistic regression analyses in this study (also see APPENDIX E). There were significant relationships among many of the predictors, and as mentioned above, age at starting swimming was significantly correlated with dryland and swim practice hours before the age of nine: $r = -0.50$ and -0.56, respectively ($p < 0.01$). In addition, dryland practice hours and swim practice hours were also highly associated ($r = 0.923$, $p < 0.01$). Consequently, the odds ratio (Tables 4.13-14) for the factors (age at starting swimming and dryland practice hours) were very high.

Table 5.2. Correlation matrix for predictors derived from the mixed-effects logistic regression analyses.

		Top 100 status binary	Age at peak imp.	Age at start swimming	Multi-sport	Sex	ST hr_wk _age5-8	Age	Pre-ad DLT wk hours
Age at peak imp.	R	-0.079	1						
	Sig.	0.12							
Age at start swimming	R	.139**	-0.022	1					
	Sig.	0.01	0.66						
Multi-sport	R	-.172**	-0.057	-.112*	1				
	Sig.	0.00	0.25	0.03					
Sex	R	-.227**	.249**	.165**	.206**	1			
	Sig.	0.00	0.00	0.00	0.00				
ST hr_wk_ age5-8	R	-.181**	.243**	**-.556****	0.027	-0.045	1		
	Sig.	0.00	0.00	**0.00**	0.58	0.37			
Age	R	-.126*	0.000	0.000	-.387**	0.000	0.000	1	
	Sig.	0.01	1.00	1.00	0.00	1.00	1.00		
Pre-ad DLT wk hours	R	-.165**	.279**	**-.502****	0.042	0.042	**.923****	0.000	1
	Sig.	0.00	0.00	**0.00**	0.40	0.40	**0.00**	1.00	

imp., improvement; ST, swim training; hr_wk, hours per week; Pre-ad DLT, preadolescent dryland training; R, correlation coefficient; Sig., significance.
** and *, Correlation is significant at the 0.01 and 0.05 level, respectively (2-tailed).

Note 1: red-colored, bold values indicate "highly correlated predictors" which were expected to cause multicollinearity issues.
Note 2: Categorical variables are age at peak imp, age at start swimming, multi-sport, sex, and ST hr_wk_age5-8, while continuous variables are age and pre-ad DLT wk hours.
Note 3: See Table 4.12 for more detailed description of each predictor.

Therefore, a new model was produced with five factors (Table 5.3). The generated factors are 1) age (Wald $\chi^2 = 11.7$, $p < 0.01$), 2) sex (Wald $\chi^2 = 11.0$, $p < 0.01$), 3) multi-sport (Wald $\chi^2 = 7.4$, $p < 0.01$), 4) age at starting swimming (Wald $\chi^2 = 4.5$, $p > 0.05$), and 5) age at starting two or more practices a day (Wald $\chi^2 = 12.8$, $p < 0.01$). All factors were revealed as significant ($p < 0.01$) with the exception of age at starting swimming ($p = 0.22$, Table 5.3). A new predictor (age at starting two or more practices a day) was included into the model, which was not included in the original models (Table 4.13-14). Age at two or more practices was included in the analysis as a factor indicating timing of intensification of training, and was also accounted as a positively contributing factor (APPENDIX F).

Table 5.3. Significant predictors detected from a mixed-effects logistic regression analysis after considering multicollinearity for the original model (Table 4.13).

Effects	Wald χ^2	p value	β estimate	Std. E.	Odds Ratio	95% CI for OR	
[Continuous variables]							
Age	11.71	0.001	-0.250	0.073 ^^	0.78	0.68	0.90
[Categorical variables]							
Sex	11.00	0.001					
Boys			-1.886	0.569 ^^	0.15	0.05	0.46
Girls			0		1		
Multi_sport	7.41	0.006					
with			-1.084	0.398 ^^	0.34	0.16	0.74
without			0		1		
Age at start swimming	4.47	0.215					
Age 7&O			1.610	0.806 ^	5.01	1.03	24.29
Age 6			1.370	0.751 *	3.94	0.90	17.16
Age 5			1.090	0.728	2.97	0.71	12.39
Age 4			0		1		
Age at >2 practice a day	12.79	0.002					
Age 15&O			1.345	0.485 ^^	3.84	1.48	9.93
Age 13-14			1.823	0.592 ^^	6.19	1.94	19.77
Age 12&U			0		1		

χ^2, qui-squared; β estimate, regression slope; Std. E., standard error; 95% CI, 95% Wald confidence interval; OR, odds ratio; >2, two or more.
Quasi-likelihood under independence model criterion (QIC) = 352.13.
^^ and ^ statistical significance from reference category ($p < 0.01$ and < 0.05, respectively); * p value = 0.068.

Note 1: Refer to Table 4.12 for more detailed descriptions of predictors.
Note 2: The reference categories for categorical variables was set at the bottom category listed for respective variables, and their β estimates were set to zero because these effects are redundant. Accordingly, significance (^^, ^, or *) indicates as compared with the reference category for each variable.

Several factors (youth training biography and milestones) influential to athletic success from youth to senior levels have been previously reported in literature (Bridge & Toms, 2013; Gullich & Emrich, 2014; Moesch et al., 2011; Vaeyens et al., 2009). Two primary factors often discussed among these studies appear to be multi-sport involvement and timing of specialization and intensification in a sport. The scientific rationale behind the two factors are identified based on existing senior elite (late successful) athletes, and thus previous studies have theoretically endorsed how to become a successful

senior-level athlete from an average youth athlete (Bridge & Toms, 2013; Gullich & Emrich, 2014; Moesch et al., 2011). On the other hand, the present study 1 centered on the top preadolescent athletes and their sustainability in sports with specific reference to competitive swimming, and was conducted to identify how to become a successful senior-level athlete from a successful youth athlete. This approach for the top preadolescent top swimmers and their sustainability prompted some different perspectives. For example, multi-sport involvement was originally hypothesized to be an identifiable factor contributing to the levels of future athletic success of the top-level preadolescent swimmers. However, assumptions of 1) the precocious status and advanced-maturation-related superiority in athletic performance in the top nine-year-old swimmers and/or 2) the early specialization in swimming to fulfill potential made difficult to make a statement on whether or not top preadolescent athletes had multi-sports involvement. Moreover, it was presumed that the timing of specialization in competitive swimming and intensification of training in the top preadolescent swimmers occurred at relatively early ages, and consequently limited the difference among the swimmers.

Did the US top 100 preadolescent swimmers participate in multi sports?

Multi-sport involvement was revealed as a significant predictor for the odds that the early successful swimmers ranked within the US top 100 across adolescence ages, and granted as a negative predictor. The results show that 34 out of the 40 survey responders (85%, 14 girl and 20 boy swimmers) enrolled in more than the sport of competitive swimming (on average, 2.3 ± 1.2 sports) during adolescence (Table 4.10). Although no effect of sex or age-related differences in multi-sport participation across adolescent ages, more boys tended to have participated in multiple sports than the girls at adolescent ages in this cohort (Figure 4.18). The reasons of multi-sport involvement being a negative factor for sustaining successful athletic status (US top 100) in this study could be pluralistic. It might be related the nature of the sustainability of successful athletic status. This should become more

difficult with increases in age as competition become more competitive and selective. However, based on the survey responders in the present study 1, some enrolled in non-swimming sports to take a break from competitive swimming where they were feeling demotivation and/or less improvement. Others enrolled in other sports to excel in those sports as they did in swimming at young ages. Therefore, one of the main reasons for preadolescent swimmers involvement in other sports was, in part, to diminish disinterest (i.e., burnout) in swimming based on the present data/ survey. This tendency was especially critical in boys as per their comments and data suggested (Table 4.14 and APPENDIX F). However, alternatively for those who had negative experience in swimming at mid-adolescence (related largely to their performance improvements) and switched sports, swimming might have been one of the athlete's multi-sports but not their domain sport. When previous studies examined senior elite athletes, the domain sport had been predetermined (Bridge & Toms, 2013; Gullich & Emrich, 2014; Moesch et al., 2011). However, this may not have been the case for the young individuals in the present study. With available data, several of the US top 100 nine-year-old swimmers switched their sports and excelled in the new sport at college levels (e.g., Rowing, Soccer, golf, basketball or Water polo). Thus, depending on the domain sport, the influence or outcome of multi-sports experience as a determinant of future athletic success must be altered.

Nevertheless, among the four previous studies (Bridge & Toms, 2013; Gullich & Emrich, 2014; Moesch et al., 2011; Vaeyens et al., 2009), Moesch et al. (2011) reported no difference in the involvement in other sports (hours of training or numbers of sports) in the context of Danish elite and near-elite athletes. In addition, Bridge & Toms (2013) and Gullich & Emrich (2014) have shown the positive influences of multi-sport involvement in only team sports athletes, but not in individual sports athletes. Therefore, it is also noted that careful consideration is required as to the true benefit of multi-sport involvement (as positive or negative) may be dependent on studied population, competition-level, types of sports, and/or any other methodological procedures.

When (what age) did the US top 100 preadolescent swimmers start specialization and intensification?

Gullich & Emrich (2014) have reported timing of specialization and intensification of training and competition in the context of German Olympic athletes (see also Chapter 2, pages 79-93). The data in CGS sports whose performances are measured in centimeters, grams, or seconds show that above and below national-level CGS sports athletes at age 14 years had complete specialization of their domain sport at ages 11.1 ± 3.8 and 13.9 ± 5.2 years, respectively, which revealed a significant difference ($p < 0.01$, Cohen's $d = -0.62$). These results suggest that an early specialization may promote early success in youth sports (Gullich & Emrich, 2014). On the other hand, at the senior-level CGS sports, world-class and national-class athletes had complete specialization of their domain sport at ages 14.3 ± 6.1 and 13.0 ± 4.8 years with no significant difference in the age ($p > 0.05$, $d = 0.23$). According to the data of Moesch et al. (2011) and Danish CGS sports athletes, the developmental stage (transition into a more intense training and competition: Wylleman & Lavalee, 2004) occurred at age 15.11 ($CI_{(lower, upper)} = 14.38, 15.84$) for elite-level athletes and at age 12.87 ($CI_{(lower, upper)} = 12.03, 13.71$) for near-elite-level athletes with a significant difference ($p < 0.05$, $d = 0.51$).

In the present study, timing of specialization and intensification of training and competition was expressed by three items (Table 4.10). First, age at starting two or more practices a day (intensification of training) was 13.3 and 14.0 years in girls and boys, respectively. Second, the age at which swimming became the primary sport (specialization of sport) was 9.7 and 10.7 years in girls and boys, respectively. Third, age at which swimming event specialization occurred (specialization of event or in sport) was 12.9 and 14.2 years in girls and boys, respectively. There was no sex-related difference in these ages. Age at which swimming became the main sport was used to assess when the US top nine-year-old swimmers considered the sport of swimming as their domain sport, while the age at which specialization of swimming events was employed for their technical specialization. Gullich & Emrich (2014) do not clearly explain how the age at "complete specialization in domain sport" was comprehend by subjects, but it

would correspond to the age at swimming event specialization (age 13.6 ± 2.9 years for combined sex data) in the present study. As the US top nine-year-old swimmers have such an early successful athletic career, the age at swimming as the main sport indicated a very early age (on average, age 10.2 ± 3.2 years). Therefore, the age of specialization for the top preadolescent swimmers indicated a comparable trend to data of Bridge & Toms (2013), Gullich & Emrich (2014), and Moesch et al. (2011). However, timing of specialization was not, in fact, associated with or revealed as a significant predictor for the odds of ranking within the US top 100 status.

On the other hand, timing of intensification of training (age at starting two or more practices a day) was associated with the dependent variable ($r = 0.20$, $p < 0.01$). In addition, though this was not included into the original best fit models (Tables 4.13-14), when including only age and sex, the factor (timing of intensification) was revealed as a positive predictor for the odd of ranking the US top 100 during adolescence: $\chi^2 = 5.39$, $p < 0.05$, $B = 0.249$, $OR = 1.28$ (95% $CI_{(lower, upper)} = 1.04, 1.58$) (APPENDIX F). The top preadolescent swimmers who had two or more practices at middle school ages (13-14 years) and high school ages (15 and older) were 7.1 and 4.2 times, respectively, more likely to be ranked in the top 100 during adolescence than those who had two or more practices by the age of 12. Moreover, it was revealed as a significant predictor and included into a model created after taking collinearity issues into account (Table 5.3). In this new model, starting two or more practices at ages 13-14 years and 15 and older was indicated 6.2 and 3.8 times, respectively, *more* likely to retain the US top 100 status during adolescence than those who had two or more practices by the age of 12.

These results suggest that the multi-sport participation and some variables of training biography also enable researchers to identify and predict future successful athletic achievement as proposed in previous literature (e.g., Gullich & Emrich, 2014). However, these predictors appear to contribute to progression of athletic success in early successful youth athletes differently than what has been documented in relation to senior elite (late-successful) athletes. Nonetheless, the study outcomes

(identifiable factors) depend on the population (competition-level, maturity status, or, race) and the type of sports.

Were the US top 100 nine-year-old swimmers early maturing children?

It is important to discuss maturity status of the US top nine-year-old swimmers when considering the influence of maturity-related advantage on sports performance with the early successful youth athletes in the present study. As shown earlier in Chapter 4 (pages 152-154, Tables 4.10-11), most survey responders (N = 40; 19 girls and 21 boys) were not early maturing children (17.5%), while average and late maturation status accounted for 32.5% and 50.0%, respectively. Maturity status was determined based on reported ages at menarche and/or peak gain in height in the 40 responders and classifications referring to average ages for a large sample of US children (Malina et al., 2016). There were also three variables of maturity status of the swimmers to predict the retention of the US top 100 status and used for the best fit (Table 4.12): reported age at peak improvement in swim performance, reported age at peak height gain, and maturity status assessed. Maturity status (early, average, or late) was associated with the dependent variable (top 100 status) ($r = 0.17$, $p < 0.01$), while other two variables were not (APPENDIX F). However, none of the three variables were detected as significant predictors for the US top 100 retention status (APPENDIX F). The results do not support the supposition that early successful swimmers are early maturing children and maturity status may predict future swimming success of the early successful swimmers.

These findings of the present study agree with previous findings in the literature regarding maturity status of senior elite athletes (Carling et al., 2012; Figueiredo et al., 2009; le Gall et al., 2010). Successful senior athletes were reportedly assessed as average or late maturing children, and in fact, most of the survey responders in the present study 1 retained their successful athletic careers in senior elite (college) levels. Survey data also indicate that the early successful swimmers in the present study

were, on average, a group of tall children, especially at ages nine to eleven years (Figures 5.4 and 5.14). There has been no data, to date, showing the long-term athletic development of highly successful young athletes like those who participated in the present study, and the results of this study 1 can provide useful insights into physical and performance characteristics of early successful athletes.

It is possible that if data from all dropouts among the US top 100 nine-year old swimmers were accessible, the results may have been different. For example, there were two responses from dropouts who withdrew from competitive swimming by the age of 18. Both dropouts were assessed to be early maturing children. Therefore, this indicates that further continuing collection of the survey responses from swimmers who ranked within the US top 100 at young ages could result in to changes to the study outcomes.

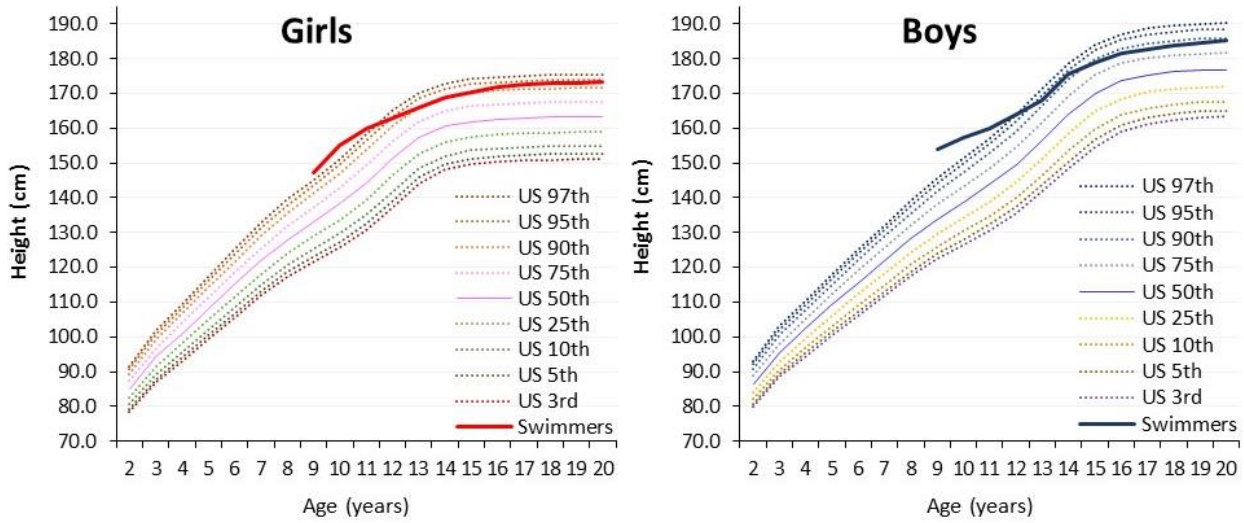


Figure 5.14. Height data for the survey responders (US top 100 nine-year-old swimmers) in the present study along with the US reference data (percentiles) as a function of age.

Study 2: Interpopulation variations in height growth and swim performance progression between the U.S. and Japan

***Question 6*:** Are there significant relationships between age-related height growth and swim performance progression for girls and boys (in the U.S. and Japan)?

***Hypothesis 6*:** Age-related height growth will be significantly correlated to age-related swim performance progression in both sexes (in the U.S. and Japan).

DISCUSSION 6:

Associations between height and physical tasks, motor skills, and physiological capacities during adolescence, especially in boys, are well documented (Beunen & Malina, 1988; Duché et al., 1992; Falk & Bar-Or, 1993; Froberg & Lammert, 1996; Heras Yague & de la Fuente, 1998; Jones & Round, 2008; Geithner et al., 2004; Kobayashi et al., 1978; Malina et al. 2004; Mirwald & Bailey, 1986; Philippaerts et al., 2006; Roemmich & Rogol, 1995; Van Praagh & Doré, 2002). Due to the difficulty of quantifying "sports performance," little data exists to determine whether or not the same relationship between height and actual performance in youth sports is present. Once again, it is possible to quantify competitive performance among swimmers as swimmers obtain times as 'performance outcomes" in a very similar environment across the world (Kojima et al., 2012; Pelayo et al., 1997), and all performance data (times) are accessible through USA Swimming database and possibly upon request to any other swimming federations.

The present data using performance times of competitive swimmers and height reference data for Japan (JPN) and the U.S. revealed that height and age-related height growth (gain) are highly correlated with swim performance and its age-related improvements, respectively, for both sexes and countries (Tables 4.16-17). These results support the study hypothesis 6.

In all four groups examined (JPN girls and boys and US girls and boys), the relationship between age-related height gain and 50-meter freestyle (50Fr) improvement indicated a better fit (higher

correlation coefficient) with curvilinear functions (Figure 4.23). In the present data, during ages eight to 18 years (pre- to late-adolescence), the magnitude of age-related height gain plateaued at approximately 5% for the examined cohort, while the magnitude of age-related 50Fr performance improvement was more than twice as great height growth (Figure 4.23). This finding may be related to the nature of cross-sectional investigation. To illustrate if this relationship was present in a longitudinal data set, the data of the survey responders in RQ5 were analyzed. The results of the 40 swimmers (survey responders, the US top 100 nine-year-old swimmers) show that significant relationships exist between height growth (%) and 45.7Fr improvement (%) during adolescence (Figure 5.15). Like the cross-sectional data in JPN and US data, the highest annual gain in height (%) reached, on average, approximately 5%. In contrast to the JPN and US data, 45.7Fr improvements (%) in early successful swimmers showed were diminished.

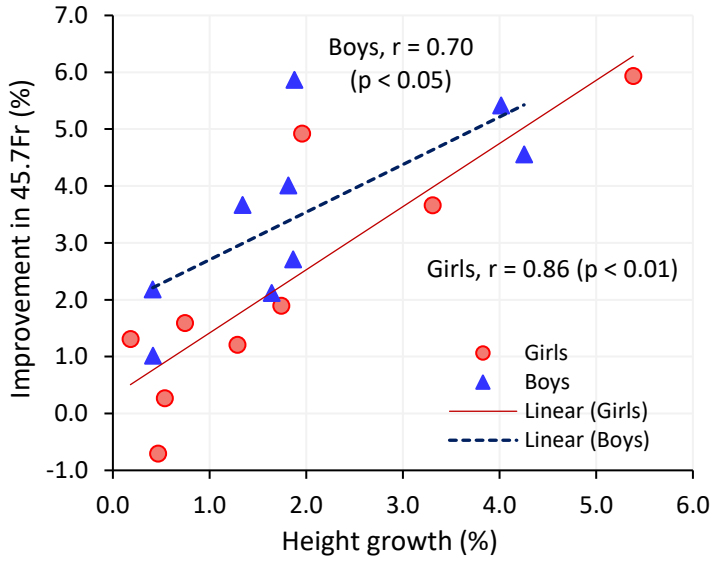


Figure 5.15. Relationship between mean annual changes (%) in height and 45.7-meter freestyle (45.7Fr) of the survey responders in the present study during adolescence.

Linear function: Girls, y = 1.1106x + 0.3057; Boys, y = 0.8371x + 1.8663.

***Question 7*:** Is there a significant interpopulation difference in age-related height growth?

***Hypothesis 7*:** The pattern of age-related height growth will be significantly different between the U.S. and Japan.

DISCUSSION 7:

For testing the hypothesis 7, no inferential statistics were conducted as the data were expected to comprehend the whole population (cohorts of US and JPN children, adolescents, and adults or swimmers). The present study examined the interpopulation differences in height (between US and JPN) from two viewpoints: 1) growth reference in 2000, and 2) age-related height growth derived from the growth references. The followings review the results and discuss the two viewpoints.

Differences in height as a function of age between US and JPN are shown Figures 4.24-25. JPN height reference data appeared to fit within the 25 to 75th percentile of US height reference. However, when carefully examining the growth curves for US and JPN, distinct interpopulation differences in height growth are present at three points during the first 20 decades of human lives: at early childhood, growth spurt, and post PHV for both sexes. First, at early childhood (before age 7), JPN children are taller than US children in both sexes by approximately 2 cm. Second, during growth spurt (early- to mid-adolescence, ages 9-12 for girls and ages 11-14 for boys), JPN adolescents are again taller than US same-age peers by 2-4 cm depending on sex and age. Finally, after the age of peak height gain (PHG) of US children (mid adolescence) to adulthood, US had a greater height than JPN in both sexes (more than 5 cm for adult height). These results support hypothesis 7, that the height growth curves between US and JPN are different.

Differences in age-related height gain are shown in Figure 4.26. When expressing age-related height gain, the pattern of annual height gain for two populations was evidently discrete for both sexes, leading to the postulation a different timing in growth and maturation exists (i.e., age at peak height velocity). There is about a two-year difference in the age at PHG between US and JPN in both sexes.

These results suggest that JPN children are early maturers as compared with US children, and support hypothesis 7 that the pattern of age-related height growth will be different between US and JPN.

Up to this point, the timing of growth and maturation is documented to be associated with early success in youth sports (e.g., Åstrand et al., 1963; Bar-Or et al., 1994; Kanitz & Bar-Or, 1974; Malina et al., 2004). Therefore, the two-year lag for the age at PHG as well as the age of take-off (i.e., onset of puberty; when growth spurt occurs) between two countries could conceivably have a large impact on athletic performances due to the early development of physical size, physiological capacities, learning process, socio-psychological behavior, and so on. The present data indicating advanced maturity status in JPN (Asian) children partially account for the athletic performance disparity at international scene. The next section discusses the above point concerning potential connections between interpopulation differences in timing of growth and maturation AND youth sports performance with specific reference to the sport of competitive swimming.

***Question 8*:** Is there a significant interpopulation difference in age-related swim performance progression?

***Hypothesis 8*:** The pattern of age-related swim performance progression will be significantly different between the U.S. and Japan.

DISCUSSION 8:

All of 50Fr swims recorded in 2008 for US and JPN were compiled for the analysis from respective countries' database. Data were arranged for each age from seven to 22 years and an age-group of 23 years and older (23&O) for both sexes. Figure 4.27 (all swims) and Figure 4.28 (top 100) show 50Fr performance data for the 17 age categories in respective countries.

In both countries' all-swim data, an effect of age on 50Fr across ages was revealed for both sexes ($p < 0.001$), while more importantly, an age × country interaction was revealed for both sexes ($p <$

0.001). It was initially assumed, based upon results of the elite world swimming championships, that US children are faster than JPN children in all age categories. However, contrary to the assumption, JPN children are faster than the same-aged US counterparts during pre- and early-adolescent ages (Figure 4.27). After the age 12 years in both sexes, US swimmers were faster than JPN. The exceptions being the finding of no statistical difference at age 12 years in girls and 10-11 years in boys. Similar results were demonstrated when analyzing the top 100 swimmers (Figure 4.28): JPN were faster during preadolescence and US were faster at age 11 and older in girls and age 12 and older in boys. These results suggest the existence of interpopulation differences in patterns of age-related progressions in 50Fr and support study hypothesis 8.

Once again, one of the main determinants contributing to adolescent (youth) sports performance is physical development concomitant with height growth (puberty) (Kojima et al., 2012; Malina et al., 2004; Pelayo et al., 1997). However, while height growth and maturity status, especially its timing, among adolescents have been reported to be highly associated with the disparity of their athletic performance within a population, there has been no comprehensive evidence supporting this contention between populations. Using national growth chart and swim time database for US and JPN, a high association between height growth and 50Fr progression was demonstrated for both countries (research question and hypothesis 6). Because the timing of maturational events (e.g., age at PHV) was also indicated to differ between the ethnically- or geographically-disparate populations, it was hypothesized that interpopulation variations in height growth patterns may be related to differences in athletic performance. The next section discusses the extent to which differences in height growth between US and JPN are related to interpopulation differences in swim performance progression, and provides insights into international youth competition outcomes with maturational consideration.

***Question 9*:** Is there a significant relationship between interpopulation differences (ratio of Japan to U.S.) in age-related height growth and swim performance progression?

***Hypothesis 9*:** There is a significant relationship between interpopulation differences (ratio of Japan to U.S.) in age-related height growth and swim performance progression.

DISCUSSION 9:

Given that swimmers reflect the general population, when interpopulation differences in median height and swim performance (50Fr) were expressed as the ratio of JPN to US for each age, a significant curvilinear relationship between the two variables was revealed for both sexes (Figure 4.31). This suggests that the difference in age-related 50Fr progression between US and JPN are, in part, accounted for by age-related height growth between countries. Furthermore, when plotting the JPN-to-US ratio of median height and 50Fr as a function of age, changes in the ratio (curve) of the two variables across adolescent ages appear to correspond each other. This was especially the case (a better fit) in girls (Figure 4.32). These results support hypothesis 9, that there is a significant relationship between interpopulation differences (ratio of Japan to U.S.) in age-related height growth and swim performance progression. Therefore, height is an important factor for sprint swim performance.

Disparity in youth sports performances among countries can result from various factors: practice/training, population size (popularity), environmental opportunities (training facilities etc.), financial or administrative resources, coaching, science and technologies, and so on. The present study addresses this subject from the standpoint of growth and maturation, and its timing compared between geographically- and ethnically-disparate athletic populations (US and JPN competitive swimmers). Interpopulation differences in timing of the age at PHG were demonstrated in both sexes from the growth reference data in respective countries (Figure 4.26), and differences in age-related progression in swim performance were also observed between countries for both sexes (Figures 4.27-30). JPN children appear to be early maturers and early developing swimmers as compared with US children.

Taller height and faster swim performance in JPN children were evident at pre- and early-adolescent ages (during growth spurt of JPN children) in both sexes (Figures 4.24 and 4.27-28) although US adults and senior swimmers are typically taller and faster than JPN counterparts. These results were anticipated to deliver two further observations: 1) a simple linear relationship between JPN-to-US ratios in height and 50Fr (Figure 4.31); and 2) a concordant timing (age) when the superiority in height and 50Fr shifts from JPN to US (or the JPN-to-US ratio intersect the equivalent ratio, i.e., 100 in Figure 4.32). The followings discuss the results concerning the two projections and consider the study limitations in the study 2.

First, the projection concerning a linear relationship between JPN-to-US ratios in height and 50Fr was true for girls but not boys, while both sexes demonstrated a significant curvilinear relationship between height and 50Fr (Figure 4.31). In the figure, larger physical size and faster swim performances between populations were plotted above 100 for JPN and below 100 for US (also in Figure 4.32). However, at ages 12, 13, and 14 years in boys, the US population was shorter in height but faster in 50Fr than JPN peers, which are plotted in the right bottom area in Figure 4.31 as being possible outliers.

Second, the ages that JPN-to-US ratio curves in height and 50Fr intersect with the equivalent ratio (100) were concordant in girls but not in boys (Figure 4.32). There was a two-year lag for boys' ages when the two ratios cross the equivalent point in Figure 4.32, which presumably resulted in the curvilinear relationship of JPN-to-US ratios of height and 50Fr in boys. Therefore, these findings describe the presence of sex-specific outcomes for the relationship between interpopulation differences in height and swim performance. For potential explanations behind the sex-specific outcomes, *a higher variance in the degree of maturity in boys* should be consideration (Baxter-Jones, 1995). In addition, *differences in sample size (50Fr) between JPN and US boy swimmers and differences in the proportions of ethnic groups between US population and USAS membership in boys* have presumably been associated with study outcomes in the boys.

A higher variance in the degree of maturity in boys

It is inferred that girls, in general, may have reached a biological limit of the earliest age at which human beings can reach puberty (development of secondary sex characteristics). Based on breast development, the Tanner stage 2 (thelarche) have been reported to occur as early as 7-8 years old (Malina et al., 2014). On the other hand, boys who are, on average, late matures as compared with girls, have a wider range of the onset and duration of puberty. The onset of boys' puberty could be as early as the earliest age of onset in girls and as old as late adolescent ages, leading to a higher variance in the degree of maturity in boys. In comparison to US boys, JPN boys were observed to be earlier maturers in the present study 2. It has been also suggested that youth sports athletes were relatively early maturing children as compared with general population (Figueiredo et al., 2009; Kanitz & Bar-Or., 1974; le Gall et al., 2010; Malina, 2011). Therefore, these variations in boys' growth could account for differences seen when US growth reference data (median height) were applied to US boy swimmers, especially during "average" ages of the onset of boys' growth spurt (age 12 years) to peak height gain (age 14 years). It is speculative that if the actual height data of boy swimmers were available for the present study, the interpopulation difference in height and the timing of growth spurt may have become smaller in boys. Consequently, the JPN-to-US ratio (curve) in height may shift to left and become flatter at ages 11 to 14 years, which would place it closer to 50Fr progression curve and shorten the two-year lag between the JPN-to-US ratios in height and 50Fr crossing the equivalent point.

Differences in participants in the sport of competitive swimming between US and JPN

In the year 2008 where the datasets in the present study were compiled from, there were 257180 and 105510 swimmers registered for USAS and Japanese Swimming Federation (JSF), respectively, while the numbers of 50Fr swim in the database were 60739 (23.6% of total memberships) for USAS and 46900 (44.5% of total memberships) for JSF (Table 5.4). JSF does not report the number of

registered memberships by sex or age, although FINA's report (FINA, 2013) indicates that there were more boys than girls in JSF at the first quarter of year 2013: JSF, 185853 swimmers (77014 girls and 108839 boys); USAS, 331189 swimmers (190114 girls and 141075 boys). According to JSF, the discrepancy in the numbers of JPN swimmers reported between JSF and FINA is due to the regulation of JSF's membership registration. JSF requires JPN swimmers who compete at an official meet sanctioned by JSF to register for the federation, whereas swimmers who do not compete but only practice at local clubs and schools are not required to register. Consequently, there seems to be 1.6 times more swimmers in JPN than reported by JSF. In US, there also appears to be more swimmers than USAS reports. The USAS membership may not include swimmers belonging to non USAS-sanctioned local such as YMCA, county clubs, etc. as well as high school and collegiate swimmers who do not compete in USAS-sanctioned competitions. Therefore, when following reports from respective countries' swimming federations, there are 2.4 to 2.7 differences in memberships between countries, which are proportional to differences in the total population between the US and Japan in the past decade (2.3-2.5 times differences).

When taking FINA's report into account, it is estimated that is a 1.8-time difference in memberships between countries. This raises the question as to whether the number of swimmers for respective countries needs to be proportionate to the total participation/enrollments. This is important to provide a proper comparison of swim performance difference between US and JPN, as USAS membership is nearly twice that of JSF. Rationale for this comparison comes from the reported association between sample size and performance outcomes within a group (Cornett & Stager, 2015). A median 50Fr of the US top 1000 and JPN 500 swimmers at adolescent ages for both sexes were calculated for the comparison between interpopulation differences in 50Fr and height. The results are shown in Figures 5.16 and 5.17.

Table 5.4. The number of swimmers registered for USAS and JSF and 50-meter freestyle swims recorded in USAS and JSF in 2008.

	USA Swimming			JPN Swimming Federation		
	Membership	50Fr	%	Membership	50Fr	%
Girls	149552	35552	23.8	n/a	21300	
Boys	107628	25187	23.4	n/a	25600	
Total	257180	60739	23.6	105510#	46900	44.5
FINA report^	331189			185853		

USAS, USA Swimming; JSF, Japanese Swimming Federation; %, 50Fr swims to membership ratio (Number of 50Fr swims ÷ Membership x 100).
this is estimated that the actual membership may be approximately 170000.
^ FINA report (FINA, 2013), membership (value) indicates the number of swimmers at the first quarter in 2013 for each federation.

First, results in in girls show that JPN-to-US ratio curves in height and 50Fr intersect with the equivalent ratio (100) at the concordant timing (age 12 years) (Figure 5.16). In addition, a linear relationship between height and 50Fr were revealed ($r = 0.80$, $p < 0.01$; Figure 5.17). In boys, the ages that height and 50Fr ratios (curves) cross the equivalent point become closer as compared with using total number of the swimmers (Figure 4.32), while the relationship between JPN-to-US ratios in height and 50Fr did not alter (non-significant linear relationship but significant curvilinear relationship).

A limitation (or complication) is noted with the relationship between sample size and performance. As stated earlier, a larger sample size hypothetically results in a better best performance outcome in a given group, while also resulting in a slower median (mean) performance of a population due the influence of an increased proportion of novice swimmers. This is displayed in Figure 5.18 as a negative relationship of the JPN-to-US ratios between memberships and median 50Fr in the 17 age-categories. Because the original datasets had a greater ratio of 50Fr swims relative to total membership in JSF (28% when including non-competitors in Japan) than USAS (24%) (Table 5.4), one could assume that median 50Fr in JPN would be faster and the JPN-to-US ratio would shift upward. However, these

are based fully on speculations, and the true data would not be available (even after a communication with JSF).

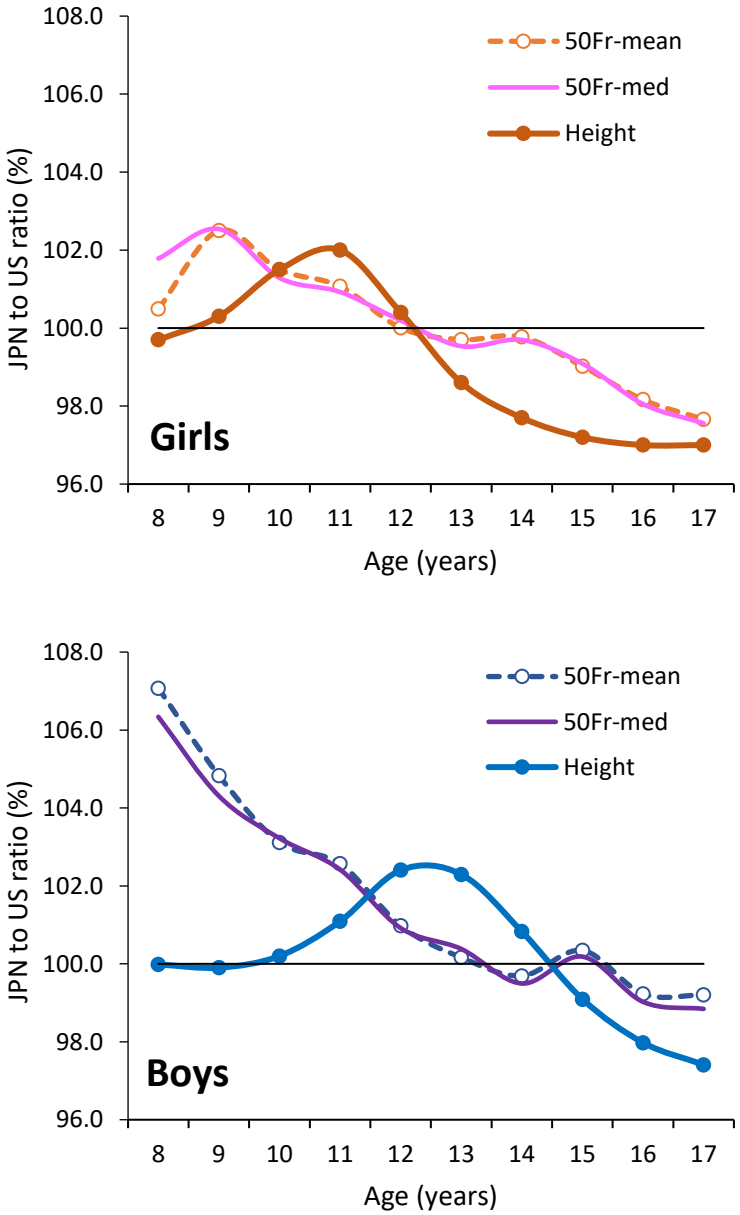


Figure 5.16. Ratio of JPN to US in height along with ratio of JPN top 500 to US top 1000 in 50-meter freestyle (50Fr) as a function of age.

A line at 100.0 (%) denotes that values (ratios) in JPN and US are the same; data presented above the line (> 100) denote that JPN children are faster than taller than US children.

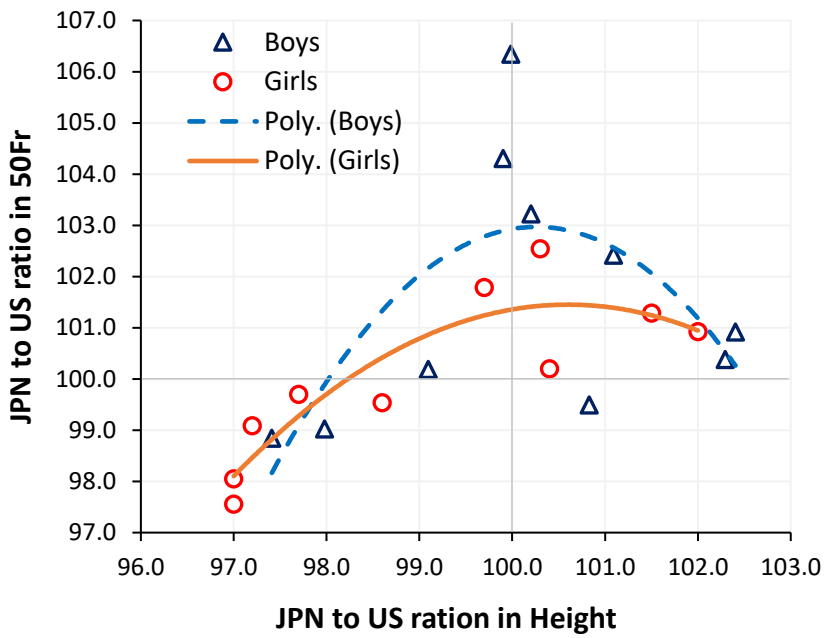


Figure 5.17. Relationships between interpopulation differences (ratio of JPN to US) in median height and 50-meter freestyle performance (50Fr: JPN top 500 and US top 1000) during adolescence.

Linear functions: Girls, $y = 0.673x + 33.345$ ($r = 0.80$, $p < 0.01$); Boys, $y = 0.3449x + 66.987$ (n.s.).
Polynomial functions: Girls, $y = -0.2582x^2 + 51.947x - 2511.5$; Boys, $y = -0.5903x^2 + 118.37x – 5831$.

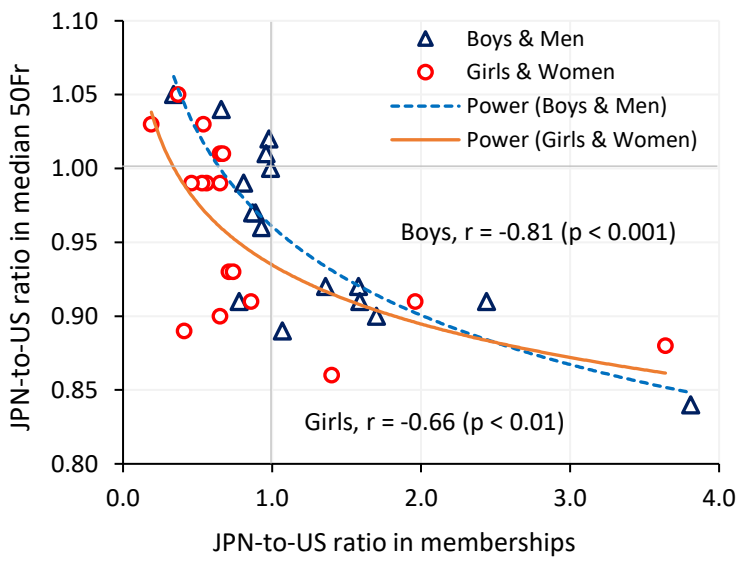


Figure 5.18. Relationships between ratios of Japanese swimmers to US swimmers in memberships (participants) and median 50-meter freestyle performance (50Fr in speed, $m \cdot sec^{-1}$) for 17 ages.
17 ages, ages seven to 22 years and an age-group of 23 & older.

Power functions: girls & women, $y = 0.9347x^{-0.063}$; boys & men, $y = 0.9607x^{-0.093}$
Linear functions: girls & women, $y = -0.0417x + 0.9956$ ($r_{(15)} = -0.57$, $p < 0.05$); boys & men, $y = -0.0546x + 1.0234$ ($r_{(15)} = -0.75$, $p < 0.01$)

Difference in the proportions of ethnic groups between US population and USAS membership

With the latest geographic data in 2015 (JPN data, Statistics Japan, 2015; US data, Martin et al., 2017), population sizes in Japan and the U.S. were 126,919,659 and 322,014,853, respectively, leading to a 2.5-time difference in population size between JPN and US. JPN population consists of 98.5% of Japanese, while US population consists of Non-Hispanic White (63.7%), Hispanic/Latino (16.3%), Non-Hispanic Black (12.2%), Asian (4.7%), and Native and others (3.0%). The U.S. is the most ethnically-diverse population country in the world. For example, among Caucasian-dominant and strong swimming countries, populations in Australia, UK, and Canada consist of 92%, 87%, and 78% of White individuals, respectively (from Wikipedia). As shown in Table 2.2ab and Figure 4.26, variations in the timing of maturity events occur among ethnically and/or geographically disparate populations exist: e.g., Asian children appear to be early maturers as compared with White children. Diversity within a population should not be an issue for the present study outcome if most of the US population and USAS members are White, and if the proportions of ethnic groups are similar between US population and USAS members.

USAS' membership demographics (USA Swimming, 2015) indicate that among the available data (i.e., members who responded to ethnicity groups), USAS swimmers consists of Non-Hispanic White (69.8%), Hispanic/Latino (6.2%), Non-Hispanic Black (2.2%), Asian (12.1%), and Native, mixed, and others (9.7%). White swimmers have made up the majority of USAS memberships over past years (Figure 5.19). As compared with the US population, large differences in membership proportions exist for Black, Hispanic/Latino, and Asians swimmers within USAS. Figure 5.19 illustrates changes in proportions in ethnic groups within USAS memberships in the past decade. Recently, there are four ethnic groups whose membership proportions within USAS have been dramatically changing: White, Asian, Hispanic/Latino, and Mixed populations. Asian and Hispanic/Latino populations have been increasing the most in the US and USAS. Available data suggest that Asian and Hispanic/Latino populations

increased in the U.S. by 43.3% and 43.0%, respectively from 2000 to 2010, while White population increased 5.7% (Grieco & Cassidy, 2001; Humes & Ramirez, 2011). On the other hand, within USAS, Asian and Hispanic/Latino swimmers increased by 151.7% and 84.0%, respectively from 2000 to 2010, while White swimmers increased by 4.3%. Therefore, as compared with US population, the growth rate of Asian and Hispanic/Latino people (swimmers) within USAS is considerably higher.

Asian and Hispanic/Latino populations have been described to be early maturing populations as compared with White population (pages 101-107 in Chapter 2). The highest growth rate was observed for Asian boys/men within USAS (Figure 5.19). The number of Asian boy/men swimmers increased by 56.8% from 2005 to 2010 during the time the datasets in the present study was established, while Asian girl/women swimmers had a 43.0% increase. Although ethnic status cannot be identified by age within USAS membership or for swim performance data used in the present study, there are observationally far more Asian swimmers in adolescent ages than senior/college levels. Therefore, based only on speculation, these findings may have affected the JPN-to-US ratios in height (Figures 4.31-32) in the present study similar to what is presumed to cause a seeming higher variance in the degree of maturity in boys. This means that the JPN-to-US ratio in height would shift left and down in Figure 4.32.

Alternatively, these speculations (potential explanations) for the observed sex-specific study outcomes concerning relationships between the JPN-to-US ratios in height and 50Fr (Figures 4.31-32) can be addressed as the study limitations. While it would be preferable to have height data for all swimmers to examine the true relationship between interpopulation differences in height growth and 50Fr progression during adolescence, the present study (study 2) applied growth reference data to swimmers in their respective countries.

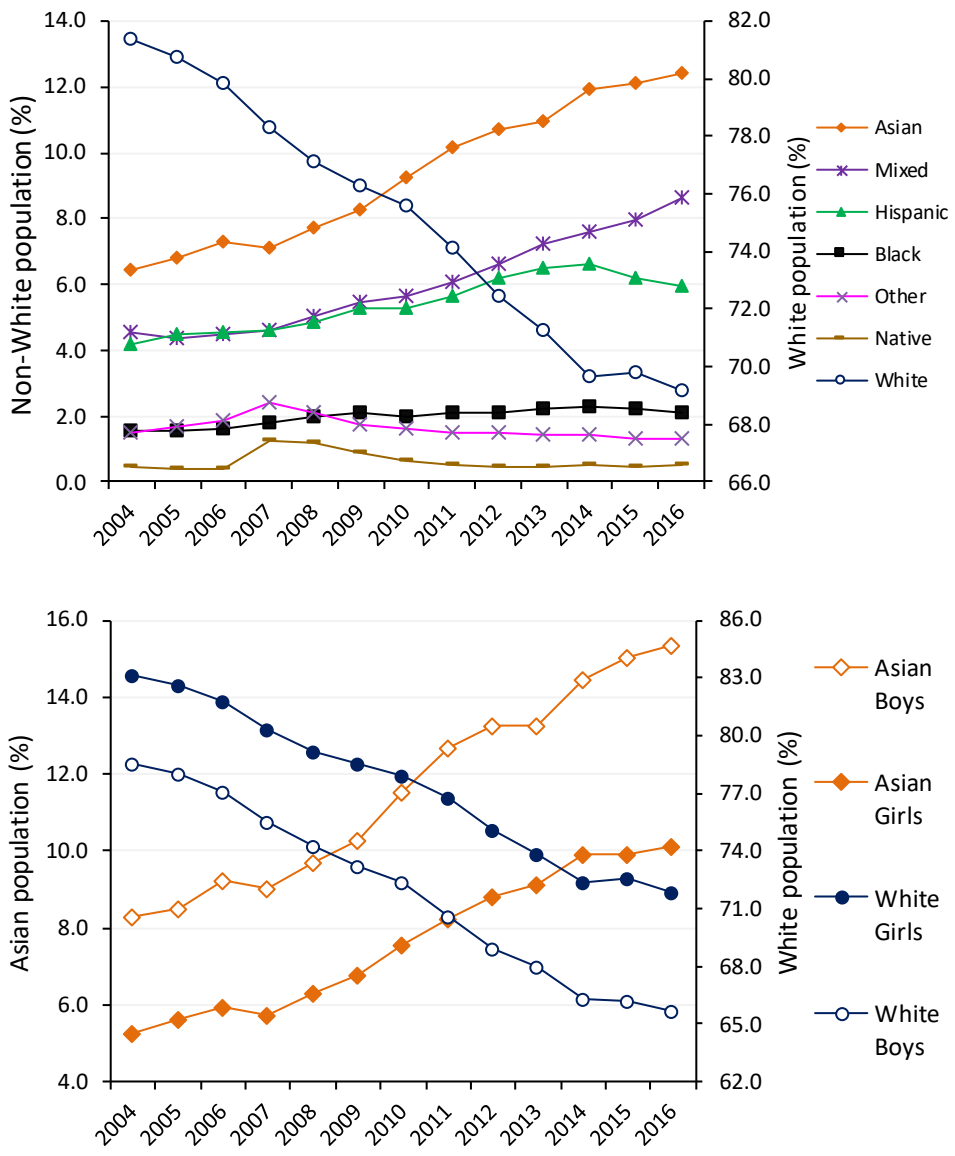


Figure 5.19. Changes in proportions of ethnic populations within USA Swimming memberships for all ages from 2004 to 2016.
Top figure, total population for each ethnic group; bottom figure, by sex (boys and girls include men and women, respectively).

Note 1: Proportions of ethnic groups in swimmers within USA Swimming (USAS) were calculated based on the total number of swimmers who responded to an ethnic group identification question on the USAS membership registration form in each year. Non-responders account for the 40-50% (46.9 ± 5.2) of the total swimmers for past 12 years.

Note 2: The total memberships of USA Swimming and the number of swimmers by ethnic group for past 12 years are summarized in APPENDIX J.

CHAPTER 6: SUMMARY AND CONCLUSIONS

The present study was centered on variations in age-related swim performance within a given population and among contrasting populations who differ in maturational pace. Three main questions concerning talent identification (TID) and long-term athlete development (LTAD) programs were addressed: 1) do *early successful* youth athletes continue to progress in their athletic careers during adolescence into adulthood, 2) what factors distinguish the future athletic success of *early successful* youth athletes, and 3) how are differences in timing of growth and maturation among populations associated with sport performance progressions?

A general lack of evidence calls into a question whether or not successful pre-adolescent athletes maintain their athletic success, remain in a sport during adolescence (e.g., age 10-18), and mature into successful late- and post-adolescent athletes. Later success is, presumably, dependent upon continued participation in the sport. In addition, differences in patterns of height growth and sport performance progression among ethnically and geographically disparate populations have been anecdotally observed, while no such informative data or connection have been reported. Because competitive swimming collects objective performance measures (competition swim times of all athletes) for all ages, all geographic regions (states or prefectures), and past years within their database, an analysis of the data provides descriptive insights into typical and atypical performance progressions as children age. As well, the persistence of participation can also be analyzed.

Consequently, the first part of the present study (Study 1) demonstrated long-term performance progression (times and national ranking) and dropout rates for successful young swimmers from late-childhood (pre-adolescence) throughout adolescence (age nine years as the baseline). Moreover, youth sports and training biographies were amassed from the cohort of the top 100 preadolescent swimmers (at age nine) in order to profile identifiable factors perhaps important for the levels of future success in the top young swimmers. The second part of the study (Study 2) then focused on differences in age-

related height growth and sprint freestyle performance between US and JPN as a means to understand the role of growth and development in this regard. Height reference data and 50-meter freestyle times during adolescent ages for respective countries were compiled and comparisons made.

The results of Study 1 indicated that nearly half of the US top 100 nine-year-old swimmers (in the 45.7-meter freestyle, 45.7Fr) in both sexes continued to rank within the US top 100, *in some swimming event,* during late adolescence (Figure 4.1 and Table 4.2), while approximately one third of them dropped out from the sport (or USA Swimming) by age 18 years (Figure 4.7 and Table 4.2), which was much less as compared with general swimming population (92%). Patterns of the performance retention at a successful level (US top 100) throughout adolescence were similar between sexes but not participation retention (dropout rate), especially at high school ages. In addition, a quarter of the top nine-year-old swimmers ranked within the US top 100 (in some swimming event) for ten consecutive years. Of the original 100 top 45.7Fr swimmers at age nine, twelve girls and four boys were eventually selected for the Junior National Team, and three girls and one boy were National Team members by age 18 years. Moreover, based on survey responses (40 swimmers out of 200; 19 girls and 21 boys), the early successful preadolescent swimmers were not necessarily early matures (Table 4.11) but were, on average, taller (early growing) children as compared with the national height growth reference, especially at early adolescence (Tables 5.4 and 5.14). There were several significant factors contributing to future success in competitive swimming and identified from the present analyses (Tables 4.13, 4.14, and 5.3). These include: 1) age, 2) weekly dryland exercise hours during ages five to eight, 3) sex, 4) multi-sport experience, 5) age at the enrollment in competitive swimming and practice, 6) age at the peak improvement in swim performance, and 7) weekly swim practice hours during ages five to eight. Most of the factors, however, were identified as negative predictors as the level of competition becomes more competitive and selective with an increase in age.

The results from Study 2 revealed three main findings. First, a high association between age-related height growth and swim performance improvement for both US and JPN exists (Figures 4.22 and 4.23). Second, there are differences in timing in height growth (Figure 4.26) and swim performance progression (Figures 4.27 and 4.28) between US and JPN for both sexes. Third, the interpopulation difference (JPN-to-US ratio) in height growth is highly associated with swim performance progression in both sexes (Figure 4.31). Japanese girls and boys appeared to be early maturers as compared with US peers (approximately a two-year difference in the age at peak height gain), while swimmers in JPN appear to develop their performance (gain growth-related advantages in performance improvements) at earlier ages than US counterparts. As a result, interpopulation differences in height growth are, to a certain extent, accounted for those in the progression in sprint swim performance, especially in girls.

In conjunction with the scientific literature, the results from the present study with specific reference to early successful, young competitive swimmers led to several conclusions. In Study 1, early success appears to be an important predictor for future success in competitive swimming, and dropout rate of early successful young swimmers during adolescence is lower than the reported rates for the broader swim population or reports in any other youth sports. Many aspects of the youth sports training biographies and maturational milestones examined (e.g., later ages at enrollment in swimming and intensification in swim training) play a positive role in the future success of the early successful young swimmers. These factors work in a manner similar to the role of those previously reported in athletes who achieved elite-level athletic status in adulthood in multiple disciplines (non-swimming sports). However, multi-sport participation was associated negatively with the sustainability of successful athletic status across adolescence in swimming, which could imply that early swimming leads to success in other sports. It was suggested that study outcomes concerning contributing factors for future success would differ based on who they referred to, such as age, sex, and competition levels of subjects (athletes) and what types of sports are examined (as the domain sport). Nevertheless, Study 1

provides important logistic and strategic insights into TID and LTAD programs and accentuates an importance of 1) not discounting early successful young stars throughout adolescence into adulthood and 2) encouraging young athletes to continue in their sports (interests) and training, even if they are not at 'a top level' or 'successful' as compared with the same age peers at early- to mid-adolescent ages. Therefore, persistent participation may represent a strategic priority on the local as well as the national level.

In Study 2, maturation-related superiority in swim performance is observable not only within a population but also between populations. Interpopulation variations in the timing of maturational events (as measured by age-related peak height gain) partially explain differences in adolescent athletic performance. Thus, timing of growth spurt or peak growth can be an interesting consideration in predicting (explaining) performance outcomes at international competitive events.

The main focus of the present studies was to profile variations in youth sports performance outcomes within and among populations with maturational consideration and specific reference to competitive swimming. Timing in maturation (height growth) has been discussed as one of main (many) explanations of disparity in youth sports performance within population and between populations. However, the present study does not try to contend that timing in height growth or maturation is the *only or main* determining factor for the disparity. For example, group size of an event has been documented to influence athletic (Cornett, 2011) and intellectual performance outcomes (Charness & Gerchak, 1996). In addition, an interaction of 'group size' and 'variation' within a group (e.g., ethnic diversity within a group) may be an important but complex factor for human performance. This point suggests that a country having diverse ethnic groups and larger size of groups (i.e., USA Swimming) has a great advantage of diverse maturity-level children leading to athletically rich talent pool and competition. Diversity within a population is considered to be advantageous in promoting elite athletic success on the international scene, as it has been shown in the case of athletic success in US. In other

words, for such an ethnically diverse population (US) it may be safe to say that a systematic, nation-wide, long-term athlete development program may not be necessary or able to exist at all as it is simply difficult or impractical to adapt a single athlete development paradigm to all children with such diverse levels of maturational status. Therefore, individual coaches and sport practitioners need to be sensitive to the important role maturation (timing and tempo) plays in the ability of a youth athlete, to optimize and evaluate training responses and competition outcomes. These conclusions may ultimately suggest that – especially with limited financial resources – sports authorities should be inclined to invest more time, and effort in coaching provisions and development agendas before a talent identification program is invoked.

Lastly, while the present analyses tried to answer to the research questions, many other questions and hypotheses have also been created. The Study 1 focused on describing the athletic careers of 200 top young swimmers in 2004 in the United States, and the data are conceivable to be altered and must be more valuable if survey responses were collected from more of the top young swimmers and dropouts (N = 40). The future study needs to first collect survey from broad groups of collegiate swimmers, and next retrospectively track their age-group and high school swimming times. This potentially increases the total sample size of early successful swimmers as well as leads to having subgroups such as different timings in success and different ethnic background among the swimmers.

In Study 2, the outcomes must attribute to an assumption: swimming population represents general population. Actual height measures of swimmers certainly improve the study outcomes. This may be, in fact, possible for Japanese swimmers as all elemental, middle, and high school students are required to record and report their physical growth (height, weight, and circumference at given body-sites) from the government. Furthermore, in both studies 1 and 2, similar analyses of swimmers in different countries and/or athletes in different disciplines would provide more useful information pertaining to variations in development of human performance.

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APPENDIX A: YOUTH SPORTS AND TRAINING BIOGRAPHY SURVEY

Name

E-mail address and/or contact phone number

Mailing address (in order to send a gift card)

Q1-1. Have you participated in any group or private swim lesson?

Q1-2. Between what ages did you participate in swim lessons?

Age Age

Q2. What age did you join a competitive swim club/team?

Age

Q3. Practice and training biography: 1) How many sessions per week & hours per session did you have swim-practice and/or dryland training, on average, at each age? If you did not swim, have dryland training, or compete at any given age, please leave blank. 2) How many swim coaches have you had at each age (per year), *excluding assistant coaches*? Please describe name(s). 3) Finally, what is your overall confidence in above training biography memory at each age?

Age	Swim practice session		Dryland session		Year-around competition	Name and number of swim coaches	Confidence level					
	session/ wk	hrs/ session	session/ wk	hrs/ session			0%	20%	40%	60%	80%	100%
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

Q4. What age did you start having doubles or more (multiple swim-training sessions per day) on a regular basis?

Age

Q5. What age did you start considering competitive swimming as your primary sport (although you may have continued to participate in other sports)?

Age

Q6. What was the age at which you started focusing on and training particularly for specific swimming events?

Age

Q7-1. Have you ever dropped out from competitive swimming?

Q7-2. At what age(s) did you drop out from competitive swimming?

Q7-3. Why did you drop out from competitive swimming?

Q8. Achievements in swimming: Please check ages when you qualified for described levels of achievements.

Age	State meet qualifier	State finalists	Jr nationals qualifier	Jr nationals finalists	Nationals qualifier	Jr or National team member
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Q9-1. Did you participate (trained and competed) in any sport(s) other than swimming before age 18?

Q9-2. How many sports other than swimming did you participate in?

1 2 3 4 5

Q9-3. What sports did you participate in?

Q9-4. For each sport, please describe practice sessions per week and hours per session. Please also check state or national achievement levels at each age.

Age	Sport:		Achievement level		
	session/ wk	hrs/ session	State	Regional	National
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					

Q10. Childhood/adolescent non-sport activities: Please describe any non-sporting (music or intellectual) activities in which you have participated. If did not participate in any non-sporting activity, please leave blank.

Type of activity	Age range				Reason for withdrawal
	start	end	session/ wk	hrs/ session	

Q11. Please recall age of menarche (girls only).

Age

Q12. Please recall ages when you had the most gain in height and swim performance improvement. If you do not remember, please leave blank.

Height	Swim

Q13. Last question!! If you remember, please write down approximate height of yours at each age (please ask your parents if possible). If you do not remember, please leave blank.

Age	Height
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
Current	

Thank you for your time and cooperation!

APPENDIX B: INITIAL CONTACT LETTER FOR STUDY SURVEY

Study title: Performance Progression and Participant Retention throughout Adolescence in Elite Young Swimmers

To Whom It May Concern,

The Counsilman Center for the Science of Swimming at Indiana University has been conducting a research project that involves how multi-sports experience and training biography through youth sports in elite young swimmers contributed to their swim performance during adolescence and into adulthood. You were identified as a swimmer who ranked within the US top 100 at age 9 in 2004, and we would like to ask you to fill out a survey regarding your involvement in youth sports training and competition and intellectual activities as well as information of height growth and physical maturation. You may take part in the online survey, which will take approximately 20-30 minutes. You will receive a $10 gift card after the completion of survey. Participation in the study is completely voluntary. Your participation will aid in our research and allow us to review your youth sports career. If you have any questions regarding the study, please contact Kosuke Kojima via email (kokojima@indiana.edu) or by phone (812-856-2893). I deeply appreciate your participation and cooperation.

[A brief summary of the study purpose]

Athletic success or successful sport performance results from a tremendous amount of effort and time investment, by the athlete, the coaches, the parents, and any financial sponsors. However, whether or not success in youth sports is predictive of an individual's future sporting success is unknown due to a lack of evidence to suggest that successful young athletes mature into successful late- and post-adolescent athletes. It is also unclear how highly successful young athletes become involved in youth sports training and competition, and what factors differentiate or contribute to late adolescent-and senior-level athletic achievements and success. The purposes of this study are to retrospectively profile 1) the performance progression, 2) dropout rate, and 3) youth sports and training biographies of elite young swimmers throughout adolescence and into adulthood. This project is, in part, in an effort to provide age-group coaches in the US and the world with insights into long-term athlete development.

Again, thank you very much for your participation and cooperation.

Sincerely,

Kosuke Kojima

kokojima@indiana.edu, (812-856-2893)
Counsilman Center for the Science of Swimming
Department of Kinesiology, Indiana University

APPENDIX C1: PERFORMANCE PROGRESSION IN THE US TOP 100 NINE-YEAR-OLD GIRL SWIMMERS DURING ADOLESCENCE

ID	45.7-meter Fr time									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1	27.84	27.10	25.81	25.25	25.30	24.87	25.92			
2	27.85	26.53	25.30	24.34	24.14	23.77	23.79	23.57	23.68	23.96
3	27.87	26.31	25.44	24.58	24.31	23.95	24.15	24.51	24.29	24.29
4	27.95									
5	27.97	25.53	26.13	23.75	23.92	23.21	23.49	23.24	23.24	22.64
6	28.05	27.95	27.35	25.71	25.03	24.29	24.75	24.63	25.50	25.11
7	28.17									
8	28.64	27.79	26.70	25.38			25.90	23.76	23.48	
9	28.68	28.05	26.58	26.30	26.61	25.49	25.61	24.38	23.86	23.96
10	28.72	27.19	26.95	25.99	25.69	24.72	24.72	25.76	24.72	24.72
11	28.86	27.33	25.96	25.41	25.17	25.60	25.60	24.65	24.05	25.52
12	28.88	27.47	27.04	26.62	26.08	24.71	26.12	26.14		
13	29.01	27.67	28.03	27.30	26.15	26.51				
14	29.01	27.37	26.10	26.47	25.51	24.82	25.35	25.43	25.13	24.66
15	29.03	26.66	26.02	25.73						
16	29.03	27.74								
17	29.08	27.15	26.23	25.50	25.09	24.02	24.34	24.01	24.01	24.66
18	29.12	29.24	28.25	27.52	26.87	26.47	25.67	26.42	27.38	
19	29.13	31.86	29.20	28.73	27.30	26.78	26.92	26.73	25.85	25.45
20	29.16	27.06	25.92	24.96	25.07	24.54	24.09	23.35	22.99	23.27
21	29.20	27.34	25.98	26.14	25.19					
22	29.23	27.96	27.07	26.38	25.97	25.27	25.30	26.19	26.09	
23	29.26	27.16	25.80	25.43	25.63	25.23		25.14	26.23	
24	29.31	26.81	25.99	25.25	23.65	23.18	23.36	23.96	24.76	24.32
25	29.34	26.82	25.74	25.20			24.71			25.19
26	29.38	27.53	25.74	24.81	23.99	23.27	22.74	23.16	22.92	23.48
27	29.40	28.55		25.34	24.91	24.50	24.73		24.77	
28	29.41	28.34	27.48	26.72	26.17	26.04	26.45	25.88	26.33	
29	29.45	28.16	26.31	25.13			24.00	24.52	23.93	
30	29.47	28.33	26.78	25.83	26.48					
31	29.47	28.89	28.06	27.05	27.04	25.95	25.71	25.52	26.57	25.35
32	29.48	28.79	26.29	26.23	26.83	26.77	26.57	26.37	27.32	27.32
33	29.50	28.07	27.81	26.52	25.68	25.62	23.99	24.19	24.62	24.87
34	29.51	28.13	27.32	26.07	25.26	25.01	25.21	25.03	24.76	24.74
35	29.56	27.69	26.31	24.48	24.58	24.25	24.62	23.55	23.52	23.69
36	29.58	28.94	28.15	26.89	26.71		25.60	25.79		
37	29.62	27.52	26.97	27.02	27.58	26.33	26.42			
38	29.68	27.90	27.04	26.36	26.34	26.00	27.69	26.40	26.11	26.11
39	29.70	27.92	27.27	26.23	27.70	27.00	27.36		27.21	
40	29.71		29.27	27.88		25.96	25.99			
41	29.74	27.97	27.70	27.70	25.89	24.85	24.95	24.38	24.80	24.80
42	29.78	28.37	27.02	26.00	24.58	23.74	24.28	25.00	24.88	24.41
43	29.82	28.29	27.23	25.54	25.06	24.18	24.78	24.52	24.32	25.01
44	29.83	27.25	26.85	25.94	25.20	25.86	24.68	24.47	25.20	24.29
45	29.83	29.01	28.51	26.26	25.86	25.65	26.37	26.69	26.50	25.94
46	29.85	28.94	28.69	27.85		28.00				
47	29.85	29.76	28.01	26.45	26.11	25.20	25.85	26.10	25.57	
48	29.91	28.89	26.77	25.83	25.75	24.63	24.60	24.08	24.62	23.67
49	29.91	27.12	27.11	26.15	26.45	26.91	26.65			
50	29.92	28.40	27.19	26.41	25.77	27.21	25.52	26.21	26.13	26.13
51	29.94	27.86	27.22	26.16	25.80	26.20	26.10	25.05	26.10	30.40
52	29.95	30.11	27.87	26.65	25.83	25.24		25.50		
53	29.99	26.80	25.88	24.56	25.55	24.22	24.54	24.13	24.24	24.24
54	30.01	27.66	27.24	27.16	27.66	26.99	26.48	26.34	26.44	25.43
55	30.01	29.39	26.90	26.69	26.22	25.92	25.64	26.49	25.68	
56	30.06	28.64	27.47	25.43						
57	30.08	28.55	27.50	26.33	26.16				25.04	
58	30.08	27.86	26.66	26.49	26.11					
59	30.10	29.30	27.51	27.49						
60	30.13	28.21	26.18	25.24	24.88	24.74	25.31	25.51	26.29	26.29
61	30.14	28.72	28.27	26.07	24.44	24.56	24.24	24.41	24.10	
62	30.16	27.03	26.64	26.20	25.63	25.61	24.11	24.60	24.60	23.93
63	30.20	27.82	25.91	25.59	25.04	24.69	24.00	24.33	24.63	24.07
64	30.21	28.82	27.23	26.17	26.03	25.39	24.88	25.24	25.24	25.24
65	30.23	28.80	27.17	26.10	25.70	26.05	24.68	24.71	24.59	24.59
66	30.23	29.21	27.17	26.52						
67	30.26	28.40	26.86	25.46	25.05	24.23	24.54	23.96	24.19	23.93
68	30.27	27.65	27.52	26.44						
69	30.29	28.60	26.91	26.34	26.51	26.77	25.98	25.92		
70	30.29	28.90	28.24	27.20	27.13		28.45			
71	30.29	28.38	27.09	26.18	26.10	25.19	24.87	24.93	24.57	24.57
72	30.30	27.97	27.71	26.66	25.60	25.58	23.84	23.27		
73	30.30	27.55	27.02	25.87	25.49	24.26	24.34	23.96	23.89	23.43
74	30.32	28.65	28.53	28.46	28.70					
75	30.33	28.17	26.80	26.71	26.99					
76	30.33	31.38	28.91	27.62	27.77	26.65	27.02	26.23	26.65	
77	30.34	27.57	26.92	26.46	26.38	25.80	25.82	25.12		
78	30.36	28.29	27.36	25.97	26.16					
79	30.38	29.16	28.04	26.68	26.16	25.79			25.00	
80	30.40	28.78	27.86	25.72	24.87	25.69	24.15	24.15	23.81	23.66
81	30.40	28.63	28.02	26.16	25.37	24.46	24.52	24.07	23.69	23.64
82	30.40	28.20	27.10	26.69	26.08	25.68	25.62	24.54	24.74	
83	30.43	29.06	27.61						24.83	
84	30.44	28.89	27.30	26.04	25.23	25.77	24.01	24.12	24.16	24.32
85	30.44									
86	30.46	28.43	28.37	27.31	26.89	26.83	26.56	27.68	27.11	26.11
87	30.46	28.92	28.40	27.91	27.05			28.60	27.57	
88	30.48	29.09	28.23	26.22	25.84	25.51	24.99	24.69	23.79	
89	30.49	28.43	26.50	25.96	25.88	26.23	25.93	26.73	25.98	25.35
90	30.52	29.34	28.46	27.21	26.02	25.46	25.83	25.31		
91	30.54	28.45	27.98	26.39	25.52	24.39	24.04	23.48	23.49	23.27
92	30.56	28.62	28.27							
93	30.56	28.13	27.59	25.94	26.05	26.16	25.40	24.44	24.61	24.61
94	30.56	27.93	26.68	26.53	26.12	26.80	26.43	25.13	25.09	24.04
95	30.57	29.24	28.18	27.30	27.04	26.98	25.69	25.36	25.45	25.45
96	30.58	28.39	28.04	27.46				27.45		
97	30.59	29.51	28.25	27.01	25.87	26.31				
98	30.61	29.12	28.08	26.31	25.53	25.80	25.76	25.18	25.12	25.92
99	30.62	29.11	28.38	26.81	25.69	26.10	26.38	26.90	26.85	26.39
100	30.62	27.94	26.68	25.20		23.24	23.07			22.98

ID	US Ranking in 45.7-meter Freestyle									
	9	10	11	12	13	14	15	16	17	18
1	1	16	11	36	143	198	1127			
2	2	4	4	2	9	15	27	31	58	168
3	3	3	5	7	10	26	76	270	221	200
4	4									
5	5	1	27	1	4	3	13	12	15	8
6	6	67	198	95	67	58	270	340	1070	522
7	7									
8	8	50	70	48			1099	51	34	
9	9	73	56	276	897	504	824	207	83	168
10	10	21	100	172	269	151	246	1279	421	361
11	11	26	18	52	105	576	796	343	133	891
12	12	31	116	414	476	670	1349	1679		
13	13	42	444	880	522	1459				
14	13	28	25	339	199	184	625	922	750	438
15	15	5	21	100						
16	15	46								
17	17	19	34	67	87	29	118	87	123	438
18	18	324	566	1116	1166	1406	876	2013	2968	
19	19	1957	1375	2845	1744	1837	2420	2405	1416	856
20	20	15	16	15	82	112	66	16	10	40
21	21	27	19	216	112					
22	22	68	123	302	418	368	580	1737	1659	
23	23	20	10	55	246	351		663	1807	
24	24	8	20	36	1	2	8	76	455	285
25	25	9	8	31			229			723
26	26	34	8	10	7	6	1	9	7	67
27	27	144		42	48	104	261		468	
28	28	110	227	469	536	961	1786	1392	1912	
29	29	86	41	23			45	279	101	
30	30	108	76	115	771					
31	30	225	458	684	1388	870	911	1013	2153	805
32	32	203	39	253	1121	1817	1931	1949	2909	1302
33	33	77	347	370	264	590	44	142	374	543
34	34	82	189	191	138	249	503	572	455	470
35	35	44	41	3	22	50	221	29	40	105
36	36	240	508	570	998		817	1297		
37	37	33	103	661	2170	1251	1731			
38	38	58	116	292	663	927	3635	1986	1682	912
39	39	61	172	253	2380	2157	3123		2790	
40	40		1444	1561		885	1191			
41	41	70	307	1328	374	192	359	212	491	417
42	42	113	112	175	22	13	104	551	549	253
43	43	102	156	74	78	39	285	279	229	617
44	44	24	85	148	118	795	241	251	814	277
45	44	256	737	263	359	620	1670	2347	2085	860
46	46	240	878	1507		3892				
47	46	507	433	327	494	336	1038	1619	1148	
48	48	225	74	115	292	134	215	104	374	102
49	48	18	131	220	749	2018	2039			
50	50	121	147	313	300	2476	760	1756	1700	916
51	51	55	154	225	321	1112	1322	586	1671	2269
52	52	683	376	428	341	356		990		
53	53	7	14	4	218	47	191	124	200	187
54	54	40	162	774	2308	2132	1824	1896	2021	846
55	54	371	92	452	562	840	854	2100	1253	
56	56	165	226	55						
57	57	144	237	282	529				689	
58	57	55	62	349	494					
59	59	340	245	1075						
60	60	94	31	35	43	161	588	1004	1877	972
61	61	183	577	191	14	116	91	221	151	
62	62	14	60	238	246	581	70	323	354	108
63	63	53	15	79	69	143	45	191	380	204
64	64	211	156	228	444	436	326	739	580	821
65	65	206	143	199	273	970	241	383	351	324
66	65	312	143	370						
67	67	121	89	61	73	49	191	76	180	155
68	68	39	247	326						
69	69	157	93	285	795	1817	1176	1436		
70	69	230	559	801	1528		4835			
71	69	116	126	230	484	331	320	499	340	320
72	72	70	311	437	237	558	31	13		
73	72	35	112	130	191	52	118	76	93	57
74	74	167	755	2380	4322					
75	75	88	77	464	1307					
76	75	1526	1076	1225	2504	1652	2551	1772	2236	
77	77	36	95	332	693	736	1011	651		
78	78	102	200	162	529					
79	79	300	451	445	529	727			648	
80	80	199	372	98	42	652	74	130	76	98
81	80	163	441	225	161	89	183	100	60	92
82	80	91	128	452	476	645	836	290	441	
83	83	274	278						515	
84	84	225	182	181	128	710	48	120	170	285
85	84									
86	86	127	641	891	1189	1907	1920	3670	2578	1178
87	86	235	664	1597	1405			4789	3138	
88	88	281	551	248	347	517	375	374	73	
89	89	127	51	158	370	1143	1137	2405	1550	805
90	90	353	706	806	438	487	1018	811		
91	91	132	417	304	203	76	54	24	36	40
92	92	160	577							
93	92	82	268	148	454	1080	668	235	366	334
94	92	63	66	374	503	1864	1746	658	720	141
95	95	324	523	880	1388	2116	893	865	1025	266
96	96	118	451	1040				3362		
97	97	409	566	651	366	1226				
98	98	292	470	279	209	736	955	686	742	857
99	99	289	652	525	269	1023	1688	2621	2436	1310
100	99	64	66	31		3	3			16

ID	US highest ranking achieved									
	9	10	11	12	13	14	15	16	17	18
1	1	1	1	1	1	7	105	815		
2	2	4	4	2	9	9	15	31	53	168
3	2	1	1	1	1	1	3	3	4	1
4	3									
5	2	1	6	1	1	2	1	6	1	5
6	1	2	2	2	1	1	5	3	19	100
7	5									
8	4	27	8	4	3	12	36	6	8	23
9	9	43	47	4	100	613	261	120	28	51
10	1	2	1	1	5	15	21	71	71	117
11	11	11	18	52	58	133	30	32	12	55
12	12	5	3	10	15	12	14	21		
13	13	13	20	29	102	228	220	351	373	61
14	11	4	1	4	7	1	3	9	17	14
15	15	2	21	9						
16	15	46								
17	7	3	11	46	50	28	51	49	98	438
18	10	134	76	218	511	510	453	1130	482	
19	19	1403	785	2136	1529	1634	1987	1917	742	207
20	11	1	1	1	3	5	8	2	9	7
21	17	19	19	181	112					
22	1	3	4	5	35	41	57	415	140	
23	9	20	10	55	132	192		548	1035	
24	24	5	4	10	1	2	4	22	121	285
25	10	9	4	31	36	66	116	30	72	41
26	20	20	4	3	1	1	1	5	2	6
27	8	26	23	10	29	44	23	40	30	14
28	28	94	91	124	330	474	1147	1081	835	
29	21	17	2	1	4	1	8	2	4	23
30	13	7	6	11	31					
31	30	189	417	116	740	266	357	274	495	483
32	27	12	15	67	166	268	295	217	204	229
33	26	77	291	85	87	45	44	38	52	57
34	34	36	189	191	138	249	393	406	399	399
35	25	42	30	3	22	13	30	18	26	10
36	2	2	6	14	18	73	17	27	23	28
37	37	33	44	552	2145	750	885	844		
38	11	35	20	134	210	370	318	164	172	78
39	9	3	23	31	176	152	58	55	155	6
40	7	16	79	105	84	119	122	40	88	80
41	41	26	105	338	52	41	25	18	24	94
42	10	113	112	138	22	13	104	551	549	253
43	43	102	98	68	13	10	52	73	59	75
44	44	24	14	66	64	67	80	39	17	45
45	44	256	355	30	37	200	262	183	92	278
46	46	240	308	845	3739	3892				
47	46	324	304	145	185	156	658	399	117	176
48	48	225	38	50	168	55	131	90	313	100
49	48	8	45	211	749	775	701			
50	32	78	147	170	181	662	477	595	1329	539
51	6	2	11	17	178	217	277	93	122	78
52	5	51	8	59	25	28	18	24	27	107
53	53	7	3	2	2	2	5	3	6	5
54	3	5	7	15	87	52	28	60	47	46
55	54	278	92	96	562	289	553	596	736	
56	56	116	226	55						
57	35	52	35	52	29	97	52	42	24	44
58	57	49	54	201	186					
59	23	173	217	832						
60	45	14	8	6	16	27	38	52	40	19
61	14	36	51	35	14	24	15	38	19	
62	62	14	60	55	64	137	70	44	27	76
63	52	37	15	73	69	143	45	191	380	204
64	7	16	8	11	8	22	19	158	43	98
65	50	107	68	98	67	40	35	62	37	84
66	65	312	143	370						
67	62	121	89	61	73	49	191	57	111	155
68	68	8	172	326						
69	69	102	93	220	448	623	699	511		
70	12	12	4	7	59	135	304	184	274	175
71	52	112	61	199	168	75	17	31	37	36
72	36	1	12	2	2	1	1	1	24	2
73	72	35	29	31	44	11	39	76	30	24
74	56	69	174	407	1011	1524				
75	75	44	67	404	856	2480				
76	75	156	73	143	329	277	238	403	467	
77	40	12	38	28	51	145	137	80	79	80
78	22	23	3	14	45	30	127	313	389	165
79	69	28	91	108	15	36	66	139	85	485
80	12	8	3	9	6	15	1	1	1	4
81	80	163	441	225	161	89	104	100	31	42
82	80	91	128	452	476	454	408	290	289	
83	43	274	278					1223	515	
84	36	109	143	122	45	46	15	8	5	10
85	84									
86	74	117	348	891	971	1524	1035	874	1136	342
87	15	16	413	192	242			695	833	
88	55	13	6	22	20	12	19	77	67	
89	89	52	51	158	370	1143	1137	2136	1550	805
90	90	222	315	416	306	320	568	326	175	175
91	77	63	123	300	98	68	22	22	14	7
92	19	121	229							
93	26	61	45	30	46	18	12	34	22	32
94	92	22	66	331	232	1172	945	395	720	119
95	94	230	258	259	282	131	52	32	17	18
96	19	13	19	99	113	328	193	433	1059	247
97	97	219	428	301	270	628				226
98	98	98	13	24	32	51	40	47	59	55
99	61	47	190	123	53	179	327	523	523	201
100	99	29	66	1	2	1	2	1	97	1

Left, 45.7-meter freestyle times; Mid, 45.7-meter freestyle national ranking; Right, the highest ranking achieved at adolescent ages (2004-2013).

APPENDIX C2: PERFORMANCE PROGRESSION IN THE US TOP 100 NINE-YEAR-OLD BOY SWIMMERS DURING ADOLESCENCE

ID	45.7-meter Fr time									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1	26.28	25.42	24.15	23.00	22.08	21.54	21.54	20.90	20.83	20.83
2	27.68	27.11	26.00	25.07	22.84	22.43	21.28	20.59	20.36	20.69
3	28.01	26.60	25.18	24.64				21.43	20.98	
4	28.11	26.82	25.51	24.12	22.97	21.77	21.25	21.33	20.67	21.26
5	28.23	25.99	24.42	22.66	22.56	22.00	21.73	21.32	21.21	21.01
6	28.30	26.96	25.89	24.61	23.00	22.29	21.73	21.47	21.32	21.06
7	28.42	27.96	26.85							
8	28.51	27.43	26.49	25.20	23.67	22.24	21.23			
9	28.55	26.87	25.39	23.97	23.87	23.31	23.13	23.15	22.63	22.97
10	28.58	28.21	26.54		25.96	22.90		21.80	21.31	
11	28.73	26.68	25.08	24.17	23.71	22.59	22.37	21.99	21.38	21.38
12	28.77	28.45	28.39	27.11	25.19	23.26	21.98	21.77	22.50	22.00
13	28.78	28.57	27.84	26.05	24.15	23.39	22.56	21.80	21.84	21.49
14	28.79	29.54								
15	28.79	27.61	27.46	25.96	25.66	24.24	23.71	22.21	21.49	20.77
16	28.80	27.09	25.82	24.43	23.67	22.95	22.64	22.38		
17	28.83	27.40	26.65	24.41	23.11	22.36	22.22			
18	28.87	26.91	26.29							
19	28.90	27.61	26.61	25.64	24.43	23.49	22.80	22.71		
20	28.96	27.65	26.76	26.55		24.77	22.41	21.65	21.06	21.35
21	29.04	28.04	27.09	26.48	25.66	23.53	22.40	21.88	21.30	21.27
22	29.08	27.56	26.32	25.06	24.12	22.82	22.28	22.14	21.02	20.58
23	29.10	28.14	27.17	25.92	25.37	23.93	23.00	22.63	22.28	22.23
24	29.13	28.24	26.77	25.41	24.26	23.22	22.28	21.83	21.41	21.87
25	29.13	27.01	24.80	23.94	22.88	21.91		20.74	20.65	
26	29.17	27.39	25.02	24.31	23.17	22.70	22.59	22.11	22.26	21.82
27	29.18	28.44	27.61	26.39	24.95	24.61				
28	29.19	29.10	26.99	26.17	25.66	24.42	23.73	23.34	23.03	22.10
29	29.23	28.32	27.29	25.97	25.44		22.88	22.63	22.23	22.95
30	29.23	27.07	26.25	24.21	23.71	22.66	21.99	21.63	21.94	22.20
31	29.33	27.82	27.89	25.76	24.90	24.66		23.36	22.43	21.35
32	29.38	27.77			26.06					
33	29.39									
34	29.41	28.52				27.40			21.98	
35	29.43	28.60	27.01	24.84	23.80	22.89	22.96	22.69	21.90	
36	29.43			34.09	29.93					
37	29.44	28.74	27.92	26.56	25.53	24.04	23.53	22.58	22.51	22.51
38	29.47	27.28	25.83	24.45						21.99
39	29.48	28.65	27.77	26.45	26.41	24.74	25.84	24.98	25.20	22.35
40	29.50	27.90	27.57	26.49	25.32	24.58	22.85	21.68	21.66	21.44
41	29.51	27.58	26.62	25.92	23.99	24.33	23.97	22.80	22.70	22.00
42	29.52	28.35	27.93	27.02	25.41	25.01	25.22	23.76	22.59	22.16
43	29.63	28.56	28.23	27.21	25.65	24.98			22.62	
44	29.64	28.67							24.10	
45	29.66	27.65	26.41	25.93	24.40	23.30	22.41	22.15	22.23	21.66
46	29.67	28.02	27.55	25.86	24.59	23.85	23.27	23.50	23.94	23.94
47	29.67	28.32	26.20	24.51	23.90	23.67	23.33	23.15		
48	29.70	28.04								
49	29.71	30.47	27.66	26.16	25.36	25.23				
50	29.71	28.53	27.99							
51	29.73	27.65	26.07	24.00	22.67	22.79	22.41	22.67	21.69	21.00
52	29.75	27.49	26.22	26.27	25.64	25.03	23.85	23.73	22.89	22.66
53	29.75	27.65	27.27	26.93	26.78	25.00	24.17	23.61		
54	29.75	28.01	26.73	26.30						
55	29.76	27.84	27.57	26.29	26.93	24.36	24.01	23.43	21.66	
56	29.77	29.38	27.56	25.97	25.56	24.47	23.28			
57	29.78	28.39	27.01	25.35	24.12	22.83	22.56	23.28	23.49	23.49
58	29.79	27.88	27.27	26.38	26.94	24.50	23.33	22.07	22.12	21.45
59	29.81	28.08	27.04							
60	29.81	28.44	26.91	24.50	23.37	22.63	22.27	22.15	21.83	21.48
61	29.81									
62	29.82	28.66	27.45	26.43	25.25					
63	29.83	28.18	27.19	26.45	25.05	23.56	22.73	21.36	20.93	20.51
64	29.84	27.87	27.10	24.34	23.21	22.13	21.42	20.90	20.22	19.83
65	29.86	27.94	26.70	24.77	22.83	21.39	21.62	21.01	20.74	20.63
66	29.87	25.36	25.07	23.49	22.56	21.17	20.92	20.54	20.52	20.30
67	29.87	28.15	28.04							
68	29.94	27.33	26.88	25.63	24.47			21.64	21.83	20.95
69	29.95	27.56	27.50	26.14	24.26	23.46	22.42	21.72	20.85	21.15
70	30.00	28.06	26.94	25.72	25.53		24.12		22.86	
71	30.01	28.32	27.87	26.89	25.71	25.34	24.06	22.47	22.31	22.00
72	30.04	28.93	28.93	27.42	26.83					
73	30.04	28.67	26.51	26.59	25.76				22.16	
74	30.05	28.26	25.94	25.18	23.59	22.41	21.07	20.25	20.36	20.07
75	30.05	28.26	27.40	26.90	25.90				24.10	
76	30.08	28.04	26.64	25.41	24.09	23.07	23.04	21.64	21.95	21.50
77	30.09	27.94	25.79	24.09	23.38	23.23	22.60			
78	30.10	28.91	26.91	24.17	23.70	23.61	22.90	24.36	24.13	
79	30.11	28.42	27.84	26.47	25.25	24.64	24.69	24.52	23.92	23.56
80	30.13	30.14	29.69	26.05	24.70	23.60	22.93	22.56	21.93	22.28
81	30.14	28.65	27.18	26.45	26.25	23.44	22.49	21.79	20.86	20.95
82	30.19	27.85	27.08	24.77	24.42	23.16	23.16	22.99	23.32	23.00
83	30.19	30.86	29.24	28.75	30.96					
84	30.19	28.22	27.67	26.42	24.79	23.33	22.91	22.53	21.78	21.78
85	30.20	32.01	30.72	30.42						
86	30.21	28.72	27.77	25.50	24.88	24.41				
87	30.21	29.67	28.78	28.95	28.50	26.90		24.26		
88	30.21	28.08	27.09	27.51	26.20					
89	30.22	29.25	29.05	28.61	26.44			23.05		
90	30.22	28.51	27.20	26.62			23.76			
91	30.23	28.70	27.45	27.18	26.79	24.79	25.65	23.79	22.54	22.00
92	30.25	28.70	27.73	26.62	25.41	23.93	23.01	22.43	21.91	21.69
93	30.26	28.39	25.52	24.56	23.41	22.56	22.00	21.48	21.50	20.99
94	30.27	27.95	26.90	25.97	24.91	23.44	21.79	22.60	22.52	21.67
95	30.27	28.66	26.88	25.01	23.63	22.33	22.77	22.75	22.98	22.57
96	30.28	28.35	27.25	26.04	26.42	24.37	23.30	22.72	22.80	
97	30.28		28.86	27.98	27.21					
98	30.29	28.88	27.33	25.77				23.11	21.51	20.82
99	30.31	28.92	27.96	26.13	26.00	24.52	23.79	23.63		
100	30.32	27.99	27.34	25.01	24.51	22.76	23.07	21.63	21.54	21.53

ID	US Ranking in 45.7-meter Freestyle									
	9	10	11	12	13	14	15	16	17	18
1	1	2	1	3	2	10	24	18	33	72
2	2	20	46	139	22	79	15	10	9	46
3	3	5	10	2				78	57	
4	4	9	18	29	29	16	14	59	24	222
5	5	3	2	1	12	23	36	57	100	98
6	6	13	35	77	31	55	36	93	124	104
7	7	70	129							
8	8	31	81	159	100	49	12			
9	9	10	15	17	140	319	559	1242	1163	1104
10	10	107	87		1323	172		188	121	
11	11	7	8	35	107	103	173	252	147	212
12	12	151	583	979	680	295	72	172	984	504
13	13	172	354	394	195	347	252	188	390	326
14	14	441								
15	14	45	250	363	1063	973	1126	385	207	74
16	16	19	30	56	100	190	283	481		
17	17	29	100	54	39	67	129			
18	18	12	65							
19	19	45	92	263	282	396	364	748		
20	20	48	117	643		1555	186	136	69	259
21	21	83	169	597	1063	423	185	206	115	177
22	22	41	67	137	188	154	147	331	65	44
23	23	100	184	348	819	702	483	678	750	636
24	24	109	119	196	217	278	147	195	154	518
25	24	16	5	16	24	18		13	22	
26	26	28	6	44	44	130	266	305	734	493
27	27	148	292	550	529	1369				
28	28	310	152	434	1063	1161	1149	1477	1683	569
29	29	123	212	368	877		412	678	692	1329
30	29	18	62	39	107	120	75	126	450	752
31	31	58	376	293	504	1430		1501	898	259
32	32	56			1412					
33	33									
34	34	163				5046			481	
35	35	182	154	110	127	168	456	735	428	
36	35			6984	5693					
37	37	214	384	648	958	810	934	641	994	802
38	38	26	31	59						591
39	39	193	334	581	1755	1508	4204	3966	4428	842
40	40	64	282	606	778	1347	391	144	286	298
41	41	43	95	348	160	1051	1444	843	1245	504
42	42	130	390	923	846	1863	3295	2104	1101	729
43	43	170	520	1050	1055	1821			1144	
44	44	198							3207	
45	45	48	73	353	264	313	186	338	692	396
46	46	80	276	321	348	636	686	1698	2993	1614
47	46	123	57	65	147	507	740	1242		
48	48	83								
49	49	785	302	432	811	2139				
50	49	165	418							
51	51	48	50	21	15	147	186	713	307	98
52	52	34	59	484	1044	1888	1295	2056	1478	1105
53	52	48	209	878	2175	1845	1712	1872		
54	52	77	112	503						
55	55	59	282	500	2349	1082	1492	1596	286	
56	56	388	279	368	983	1221	693			
57	57	238	154	183	188	157	252	1400	2340	1393
58	58	63	209	540	2362	1245	740	284	593	229
59	59	89	162							
60	59	148	137	63	59	112	143	338	383	316
61	59									
62	62	195	248	575	725					
63	63	105	191	581	592	442	319	63	48	25
64	64	62	173	46	47	36	20	18	5	3
65	65	66	105	98	20	7	28	24	29	40
66	66	1	7	8	12	4	4	7	17	13
67	66	102	437							
68	68	27	132	260	294			131	383	111
69	69	41	264	424	217	382	190	158	38	136
70	70	87	147	286	958		1643		1440	
71	71	123	369	852	1099	2283	1556	550	784	504
72	72	264	882	1209	2234					
73	72	198	83	661	1142				626	
74	74	114	38	155	87	74	7	2	9	8
75	74	114	233	857	1268				3207	
76	76	83	98	195	178	219	506	131	459	268
77	77	66	28	26	60	283	275			
78	78	256	137	35	106	475	425	3043	3239	
79	79	142	351	592	725	1406	2495	3275	2982	1421
80	80	651	1382	394	411	467	442	623	442	797
81	81	193	186	581	1581	375	222	182	39	111
82	82	60	168	98	276	259	602	1036	2087	1117
83	82	991	1085	2398	6434					
84	82	108	304	568	447	324	428	595	362	389
85	85	1637	2121	4083						
86	86	209	334	224	494	1142				
87	86	485	811	2620	4252	4483		2881		
88	86	89	169	1284	1524					
89	89	356	969	2272	1792			1120		
90	89	162	193	681			1183			
91	91	204	248	1031	2187	1587	3918	2142	1038	504
92	92	204	325	681	1305	702	487	520	432	339
93	93	138	19	71	62	97	79	95	197	95
94	94	68	136	368	513	375	44	662	1005	330
95	94	195	132	133	92	64	344	783	1597	1031
96	96	130	205	391	1765	1098	713	759	1373	
97	96		848	1685	2690					
98	98	248	221	297				1188	203	67
99	99	259	406	419	1348	1276	1216	1895		
100	100	73	222	133	315	141	525	126	218	340

ID	US highest ranking achieved									
	9	10	11	12	13	14	15	16	17	18
1	1	1	1	1	1	1	1	1	1	3
2	2	4	16	7	3	10	7	2	8	17
3	3	5	10	2				78	57	3
4	4	9	18	14	13	16	14	10	3	5
5	5	2	2	1	8	12	22	15	35	115
6	6	12	18	19	13	17	13	16	53	38
7	6	16	1	31	87	331	370	210	204	143
8	3	30	12	14	8	9	7			
9	6	3	2	1	42	134	1073	433	270	118
10	2	4	6	9	8	3	2	7	25	2
11	11	4	6	14	15	8	10	13	21	17
12	9	13	6	14	8	19	10	3	4	2
13	13	54	64	74	77	35	84	71	52	84
14	7	134								
15	3	4	77	56	19	5	12	14	1	1
16	4	12	22	28	100	190	283	481		
17	2	5	5	8	34	9	83			
18	12	8	65							
19	19	45	56	143	160	122	214	443	658	
20	11	33	95	244		138	49	109	54	35
21	21	83	102	120	75	43	71	51	23	81
22	12	14	18	31	125	23	6	307	65	13
23	10	34	161	124	236	280	214	559	344	257
24	6	6	57	71	169	226	121	195	154	298
25	16	16	2	9	11	3	3	2	1	1
26	26	28	4	11	44	130	232	305	713	482
27	5	5	24	157	306	302	808	609		
28	14	21	49	97	29	43	35	28	52	28
29	24	50	49	101	149		164	220	268	266
30	10	18	26	22	65	97	75	126	417	323
31	31	58	376	293	504	1430		1501	898	166
32	13	7	10	35	103	65	58	63	124	142
33	33									
34	13	104				2248			481	
35	35	37	56	34	82	122	235	456	385	
36	35		7439	3639	2853					
37	37	44	48	33	126	140	97	126	91	169
38	4	2	1	8						220
39	39	144	109	160	218	102	66	112	100	141
40	40	48	149	260	451	874	391	107	191	72
41	8	3	2	6	7	22	16	24	14	18
42	7	45	39	205	166	430	505	407	185	98
43	31	132	89	300	392	190	74	46	23	56
44	44	198							3207	
45	27	24	32	40	72	117	61	56	19	32
46	26	21	31	37	24	54	75	106	139	148
47	9	27	3	1	1	3	12	6	389	46
48	23	9								
49	6	16	29	20	50	187				
50	49	13	180							
51	9	10	12	5	6	15	6	16	24	44
52	9	8	20	50	272	131	87	1203	41	89
53	52	48	5	29	314	169	192	216		
54	7	7	5	5	10	11	16	55	15	51
55	55	59	60	145	384	484	849	897	286	
56	8	5	13	16	16	20	20	12	5	2
57	57	125	145	183	188	148	123	163	223	405
58	58	63	134	232	398	446	194	89	137	87
59	59	89	141							
60	59	13	15	14	17	5	12	25	31	35
61	59	2367								
62	48	118	248	575	725					
63	63	101	130	135	116	87	46	63	48	25
64	19	17	2	3	12	15	14	12	5	3
65	39	28	16	34	20	7	28	24	29	36
66	66	1	6	8	5	1	2	7	7	13
67	27	102	76							
68	36	27	132	100	254			131	355	111
69	52	18	208	227	217	246	153	71	35	120
70	70	45	52	96	166	161	184	192	109	698
71	2	3	16	70	88	92	40	67	22	140
72	19	49	33	88	401		269		187	
73	72	198	83	271	818				626	
74	74	30	38	141	87	74	7	2	624	8
75	24	43	57	134	391	828			2004	
76	41	23	31	34	10	6	12	34	55	93
77	8	8	4	3	7	11	43	82	211	268
78	78	256	128	35	106	151	87	78	148	49
79	4	10	4	7	60	40	41	32	53	168
80	3	77	45	73	27	16	8	31	32	105
81	3	5	13	46	274	138	96	69	39	100
82	24	11	9	19	15	112	133	394	294	293
83	78	464	1085	1976	4639					
84	82	21	40	45	57	65	28	132	71	371
85	85	1132	2121	3906						
86	35	34	57	22	10	7	13	9	22	73
87	5	39	39	97	897	516	399	303	270	319
88	18	12	12	76	341					
89	68	227	556	452	483	152	223	201	1430	
90	87	39	120	408			1183			
91	70	20	24	79	280	212	238	355	180	174
92	54	204	96	343	508	555	377	337	281	338
93	93	138	19	71	54	74	452	77	197	69
94	62	38	24	81	43	207	27	328	353	141
95	14	27	41	23	11	25	37	75	143	203
96	23	75	41	88	148	513	282	228	437	
97	96		795	955	2039					
98	98	248	221	297				789	203	86
99	99	234	120	98	374	775	729	970	1225	
100	85	25	40	53	234	136	154	126	218	340

Left, 45.7-meter freestyle times; Mid, 45.7-meter freestyle national ranking; Right, the highest ranking achieved at adolescent ages (2004-2013).

APPENDIX C3: PERFORMANCE PROGRESSION IN THE US TOP 100 18-YEAR-OLD GIRL SWIMMERS IN 45.7-METER FREESTYLE DURING ADOLESCENCE

ID	45.7-meter Fr time									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1			25.81	24.97	24.60	23.24	23.19	22.44	22.76	21.89
2	31.25	29.57	27.50	25.43	25.07	24.04	23.73			22.37
3	31.36	26.19	24.59	23.81	23.74	23.35	22.79	23.11	22.94	22.49
4	33.45	29.73	26.83	25.19	24.35	23.98	23.92	23.44	23.67	22.53
5	31.25	29.36	27.86	26.12	25.41	23.92	23.55	23.66	23.01	22.74
6	31.62	26.73	25.06	24.57	23.98	23.25	23.26	23.25	22.89	22.74
7				30.78	27.96		24.39	22.98	24.15	22.79
8	37.63	29.28	28.06	25.04	24.54	23.89	23.22	23.50	23.29	23.01
9					25.24	24.74	24.09	23.82	23.32	23.01
10	32.26	28.61	27.67	25.86	25.19	23.78	23.74	24.57	23.98	23.02
11				29.46	26.69	25.26	23.74	23.43	22.96	23.04
12		29.98	28.37	26.51	26.14	24.29	24.03	24.07	23.88	23.05
13	32.83	28.90	28.03	26.75	25.24	24.72	24.55	24.24	23.88	23.09
14		33.06	30.33	28.87	28.99	26.67	24.68	24.35	23.86	23.13
15	38.06	32.11	28.13	27.81	27.37	24.54	24.43	23.16	23.25	23.13
16	36.75	29.59	27.81	25.95	25.30	25.63		24.47		23.14
17		30.87	29.09	26.75	25.13	24.32	24.11	23.93	24.14	23.15
18			27.43	25.48	25.13	24.67	24.40	24.09	23.96	23.22
19	30.54	28.45	27.98	26.39	25.52	24.39	24.04	23.48	23.49	23.27
20	32.77	30.64	29.43	27.79	27.16	24.54	23.83	23.39	23.43	23.28
21	34.92	30.55	29.04	26.49	24.98	24.73	23.95	24.22	23.50	23.29
22				29.37	27.73	27.59	26.02	24.88	23.68	23.30
23		29.80	27.15	25.66	24.55	24.74	24.19	24.39	24.09	23.31
24		38.51	31.08	28.66		25.36	23.91	24.10	23.42	23.32
25	36.47	32.13	28.57	27.56	26.29	25.70	24.16	23.62	23.67	23.34
26		35.34		25.77	24.57	24.29	24.33	23.74	23.78	23.39
27	30.30	27.55	27.02	25.87	25.49	24.26	24.34	23.96	23.89	23.43
28	34.10	30.06	28.47	27.23	25.63	24.79	24.23	23.69	23.48	23.44
29				27.17	24.77	24.19	24.35	23.30	23.89	23.45
30			27.23	25.85	25.40	24.56	24.24	23.99	24.00	23.46
31	29.38	27.53	25.74	24.81	23.99	23.27	22.74	23.16	22.92	23.48
32	40.05	31.53	27.29	24.72	24.09	23.53	24.01	23.29	23.38	23.49
33		35.97	30.17	27.87	25.91	25.17	24.64	24.94		23.49
34					29.17	26.04	25.19	24.46	24.06	23.50
35			30.23	27.31	26.20	25.41	24.71	24.50	25.21	23.50
36	38.44	31.93	31.17	27.02	26.28	24.28	24.26	24.48	25.72	23.54
37	29.16	27.06	25.92	24.96	25.07	24.54	24.09	23.35	22.99	23.54
38			28.46	25.50	25.01	24.05	23.84	23.65	23.83	23.58
39		37.20	32.44	29.26	27.54	25.95	24.84	24.07	23.96	23.58
40			29.89	28.07	25.99	23.51	23.43	23.11	23.33	23.59
41			32.55	28.48	25.94	24.47	24.36	23.46	23.61	23.60
42		35.96	30.32	27.85	27.28	27.02	25.14	24.21	23.85	23.60
43				27.08	25.56	24.75	24.27	24.12	23.69	23.61
44		32.58	28.91	25.98	26.31	25.76	25.02	24.41	23.85	23.61
45	33.57	30.18	29.06	27.00	26.20	24.74	24.36	24.11		23.64
46	30.86	28.82	26.23	26.08	24.80	24.34	24.33	24.18	24.55	23.64
47	43.59	35.61	29.16	27.29	26.76		25.57	25.83	24.37	23.65
48				26.36	25.54	24.16	24.05	23.68	24.89	23.65
49	30.40	28.78	27.86	25.72	24.87	25.69		24.15	23.81	23.66
50	29.91	28.89	26.77	25.83	25.75		24.60	24.08	24.62	23.67
51		33.27	29.11	26.96	25.50	24.46	24.67	24.19	24.26	23.68
52				30.73	27.67	27.03	25.40	24.78	24.33	23.68
53	36.57	31.10	29.08	26.49	24.90	24.52	24.50	23.93	23.99	23.69
54		30.61	27.50	26.37	25.89	25.83	25.24	24.90	24.42	23.69
55					25.51	25.07		24.79	24.68	23.70
56	31.26	29.05	26.40	25.92	25.19	23.76	23.27	22.83	22.75	23.70
57	33.50	29.38	27.53	25.61	24.40	23.91	24.22	24.56	24.19	23.73
58			28.40		25.90	24.60	24.67		23.76	23.73
59	40.53	35.51	31.35	29.10	27.87	26.35	25.55	24.92	25.02	23.73
60					29.17		25.31	23.71	23.65	23.74
61					26.30	24.79	24.29	24.03	23.63	23.76
62	34.11	32.67	29.08	25.95	25.86	24.21	24.23	23.75	23.83	23.78
63		30.75	27.64	25.99	25.68		23.95	24.14	24.71	23.78
64	41.96	32.44	28.60	27.30	25.62	24.95	24.90	24.68	24.02	23.78
65			26.98	25.40	25.24	24.48	24.26	23.92	23.77	23.78
66	30.90	29.21	27.31	26.15	27.21	24.91	24.04	23.51	24.35	23.81
67	37.80	31.74	28.71	26.70	25.83	24.56	24.47	24.51	23.69	23.82
68	39.53	32.69	28.47	25.96	25.76	24.43	23.90	23.86	23.89	23.83
69		35.77	30.31	28.63	27.33	25.03	24.85	24.43	23.98	23.86
70			30.71	25.37	24.74	24.70		24.56	24.43	23.86
71	32.49	30.12	27.22	24.93	24.90	24.25	23.95	24.10	23.82	23.88
72		33.94	31.95	27.48	27.05	25.76	24.73	24.09	24.00	23.88
73	31.74	29.10	27.24	25.95	24.67	24.30	24.67	24.34	24.01	23.89
74				28.47	26.44	25.57	25.29	24.57	24.49	23.90
75	33.58	30.50	28.06	26.42	27.16	25.96	25.69	25.72	24.85	23.91
76	38.10	31.71	28.91	26.91	25.51	24.34	24.25	23.67	23.74	23.91
77					28.54	26.60	25.41	24.21		23.92
78	32.31	28.31	27.03	26.84	26.97	25.05	24.40	24.11	24.52	23.92
79	39.96	32.51	30.44	27.60	25.64	25.09	24.24	24.30	24.06	23.93
80	30.26	28.40	26.86	25.46	25.05	24.23	24.54	23.96	24.19	23.93
81	35.94		29.26	26.20	25.45	23.87	24.08	24.18	24.08	23.94
82						24.38	24.09	24.05		23.95
83	32.11	30.13	26.66	25.90	25.36	24.66	24.54	24.39	24.24	23.95
84	34.25	30.95	27.65	26.29	25.83	24.46	24.00	23.82	23.18	23.95
85	32.53	30.55	29.03	27.22	26.45	25.04	24.35	24.34	24.10	23.95
86	27.85	26.53	25.30	24.34	24.14	23.77	23.79	23.57	23.68	23.96
87	34.25	30.10	27.39	25.45	25.16	25.02	24.99		25.11	23.98
88	31.90	31.25	29.30	27.68	26.49	25.26	24.80	24.50	23.81	23.98
89			37.33	30.20	27.09	25.71	24.62	23.98	23.72	23.98
90	35.87	32.79	28.36	26.26	25.75	25.14	24.57	24.04	24.32	23.98
91				26.89	25.72	24.95	24.77	24.28	24.06	23.99
92	34.37	30.59	29.36	26.96	26.03	25.12	24.60	24.34	24.00	24.00
93	35.48	33.00	29.27	26.63	25.20	24.86	23.90	24.59	23.97	24.00
94	36.51	33.72	30.77	27.94	25.91	25.82	24.68	24.43	24.31	24.01
95	34.81	30.62	28.74	25.97	24.74	24.58	24.17	24.17	24.20	24.02
96	36.71	34.46	30.62	29.18	26.66	25.36	24.87	24.40	24.47	24.02
97	31.17	29.63	28.35	26.91	26.46	25.99	26.03	24.78	25.54	24.02
98					28.49	26.45	26.74	25.24	24.97	24.03
99	38.73	30.14	28.18	26.36	25.30	24.73	24.16	24.23	23.85	24.03
100	31.80	29.13	26.85	25.71	25.23	24.47	24.18	23.67	23.80	24.03

ID	National Ranking in 45.7-meter Freestyle									
	9	10	11	12	13	14	15	16	17	18
1			11	16	24	3	4	1	2	1
2	198	432	237	55	82	30	20			2
3	211	2	1	1	3	7	2	7	8	3
4	879	494	82	30	12	27	38	21	55	4
5	198	359	372	206	170	25	14	36	11	5
6	263	6	2	5	6	5	6	12	5	5
7				6621	2842		138	5	165	7
8	3771	335	458	19	18	22	5	25	20	8
9					133	161	66	55	22	8
10	420	159	299	124	112	16	21	309	114	10
11				4161	969	365	21	19	9	11
12		606	641	360	516	58	52	100	90	12
13	618	230	444	488	133	151	201	161	90	13
14		3254	2768	3076	4936	1683	241	202	86	14
15	4137	2186	493	1466	1858	112	151	9	16	14
16	3041	441	347	153	143	598		251		16
17		1144	1266	488	93	63	72	69	164	17
18			219	65	93	138	143	106	107	18
19	93	132	417	304	203	76	54	24	36	19
20	596	998	1621	1438	1570	112	29	18	31	20
21	1695	931	1214	349	57	155	40	152	37	21
22				4001	2426	3159	1222	473	58	22
23		525	140	87	20	161	86	214	148	23
24		9491	3794	2699		416	37	109	30	24
25	2798	2215	770	1155	621	664	79	33	55	25
26		6015		108	21	58	115	48	71	26
27	74	35	112	130	191	52	118	76	93	27
28	1220	651	714	823	246	177	89	40	34	28
29				783	37	42	122	15	93	29
30			156	121	167	116	91	84	120	30
31	28	34	8	10	7	6	1	9	7	31
32	5710	1649	177	9	8	10	48	14	27	32
33		6774	2539	1542	384	324	225	506		32
34					5319	961	492	244	137	34
35			2636	891	552	454	251	265	825	34
36	4462	2011	3930	661	615	56	98	257	1289	36
37	22	15	16	15	82	112	66	16	10	36
38			706	67	65	31	31	34	80	38
39		8184	5840	3782	2109	872	308	100	107	38
40			2171	1819	423	9	9	7	23	40
41			6021	2412	394	93	126	22	47	41
42		6763	2758	1507	1707	2183	462	148	83	41
43				704	223	167	101	120	60	43
44		2699	1076	168	638	700	389	221	83	43
45	945	721	1232	644	552	161	126	112		45
46	140	211	34	195	39	67	115	139	330	45
47	8150	6370	1332	865	1047		796	1334	249	47
48				292	212	38	58	39	554	47
49	82	199	372	98	42	652		130	76	49
50	50	225	74	115	292		215	104	374	50
51		3496	1287	628	195	89	233	142	208	51
52				6522	2323	2200	668	410	234	51
53	2868	1299	1254	349	46	108	174	69	118	53
54		976	237	299	374	773	525	487	264	53
55					199	274		419	411	55
56	200	272	45	143	112	14	7	4	1	55
57	906	368	250	81	13	24	88	300	180	57
58			664		381	128	233		68	57
59	6084	6238	4195	3489	2668	1266	782	494	672	57
60					5319		588	46	52	60
61					628	177	109	88	49	61
62	1222	2795	1254	153	359	44	89	50	80	62
63		1076	287	172	264		40	127	424	62
64	7112	2560	798	880	243	223	334	369	128	62
65			107	49	133	98	98	68	70	62
66	148	312	185	220	1630	208	54	26	243	66
67	3926	1837	899	458	341	116	161	270	60	67
68	5332	2818	714	158	297	83	34	61	93	68
69		6543	2743	2657	1793	257	312	229	114	69
70			3288	45	33	144		300	270	69
71	495	690	154	12	46	50	40	109	78	71
72		4340	5090	1061	1405	700	261	106	120	71
73	292	285	162	153	29	62	233	196	126	73
74				2395	740	554	570	309	292	74
75	953	908	458	316	1570	885	893	1238	525	75
76	4172	1811	1076	584	199	67	94	37	65	76
77					3980	1571	677	148		77
78	441	106	114	548	1286	263	143	112	311	77
79	5644	2631	2898	1202	252	286	91	181	137	79
80	69	121	89	61	73	49	191	76	180	79
81	2378		1437	238	182	20	64	139	146	81
82						75	66	94		82
83	385	696	62	138	155	137	191	214	200	82
84	1304	1190	293	272	341	89	45	55	13	82
85	512	931	1211	813	749	259	122	196	151	82
86	4	4	4	2	9	15	27	31	58	86
87	1304	676	206	60	103	255	375		735	87
88	328	1410	1476	1304	781	365	290	265	75	87
89			12036	5570	1468	670	221	81	64	87
90	2329	2946	639	263	292	308	204	89	229	87
91				570	281	223	277	171	137	91
92	1369	962	1543	628	444	300	215	196	120	92
93	2062	3195	1444	416	118	196	34	319	113	92
94	2829	4089	3393	1640	384	763	241	229	226	94
95	1627	982	927	162	33	124	81	135	186	95
96	3004	4950	3155	3652	938	416	320	218	285	95
97	185	454	633	584	756	917	1242	410	1111	95
98					3887	1379	2159	739	631	98
99	4711	703	523	292	143	155	79	154	83	98
100	311	294	85	95	128	93	84	37	74	98

Left, 45.7-meter freestyle times; Right, 45.7-meter freestyle US ranking

APPENDIX C4: PERFORMANCE PROGRESSION IN THE US TOP 100 18-YEAR-OLD BOY SWIMMERS IN 45.7-METER FREESTYLE DURING ADOLESCENCE

ID	45.7-meter Fr time									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1	30.44	27.43	26.97	25.20	24.03	22.36	20.60	20.23	20.00	19.67
2	30.57	27.53	26.80	26.54	25.05	24.61	23.22	21.14	20.54	19.80
3	29.84	27.87	27.10	24.34	23.21	22.13	21.42	20.90	20.22	19.83
4		29.73	29.05	25.49	23.49	22.00	20.56	20.45	19.85	19.85
5	33.57	29.96	28.19	24.74	24.11	21.18	21.45	21.15	20.35	19.91
6	36.73	29.63	27.44	24.66	23.25	22.04	21.22	20.67	20.24	20.03
7	30.05	28.26	25.94	25.18	23.59	22.41	21.07	20.25	20.36	20.07
8			33.13		25.79	22.83	21.92	21.09	20.57	20.13
9	38.18	29.16	26.39	24.15	22.04	21.01	20.88	20.49	21.07	20.27
10	29.87	25.36	25.07	23.49	22.56	21.17	20.92	20.54	20.52	20.30
11	31.83	28.58	26.84	25.72	24.16	22.38	21.40	20.88	20.23	20.33
12		29.74	26.14	24.12	22.53	21.87	22.05	20.58	20.10	20.35
13			28.43	26.41	25.98	23.28	22.36	21.59	20.82	20.35
14				26.48	25.88	23.33	22.57	21.36	21.73	20.37
15					23.41	22.63	21.82	21.12	20.67	20.37
16	35.40	30.55	27.16	25.44	23.83	22.05	21.08	20.55	20.44	20.39
17						21.16	21.16	20.36	20.07	20.43
18	36.87	31.45	29.94	25.35	23.77	22.22	21.89	20.77	20.61	20.47
19					26.34	23.99	22.15	21.69	21.56	20.49
20	29.83	28.18	27.19	26.45	25.05	23.56	22.73	21.36	20.93	20.51
21	32.29	28.93	27.53	26.08	24.50	23.12	22.88	21.35	20.84	20.52
22				28.85	24.69	24.23	22.20	21.39	21.35	20.52
23		35.94	30.39	26.76	26.14	22.81	21.82	22.14	21.67	20.53
24		30.28	28.56	26.21	25.12	22.98	22.70	21.45	21.06	20.54
25		30.38	28.54	26.58	26.72	24.14	24.20	21.44	21.20	20.58
26	31.40	28.71	26.92	25.87	24.48	22.32	21.87	21.26	20.98	20.59
27		29.83	28.19	26.17	26.53	24.75	23.71	21.95	21.29	20.61
28				26.93		22.76	21.81	20.95	20.78	20.61
29			34.55	29.78	24.40	23.58	22.68	21.42	20.69	20.61
30							23.55	21.79	21.45	20.62
31	30.82	27.47	25.68	25.16	24.36	23.65	22.15	21.11	20.71	20.62
32						23.81	22.97	22.08	21.89	20.62
33	29.86	27.94	26.70	24.77	22.83	21.39	21.62	21.01	20.74	20.63
34			37.25		30.75	23.80	22.63	21.92	21.00	20.63
35	33.84	31.69		26.14	23.54	22.27	21.31	21.22	21.37	20.65
36				29.02	27.37	23.77	22.74	22.48	21.71	20.65
37	30.68	29.48	29.68	26.37	24.17	22.43	21.23	20.90	20.90	20.66
38						25.05	22.54	21.89	21.53	20.69
39	27.68	27.11	26.00	25.07	22.84	22.43	21.28	20.59	20.36	20.69
40					24.19	22.87	21.69	21.66	21.45	20.69
41	30.98	28.87	28.15			24.30	21.89	21.26	20.58	20.69
42	34.01	30.85	29.72	28.23	26.33		24.84	22.84	22.17	20.70
43	30.61	28.25	28.74	26.12	23.43	22.81	22.01	21.26	21.28	20.74
44			27.75	25.78	25.48	23.15	22.09	21.39	20.95	20.75
45							23.95	22.48	21.69	20.75
46	32.45	28.14	26.47	25.22	24.64	22.84	21.46	21.78	20.68	20.76
47			33.07	29.16	26.66	25.24	23.67	22.14	22.09	20.77
48		29.42	25.98		22.66	22.66	21.89	21.27	20.92	20.78
49	37.23	32.17	31.63	28.48	27.06	24.86	23.20	22.23	21.42	20.79
50		30.62	28.67	26.51	24.72	22.78	22.30	21.42	21.19	20.79
51	33.02	30.35	28.83	28.27	25.41	23.45	22.16	21.17	20.86	20.79
52					26.62	23.39	22.22	21.50	20.96	20.80
53								22.70	21.65	20.80
54			30.54	26.94	25.73	23.61	24.00	22.45	21.32	20.81
55	39.54	34.75	28.25	24.09	22.49	21.41	20.97	20.84	20.52	20.82
56	30.29	28.88	27.33	25.77			23.49	23.11	21.51	20.82
57			47.78	27.73	26.35	23.92	22.78	22.27	21.37	20.82
58		33.84	28.77	24.89	23.69	22.61	22.92	21.71	21.69	20.82
59			29.76	24.51	22.23	20.81	20.97	20.94	20.89	20.85
60			32.20	30.56	27.65	24.19	22.51	21.76	22.05	20.85
61				27.50	24.45	22.74	22.05	21.46	21.02	20.86
62	39.38	33.14	30.23	26.69	24.89	22.32	21.79	21.52	21.40	20.86
63	36.18	32.74		30.81	26.91	23.52	22.50	21.36	21.11	20.89
64	40.64	34.81		30.09	28.01	24.79	23.48	22.23	21.41	20.91
65				33.07	27.20	24.75	23.48	21.75	21.50	20.92
66			31.29	26.79	23.41	21.40	21.66	21.20	21.08	20.93
67	30.54	29.05	27.48	25.21	23.74	21.71	21.41	21.13	21.13	20.93
68	33.34	30.97	27.82	25.18	24.72	22.56	21.69	21.15	21.14	20.94
69	31.99	29.53	27.20	25.46	23.16	22.87	22.45	21.97	21.09	20.94
70	34.13	31.85	29.13	27.29	24.75	23.69	22.08	21.48	21.15	20.95
71				27.20	23.50	22.56	21.99	21.37	20.90	20.96
72	33.82	30.46	30.09	28.13	25.57	24.25	22.80	21.99	21.47	20.97
73		31.87	27.43	25.87	25.34	23.31	22.35	21.64	21.22	20.97
74	38.53	32.49	28.68	26.24	25.05	23.60	22.75	22.29	22.29	20.98
75	32.62	30.60	28.60	26.61	25.36	22.30	21.64	20.69	20.65	20.98
76	30.67	28.44	26.59	26.20	25.33	24.65	23.09	21.63	21.38	20.98
77	32.35	31.09	28.51	27.39	25.49	24.05	22.55	21.08	21.14	20.99
78	30.26	28.39	25.52	24.56	23.41	22.56	21.77	21.48	21.50	20.99
79	33.42	31.48	28.21	27.10	26.45	24.79	23.93	22.02	21.55	21.03
80				30.87	27.16	24.68	23.89	23.73	21.50	21.03
81		28.25	27.14	26.33	25.50	22.76	23.37	22.29	20.99	21.03
82	34.31	30.95	30.95	25.44	23.84	22.55	21.99	22.27	21.97	21.05
83	31.45	28.17	27.41	24.71	23.57	22.09	22.07	21.24	21.69	21.05
84					26.41	22.99	21.78	21.16	21.16	21.06
85	28.30	26.96	25.89	24.61	23.00	22.29	21.73	21.47	21.32	21.06
86	32.49	30.18		26.38	24.75	23.06	21.96	21.37	20.97	21.06
87	30.83	29.17	28.32	26.36	27.85	26.38	23.41	22.45	21.88	21.06
88			30.74			22.93	22.70	21.54	20.83	21.06
89	38.27	29.99	28.66	27.20	25.85	24.47	23.77	23.21	21.19	21.08
90					31.97	25.51	24.36	22.38	21.33	21.08
91	31.07	28.12	26.59	25.40	24.74	23.41	23.21	23.21	21.17	21.12
92		35.79	29.97	26.52	24.10	22.88	22.09	21.93	21.27	21.12
93		30.42	28.55	26.18	25.09	23.34	22.10	22.24	21.36	21.12
94	35.53	29.46	28.15	25.51	24.25	22.77	22.28	22.23	21.43	21.12
95	33.33	30.49	29.52	27.82	25.35	22.89	22.74	22.11	21.58	21.13
96	34.45	31.22	31.06	28.86	25.11	23.62	22.91	23.35		21.13
97		36.98	31.90	29.19	28.55	26.61	23.30	22.32	22.06	21.13
98			30.99	27.89	26.90	26.66	23.81	22.12	21.56	21.13
99					27.37	25.47	23.70	22.05	21.55	21.13
100	30.78	28.63	27.06	25.70	24.36	23.25	22.48	21.74	21.71	21.13

ID	National Ranking in 45.7-meter Freestyle									
	9	10	11	12	13	14	15	16	17	18
1	115	31	149	159	170	67	2	1	2	1
2	138	38	124	636	592	1369	656	32	19	2
3	64	62	173	46	47	36	20	18	5	3
4		510	969	223	73	23	1	5	1	4
5	837	591	511	94	187	18	21	35	8	5
6	2250	468	246	82	48	27	11	11	7	6
7	76	114	38	155	87	74	7	2		7
8			4256		1167		61	28	20	8
9	2980	327	70	32	1	2	3	6	73	9
10	67	1	7	8	12	4	4	7	17	10
11	342	175	126	286	196	71	18	16	6	11
12		511	53	29	11	17	95	9	4	12
13			603	562	1336	304	169	115	32	12
14				597	1255	324	258	63	333	14
15							48	30		14
16	1599	825	183	205	131	28	8	8	13	16
17							10	3		17
18	2325	1303	1584	183	121	44	57	14	33	18
19					1685	752	118	149	223	19
20	63	105	191	581	592	442	319	63	48	20
21	442	264	272	403	306	242	412	62	36	21
22				2510	404	965	124	73	129	21
23		4387	1887	762	1485	152	48	331	298	23
24		701	667	460	645	197	303	84	69	24
25		741	658	657	2100	890	1745	80	97	25
26	274	208	141	324	298	61	56	49	57	26
27		546	511	434	1887	1525	1126	237	114	27
28				878			47	22	30	27
29			5401	3472	264	451	298	76	26	27
30							958	182	173	30
31	176	33	22	151	248	493	118	29	28	30
32						613	462		421	30
33	66	66	105	98	20	7	28	24	29	33
34			7054		6292	603	282	221	62	33
35	937	1399		424	82	53	16	43	140	35
36				2690	2859	580	324	556	323	35
37	157	418	1372	537	198	79	12	18	45	37
38						1910	244	209	211	38
39	2	20	46	139	22	79	15	10	9	38
40					202	164	32	140	173	38
41	201	245	488			1019	57	49	21	38
42	1011	986	1418	1890	1676		2738		635	42
43	145	110	780	416		152	81	49	113	43
44			330	302	910	254	103	73	51	44
45								556	307	44
46	482	100	78	164	376	159	22	179	25	46
47			4185	2824	2014	2157		331	567	47
48		401	44		14	120	57	53	47	48
49	2508	1742	2916	2139	2510	1683	630	397	160	49
50		855	739	614	417	145	157	76	94	49
51	642	813	835	1940	846	379	121	39	39	49
52					2003	347	129	101	53	52
53								741	282	52
54			1984	883	1112	475	1472	534	124	54
55	3577	3550	530	26	9	9	5	15	17	55
56	100	248	221	297				1188	203	55
57			9402	1450	1691	696	349	422	140	55
58		2876	801	116	105	107	435			55
59			1452	65	4	1	5	21	44	59
60			3440	4247	3214	931	229	166	535	59
61				1278	288	137	95	87	65	61
62	3506	2356	1785	728	500	61	44	103	152	61
63	1941	2109		4507	2320	418	226	63	80	63
64	4050	3589		3767	3683	1587	890	397	154	64
65				6358	2678	1525	890	164	197	65
66			2581	784	62	8	31	41	76	66
67	134	294	259	162	115	13	19	31	84	67
68	746	1038	348	155	417	97	32	35	87	68
69	381	438	193	214	42	164	207	243	77	68
70	1044	1532	1014	1102	431	521	95	95	90	70
71				1043	76	97	75	67	45	71
72	928	780	1687	1796	992	979	364	252	186	72
73		1542	245	324	795	319	167	131		72
74	3140	1948	749	469	592	467	332			74
75	529	843	691	673	811	58	29	12	22	74
76	156	148	89	446	786	1419	545	126	147	74
77	459	1103	654	1183	918	817	250	27	87	77
78	95	138	19	71	62	97		95	197	77
79	776	1322	516	970	1805	1587	1392	267	220	79
80				4561	2618	1447	1336	2056	197	79
81		110	181	517	930	141	784	433	59	79
82	1124	1030	2298	205	133	94	75	422	472	82
83	282	104	235	87	85	32	99	47	307	82
84					1755	203	42	37	91	84
85	6	13	35	77	31	55	36	93	124	84
86	498	662		540	431	216	68			84
87	179	330	533	531	3479	3788	827	534	413	84
88			2146			184	303	108	33	84
89	3020	601	737	1043	1226	1221	1195	1306	94	89
90					6999	2553	1983	481	126	89
91	218	95	89	191	426	358	642			91
92		4278	1608	619	184	166	103	225	110	91
93		766	663	439	621		107	404	135	91
94	1655	411	488	230	214	143	147	397	167	91
95	742	797	1253	1535	802	168	324	305	235	95
96	1187	1153	2390	2523	633	482	428	1491		95
97		5028	3149	2865	4304	4105	713	449	544	95
98			2323	1596	2310	4164	1240	315	475	95
99						2494	1113	279	220	95
100	172	189	165	280	248	292	219	160	323	95

Left, 45.7-meter freestyle times; Right, 45.7-meter freestyle US ranking

APPENDIX D: LOG-TRANSFORMED TIMES IN 45.7-METER FREESTYLE IN THE US TOP 100 NINE-YEAR-OLD SWIMMERS IN 2004 FOR THE SUB-SEQUENT 10 YEARS AND THOSE OF THE US TOP 50TH, 100TH, 500TH, 1000TH, AND ALL-TIME SWIMS FOR 10 AGE CATEGORIES FROM 2004 TO 2015

GIRLS

	Log-transformed all-time US 45.7Fr times (2004-2015)																			
	Top 100 9-year olds			50th			100th			500th			1000th			All-time swims			
Age	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	Median	CI_{lower}	CI_{upper}
9	3.393 ± 0.025	3.388	3.398	3.390 ± 0.007	3.385	3.394	3.409 ± 0.008	3.404	3.414	3.469 ± 0.010	3.499	3.514	3.506 ± 0.012	3.499	3.514	3.744 ± 2.493	3.704	3.601	3.830
10	3.340 ± 0.034 *	3.333	3.347	3.318 ± 0.008 *	3.313	3.323	3.335 ± 0.008 *	3.330	3.340	3.385 ± 0.010 *	3.408	3.423	3.416 ± 0.012 *	3.408	3.423	3.643 ± 1.953	3.606	3.507	3.724
11	3.304 ± 0.033 *	3.297	3.310	3.269 ± 0.008 *	3.264	3.275	3.285 ± 0.009 *	3.279	3.291	3.330 ± 0.009 *	3.351	3.364	3.357 ± 0.011 *	3.351	3.364	3.556 ± 1.754	3.521	3.436	3.627
12	3.267 ± 0.034 *	3.260	3.274	3.228 ± 0.009 *	3.223	3.234	3.243 ± 0.008 *	3.237	3.248	3.284 ± 0.009 *	3.302	3.315	3.308 ± 0.010 *	3.302	3.315	3.476 ± 1.566	3.445	3.371	3.537
13	3.252 ± 0.036	3.244	3.260	3.207 ± 0.010 *	3.201	3.213	3.220 ± 0.009 *	3.214	3.226	3.261 ± 0.010 *	3.277	3.291	3.284 ± 0.011	3.277	3.291	3.423 ± 1.758	3.396	3.336	3.474
14	3.234 ± 0.042	3.224	3.244	3.187 ± 0.011 *	3.180	3.194	3.200 ± 0.011 *	3.194	3.207	3.240 ± 0.011 *	3.257	3.272	3.265 ± 0.012	3.257	3.272	3.382 ± 2.019	3.360	3.304	3.427
15	3.227 ± 0.044	3.217	3.238	3.176 ± 0.009	3.170	3.182	3.190 ± 0.010	3.184	3.196	3.231 ± 0.011	3.249	3.265	3.257 ± 0.013	3.249	3.265	3.354 ± 1.214	3.336	3.284	3.395
16	3.221 ± 0.046	3.210	3.232	3.170 ± 0.011	3.163	3.176	3.183 ± 0.012	3.176	3.191	3.225 ± 0.012	3.243	3.262	3.252 ± 0.015	3.243	3.262	3.334 ± 1.111	3.319	3.268	3.374
17	3.220 ± 0.046	3.208	3.231	3.166 ± 0.011	3.159	3.173	3.180 ± 0.011	3.173	3.187	3.223 ± 0.014	3.242	3.263	3.253 ± 0.017	3.242	3.263	3.317 ± 1.071	3.303	3.253	3.357
18	3.209 ± 0.050	3.195	3.223	3.161 ± 0.012	3.154	3.169	3.177 ± 0.013	3.168	3.185	3.237 ± 0.025	3.268	3.337	3.302 ± 0.054 *	3.268	3.337	3.291 ± 1.151	3.272	3.224	3.331

BOYS

	Log-transformed all-time US 45.7Fr times (2004-2015)																			
	Top 100 9-year olds			50th			100th			500th			1000th			All-time swims			
Age	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	CI_{lower}	CI_{upper}	Mean ± SD	Median	CI_{lower}	CI_{upper}
9	3.385 ± 0.024	3.380	3.390	3.378 ± 0.009	3.373	3.384	3.399 ± 0.010	3.393	3.405	3.466 ± 0.014	3.457	3.475	3.511 ± 0.017	3.500	3.522	3.734 ± 2.172	3.689	3.578	3.824
10	3.336 ± 0.034 *	3.329	3.343	3.314 ± 0.009 *	3.308	3.320	3.332 ± 0.009 *	3.326	3.338	3.388 ± 0.011 *	3.381	3.395	3.426 ± 0.015 *	3.417	3.436	3.640 ± 2.012	3.597	3.494	3.725
11	3.296 ± 0.041 *	3.287	3.304	3.262 ± 0.011 *	3.255	3.269	3.281 ± 0.011 *	3.274	3.288	3.336 ± 0.013 *	3.328	3.344	3.369 ± 0.015 *	3.359	3.378	3.560 ± 1.850	3.520	3.428	3.635
12	3.252 ± 0.059 *	3.239	3.264	3.192 ± 0.012 *	3.185	3.200	3.210 ± 0.012 *	3.202	3.218	3.264 ± 0.013 *	3.255	3.272	3.297 ± 0.015 *	3.287	3.307	3.467 ± 1.679	3.430	3.346	3.536
13	3.213 ± 0.062 *	3.200	3.227	3.147 ± 0.012 *	3.140	3.155	3.165 ± 0.011 *	3.157	3.172	3.213 ± 0.013 *	3.205	3.221	3.242 ± 0.015 *	3.233	3.252	3.380 ± 1.459	3.349	3.280	3.438
14	3.159 ± 0.050 *	3.147	3.170	3.108 ± 0.011 *	3.101	3.114	3.121 ± 0.011 *	3.114	3.128	3.167 ± 0.012 *	3.159	3.174	3.195 ± 0.013 *	3.186	3.203	3.303 ± 1.259	3.277	3.219	3.352
15	3.128 ± 0.045 *	3.117	3.139	3.085 ± 0.011 *	3.078	3.092	3.098 ± 0.012 *	3.090	3.105	3.143 ± 0.013	3.135	3.151	3.170 ± 0.015	3.160	3.179	3.250 ± 1.008	3.232	3.183	3.291
16	3.107 ± 0.045	3.096	3.118	3.062 ± 0.012 *	3.054	3.069	3.075 ± 0.011 *	3.068	3.082	3.117 ± 0.013 *	3.108	3.125	3.145 ± 0.016	3.135	3.155	3.214 ± 0.908	3.199	3.153	3.252
17	3.091 ± 0.047	3.079	3.102	3.049 ± 0.011	3.042	3.056	3.062 ± 0.012	3.055	3.070	3.105 ± 0.017	3.094	3.116	3.137 ± 0.028	3.119	3.155	3.187 ± 0.867	3.174	3.129	3.224
18	3.074 ± 0.040	3.063	3.085	3.038 ± 0.013	3.030	3.046	3.052 ± 0.013	3.044	3.060	3.104 ± 0.019	3.092	3.117	3.150 ± 0.032	3.129	3.170	3.162 ± 0.955	3.147	3.103	3.197

* Significantly different from one-year younger age ($p < 0.005$ with Bonfferoni correction [0.05 / 10 = 0.005])

APPENDIX E: CORRELATION MATRIX TABLE OF THE DEPENDENT VARIABLE (US TOP 100 STATUS) WITH AND AMONG PREDICTORS USED FOR THE MIXED-EFFECTS LOGISTIC REGRESSION ANALYSES FOR HYPOTHESIS 5

		Top 100 status binary	Age at peak imp.	Age at start swimming	Age_doubles	Maturity status	Multi-sport	Sex	Sex × multi-sport	DLT_age5-8	ST_age5-8	ST hr_session_age5-8	ST hr_wk_age5-8	Age	Age at doubles	APHV	Pre-ad DLT duration	Pre-ad DLT frequency	Pre-ad DLT wk hours	Pre-ad ST duration	Pre-ad ST frequency	Pre-ad ST wk hours
Top 100 status binary	R	1	-0.079	.139**	.198**	.171**	-.172**	-.227**	-.260**	-.196**	-.117*	-.150**	-.181**	-.126*	.159**	0.047	-.220**	-.191**	-.165**	-0.068	-.129**	-0.021
	Sig.		0.116	0.005	0.000	0.001	0.001	0.000	0.000	0.000	0.019	0.003	0.000	0.012	0.001	0.345	0.000	0.000	0.001	0.177	0.010	0.669
Age at peak imp.	R	-0.079	1	-0.022	.100*	.516**	-0.057	.249**	.184**	.218**	-.145**	.356**	.243**	0.000	.148**	.627**	.267**	.154**	.279**	0.033	.182**	-0.005
	Sig.	0.12		0.66	0.05	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.92
Age at start swimming	R	.139**	-0.022	1	0.003	.122*	-.112*	.165**	0.092	-.110*	-.318**	-.538**	-.556**	0.000	0.048	.182**	-.522**	-.586**	-.502**	-.225**	-.124*	-.240**
	Sig.	0.01	0.66		0.95	0.01	0.03	0.00	0.07	0.03	0.00	0.00	0.00	1.00	0.34	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Age_doubles	R	.198**	.100*	0.003	1	.156**	-0.068	.133**	0.083	-.322**	-.163**	-0.050	-.112*	0.000	.893**	.240**	0.023	-.160**	-0.034	-.291**	-.130**	-.181**
	Sig.	0.00	0.05	0.95		0.00	0.18	0.01	0.10	0.00	0.00	0.31	0.02	1.00	0.00	0.00	0.64	0.00	0.50	0.00	0.01	0.00
Maturity status	R	.171**	.516**	.122*	.156**	1	-.120*	-.121*	-.150**	.106*	-.205**	0.078	0.092	0.000	.221**	.771**	0.009	0.021	0.096	.117*	.137**	.154**
	Sig.	0.00	0.00	0.01	0.00		0.02	0.02	0.00	0.03	0.00	0.12	0.07	1.00	0.00	0.00	0.85	0.68	0.06	0.02	0.01	0.00
Multi-sport	R	-.172**	-0.057	-.112*	-0.068	-.120*	1	.206**	.579**	.219**	.136**	0.064	0.027	-.387**	-0.067	-0.054	0.095	.098*	0.042	.247**	.214**	.224**
	Sig.	0.00	0.25	0.03	0.18	0.02		0.00	0.00	0.00	0.01	0.20	0.58	0.00	0.18	0.28	0.06	0.05	0.40	0.00	0.00	0.00
Sex	R	-.227**	.249**	.165**	.133**	-.121*	.206**	1	.917**	0.025	0.011	0.075	-0.045	0.000	.158**	.395**	.108*	-0.040	0.042	-0.065	0.038	-0.070
	Sig.	0.00	0.00	0.00	0.01	0.02	0.00		0.00	0.61	0.82	0.14	0.37	1.00	0.00	0.00	0.03	0.42	0.40	0.20	0.45	0.16
Sex × multi-sport	R	-.260**	.184**	0.092	0.083	-.150**	.579**	.917**	1	.110*	0.065	0.088	-0.026	-.158**	.104*	.307**	.128*	0.007	0.052	0.047	.119*	0.033
	Sig.	0.00	0.00	0.07	0.10	0.00	0.00	0.00		0.03	0.19	0.08	0.60	0.00	0.04	0.00	0.01	0.90	0.30	0.35	0.02	0.51
DLT_age5-8	R	-.196**	.218**	-.110*	-.322**	.106*	.219**	0.025	.110*	1	.141**	.361**	.355**	0.000	-.268**	0.095	.335**	.270**	.306**	.704**	.733**	.539**
	Sig.	0.00	0.00	0.03	0.00	0.03	0.00	0.61	0.03		0.00	0.00	0.00	1.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
ST_age5-8	R	-.117*	-.145**	-.318**	-.163**	-.205**	.136**	0.011	0.065	.141**	1	.309**	.307**	0.000	-.231**	-.239**	.589**	.568**	.392**	.099*	.112*	0.076
	Sig.	0.02	0.00	0.00	0.00	0.00	0.01	0.82	0.19	0.00		0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.13
ST hr_session_age5-8	R	-.150**	.356**	-.538**	-0.050	0.078	0.064	0.075	0.088	.361**	.309**	1	.872**	0.000	-.117*	0.057	.864**	.723**	.858**	.223**	.176**	.116*
	Sig.	0.00	0.00	0.00	0.31	0.12	0.20	0.14	0.08	0.00	0.00		0.00	1.00	0.02	0.26	0.00	0.00	0.00	0.00	0.00	0.02
ST hr_wk_age5-8	R	-.181**	.243**	-.556**	-.112*	0.092	0.027	-0.045	-0.026	.355**	.307**	.872**	1	0.000	-.194**	-0.012	.840**	.855**	.923**	.255**	.268**	.180**
	Sig.	0.00	0.00	0.00	0.02	0.07	0.58	0.37	0.60	0.00	0.00	0.00		1.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.00
Age	R	-.126*	0.000	0.000	0.000	0.000	-.387**	0.000	-.158**	0.000	0.000	0.000	0.000	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Sig.	0.01	1.00	1.00	1.00	1.00	0.00	1.00	0.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Age at doubles	R	.159**	.148**	0.048	.893**	.221**	-0.067	.158**	.104*	-.268**	-.231**	-.117*	-.194**	0.000	1	.307**	-0.088	-.216**	-.111*	-.281**	-0.029	-.160**
	Sig.	0.00	0.00	0.34	0.00	0.00	0.18	0.00	0.04	0.00	0.00	0.02	0.00	1.00		0.00	0.08	0.00	0.03	0.00	0.57	0.00
APHV	R	0.047	.627**	.182**	.240**	.771**	-0.054	.395**	.307**	0.095	-.239**	0.057	-0.012	0.000	.307**	1	0.014	-0.067	0.042	0.050	.148**	0.090
	Sig.	0.34	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.06	0.00	0.26	0.81	1.00	0.00		0.79	0.18	0.41	0.32	0.00	0.07
Pre-ad DLT duration	R	-.220**	.267**	-.522**	0.023	0.009	0.095	.108*	.128*	.335**	.589**	.864**	.840**	0.000	-0.088	0.014	1	.815**	.896**	.228**	.221**	.151**
	Sig.	0.00	0.00	0.00	0.64	0.85	0.06	0.03	0.01	0.00	0.00	0.00	0.00	1.00	0.08	0.79		0.00	0.00	0.00	0.00	0.00
Pre-ad DLT frequency	R	-.191**	.154**	-.586**	-.160**	0.021	.098*	-0.040	0.007	.270**	.568**	.723**	.855**	0.000	-.216**	-0.067	.815**	1	.918**	.150**	.217**	.104*
	Sig.	0.00	0.00	0.00	0.00	0.68	0.05	0.42	0.90	0.00	0.00	0.00	0.00	1.00	0.00	0.18	0.00		0.00	0.00	0.00	0.04
Pre-ad DLT wk hours	R	-.165**	.279**	-.502**	-0.034	0.096	0.042	0.042	0.052	.306**	.392**	.858**	.923**	0.000	-.111*	0.042	.896**	.918**	1	.171**	.203**	.103*
	Sig.	0.00	0.00	0.00	0.50	0.06	0.40	0.40	0.30	0.00	0.00	0.00	0.00	1.00	0.03	0.41	0.00	0.00		0.00	0.00	0.04
Pre-ad ST duration	R	-0.068	0.033	-.225**	-.291**	.117*	.247**	-0.065	0.047	.704**	.099*	.223**	.255**	0.000	-.281**	0.050	.228**	.150**	.171**	1	.733**	.947**
	Sig.	0.18	0.51	0.00	0.00	0.02	0.00	0.20	0.35	0.00	0.05	0.00	0.00	1.00	0.00	0.32	0.00	0.00	0.00		0.00	0.00
Pre-ad ST frequency	R	-.129**	.182**	-.124*	-.130**	.137**	.214**	0.038	.119*	.733**	.112*	.176**	.268**	0.000	-0.029	.148**	.221**	.217**	.203**	.733**	1	.776**
	Sig.	0.01	0.00	0.01	0.01	0.01	0.00	0.45	0.02	0.00	0.03	0.00	0.00	1.00	0.57	0.00	0.00	0.00	0.00	0.00		0.00
Pre-ad ST wk hours	R	-0.021	-0.005	-.240**	-.181**	.154**	.224**	-0.070	0.033	.539**	0.076	.116*	.180**	0.000	-.160**	0.090	.151**	.104*	.103*	.947**	.776**	1
	Sig.	0.67	0.92	0.00	0.00	0.00	0.00	0.16	0.51	0.00	0.13	0.02	0.00	1.00	0.00	0.07	0.00	0.04	0.04	0.00	0.00	

* and **, Significant correlation ($p < 0.05$ and $p < 0.01$, respectively); See Table 4.12 for detailed descriptions of the variables.

APPENDIX F: OUTPUTS AND PLOTS PRODUCED FROM THE MIXED-EFFECTS LOGISTIC REGRESSION ANALYSES TO TEST HYPOTHESIS 5

Predictors: Age (continuous variable) and Sex (categorical variable)

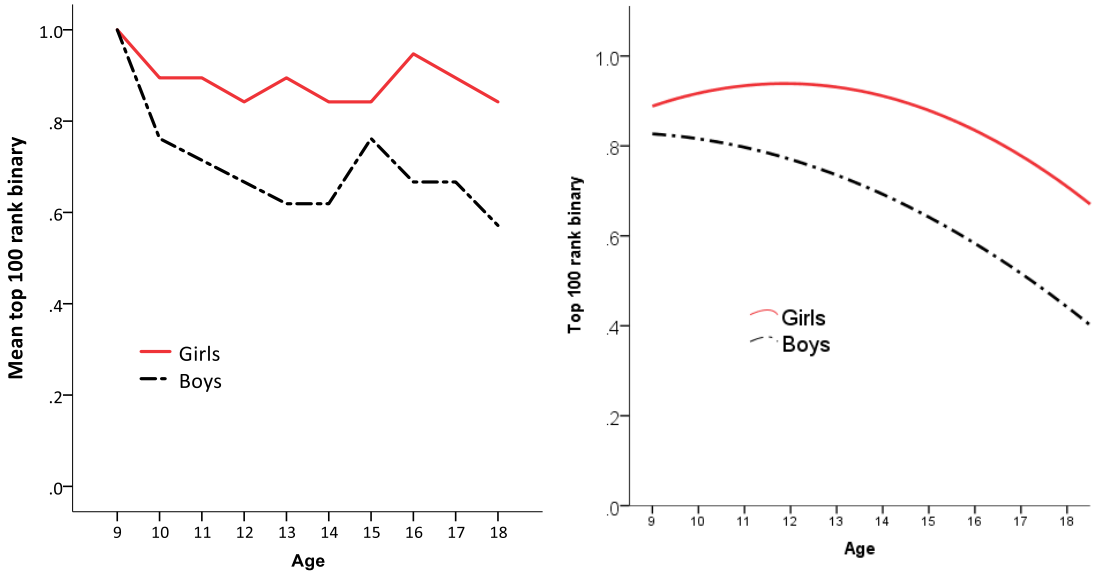


Figure F.1. Changes in the odds of being ranked within the US top 100 during adolescence in the 40 survey responders.
Left, raw changes in the odds as a function of age; Right, regression lines.

Note: 1.0, indicating that all swimmers were ranked within the US top 100 (100%) and 0 as no one (0%).

Table F.1. Statistical output table for the predictors.

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	10.50	0.001	-0.168	0.052	^^	0.85	0.76	0.94
Sex	6.93	0.008						
Boys			-1.259	0.478	^^	0.28	0.11	0.73
Girls			0			1		

^^, Significance at $p < 0.01$.

Predictors: Age (continuous variable), Sex and multi-sport participation (categorical variables)

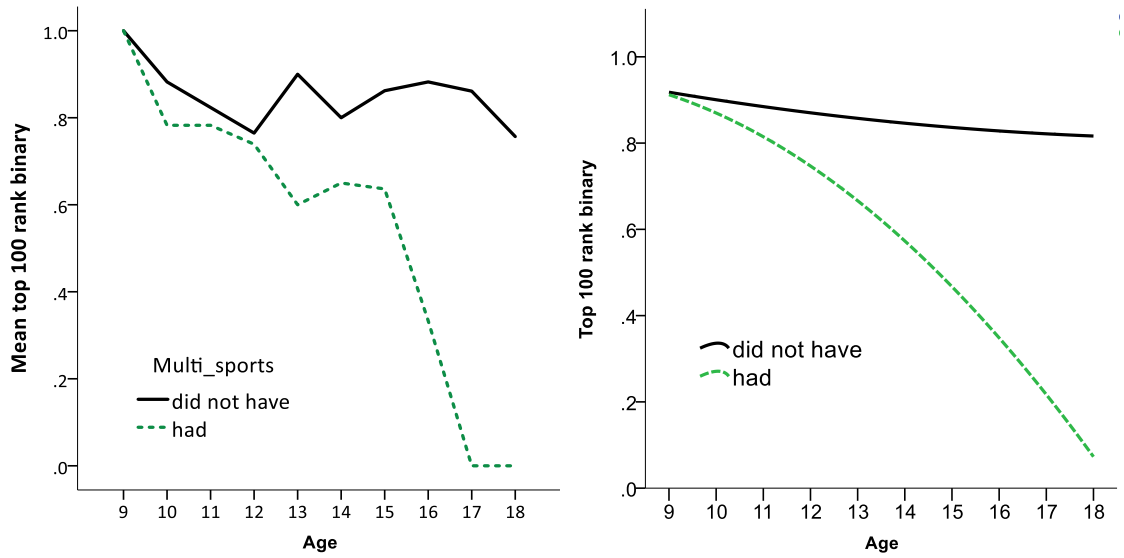


Figure F.2. Changes in the odds of being ranked within the US top 100 during adolescence in the 40 survey responders.
Left, raw changes in the odds as a function of age; Right, regression lines.

Note: 1.0, indicating that all swimmers were ranked within the US top 100 (100%) and 0 as no one (0%).

Table F.2. Statistical output table for the predictors.

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	12.49	0.000	-0.233	0.066	^^	0.79	0.70	0.90
Sex	6.63	0.010						
Boys			-1.173	0.455	^^	0.31	0.13	0.76
Girls			0			1		
Multi_sport	6.79	0.009						
with			-0.878	0.337	^	0.42	0.22	0.80
without			0			1		

^ and ^^, Significance at $p < 0.05$ and $p < 0.01$, respectively.

Predictors: Age (continuous variable), Sex × multi-sport participation (categorical variable)

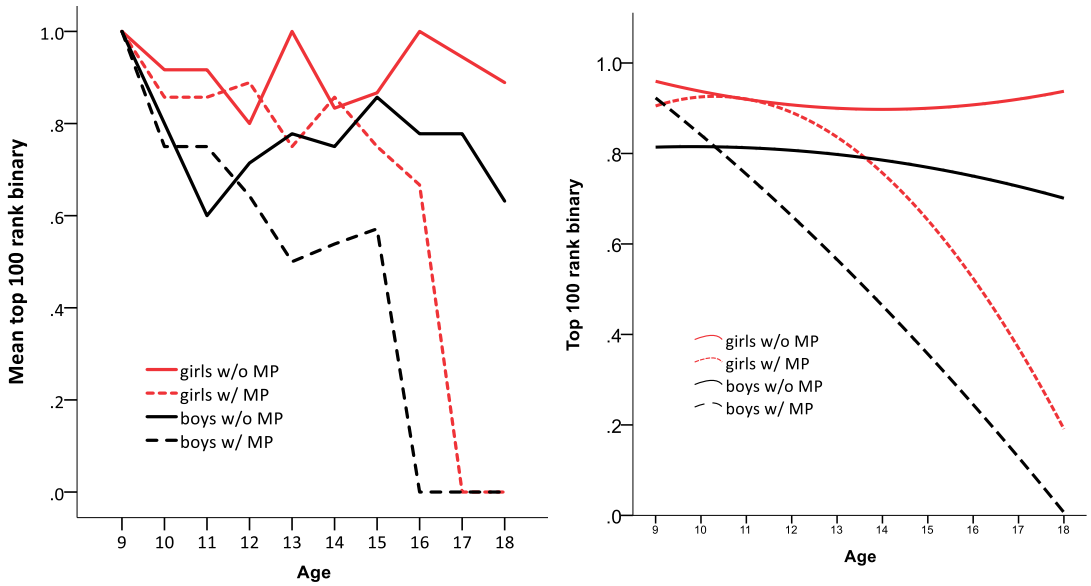


Figure F.3. Changes in the odds of being ranked within the US top 100 during adolescence in the 40 survey responders.
Left, raw changes in the odds as a function of age; Right, regression lines.

Note: 1.0, indicating that all swimmers were ranked within the US top 100 (100%) and 0 as no one (0%).

Table F.3. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	12.70	0.000	-0.233	0.065	^^	0.79	0.70	0.90
Sex × multi-sport	13.84	0.003						
Boys with MP			-2.086	0.566	^^	0.12	0.04	0.38
Boys without MP			-1.254	0.494	^	0.29	0.11	0.75
Girls with MP			-1.018	0.535		0.36	0.13	1.03
Girls without MP			0			1		

^ and ^^, Significance at $p < 0.05$ and $p < 0.01$, respectively.

Predictors: Age and swim training biography before age 9 years (continuous variables), and Sex (categorical variable)

Table F.4. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	9.95	0.002	-0.175	0.055	^^	0.84	0.75	0.94
Sex	6.39	0.011						
Boys			-1.241	0.491	^^	0.29	0.11	0.76
Girls			0			1		
Pre-ad ST duration	1.31	0.253	-0.932	0.816		0.39	0.08	1.95
Pre-ad ST frequency	0.77	0.382	-0.201	0.229		0.82	0.52	1.28

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	10.30	0.001	-0.171	0.053	^^	0.84	0.76	0.94
Sex	6.59	0.010						
Boys			-1.239	0.483	^^	0.29	0.11	0.75
Girls			0			1		
Pre-ad ST wk hours	2.94	0.086	-0.152	0.088		0.86	0.72	1.02

^^, Significance at $p < 0.01$.

Note: No plot is available for continuous variables as there is only one category.

Predictors: Age (continuous variable), and Sex and swim training biography before age 9 years

(categorical variables)

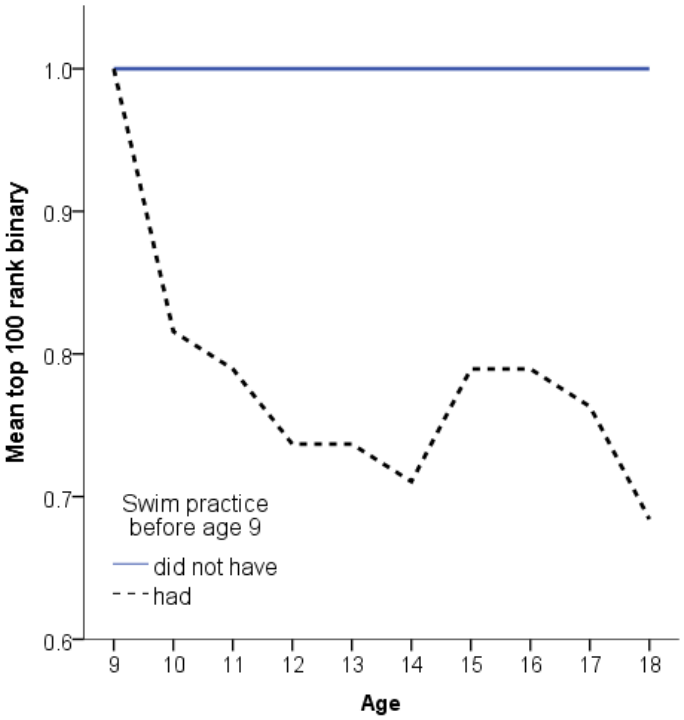


Figure F.5. Changes in the odds of being ranked within the US top 100 during adolescence in the 40 survey responders.

Note: 1.0, indicating that all swimmers were ranked within the US top 100 (100%) and 0 as no one (0%).

Table F.5. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.	Odds Ratio	95% CI for OR
Age						
Sex						
Boys						
Girls	a sparsity problem in data					
ST_age5-8						
had						
did not have						

Predictors: Age (continuous variable), and Sex and swim training biography before age 9 years

(categorical variables)

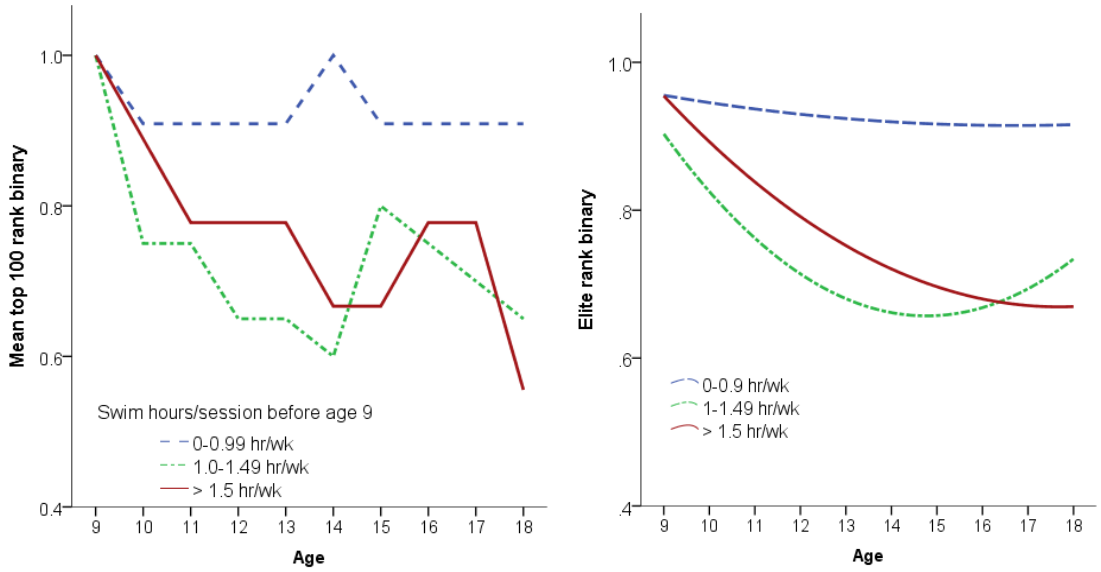


Figure F.6. Changes in the odds of being ranked within the US top 100 during adolescence in the 40 survey responders.
Left, raw changes in the odds as a function of age; Right, regression lines.

Note: 1.0, indicating that all swimmers were ranked within the US top 100 (100%) and 0 as no one (0%).

Table F.6. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	10.69	0.001	-0.189	0.058	^^	0.83	0.74	0.93
Sex	8.66	0.003						
Boys			-1.452	0.493	^^	0.23	0.09	0.62
Girls			0			1		
ST hr_session_age5-8	4.90	0.087						
>1.50 hr• session^{-1}			-1.440	0.939		0.24	0.04	1.49
1.00-1.49 hr• session^{-1}			-1.856	0.846	^	0.16	0.03	0.82
< 0.99 hr• session^{-1}			0			1		

^ and ^^, Significance at $p < 0.05$ and $p < 0.01$, respectively.

Predictors: Age (continuous variable), and Sex and swim training biography before age 9 years

(categorical variables)

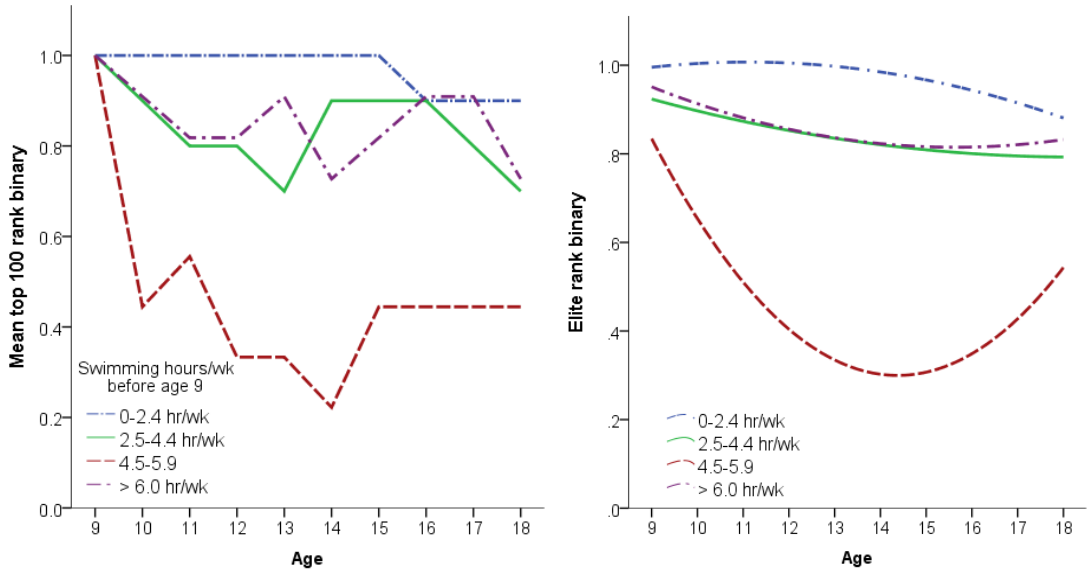


Figure F.7. Changes in the odds of being ranked within the US top 100 during adolescence in the 40 survey responders.
Left, raw changes in the odds as a function of age; Right, regression lines.

Note: 1.0, indicating that all swimmers were ranked within the US top 100 (100%) and 0 as no one (0%).

Table F.7. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	8.85	0.003	-0.205	0.069	^^	0.81	0.71	0.93
Sex	8.98	0.003						
Boys			-1.299	0.433	^^	0.27	0.12	0.64
Girls			0			1		
ST hr_wk_age5-8	22.73	0.000						
6.0 and more hr・wk^{-1}			-1.821	1.090		0.16	0.02	1.37
4.5-5.9 hr・wk^{-1}			-3.579	1.001	^^	0.03	0.00	0.20
2.5-4.4 hr・wk^{-1}			-2.020	1.028	^	0.13	0.02	1.00
0-2.4 hr・wk^{-1}			0			1		

^ and ^^, Significance at $p < 0.05$ and $p < 0.01$, respectively.

Predictors: Age and dryland training biography before age 9 years (continuous variables), and Sex (categorical variable)

Table F.8. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	10.11	0.001	-0.172	0.054	^^	0.84	0.76	0.94
Sex	6.50	0.011			^^			
Boys			-1.317	0.517		0.27	0.10	0.74
Girls			0			1		
Pre-ad DLT duration	0.61	0.434	-0.976	1.247		0.38	0.03	4.34
Pre-ad DLT frequency	0.81	0.368	-0.302	0.335		0.74	0.38	1.43

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	10.44	0.001	-0.169	0.0523	^^	0.85	0.76	0.94
Sex	7.301	0.007						
Boys			-1.310	0.4850	^^	0.27	0.10	0.70
Girls			0			1		
Pre-ad DLT wk hours	2.349	0.125	-0.692	0.4513		0.50	0.21	1.21

^^, Significance at $p < 0.01$.

Note: No plot is available for continuous variables as there is only one category.

Predictors: Age (continuous variable), and Sex and dryland training biography before age 9 years

(categorical variables)

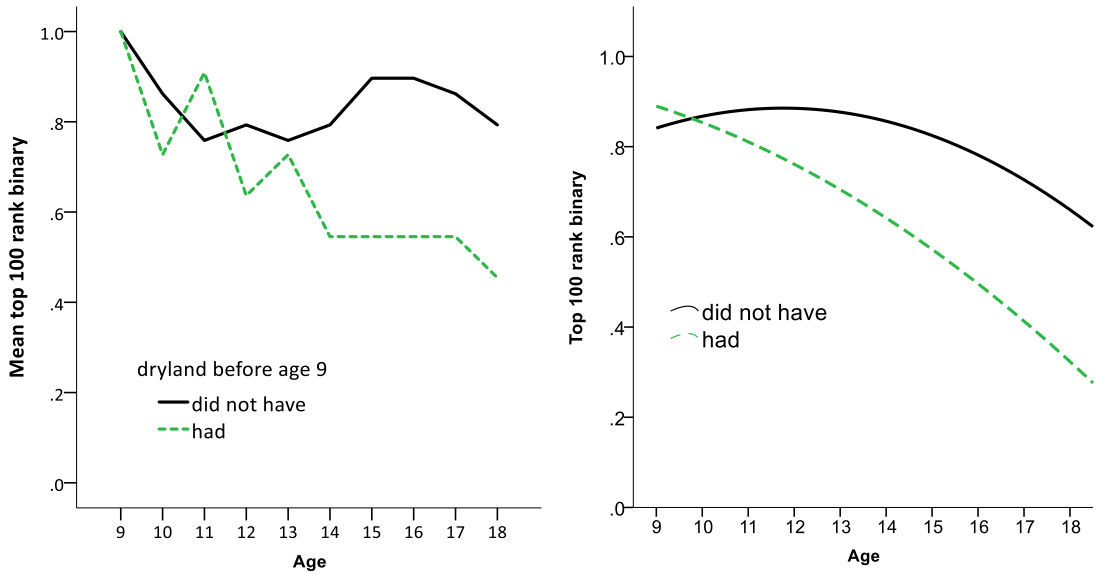


Figure F.9. Changes in the odds of being ranked within the US top 100 during adolescence in the 40 survey responders.
Left, raw changes in the odds as a function of age; Right, regression lines.

Note: 1.0, indicating that all swimmers were ranked within the US top 100 (100%) and 0 as no one (0%).

Table F.9. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	9.39	0.002	-0.177	0.058		0.84	0.48	0.94
Sex	7.35	0.007						
Boys			-1.294	0.478	^^	0.27	0.11	0.70
Girls			0			1		
DLT_age5-8	5.01	0.025						
had			-1.116	0.498	^	0.33	0.12	0.87
did not have			0			1		

^ and ^^, Significance at $p < 0.05$ and $p < 0.01$, respectively.

Predictors: Age and age at starting two or more practice a day (continuous variables), and Sex (categorical variable)

Table F.10. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	9.26	0.002	-0.175	0.057	^^	0.84	0.75	0.94
Sex	8.67	0.003						
Boys			-1.462	0.496	^^	0.23	0.09	0.61
Girls			0			1		
Age at doubles	5.39	0.020	0.249	0.107	^	1.28	1.04	1.58

^ and ^^, Significance at $p < 0.05$ and $p < 0.01$, respectively.

Note: No plot is available for continuous variables as there is only one category.

Predictors: Age (continuous variable), and Sex and age at starting two or more practice a day

(categorical variables)

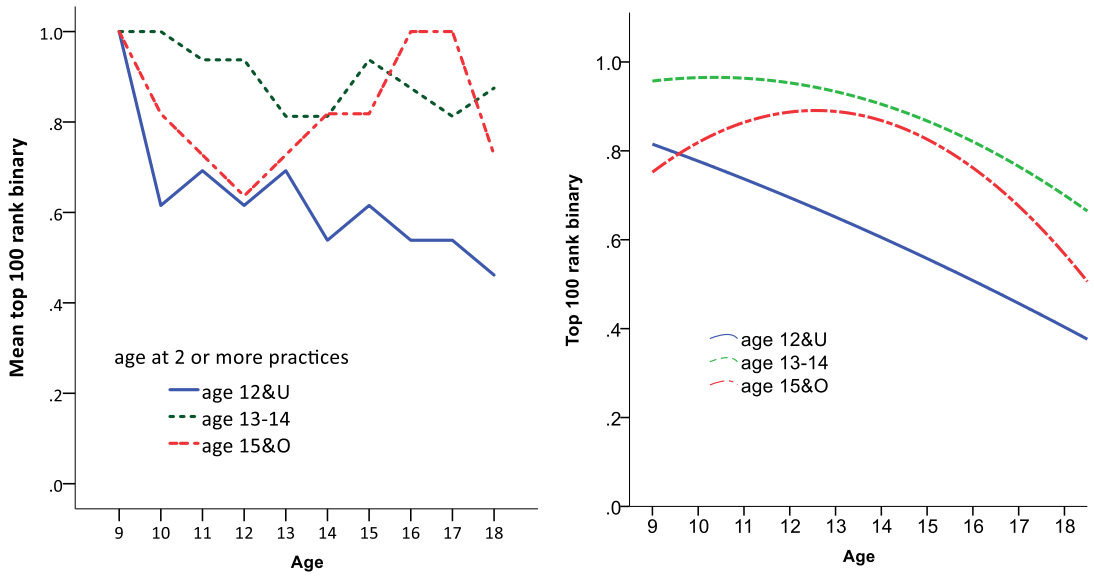


Figure F.11. Changes in the odds of being ranked within the US top 100 during adolescence in the 40 survey responders.
Left, raw changes in the odds as a function of age; Right, regression lines.

Note: 1.0, indicating that all swimmers were ranked within the US top 100 (100%) and 0 as no one (0%).

Table F.11. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	8.49	0.004	-0.182	0.063	^^	0.83	0.74	0.94
Sex	9.16	0.002						
Boys			-1.545	0.510	^^	0.21	0.08	0.58
Girls			0			1		
Age_doubles	13.56	0.001						
Age 15&O			1.422	0.604	^	4.15	1.27	13.54
Age 13-14			1.959	0.575	^^	7.09	2.30	21.89
Aage 12&U			0			1		

^ and ^^, Significance at $p < 0.05$ and $p < 0.01$, respectively.

Predictors: Age (continuous variable), and Sex and age at enrollment in swimming (categorical variables)

Table F.12. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	10.04	0.002	-0.166	0.052	^^	0.85	0.76	0.94
Sex	10.85	0.001						
Boys			-1.664	0.505	^^	0.19	0.07	0.51
Girls			0			1		
Age at start swimming	6.50	0.090						
Age 7&O			1.645	0.761	^	5.18	1.17	23.04
Age 6			1.184	0.652		3.27	0.91	11.72
Age 5			0.941	0.526		2.56	0.91	7.19
Age 4			0			1		

^ and ^^, Significance at $p < 0.05$ and $p < 0.01$, respectively.

Note: Plot is not available as the predictor (age at enrollment in swimming) was not revealed as significant ($p = 0.09$).

Predictors: Age (continuous variable), and Sex and age at peak improvement in swim performance (categorical variables)

Table F.13. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	9.70	0.002	-0.168	0.054	^^	0.85	0.76	0.94
Sex	8.87	0.003						
Boys			-1.413	0.475	^^	0.24	0.10	0.62
Girls			0			1		
Age at peak imp.	3.16	0.368						
Age 16&O			0.356	0.652		1.43	0.40	5.13
Age 15			0.929	0.673		2.53	0.68	9.46
Age 14			1.284	0.903		3.61	0.62	21.23
Age 12-13			0			1		

^^, Significance at $p < 0.01$.

Note: Plot is not available as the predictor (age at enrollment in swimming) was not revealed as significant ($p = 0.37$).

Predictors: Age (continuous variable), and Sex and maturity status (categorical variables)

Table F.14. Statistical output table for the predictors

Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	9.52	0.002	-0.168	0.055	^^	0.85	0.76	0.94
Sex	6.74	0.009						
Boys			-1.216	0.469	^^	0.30	0.12	0.74
Girls			0			1		
Maturity status	2.07	0.355						
Late			0.978	0.681		2.66	0.70	10.10
Average			0.685	0.715		1.98	0.49	8.06
Eearly			0			1		

^^, Significance at $p < 0.01$.

Note: Plot is not available as the predictor (age at enrollment in swimming) was not revealed as significant ($p = 0.36$).

Predictors: Age (continuous variable), and Sex and age at peak height velocity (APHV) (categorical variables)

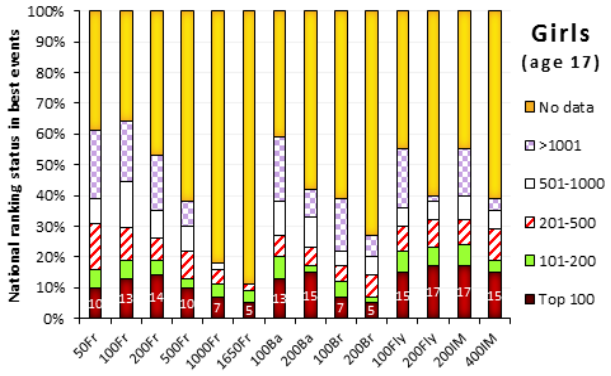
Table F.15. Statistical output table for the predictors

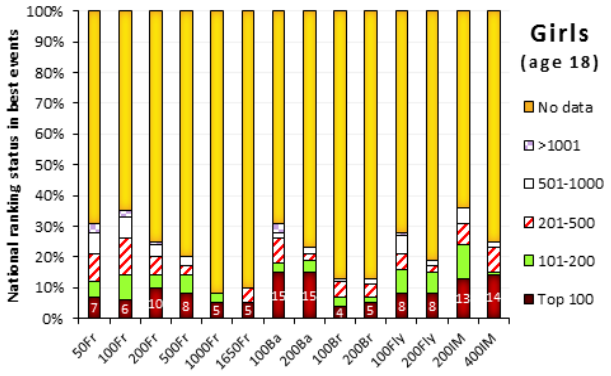
Effects	Wald χ^2	p value	β Estimate	Std. E.		Odds Ratio	95% CI for OR	
Age	9.35	0.002	-0.166	0.054	^^	0.85	0.76	0.94
Sex	9.25	0.002						
Boys			-1.693	0.557	^^	0.18	0.06	0.55
Girls			0			1		
APHV	2.97	0.085	0.251	0.146		1.29	0.97	1.71

^^, Significance at $p < 0.01$.

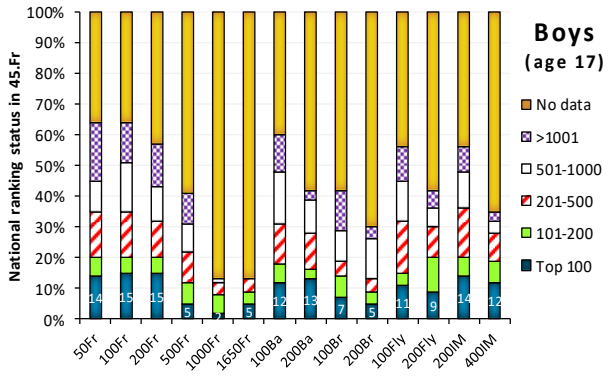
Note: Plot is not available as the predictor (age at enrollment in swimming) was not revealed as significant ($p = 0.09$).

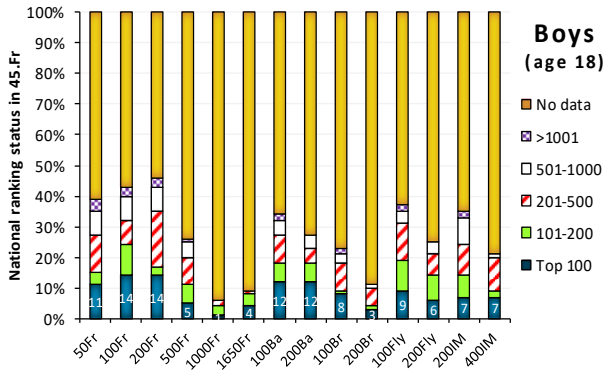
APPENDIX G1: SWIM PERFORMANCE BIOGRAPHY OF THE US TOP 100 NINE-YEAR-OLD GIRL SWIMMERS AT ADOLESCENT AGES (US RANKING STATUS FOR 14 COMPETITIVE SWIMMING EVENTS AT EACH AGE)


Girls
(age 17)
National ranking status in best events
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
No data
>1001
501-1000
201-500
101-200
Top 100
50Fr
100Fr
200Fr
500Fr
1000Fr
1650Fr
100Ba
200Ba
100Br
200Br
100Fly
200Fly
200IM
400IM

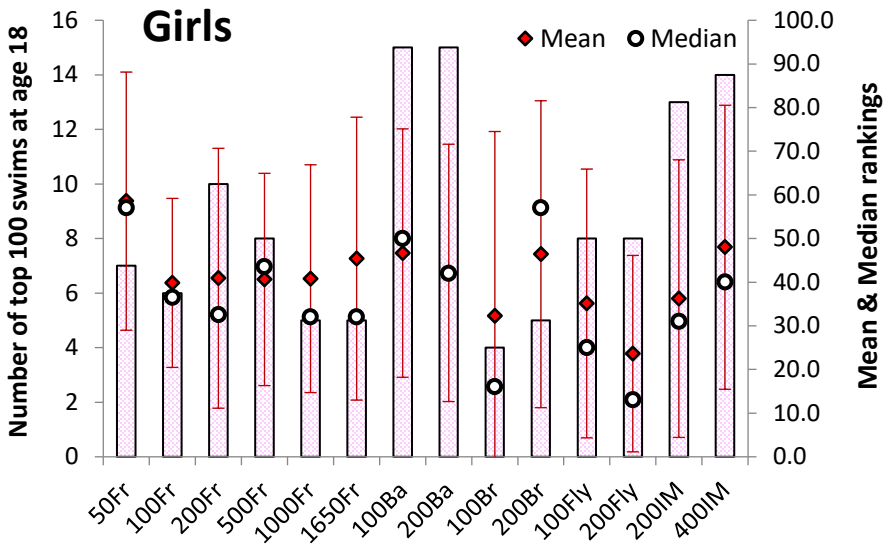

Girls
(age 18)
National ranking status in best events
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
No data
>1001
501-1000
201-500
101-200
Top 100
50Fr
100Fr
200Fr
500Fr
1000Fr
1650Fr
100Ba
200Ba
100Br
200Br
100Fly
200Fly
200IM
400IM

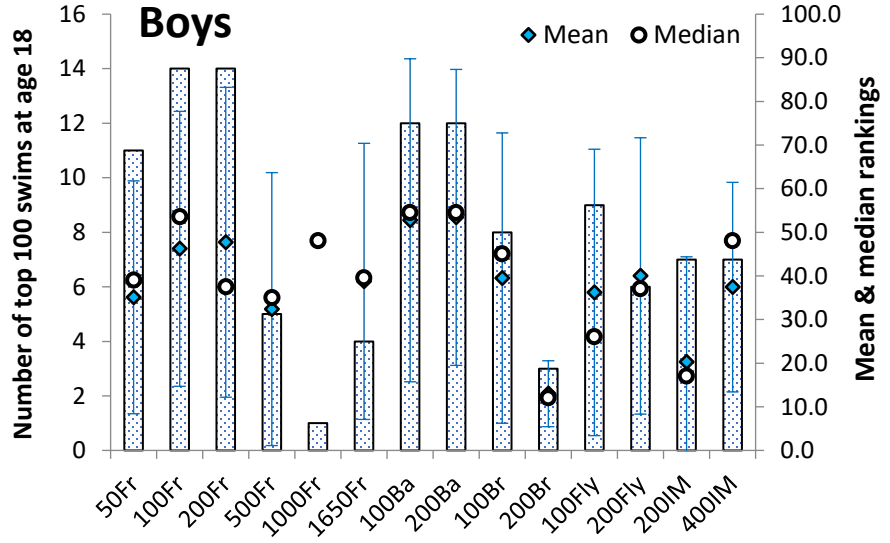
APPENDIX G2: SWIM PERFORMANCE BIOGRAPHY OF THE US TOP 100 NINE-YEAR-OLD BOY SWIMMERS AT ADOLESCENT AGES (US RANKING STATUS FOR 14 COMPETITIVE SWIMMING EVENTS AT EACH AGE)


Boys
(age 17)
National ranking status in 45.Fr
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
No data
>1001
501-1000
201-500
101-200
Top 100
50Fr
100Fr
200Fr
500Fr
1000Fr
1650Fr
100Ba
200Ba
100Br
200Br
100Fly
200Fly
200IM
400IM


Boys
(age 18)
National ranking status in 45.Fr
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
No data
>1001
501-1000
201-500
101-200
Top 100
50Fr
100Fr
200Fr
500Fr
1000Fr
1650Fr
100Ba
200Ba
100Br
200Br
100Fly
200Fly
200IM
400IM

APPENDIX H: SWIM PERFORMANCE BIOGRAPHY OF THE US TOP 100 NINE-YEAR-OLD SWIMMERS AT AGE 18 YEARS (THE NUMBER OF THE US TOP 100 NINE-YEAR-OLD SWIMMERS RANKED WITHIN THE TOP 100 AT AGE 18 YEARS OLD: GIRLS, N = 43; BOYS N = 38)

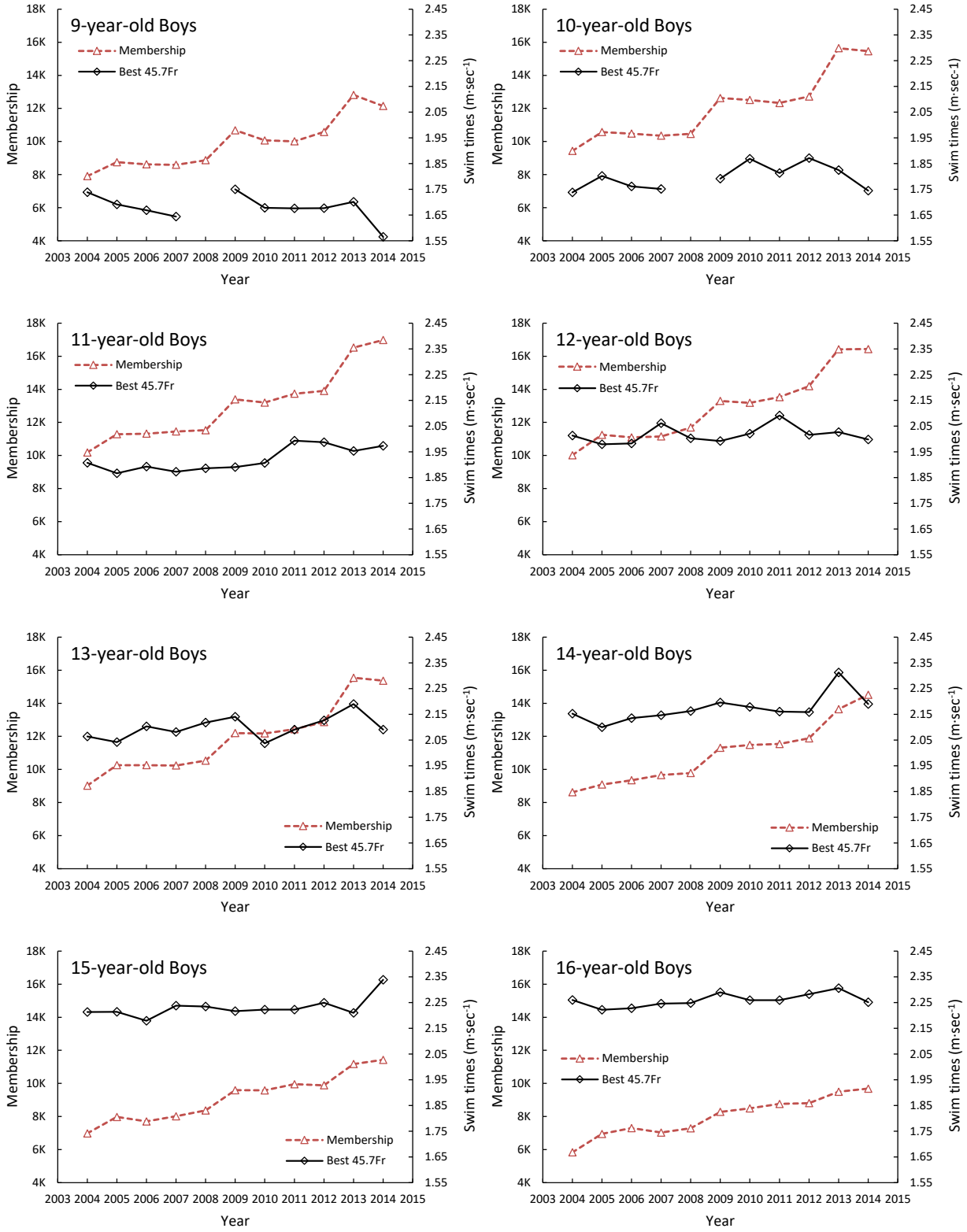


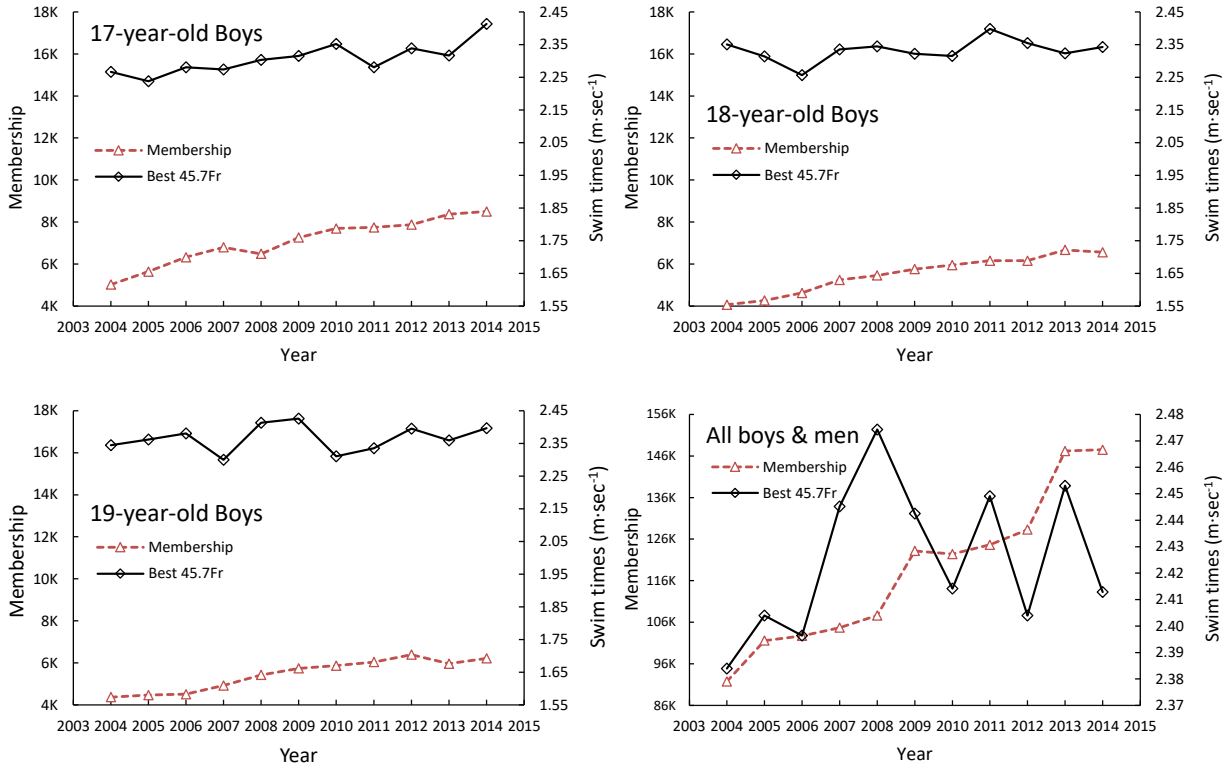


Note 1: girls, n = 43; boys, n = 38

Note 2: several swimmers show up in various events repeatedly (on average 2.9 events in girls and 3.0 events in boys)

APPENDIX I: CHANGES IN THE BEST PERFORMANCE IN 45.7-METER FREESTYLE (45.7FR, M·S^{-1}) AND MEMBERSHIP IN US BOY AND MEN SWIMMERS AS A FUNCTION OF YEAR (2004 TO 2014) FOR 11 AGE CATEGORIES AND TOTAL SAMPLE.





Note 1: Primary and secondary Y-axes were matched for all age categories nine to 19 years), while those for total sample were different from other age categories in order for a better visual inspection.

Note 2: The best performance in total sample (all boys & men) represents the fastest 45.7Fr in each year.

APPENDIX J: THE NUMBER OF SWIMMERS IN USA SWIMMING BY ETHNIC GROUP FROM 2000 TO 2016

		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Black	Female					1155	1220	1257	1432	1611	1773	1624	1630	1564	1808	1838	2106	2348
	Male					870	958	979	1129	1292	1556	1390	1442	1426	1601	1654	1835	2000
	Total	2016	2134	2061	2141	2025	2178	2236	2561	2903	3329	3014	3072	2990	3409	3492	3941	4348
Native*	Female					373	363	339	292	280	258	234	243	234	233	247	255	287
	Male					187	193	195	156	173	165	156	150	142	176	171	174	180
	Total	571	584	571	509	560	556	534	448	453	423	390	393	376	409	418	429	467
Asian	Female					4102	4639	4946	4777	5390	6133	6632	6802	7087	7788	8454	9942	11707
	Male					4184	4783	5304	5349	5965	7052	7500	7890	8000	8746	9653	11734	13800
	Total	5615	6072	6411	7059													
Hispanic/ Latino	Female					2993	3384	3531	3568	3812	4369	4215	4290	4639	5170	5219	5826	6563
	Male					2387	2809	2871	3036	3296	4027	3859	3897	4040	4652	4849	5190	5671
	Total	4389	4664	4752	5338	5380	6193	6402	6604	7108	8396	8074	8187	8679	9822	10068	11016	12234
Native Haw. & Pac. Isl.**	Female								778	749	545	339	181	137	163	189	225	329
	Male								560	570	425	222	134	121	140	137	190	259
	Total	784	877	899	977				1338	1319	970	561	315	258	303	326	415	588
White	Female					65082	68216	67869	67227	67652	71365	68225	63492	60486	63064	61860	72986	83150
	Male					39607	43818	44290	44793	45588	50295	47010	44023	41509	44799	44219	51693	59046
	Total	110451	112345	109965	110495	104689	112034	112159	112020	113240	121660	115235	107515	101995	107863	106079	124679	142196
Other	Female					1043	1192	1382	1838	1648	1452	1326	1148	1093	1110	1135	1177	1379
	Male					869	1097	1261	1604	1415	1340	1137	1014	1020	1022	1073	1158	1273
	Total	1949	2260	2038	2105	1912	2289	2643	3442	3063	2792	2463	2162	2113	2132	2208	2335	2652
Mixed	Female					3524	3565	3706	3841	4301	4925	4958	4991	5271	6118	6548	8036	10051
	Male					2324	2514	2560	2744	3131	3808	3655	3781	4012	4774	4993	6145	7635
	Total	5351	5957	5808	5854	5848	6079	6266	6585	7432	8733	8613	8772	9283	10892	11541	14181	17686
Response	Female					78272	82579	83030	83753	85443	90820	87553	82777	80511	85454	85490	100553	115814
	Male					50428	56172	57460	59371	61430	68668	64929	62331	60270	65910	66749	78119	89864
	Total	131126	134893	132505	134478	128700	138751	140490	143124	146873	159488	152482	145108	140781	151364	152239	178672	205678
No Response	Female					62327	65005	63550	63100	64109	72162	76943	83763	92092	107935	106924	89760	73690
	Male					41334	45426	45286	45323	46198	54497	57475	62311	68011	81269	80740	68652	56668
	Total	90248	97371	95712	100535	103661	110431	108836	108423	110307	126659	134418	146074	160103	189204	187664	158412	130358
Sum	Female					140599	147584	146580	146853	149552	162982	164496	166540	172603	193389	192414	190313	189504
	Male					91762	101598	102746	104694	107628	123165	122404	124642	128281	147179	147489	146771	146532
	Total	221374	232264	228217	235013	232361	249182	249326	251547	257180	286147	286900	291182	300884	340568	339903	337084	336036

*American Indian & Alaskan Native; ** Native Hawaiian & Pacific Islander. Response, the number of swimmers who indicate their ethnicity.

KOSUKE KOJIMA

EDUCATION

Indiana University — Bloomington, IN

Doctor of Philosophy in Human Performance, Kinesiology — *November, 2017*

Thesis title: Variations in age-related performance progression in competitive swimming

Master of Science, Kinesiology (Exercise Physiology) — *May, 2010*

Thesis title: USA Swimming age classification: are current competitive age-groups appropriate?

Tokyo Metropolitan University — Tokyo, Japan

Master of Science, Exercise and Sports Science — *March, 2004*

Thesis title: Effects of 6-month high-intensity resistance training on skeletal muscle and internal organ masses in young male athletes

Chuo University — Tokyo, Japan

Bachelor of Laws, Faculty of Law — *March, 2001*

WORK EXPERIENCE

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Assistant Instructor — *April 1999-March 2002*

Coaching

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Volunteer Assistant Coach — *September 2017-present*

Counsilman Center Swim Team, member of USA Swimming — Bloomington, IN

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Assistant Coach — *February 2005-July 2008*

Chuo University — Tokyo, Japan

Volunteer Assistant Coach — *April 2002-March 2004*

RESEARCH PUBLICATIONS and PRESENTATIONS

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[Academic presentations during graduate studies at Indiana University]

12. Kojima, K., Jamison, P. L., Brammer, C. L., & Stager, J. M. (2017). Interpopulation Variations in Height Growth: a Potential Explanation for Differences in Adolescent Swim Performance. *Medicine & Science in Sports & Exercise*, *49*(5S), 5.
13. Goss, C. S., Greenshields, J. T., Brammer, C. L., Kojima, K., Wright, B. V., & Stager, J. M. (2017). Absence of Cardiac Drift during a Prolonged, Submaximal Swim Bout: 2555 Board# 75 June 2 9. *Medicine & Science in Sports & Exercise*, *49*(5S), 719.
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22. Kojima, K., and Stager, J. M. (2010). Competitive systematization in age-group swimming: an evaluation of performances, maturational considerations, and international paradigms. XIth International Symposium for Biomechanics and Medicine in Swimming (Oslo, Norway): Biomechanics and Medicine in Swimming, 130.
23. Kojima, K., Jamison, P. L., Brammer, C. L. and Stager, J. M. (2009). USA Swimming age classification: are current competitive age-groups appropriate? 56th Annual Meeting of the American College of Sports Medicine (Seattle, USA): American College of Sports Medicine, 41 (5S), 148.

ATHLETIC ACCOMPLISHMENTS

Counsilman Center Swim Team — Bloomington, IN

- Indiana Senior Short Course Championships
  - 200-yard Individual Medley 1st place (2009 & 2011)
- Indiana Senior Long Course Championships
  - 200-meter Individual Medley 2nd place (2007 & 2009)

DOC IU Masters Swimming — Bloomington, IN

- 2009 USMS National LC Championships (30-34 age group) — *August 2009*
  - 200-meter Individual Medley: 1st place, 2:07.97 (World and meet records)
  - 100-meter Breaststroke: 1st place

Chuo University — Tokyo, Japan

- Team captain (1999-2000)
- Japan Inter Collegiate Championships
  - Men's Team Championships title (1997-2000)
  - 200-meter Individual Medley: 4th (1997), 1st (1998, 29th in the world), 5th (1999, the top 100 in the world), 6th (2000)
  - 400-meter Individual Medley: 7th (1997), 6th (1998), 7th (1999)
- Japan National Long Course Championship

200-meter Individual Medley: 4th (1997), runner-up (1998), 6th (1999)

CERTIFICATIONS, SKILLS, & INTERESTS

- USA Swimming Level 1 Coach, Red Cross CPR/AED and Lifeguarding and First Aid certified.
- Skilled in Excel and Word programs and Hy-tek, Colorado timing system.
- Practiced in creating and managing database for data organization, including creating forms for data input and reports for data summary.
- Interested in all aspects of the measurement of swim performance (e.g., instantaneous velocity and swim power).
- Interested in bridging the gap between the science of swimming and the coaching of swimmers.
- Fluent in Japanese and English.

AWARDS

- American Swimming Coaches Association: Coach of Excellence for 2014 (December, 2014)
- American Kinesiology Association: Doctoral Scholar Award (April, 2017)