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Maturational pace and performance in female collegiate swimmers

Alan Duski

Maturational Pace and Performance in Female Collegiate Swimmers

by

Alan Duski

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Thesis Committee:

Andrew Cornett, Ph.D., Chair

Stephen McGregor, Ph.D.

Jonathan Ehrman, Ph.D.

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Abstract

Maturational pace refers to the rate at which individuals progress towards the biologically mature state. The purpose of this research was (1) to compare maturational pace between the female collegiate swimmers and non-athletic controls and (2) to determine whether maturational pace differs as a function of performance level. Maturational pace can be quantified retrospectively in women using age at menarche (AaM), with younger AaM corresponding to a faster maturational pace and older AaM a slower pace. Collegiate swimmers were significantly older at menarche (13.60 years ± 1.52 SD) than non-athletic controls (12.75 years ± 1.44 SD). In addition, the top-performing third of college swimmers in our sample were significantly older at menarche (14.06 years ± 1.59 SD) than the bottom-performing third (13.32 years ± 1.35 SD). We can conclude that (1) collegiate swimmers are older at menarche than controls and (2) swim performance is associated with later ages at menarche.

Table of Contents

List of Tables

List of Figures

Chapter I

Introduction

Maturational pace refers to the rate at which individuals progress towards the biologically mature state. Age at menarche (AaM) is a well-accepted and commonly used method for retrospectively quantifying maturational pace, with earlier AaM being associated with a faster maturational pace and later AaM a slower one. In general, this research demonstrated that female athletes tend to be older at menarche (i.e., have a slower maturational pace) than their non-athletic peers (Brooks-Gunn & Warren, 1988; Constantini & Warren, 1995; Di Cagno et al., 2012; Frisch et al., 1981; Malina, Harper, Avent, & Campbell, 1973; Malina, Spirduso, Tate, & Baylor, 1978; Mokha & Sidhu, 1989; Mukherjee, Mishra, & Ray, 2014; Sidhu & Grewal, 1980; Stager, Robertshaw, & Miescher, 1984; Stager & Hatler, 1988; Torstveit & Sundgot-Borgen, 2005; Warren, 1980). However, while this finding is well accepted, neither the mechanism nor the performance implications are well understood.

One common explanation for the later AaM in athletes is that pre-menarcheal training acts to “delay” menarche. This explanation is supported by data that showed girls were 5 months older at menarche for each year of training completed prior to menarche (Frisch et al., 1981). Their conclusion was that the intense physical activity in combination with other factors such as nutrition, body composition, and psychological stress contributed to the later menarche in athletic girls. Sidhu and Grewal (1980) had similar finding in their study of female athletes across a variety of sporting disciplines in India. They found that athletes who started participating in sport before the onset of puberty were significantly older at menarche than athletes who started participating in sport after the onset of puberty, and they concluded from their finding that strenuous physical activity delays menarche in girls (Sidhu & Grewal, 1980). Although the research design used by Frisch et al. and Sidhu and Grewal was flawed (Stager, Wigglesworth, & Hatler, 1990), it remains possible that early physical training can delay menarche in athletes.

Another explanation for the later AaM in athletes is that there are certain physical traits associated with later AaM that are also associated with athletic success, and thus, athletes with later AaM are being selected for on the basis of these physical traits. According to this explanation, then, older AaM in athletes are not the result of a training-induced delay; rather, there are advantages associated with late maturation that contribute to more late maturers continuing in the sport. For instance, late maturers usually have less weight for height and more linear body shapes (Malina et al., 1978). Importantly, these are traits that tend to be associated with athletic success (McNeill & Livson, 1963; Meleski, Shoup, & Malina, 1982). Even though these physical traits related with late maturation could play an important role in athletic success, the extent to which this occurs is unknown.

Both explanations for the later AaM in athletes logically lead to the same hypothesis: there is a relationship between AaM and athletic success. As for the first explanation, it seems reasonable to suppose that the athletes that have been training the longest and the hardest would also be the most successful. And if prolonged, intensive physical training does delay menarche, the best athletes would be expected to have the latest AaM. The second explanation is that physical characteristics associated with late maturation (e.g., less weight per height and more linear body shape) are more suitable for success in sports, and thus, these athletes are being selected for continued participation (by themselves or others; Malina et al., 1978). Once again, if this is true, then the most successful athletes would also be the later maturers.

A few studies have investigated the relationship between AaM and athletic success. Malina et al. (1978) looked at the AaM and menstrual characteristics in athletes at different competitive levels and in different sports. The main finding was that athletes at the highest competitive level (Olympic-level volleyball players) attained menarche significantly later than college-level athletes, high school-level athletes, and non-athletes (Malina et al., 1978). One weakness of the study is that the sport was not held constant while comparing across the competitive levels, despite the fact that AaM was subsequently shown to differ by sport (Baxter-Jones, Helms, Baines-Preece, & Preece, 1994; Erlandson, Sherar, Mirwald, Maffulli, & Baxter-Jones, 2008; Peltenburg, Erich, Bernink, Zonderland, & Huisveld, 1984). The Olympic-level athletes were all volleyball players, but the high school and college-level athletes came from a variety of different sports.

Stager et al. (1984) addressed this weakness by studying the same relationship within a single sport, swimming. When they divided their sample according to swim performance, they found that the fastest swimmers attained menarche significantly later than the slowest swimmers. While this was an important finding, the study did have weaknesses. Most notably, the sample consisted of sub-elite swimmers, so the extent to which their findings extend to national- and even international-level swimmers is unknown.

Based on the questions left unanswered by Malina et al. (1978) and Stager et al. (1984), the main purpose of this study is to investigate the relationship between AaM and swimming performance within a single sporting discipline and across a wide range of performance levels. We hypothesize that there will be a significant relationship between AaM and swim performance such that AaM will increase as the performance level of the athletes in question increases.

Chapter II

Review of Literature

In the pages that follow, we summarize and review much of the work that has been done on maturational pace (as determined by age at menarche) and athletic performance. We have divided this review of literature into the following sections: (1) Age at Menarche in Non-athletes, (2) Age at Menarche in Athletes, and (3) Age at Menarche and Sport Performance.

Age at Menarche in Non-athletes

Maturational pace can be quantified using age at menarche (AaM), the age at which girls begin menstruating. AaM is typically either determined prospectively or retrospectively. Prospective determination of menarche is obtained by following participants for a long period of time and observing the time when menarche is attained. Retrospective determination, on the other hand, involves interviewing or surveying individuals and having them recall the age at which they began menstruating. Of the two methods, retrospective determination of AaM is used more commonly in the literature; in fact, 25 out of the 26 studies that we have reviewed used retrospective methods to determine AaM.

Retrospective AaM determination. Since retrospective AaM determination often requires women to recall the timing of an event that occurred years earlier, it is important to consider the error that might be introduced into the measurement. Damon, Damon, Reed, and Valadian (1969) reported no statistically significant difference between the means of the recalled AaM and the actual AaM. There was a strong correlation between the two measures with a correlation coefficient (r) of 0.78, which is similar to another study that reported correlation of 0.75 between the recalled AaM and observed AaM (Livson & McNeill, as cited in Damon et al., 1969). Damon et al. (1969) had participants recall their AaM 19 years after the menarche was attained, and found a mean difference of 0.17 years between the recalled AaM and observed AaM. Another study found the mean difference of 0.2 years between the recalled AaM and observed AaM with the collection of data for the recalled AaM 39 years after the menarche was attained (Damon & Bajema, 1974). These studies suggest that most women can recall their AaM within a range of two to three months from the actual event, which is fairly accurate for the purpose of group comparison (Damon & Bajema, 1974).

Mean Age at Menarche in Non-athletes. Although our review of literature focused on AaM in athletes, many studies also presented values for AaM in non-athletes or the general population for comparison purposes. Table 1 presents means and standard deviations for these control groups for the studies that provided such values. The median value for the mean AaM values in Table 1 is 12.8 years. In addition, the median value for the standard deviation values in Table 1 is 1.3 years. If we assume that AaM is normally distributed in the general population, then this typical standard deviation value suggests that about two-thirds of girls begin menstruating between 11.5 and 14.1 years, and about 95% of girls begin menstruating between 10.2 and 15.4 years.

Table 1. *Mean (standard deviation) for Age at Menarche (AaM; in years) for Thirteen Studies on Non-athletes.*

Study	**AaM**
Brooks-Gunn & Warren (1988)	12.8 (1.1)
Di Cagno et al. (2012)	12.8 (1.2)
Constantini & Warren (1995)	13.0 (1.7)
Frisch et al. (1981)	12.7 (1.3)
Malina et al. (1973)	12.2 (1.6)
Malina et al. (1978)	12.3 (1.2)
Mokha & Sidhu (1989)	14.4 (1.4)
Mukherjee et al. (2014)	12.3 (1.3)
Sidhu & Grewal (1980)	14.0 (1.4)
Stager et al. (1984)	13.0 (1.6)
Stager & Hatler (1988)	12.9 (1.3)
Torstveit & Sundgot-Borgen (2005)	13.0 (1.3)
Warren (1980)	12.5 (1.2)

Note: Values are means (standard deviation).

Weight as a Factor Affecting AaM. Later AaM and menstrual dysfunction are very common in athletes with low body mass and low body fat. In sports such as gymnastics, rhythmic gymnastics, and ballet, athletic success might be dependent upon anthropometric profile and body composition, and thus, athletes are being selected on the basis of these physical characteristics. Or it might be that later AaM and menstrual dysfunction in athletes are the result of intensive physical training and low caloric intake that causes changes in the anthropometric profile and body composition, which can trigger occurrence of primary and secondary amenorrhea. The primary amenorrhea indicates the absence of first menstruation by age 16 (Tate, 2012). On the other hand, if a woman already had a menstruation and later experienced the absence of a menstruation, this condition is called secondary amenorrhea (Tate, 2012).

According to the data from the longitudinal growth studies that showed early and late maturing girls attained menarche at the same mean weight but late maturers are taller at menarche, Frisch and Revelle (1970) suggested a critical body weight hypothesis. Critical body weight hypothesis suggests a minimum body weight necessary for the onset of first menstrual cycle in amenorrheic girls and the restoration of menstrual cycle in postmenarcheal girls. At the onset of rapid and intense increase in height (peak height velocity), the average height in late maturing girls increased significantly with the age of initiation of peak height velocity (Frisch & Revelle, 1970). On the other hand, the average weight at the onset of rapid and intense increase in weight (peak weight velocity) did not differ between early and late maturers (Frisch & Revelle, 1970). According to Frisch and Revelle (1970), late maturers had the same average weight as early maturers during the onset of peak weight velocity, but they are taller on average during this event, which indicates that late maturers have less weight for height compared to early maturers. The comparison of two groups and their anthropometric profile at the onset of these adolescent events led to a suggestion of the critical body weight hypothesis.

First menstrual cycle occurs after the peak height velocity and the peak weight velocity (Frisch & Revelle, 1970). Frisch and McArthur (1974) reported a minimum body weight for the height essential for the onset of menarche in amenorrheic girls and for the restoration of menstrual cycle in postmenarcheal girls, which is based on the previous findings discussed earlier. They found that 22% fat of body weight is necessary for the restoration and maintenance of menstrual cycle in women of ages 16 years and older (Frisch & McArthur, 1974). The weight for the height observed at menarche are around 10% lower than the weight for the same height necessary for the restoration of menstrual cycle for the postmenarcheal women of ages 16 years and older (Frisch & McArthur, 1974). In addition to these findings, they reported the increase in body fat from the ages of menarche to the age of 18 regardless of timing of maturation (Frisch & McArthur, 1974). There is also a minimum of 17% fat of body weight necessary for the onset of menstrual cycle in primary amenorrheic girls due to the undernutrition (Frisch & McArthur, 1974).

Age at Menarche in Athletes

In sports in which appearance plays an important role in athletic success, there might be a preselection of athletes with low body weight. Athletes participating in sports in which low body weight is necessary for success had significantly later AaM than athletes participating in sports in which body weight does not play an important role in athletic success (Baxter-Jones et al., 1994; Erlandson et al., 2008). Following example of the previous research (Torstveit & Sundgot-Borgen, 2005), we divided this section of the review of literature into following sections: (1) AaM in leanness sports and (2) AaM in non-leanness sports.

Age at menarche in leanness sports. This section of the review of literature is focused on AaM in athletes participating in leanness sports in which appearance plays an important role in athletic success. The following studies retrospectively obtained AaM in gymnastics, rhythmic gymnastics, ballet, and synchronized swimming.

Athletic success and performance in many sports is dependent upon physical characteristics of an athlete (Avila-Carvalho, Klentrou, Palomero, & Lebre, 2013). Even though certain anthropometric characteristics of an athlete may not guarantee success in sports, it can have a significant contribution to an overall athletic performance. There are many factors that can contribute to the performance and overall athletic success, such as anthropometric profile, body composition, training experience and workload, nutrition, environmental and socioeconomic factors, and those of psychological nature due to the training and competition. Most of the elite athletes start training for sport from a young age. Training for sport before puberty can cause a significant stress on the body and delay in maturation. Avila-Carvalho et al. (2013) analyzed anthropometrics, body composition, training experience, and AaM in elite rhythmic gymnasts. According to Avila-Carvalho et al. (2013), adult gymnasts (16.6 years ± 1.2 SD) with a longer training experience before menarche had significantly later AaM compared to young gymnasts (14.8 years ± 1.1 SD). Training experience before menarche and chronological age were both correlated with AaM (Avila-Carvalho et al., 2013).

Combination of high training volume, low caloric intake, and low percentage of body fat can cause menstrual disturbance and delay the onset of menarche (Thompson & Sherman, as cited in Di Cagno et al., 2012). Di Cagno et al. (2012) investigated the influence of training workload and dietary habits on the AaM and menstrual history in the elite rhythmic gymnasts. According to Di Cagno et al. (2012), post-menarche trained gymnasts (15.0 years ± 1.5 SD) were significantly older at menarche compared to general population (12.8 years ± 1.2 SD). There was a significant correlation between training workload, body weight, diet restrictions, technical level, and age at menarche (Di Cagno et al., 2012). In this study, training workload and body mass were found to be significant factors for later AaM in elite rhythmic gymnasts (Di Cagno et al., 2012).

Georgeopoulos et al. (1999) investigated genetics and environmental factors with growth and sexual maturation in elite rhythmic gymnasts. Gymnasts were significantly taller and lighter than the average height and weight for the same age of the control group (Georgeopoulos et al., 1999). According to Georgeopoulos et al. (1999), elite rhythmic gymnasts (14.3 years ± 1.5 SD) were significantly older at menarche than their mothers and sisters (13.7 years ± 1.5 SD). The mothers' mean AaM was identical to the mean AaM of the gymnast's sisters (Georgeopoulos et al., 1999). The AaM was positively correlated with the intensity of training and negatively correlated with the body fat (Georgeopoulos et al., 1999).

Frisch, Wyshak, and Vincent (1980) investigated the AaM and amenorrhea in ballet dancers. Postmenarcheal dancers (13.7 years ± 1.2 SD) were significantly older at menarche compared to the average American girls (Frisch et al., 1980). Frisch et al. (1980) also reported high incidence of primary and secondary amenorrhea and irregular menstrual periodicity in dancers. Premenarcheal dancers were significantly leaner compared to postmenarcheal dancers, and their average weight was below the critical weight for the height necessary for the onset of menarche and the maintenance of regular menstrual cycles in well-nourished women with average physical activity (Frisch et al., 1980). Frisch et al. (1980) argue that delay menarche was strongly affected by high training volume and low caloric intake in ballet dancers.

On the other hand, Warren (1980) investigated the effects of training on puberty and normal reproductive function in ballet dancers who maintain a high level of physical activity from early adolescence. According to Warren (1980), dancers (15.4 years ± 1.9 SD) were significantly older at menarche compared to the control group (12.5 years ± 1.2 SD). The average body weight and percentage of body fat were significantly lower in ballet dancers, as well as higher prevalence of menstrual dysfunctions. Warren (1980) suggests that training workload and exercise-induced energy deficiency with the combination of low body weight may have caused later AaM and amenorrhea in ballet dancers.

Low body weight and exercise-induced energy deficiency as a result of high training volume and eating disorders can cause delay in menarche and prevalence of amenorrhea. Brooks-Gunn, Warren, and Hamilton (1987) investigated eating problems and amenorrhea in ballet dancers. According to Brooks-Gunn et al. (1987), dancers (14.3 years ± 1.8 SD) were significantly older at menarche than the control group (12.8 years ± 1.1 SD). Furthermore, 33% of the dancers reported eating disorders such as anorexia nervosa and bulimia (Brooks-Gunn et al., 1987). Brooks-Gunn et al. (1987) argue that amenorrhea might have been related with the eating disorders. In addition, leanness, absolute weight, and dieting were significantly related to the prolonged amenorrhea (Brooks-Gunn et al., 1987). In another study by Brooks-Gunn and Warren (1988), dancers (13.3 years ± 1.3 SD) were significantly older at menarche compared to the control group (12.8 years ± 1.1 SD). Dancers were lighter, had lower body mass, and reported higher eating problem scores compared to non-dancers (Brooks-Gunn & Warren, 1988). Body mass and AaM were negatively correlated in dancers (Brooks-Gunn & Warren, 1988).

Baxter-Jones at al. (1994) investigated the effects of training and genetics on AaM in intensively trained athletes participating in gymnastics, swimming, and tennis. According to Baxter-Jones et al. (1994), gymnasts (14.3 years ± 1.4 SD) were significantly older at menarche compared to swimmers (13.3 years ± 1.1 SD) and tennis players (13.2 years ± 1.4 SD). In addition, gymnasts trained significantly more hours than tennis players, but not more than swimmers (Baxter-Jones et al., 1994). Type of sport and maternal menarcheal age had significant influence on athlete’s AaM (Baxter-Jones et al.

1994). On the other hand, Erlandson et al. (2008) looked at the relationship between the somatic growth, sexual maturation, and final adult height of elite adolescent female gymnasts, swimmers, and tennis players. According to Erlandson et al. (2008), gymnasts (14.5 years ± 1.5 SD) were significantly older at menarche than the tennis players (13.3 years ± 1.4 SD) and swimmers (13.3 years ± 1.4 SD). Erlandson et al. (2008) argue that differences in height between the three sporting groups are due to the preselection of certain physical characteristics, rather than the effect of training on final adult stature.

The last study that was reviewed in this section was focused on the AaM in synchronized swimming. Synchronized swimming was included in this section of the review of the literature because appearance plays an important role in athletic success. Ramsey and Wolman (2001) investigated menstrual characteristics in the highest ranked synchronized swimmers. According to Ramsey and Wolman (2001), there was no significant incident report of menstrual abnormalities in synchronized swimmers. The mean AaM in synchronized swimmers was 13.7 years (Ramsey & Wolman, 2001).

Table 2 presents means and standard deviation values for the AaM for athletes participating in leanness sports in which appearance plays an important role in athletic success.

Table 2. *Mean (standard deviation) for Age at Menarche (AaM; in years) for Athletic Samples.*

Study	**Sample Characteristics**	**AaM**
Avila-Carvalho et al. (2013)	Rhythmic gymnastics	Young = 14.8 (1.1)
		Adult = 16.6 (1.2)
Baxter-Jones et al. (1994)	Gymnastics, swimming, tennis	Gymnasts = 14.3 (1.4)
Brooks-Gunn et al. (1987)	Ballet dancers	14.3 (1.8)
Brooks-Gunn & Warren (1988)	Dancers	13.3 (1.3)
Di Cagno et al. (2012)	Rhythmic gymnasts	15.0 (1.5)
Erlandson et al. (2008)	Gymnastics, swimming, tennis	Gymnasts = 14.5 (1.5)
Frisch et al. (1980)	Ballet dancers	13.7 (1.2)
Georgopoulos et al. (1999)	Rhythmic gymnastics	14.3 (1.5)
Ramsay & Wolman (2001)	Synchronized swimming	13.7 (0.9)
Warren (1980)	Ballet dancers	15.4 (1.9)

Note: Values are means (standard deviation).

Age at menarche in non-leanness sports. This section of the review of literature is focused on the AaM in athletes participating in non-leanness sports. The following studies assessed AaM in various sports in which appearance and body weight does not play an important role in athletic success. Since the different sports require different physical characteristics necessary for success, we would expect different ages at menarche across different sports.

One common explanation for the later AaM in athletes is that pre-menarcheal training acts to “delay” menarche. This explanation is supported by data that showed girls were 0.4 years older at menarche for each year of training prior to menarche (Frisch et al., 1981). Frisch et al. (1981) reported on AaM in college swimmers and runners in relation to the age of initiation of training (AIT). According to Frisch et al. (1981), pre-menarche trained athletes (15.1 years ± 2.1 SD) were significantly older at menarche than the postmenarche-trained athletes (12.8 years ± 0.9 SD). Frisch et al. (1981) suggested that later AaM observed in post-menarche trained athletes is the result of intense physical training before the onset of menarche that act to delay menarche.

If the later AaM observed in athletes is the result of training-induced delay, we would expect to see later AaM in swimmers since most of the swimmers start training from a young age. Stager et al. (1984) also investigated the AaM in relation to the age of initiation of training and athletic performance. According to Stager et al. (1984), collegiate swimmers (14.3 years ± 1.5 SD) were significantly older at menarche than the control group (13.0 ± 1.6 SD). Swimmers who started training before the onset of menarche (13.5 ± 1.2 SD) were significantly older at menarche than swimmers who started training after the menarche (12.7 ± 1.3 SD; Stager et al., 1984). There was no significant difference in AaM between post-menarche trained athletes (12.7 years ± 1.3 SD) and the control group (13.0 years ± 1.6 SD; Stager et al., 1984). Stager and Hatler (1988) also looked at the relationship between the AaM, prepubertal training, and genetics in swimmers. According to Stager and Hatler (1988), swimmers (14.3 years ± 1.5 SD) were significantly older at menarche than the control group (12.9 years ± 1.3

SD). The sisters of the swimmers had significantly later AaM than the control group and their sisters (Stager & Hatler, 1988). Stager and Hatler (1988) suggest that the later AaM observed in swimmers is due to the inherited characteristics and intense physical training before the onset of menarche.

Constantini and Warren (1995) investigated various factors that might affect later AaM and menstrual dysfunction in swimmers. According to Constantini and Warren (1995), swimmers (13.8 years ± 1.7 SD) were significantly older at menarche compared to the control group (13.0 years ± 1.7 SD). Menstrual irregularities with longer durations were substantially higher across swimmers (Constantini & Warren, 1995). The most important finding in this study is the difference in hormonal level between swimmers and the control group. The levels of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) were above average, as well as LH/FSH ratio (Constantini & Warren, 1995). Constantini & Warren (1995) argue that the hormonal changes are the causing factor for later AaM and menstrual dysfunction in swimmers and not the body composition or dietary factors like we have seen in leanness sports.

Torstveit and Sundgot-Borgen (2005) investigated the AaM in the Norwegian elite female athletes. According to Torstveit and Sundgot-Borgen (2005), athletes (13.4 years ± 1.4 SD) were significantly older at menarche compared to the control group (13.0 years ± 1.3 SD). Athletes who started sport specific training before menarche reported significantly later AaM compared to athletes who started training after the menarche (Torstveit & Sundgot-Borgen, 2005).

Malina, Ryan, and Bonci (1994) reported on the AaM in athletes in seven different sports, and the AaM of their mothers and sisters. The mean AaM was 13.8 years for all athletes, and 13.4 years for their mothers, which was not statistically significant (Malina et al., 1994). Even though there wasn't a significant difference in the mean AaM between mothers who were athletes and mothers who were not athletes, Malina et al. (1994) suggest that the later AaM observed in athletes is rather familial than influenced by training. Sidhu and Grewal (1980) also looked at the AaM in various sports. According to Sidhu and Grewal (1980), athletes (15.2 years ± 1.5 SD) were significantly older at menarche compared to girls who didn't take any active part in sport participation (14.0 years ± 1.4 SD). Athletes participating in basketball had later AaM compared to other sports (Sidhu & Grewal, 1980). There was no significant difference between various athletic groups except for sprinters and throwers of discus and javelin (Sidhu & Grewal, 1980). Another study reported on the AaM in athletes in various sports and a general population (Malina, Bouchard, Shoup, Demirjian, & Lariviere, 1979). According to Malina et al. (1979), swimmers (13.1 years ± 1.3 SD) attained menarche significantly earlier than the gymnasts (14.5 years ± 0.8 SD), runners (14.3 years ± 1.6 SD), and rowers (13.7 years ± 1.1 SD). There was a significant correlation between the AaM and family size, and AaM and birth order (Malina et al., 1979).

The following three studies assessed AaM in girls active and not active in sport. According to Geithner, Woynarowska, and Malina (1998), the mean AaM of girls actively training for sport were not significantly different compared to girls not active in sport. Training for sport during puberty and the adolescent spurt didn't affect somatic and sexual maturation in girls (Geithner et al., 1998). The results of this study corresponds to other studies that showed athletes who started training after the menarche were not significantly older at menarche than the general population (Stager et al., 1984; Mokha & Sidhu, 1989).

According to Malina et al. (1973), girls active in sport (13.6 years ± 1.3 SD) were significantly older at menarche compared to girls not active in sport (12.2 years ± 1.6 SD). Another study reported on AaM and sport participation. According to Mukherjee et al. (2014), girls active in sport (13.7 years ± 1.3 SD) attained menarche significantly later than girls not active in sport (12.3 years ± 1.3 SD). In this study, athletic status and monthly income of the household were found to be significant predictors of the AaM (Mukherjee et al., 2014). Mukherjee et al. (2014) suggested that menstrual functioning among adolescence is significantly influenced by their athletic status.

Table 3 presents means and standard deviations for the AaM in athletes participating in non-leanness sports in which appearance and body weight does not play an important role in athletic success.

Table 3. *Mean (standard deviation) for Age at Menarche (AaM; in years) for Different Sports.*

Study	Sample Characteristics	AaM
Baxter-Jones et al. (1994)	Gymnastics, swimming, tennis	Swimming = 13.3 (1.1)
		Tennis = 13.2 (1.4)
Constantini & Warren (1995)	Swimmers	13.8 (1.7)
Erlandson et al. (2008)	Gymnastics, swimming, tennis	Swimming = 13.3 (1.4)
		Tennis = 13.3 (1.4)
Frisch et al. (1981)	Swimmers, runners	Training before menarche = 15.1 (2.1)
		Training after menarche = 12.8 (0.9)
Geithner et al. (1998)	Active v. non active	Active = 13.2 (0.7)
		Non-active = 12.9 (0.8)
Krawczyk, Sklad, & Majle (1994)	Various	13.0 (1.2)
Malina et al. (1973)	Active v. non active	Active = 13.6 (1.3)
		Non-active = 12.2 (1.6)
Malina et al. (1978)	Different competitive levels	High-school = 13.0 (1.2)
		College = 13.0 (1.3)
		Olympic volleyball = 14.2 (0.9)
Malina et al. (1979)	Various	13.7 (1.4)
Malina et al. (1994)	Active v. non active	Active = 13.8 (1.5)

Table 3 (continued). *Mean (standard deviation) for Age at Menarche (AaM; in years) for Different Sports.*

Mokha & Sidhu (1989)	Basketball, volleyball; different competitive levels	Basketball before menarche = 15.9 (1.3)
		Basketball after menarche = 14.7 (1.3)
		Volleyball before menarche = 15.7 (1.5)
		Volleyball after menarche = 14.1 (1.3)
Mukherjee et al. (2014)	Active v. non active	Active = 13.7 (1.3)
		Non-active = 12.3 (1.3)
Sidhu & Grewal (1980)	Various	15.2 (1.5)
Stager et al. (1984)	Swimmers	Pre-collegians = 13.0 (1.2)
		Collegians = 14.3 (1.5)
		Trained before menarche = 13.5 (1.2)
		Trained after menarche = 12.7 (1.3)
Stager & Hatler (1988)	Swimmers	14.3 (1.5)
Torstveit & Sundgot-Borgen (2005)	Elite athletes	13.4 (1.4)

Note: Values are mean (standard deviation).

Age at Menarche and Sport Performance

Later maturation is very common among female athletes. Athletic success in some sports might be related to the AaM, as we see more often that later maturing girls are better performers. One possible explanation for later AaM in athletes is that there are certain physical characteristics associated with late maturation that are also associated with athletic success. According to this explanation, athletes with later AaM are being selected for continued participation on the basis of these physical characteristics that are more suitable for athletic success.

There is evidence to suggest that late maturers and better athletic performers have less weight per height and more linear body shapes than early maturers and worse athletic performers, respectively. McNeill and Livson (1963) investigated the relationship between maturational pace and somatotype, the primary description of body build. Endomorphy and ectomorphy were significantly related with the maturational rate (McNeill & Livson, 1963). There was significant positive correlation between endomorphy and earlier maturation and negative correlation between ectomorphy and earlier maturation (McNeill & Livson, 1963), which suggest that earlier maturers are more broadly build. On the other hand, Meleski, Shoup, and Malina (1982) looked at the body size, physique, and body composition in female competitive swimmer compared to a general population. Female swimmers were on average taller and leaner with smaller skinfold thickness than non-athletic controls (Meleski et al., 1982). Swimmers were on average, meso-ectomorphic body builds (Meleski et al., 1982).

A few studies have even investigated relationship between the AaM and athletic success. Malina et al. (1978) looked at the AaM and selected menstrual characteristics in athletes at different competitive levels and in different sports. Athletes at the highest competitive level (Olympic volleyball players) attained menarche significantly later than the college-level athletes, high school-level athletes in various sports, and non-athletes (Malina et al., 1978). There was no significant difference in the average AaM between the college-level athletes and high school-level athletes (Malina et al., 1978). Stager et al. (1984) also looked at the relationship between the AaM and athletic performance. According to Stager et al. (1984), the fastest 20% of swimmers (14.8 years ± 1.1 SD) attained menarche significantly later than the slowest 20% of swimmers (13.9 ± 1.3 SD). Stager et al. (1984) suggested that the AaM and swimming performance are related based on the later AaM observed in better performers.

Krawczyk, Sklad, and Majle (1994) investigated AaM in different sports and different athletic experience. The average AaM in all athletes was 13 years, but the AaM differed across athletes with different athletic experience. According to Krawczyk et al. (1994), highly advanced athletes (13.5 years ± 1.4 SD) attained menarche significantly later than moderately advanced athletes (13.0 years ± 1.2 SD) and least advanced athletes (12.5 years ± 1.0 SD). Athletes that were younger than 15 years were considered least advanced athletes, moderately experienced athletes were between 15 and 19 years of age, and athletes that were over 19 years old were considered highly experienced athletes (Krawczyk et al., 1994). Mokha and Sidhu (1989) also investigated the difference in AaM in athletes across different competitive levels (International, national, intervarsity, and district). Later AaM was observed in athletes at a higher competitive level compared to those athletes at the lower competitive level (Mokha & Sidhu, 1989).

Later AaM is commonly observed in all female athletes. More predominantly later AaM is observed in athletes participating in leanness sports where appearance plays an important role in athletic success. On the other hand, swimmers mature significantly earlier than the gymnasts (Baxter-Jones et al., 1994; Erlandson et al., 2008). However, it was hypothesized that if later AaM is observed in all athletes, then swimmers should also have later AaM. Furthermore, if there is a relationship between the AaM and athletic success, then swimmers at a higher performance level should attain menarche later than swimmers at a lower performance level.

Chapter III

Methods

The purpose of this study was to determine if female collegiate swimmers have a slower maturational pace than the general population and if maturational pace is related to performance in this group of swimmers. Age at menarche (AaM) was used to retrospectively quantify maturational pace, with earlier AaM being associated with a faster maturational pace and later AaM a slower one. The three research questions for this study, and their associated research hypotheses, were as follows:

Research Question 1: Is AaM the same for collegiate competitive swimmers and general population?
Research Hypothesis 1: The collegiate competitive swimmers will be significantly older at menarche than the general population.

Research Question 2: Is AaM the same for collegiate competitive swimmers across three different performance levels?
Research Hypothesis 2: The High Performance group will be significantly older at menarche than the Middle Performance group, and the Middle performance group will be older at menarche than the Low Performance group.

Research Question 3: Is there a relationship between AaM and swim performance?
Research Hypothesis 3: There will be a significant positive correlation between AaM and swim performance.

Subject Recruitment

Our control group consisted of students from Eastern Michigan University with no history of collegiate swimming. The data for the control group was obtained as part of a separate study. The participants in the study provided their informed consent prior to participation. For our experimental group, we recruited current or recent collegiate competitive swimmers. It was important that the competitive swimmers were from a wide range of performance levels. In order to accomplish this, the participants were recruited from NCAA divisions I, II, and III swim programs. The participants were all 18 years of age or older, and all provided their informed consent prior to participation.

Study Protocol

Prior to data collection, we submitted an application to the Eastern Michigan University Human Subject Committee to gain permission to study human subjects (see Appendix A). Once permission was granted to use humans as research subjects, we contacted the coaches of collegiate varsity swim teams and asked permission to use their swim team members as our participants for the study. If they agreed to include their swim team as the participants for the study, we asked them to send an email out to their swim team members with the description of the study as well as a link to the actual survey. Before participants were able to complete the survey, they had to electronically sign the informed consent form (see Appendix B). In the informed consent form, and in the recruitment script, we emphasized that participants must be at least 18 years of age, participation was voluntary, and they could withdraw from the study at any time without negative consequences. The participants were not able to continue to the survey unless they provided their informed consent.

Data Collection

The participants in the study simply completed a brief online survey regarding height, weight, race/ethnicity, training history, competitive swimming participation history, and AaM (as a means of estimating maturational pace; see Appendix C). The majority of swimmers (94%) provided their AaM. AaM was obtained retrospectively and reported to the nearest month. Although collecting data for age at menarche retrospectively can introduce error into the measurement, the literature shows that recalled age at menarche usually varies about two to three months within the actual date of menstruation onset (Damon et al., 1969; Damon & Bajema, 1974). For the purpose of group comparison, retrospective AaM estimates are considered to be accurate and reliable for making generalizations and drawing conclusions (Malina, 1983).

The data from the online survey was initially coded to protect subject confidentiality. We needed to code the data at first because we needed to pair a subject's questionnaire responses with swim performance data. Swim performance data were collected from the USA Swimming performance database. USA Swimming, the national governing body of swimming in the United States, keeps performance data for all its registered members and makes them available to the public through their website. In addition, once the questionnaire data were connected with the subject's swim performance data from the USA Swimming performance database, the file linking the subject IDs to identifiers was deleted. This served to make the data file anonymous. At the end of our study, we will remove the data from the online server.

Every swim performance time listed in the USA Swimming time database is given a HY-TEK Power Point score. The American record in each event corresponds to a Power Point score of approximately 1,100. Thus, while it is technically possible to achieve a Power Point score over 1,100, the scores generally range from 0 to 1,100 points, with higher scores indicating better swim performances. The point system is based on the algorithm that is adjusted for each age level and competitive event. As a result, the HY-TEK Power Point score provides us with a means of standardizing performance across different competitive strokes and event distances. The majority of swimmers (84%) appeared in the USA Swimming database, and many had dozens of performance records listed. In order to reduce the many swim performances into a single performance value, we selected each swimmer's best swim performance (highest HY-TEK Power Point score) during the 2015–2016 NCAA swim season. In addition, 80% of collegiate swimmers provided their AaM and had performance data available in the USA Swimming database.

Statistical Analysis

The independent variables, dependent variables, statistical hypotheses, and statistical analyses are described below for the three research questions. We used an alpha level of 0.05 to determine significance for all statistical tests.

Research Question 1: Is AaM the same for collegiate competitive swimmers and general population?

Independent Variable 1: There was one independent variable associated with this research question: competitive swimming participation. This variable had two levels: (1) individuals who had never been collegiate competitive swimmers and (2) individuals who were collegiate competitive swimmers during the 2015–2016 NCAA swim season.

Dependent Variable 1: There was one dependent variable for this research question, and it was AaM as determined by the questionnaire.

Statistical Hypothesis 1:

H_0: $\mu_1 = \mu_2$. The population mean for AaM is the same for collegiate competitive swimmers and the general population.

H_1: $\mu_1 \neq \mu_2$. The population mean for AaM is not the same for collegiate competitive swimmers and the general population.

Statistical Analysis 1:

We used an independent samples t test in order to test the null hypothesis. The decision to reject or fail to reject the null hypothesis was based on the probability of the obtained test statistic (t). If the probability of obtaining the computed test statistic was greater than 0.05, we would fail to reject the null hypothesis and conclude that there is not a difference in the population mean for AaM between collegiate competitive swimmers and individuals with no history of collegiate swimming. If the probability of obtaining the computed test statistic was less than 0.05, we would reject the null hypothesis, which would lead to the conclusion that the population mean for AaM is different for collegiate competitive swimmers and individuals with no history of collegiate swimming.

Research Question 2: Is AaM the same for collegiate competitive swimmers across three different performance levels?

Independent Variable 2: There was one independent variable associated with this research question: performance level. This variable had three levels: (1) High Performance group, (2) Middle Performance group, and (3) Low Performance group.

Dependent Variable 2: There was one dependent variable for this research question, and it was AaM, as determined by the questionnaire.

Statistical Hypothesis 2:

H_0: $\mu_1 = \mu_2 = \mu_3$. The population mean for AaM is the same for collegiate competitive swimmers across three performance levels.

H_1: $\mu_1 \neq \mu_2$ and/or $\mu_1 \neq \mu_3$ and/or $\mu_2 \neq \mu_3$. The population mean for AaM is not the same for collegiate competitive swimmers across all three performance levels.

Statistical Analysis 2:

The performance levels were identified using frequency distribution, a simple way to organize and describe data. We recorded the highest Power Point score for each swimmer during the 2015–2016 NCAA swim season and arrange them in descending (highest to the lowest) order. The top 33.3% of collegiate swimmers according to Power Point score were considered as the High Performance group, the middle 33.3% as the Middle Performance group, and the bottom 33.3% as the Low Performance group. The Power Point score for the Low Performance group ranges from 0 to 742, for the Middle Performance group 743 to 840, and for the High Performance group 841 to 1100. The mean Power Point score for the Low Performance group was 640, for the Middle Performance group it was 794, and 909 for the High Performance group.

Data was analyzed using one-way ANOVA. If the probability of obtaining the computed test statistic (F) was more than 0.05, we would fail to reject null hypothesis, and conclude that the population mean for AaM is not different for swimmers at different performance levels. If the probability of obtaining the computed test statistic was less than 0.05, we would reject the null hypothesis. When rejecting the null hypothesis, we can conclude that the AaM is not equal across three different performance groups. Finding a significant F ratio and rejecting the null hypotheses was not sufficient enough to tell us which group comparison might actually differ significantly. Further analysis is necessary to determine which groups differ from each other. The Tukey HSD post hoc test would be used to determine if AaM is different for each pair of performance levels, if necessary.

Research Question 3: Is there a relationship between AaM and swim performance?

Variables 3: We looked at the relationship between two variables. One variable was the highest HY-TEK Power Point score across a swimmer's 2015–2016 NCAA swim season. The second variable was AaM, as determined by the questionnaire.

Statistical Hypothesis 3:

H_0: $\rho = 0$. There is no relationship between AaM and swim performance.

H_1: $\rho \neq 0$. There is a relationship between AaM and swim performance.

Statistical Analysis 3:

Data was analyzed using the Pearsons product-moment correlation. If the probability of obtaining the observed test statistics (r) was more than 0.05, we would fail to reject null hypothesis, and conclude that there is not a relationship between AaM and swim performance. If the probability of obtaining the observed test statistic was less than 0.05, we would reject the null hypothesis, which would lead us to the conclusion that there is a relationship between the AaM and swim performance.

Chapter IV

Results

A total of 560 women participated in this study by completing the questionnaire that asked questions regarding height, weight, race/ethnicity, maturational pace (as determined by AaM), and sports participation history. The respondents were divided into two groups: (1) current or recent collegiate swimmers (N = 285) and (2) those with no history of collegiate swimming (N = 275). The 275 women with no history of collegiate swimming (control group) identified as one of the two race/ethnicity: Black or African American (17.8%), and White or Caucasian (71.3%). The remaining respondents identified as American Indian or Alaskan Native (0.4%), Asian or Pacific Islander (2.9%), Hispanic (2.2%), and Multiple or Other (5.4%). In addition, 285 collegiate swimmers submitted questionnaire responses, although 18 did not provide a response for the questions regarding menarcheal age. The sample primarily identified as White or Caucasian (86.7%), with the remaining respondents identifying as American Indian or Alaskan Native (0.7%), Asian or Pacific Islander (3.2%), Black or African American (0.7%), Hispanic (3.2%), Multiple or Other (4.2%), and 1.3% of collegiate swimmers did not provide a response for the question regarding race/ethnicity. Of the 285 collegiate swimmers who completed the questionnaire, 267 provided their AaM and 227 provided AaM and had performance data available in the USA Swimming database.

The questionnaire responses were analyzed along with performance data from the USA Swimming database in order to test the statistical hypotheses and answer the research questions. The results are presented below.

Research Question 1: Is AaM the same for collegiate competitive swimmers and general population?

H_0: $\mu_1 = \mu_2$. The population mean for AaM is the same for collegiate competitive swimmers and the general population.

H_1: $\mu_1 \neq \mu_2$. The population mean for AaM is not the same for collegiate competitive swimmers and the general population.

The null hypothesis above was tested using an independent samples t test. There was a significant difference in AaM between collegiate competitive swimmers and collegiate women in the general population ($t_{540} = 6.71$, $p < 0.001$). As a result, the null hypothesis was rejected, which leads to the conclusion that collegiate competitive swimmers are older at menarche (13.60 years ± 0.09 SE) than collegiate women in the general population (12.75 years ± 0.09 SE; see Figure 1).

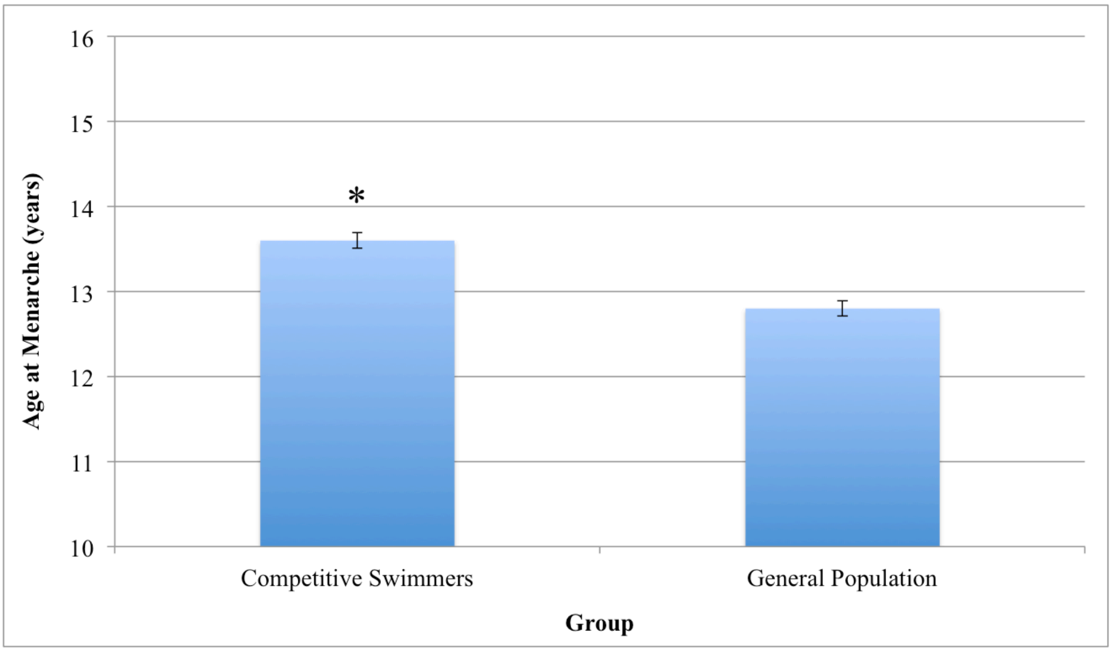

Figure 1. Age at menarche (years) of female collegiate swimmers and the general population.
Note: Bars represent mean values ± one standard error. * indicates that female collegiate swimmers were significantly older at menarche than collegiate women in the general population ($p < 0.001$).

Research Question 2: Is AaM the same for collegiate competitive swimmers across three different performance levels?

H_0: $\mu_1 = \mu_2 = \mu_3$. The population mean for AaM is the same for collegiate competitive swimmers across three performance levels.

H_1: $\mu_1 \neq \mu_2$ and/or $\mu_1 \neq \mu_3$ and/or $\mu_2 \neq \mu_3$. The population mean for AaM is not the same for collegiate competitive swimmers across all three performance levels.

The null hypothesis above was tested using one-way ANOVA. There was a significant difference in AaM across three different performance levels ($F_{2, 224} = 4.71$, $p = 0.01$). As a result, the null hypothesis was rejected, which leads to the conclusion that the AaM is not the same across three different performance groups. Tukey's HSD post hoc test indicated that the High Performance group (14.06 years ± 0.18 SE) was significantly older at menarche than the Low Performance group (13.32 years ± 0.15 SE; see Figure 2). In addition, the mean Power Point score for the High Performance group was 909 and the mean Power Point score for the Low Performance group was 640.

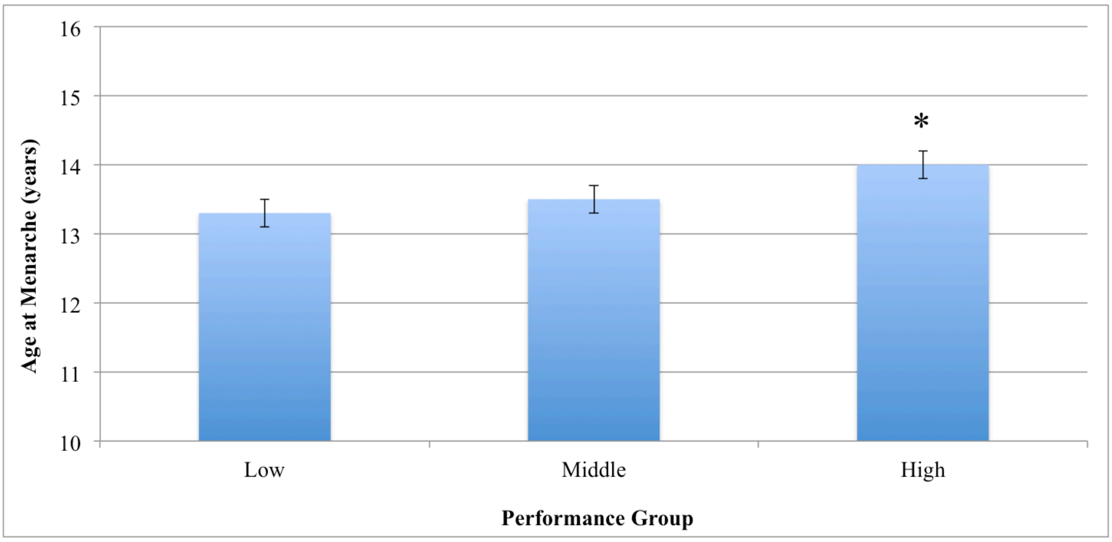

Figure 2. Age at menarche (years) as a function of swim performance.
Note: Bars represent mean values ± two standard error. * indicates that the group was significantly older at menarche than the Low Performance group (p = 0.01).

Research Question 3: Is there a relationship between AaM and swim performance?

H_0: $\rho = 0$. There is no relationship between AaM and swim performance.

H_1: $\rho \neq 0$. There is a relationship between AaM and swim performance.

The null hypothesis above was tested using the Pearsons product-moment correlation. There was a significant correlation between the AaM and swim performance ($r = 0.14$, $p = 0.03$). As a result, the null hypothesis was rejected, which leads to the conclusion that there is a relationship between AaM and swim performance (see Figure 3). Correlation coefficient ($r = 0.14$) indicates a week correlation for our outcome variable (Swim Performance) and our predictor variable (AaM). In addition, coefficient of determination ($r^2 = 0.02$) for our model, tells us that our predictor variable accounts for 2% of the variance in our outcome variable.

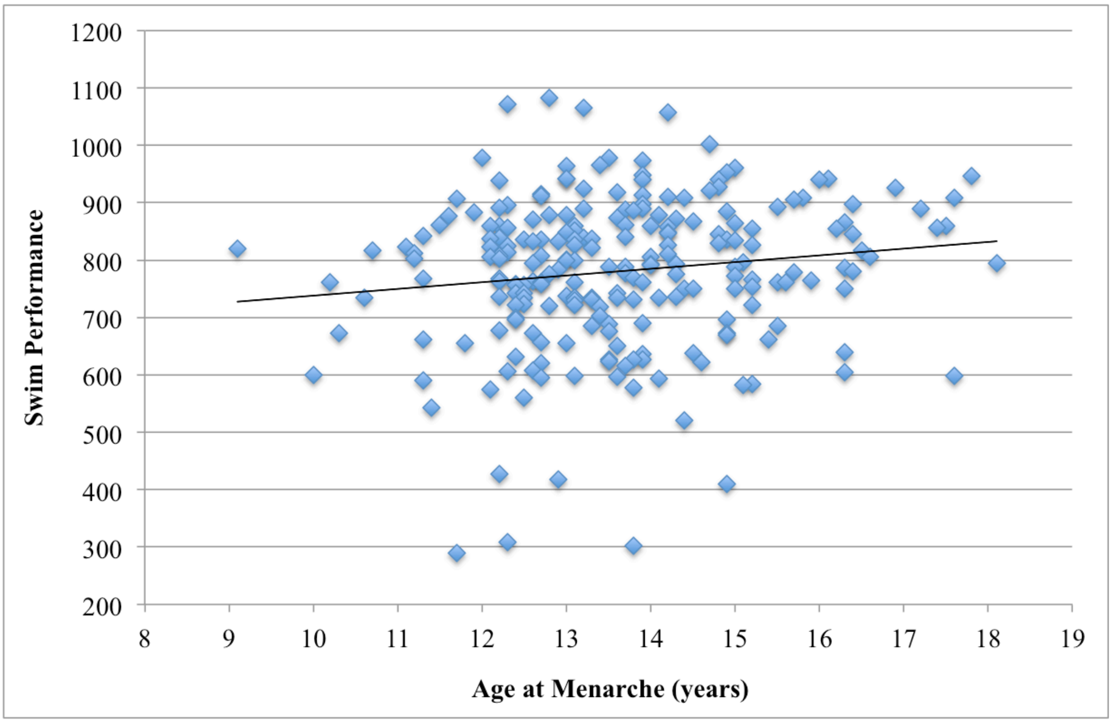

Figure 3. Relationship between swim performance (as determined by USA Swimming Power Point score) and age at menarche (years).
Note: There was significant positive correlation between age at menarche and swim performance ($p = 0.03$).

Chapter V

Discussion

The main purpose of this research was to investigate the relationship between AaM and swimming performance. This discussion is divided into three sections: (1) AaM in athletes and non-athletes, (2) AaM and swim performance, and (3) delayed or later menarche in athletes?

AaM in Athletes and Non-athletes

Although this research was focused on maturational pace in athletes, our first research question looked at the differences in maturational pace (as determined by AaM) between female collegiate swimmers and a non-athletic control group. Our findings indicate that the collegiate competitive swimmers included in our sample were significantly older at menarche (13.60 years ± 0.09 SE) than collegiate women in the general population (12.75 years ± 0.09 SE). This finding of a slower maturational pace (or older AaM) in athletes is hardly novel; similar results have been reported on many occasions and across multiple disciplines (Brooks-Gunn & Warren, 1988; Constantini & Warren, 1995; Di Cagno et al., 2012; Frisch et al., 1981; Malina et al., 1973; Malina et al., 1978; Mokha & Sidhu, 1989; Mukherjee et al., 2014; Sidhu & Grewal, 1980; Stager et al., 1984; Stager & Hatler, 1988; Torstveit & Sundgot-Borgen, 2005; Warren, 1980).

The mean value obtained for the AaM of our control group is in agreement with the typical value for the AaM in the general population. As explained in the literature review, we reviewed 13 studies that compared AaM between athletes and a non-athletic control group. The median value for AaM of the control groups for these 13 studies is 12.8 years (see Table 1), which corresponds very closely to the mean AaM for our control group (12.75 years).

In addition, AaM for collegiate competitive swimmers in the present study is similar to previous reports on AaM in swimmers. The mean value obtained for the AaM of our experimental group (collegiate competitive swimmers) is 13.6 years, whereas the median value for the studies that presented AaM in competitive swimmers is 13.3 years (see Table 4).

Table 4. *Mean (standard deviation) for Age at Menarche (AaM; in years) from Ten Studies on Competitive Swimmers.*

Study	**AaM**
Malina et al. (1978)	12.8 (1.2)
Malina et al. (1979)	13.1 (1.3)
Baxter-Jones et al. (1994)	13.3 (1.1)
Erlandson et al. (2008)	13.3 (1.4)
Krawczyk et al. (1994)	13.3 (1.1)
Stager et al. (1984)	13.4 (1.4)
Present Study	13.6 (1.5)
Constantini & Warren (1995)	13.8 (1.7)
Frisch et al. (1981)	13.8 (2.3)
Stager & Hatler (1988)	14.3 (1.5)

Note: Values are mean (standard deviation).

Maturational Pace and Swim Performance

In general, it is well accepted that female athletes are older at menarche (i.e., are slower maturers) than non-athletes, but the explanation for this is not well understood. It has been suggested previously that later AaM in athletes may be due to the pre-menarcheal training that acts to “delay” menarche (Frisch et al., 1981). This explanation is supported by data that showed girls were 0.4 years older at menarche for each year of training completed before the attainment of menarche (Frisch et al., 1981). Another explanation for later AaM in athletes is that there are certain physical traits associated with later AaM that are also associated with athletic success, and thus, athletes with later AaM are being selected for continued participation (by themselves or others) on the basis of these physical traits (Malina et al., 1978). If one or both explanations for later AaM in athletes were true, we would expect a relationship between AaM and athletic performance.

We tested the relationship between AaM and swim performance by assigning the collegiate swimmers into groups based on swim performance. We were then able to determine whether or not there was evidence the performance groups differed with respect to AaM. Our analyses indicated that the High Performance group (14.06 years ± 0.18 SE) was significantly older at menarche than the Low Performance group (13.32 years ± 0.15 SE).

Our finding that better performers are older at menarche is consistent with previous literature. Malina et al. (1978) investigated AaM and selected menstrual characteristics in athletes at different competitive levels and in different sports. Athletes at the highest competitive level (Olympic-level volleyball players) attained menarche significantly later (14.2 years ± 0.9 SD) than college-level athletes (13.0 years ± 1.3 SD) and high school-level athletes (13.0 years ± 1.2 SD) in various sports (e.g., golf, volleyball, swimming, basketball, gymnastics, track, and tennis). However, this study was problematic in that sport was not held constant, although AaM was subsequently shown to differ by sport (Baxter-Jones et al., 1994; Erlandson et al., 2008; Peltenburg et al., 1984). Another problem with the study was that Malina et al. used competitive level as their performance measure, and this is only a rough measure of an athlete's performance. Nevertheless, these findings were consistent with the findings from our study.

Stager et al. (1984) addressed the weaknesses from Malina et al. (1978) when they investigated the relationship between AaM and performance within a single sporting discipline (swimming) with accurate and reliable performance measures. They found that the fastest swimmers attained menarche significantly later (13.2 years ± 0.7 SD) than the slowest swimmers (12.1 years ± 1.2 SD), a finding consistent with the present study.

They divided the sample size according to swim performance in one event, 100-yards freestyle. While it was an important finding, the study did have weaknesses. One of the weaknesses was that the sample consisted of sub-elite swimmers, so the extent to which their findings extend to elite swimmers is unknown. The other weakness of the study was that sample was divided according to performance in only one swimming event, the 100-yard freestyle.

We addressed the weaknesses in the study by Stager et al. (1984) by using competitive swimmers from a wide range of performance levels. Further, we chose not to limit our study to a single event, but rather considered performances in competitive events, regardless of event stroke and distance. We did this by using the USA Swimming Power Point score for each performance. This provided a means of standardizing swim performances across events. We recorded the highest Power Point score for each subject for the 2015–2016 season, as the mean of identifying the best swimming performance for each athlete. The mean Power Point score for the High Performance group was 909 and the mean score for the Low Performance group was 640. Thus, the mean Power Point score for the High Performance group was 29.6% higher the Low Performance group. But again, this difference between groups is for a standardized performance score. It does not mean that the High Performance group was 29.6% faster than the Low Performance group.

In order to determine the typical time difference between groups, we first had to convert the Power Point scores back into times for each event. To do so, we determined the performance time (in seconds) for Power Point scores of 909 and 640 (the mean values for the High and Low Performance groups, respectively) for all NCAA swim events. We then calculated the percent difference in time across all events and found that the performances for the High Performance group were, on average, 10.34% (SD 1.02%)

faster than the performances for the Low Performance group. The absolute time difference is dependent on the event distance and competitive stroke. We can gain a sense of this time difference by looking at the 91.44-m (100-yard) race distance. A 10% difference in performance at this distance corresponds to about 5.5 to 6.0 s in time, depending on competitive stroke.

Delayed or Later Menarche in Athletes?

While it is well accepted that athletes tend to be older at menarche than non-athletes, the mechanism behind this relationship is not clear. Frisch et al. (1981) explained that the later AaM in athletes occurs because pre-menarcheal training acts to "delay" menarche. Frisch et al. (1981) analyzed AaM and age at initiation of training (AIT) in college swimmers. Swimmers who started training before the onset of menarche (15.0 years ± 0.6 SE) were significantly older at menarche than the postmenarche-trained swimmers (12.6 years ± 0.2 SE). We performed the same methods on our data for comparison purposes. We found that the pre-menarche trained swimmers (i.e., began training prior to menarche) had an AaM of 13.6 years ± 0.1 SE whereas the post-menarche trained swimmers (i.e., began training after menarche) had an AaM of 12.7 years ± 0.3 SE. However, while these findings seem to suggest that pre-menarcheal training delays menarche, Stager et al. (1990) demonstrated that the approach used by Frisch et al. (1981) was methodologically flawed.

As a result, we needed to find an alternate, unbiased method for assessing the argument that training delays menarche. One way that we were able to do that was to assess the relationship between AaM and AIT. If training delays menarche, then we would expect an inverse relationship between the variables. And we would expect this because the earlier a swimmer started training, the more menarche would be delayed. However, we did not find a correlation between AaM and AIT. This does not necessary mean that training does not delay menarche. It simply means that we failed to detect such an effect.

Another possible explanation for the older AaM in athletes as compared to non-athletes is that there are certain characteristics associated with later menarche that are also associated with athletic success. Thus, there is a selection pressure that leads to a disproportionate number of late maturers staying in the sport. For instance, Malina et al. (1978) explained that late maturing girls are usually more linear in physique and have less weight for height than the early maturers. And since previous research has shown that late maturers and better performers are more linear in body shape and have less weight per height (McNeill & Livson, 1963; Meleski et al., 1982), it's possible that late maturers are being selected for continued participation on the basis of these traits.

While we were not able to test this hypothesis directly with our data, analysis of our self-reported height and weight values provided some evidence for this hypothesis. We found statistically significant relationship between (1) AaM and swim performance, (2) AaM and BMI, and (3) swim performance and BMI. Taken together, these results seem to support the idea that late-maturing athletes are selected for continued participation due to common physical traits between athletic success and later menarche. Table 5 presents means and standard deviations for the height, weight, BMI, and AIT for the Low, Middle, and High Performance groups of female collegiate swimmers.

Table 5. *Mean (standard deviation) for Height (cm), Weight (kg), BMI (kg/m^2), and AIT (years) for the Low, Middle, and High Performance Groups of Female Collegiate Swimmers.*

Performance Groups	**Height (cm)**	**Weight (kg)**	**BMI (kg/m^2)**	**AIT (years)**
Low Performance group	168.9 (5.9)	66.2 (7.5)	23.2 (2.5)	7.6 (2.3)
Middle Performance group	169.4 (6.6)	65.0 (6.4)	22.7 (2.0)	7.3 (2.2)
High Performance group	172.9* (6.7)	67.1 (5.6)	22.5 (2.3)	7.9 (2.7)

Note: Values are mean (standard deviation). Low, Middle, and High Performance groups were determined by the HY-TEK Power Point scores, which are standardized performance scores. The lowest one-third of performers were assigned to the Low Performance group, the middle one-third of performers to the Middle Performance group, and the highest one-third of performers to the High Performance group. * indicates that the group was significantly taller than the Middle Performance group and Low Performance group ($p < 0.01$).

Chapter VI

Summary and Conclusion

Age at menarche (AaM) is a well-accepted and commonly used method for retrospectively quantifying maturational pace, with earlier AaM being associated with a faster maturational pace and later AaM a slower one. Research focused on maturational pace in athletes has consistently demonstrated that female athletes are slower maturers (i.e., older at menarche) than non-athletes (Constantini & Warren, 1995; Frisch et al., 1980; Frisch et al., 1981; Malina et al., 1973; Mokha & Sidhu, 1989; Sidhu & Grewal, 1980; Stager et al., 1984; Stager & Hatler, 1988). However, while it is accepted that athletes tend to be older at menarche than non-athletes, the performance implications of the later AaM in athletes is not well understood. Thus, the main purpose of our project was to investigate the relationship between the AaM and performance for female collegiate-level swimmers. Our primary working hypothesis was that AaM would be positively correlated with performance in swimmers.

In an effort to test our hypotheses, we constructed a questionnaire that asked questions regarding developmental pace and sports participation history, and requested two groups of college-age women complete it: (1) current or recent collegiate swimmers and (2) those with no history of collegiate swimming. In the end, our sample consisted of 560 women who completed the questionnaire, 285 collegiate swimmers and 275 college-age women with no history of collegiate swimming (general population). When comparing the AaM between the collegiate swimmers and the general population, we found that the collegiate competitive swimmers were older at menarche (13.60 years ± 0.09 SE) than collegiate women in the general population (12.75 years ± 0.09 SE). This finding was in agreement with the previous research, which showed that swimmers are older at menarche than the general population (Baxter-Jones et al., 1994; Frisch et al., 1981; Stager et al., 1984; Stager & Hatler, 1988).

Our next step was to focus on the collegiate swimmers in order to determine if AaM was related to swim performance. To do this, we needed to obtain swim performance data for the questionnaire respondents. We used the USA Swimming performance database in an effort to locate this data. Of the 285 collegiate swimmers who completed the questionnaire, 227 provided their AaM and had performance data available in the USA Swimming database. Next, we were faced with the challenge of combining athletes' swim performances across many years and different events into a single performance variable. We did this by limiting our focus to the 2015–2016 swim season, and using the USA Swimming Power Point score for each event. The USA Swimming Power Point score is a score ranging from 0 to 1,100 (with higher scores indicating better performance) that standardizes performance across different swimming events. For each athlete, we chose the swim performance from the 2015–2016 season with the highest Power Point score. We then divided our sample into thirds based on the USA Swimming Power Point score: (1) Low Performance group, (2) Middle Performance group, and (3) High Performance group. We found that the High Performance group (14.06 years ± 0.18 SE) was significantly older at menarche than the Low Performance group (13.32 years ± 0.15 SE), although the Middle Performance group (13.54 years ± 0.19 SE) did not differ from the other two performance groups. This finding was consistent with the findings from Malina et al. (1978) and Stager et al. (1984).

Our data clearly supported our initial hypothesis that there is a positive correlation between AaM and performance in collegiate-level swimmers. However, the underlying mechanism still remained unclear, so we conducted some additional analyses in an effort to gain some insight. One explanation for the older ages at menarche in athletes is that pre-menarcheal training acts to delay menarche (Frisch et al., 1981). For this to be true, athletes must, of course, begin training prior to menarche. This was certainly the case in our sample of collegiate swimmers as 96.2% of respondents indicated that they began training prior to menarche. In addition, if pre-menarcheal training delays menarche, then we might expect AaM to get older as AIT gets younger. However, when we tested the relationship between AaM and AIT, we did not find a significant relationship between the two variables ($r = 0.06$, $p = 0.33$). Thus, while our data did not support the argument that premenarcheal training delays menarche, it certainly cannot rule it out either.

The other common explanation for the older AaM in athletes is that certain physical traits associated with later AaM are also associated with athletic success (Malina et al., 1978; Stager et al., 1984). In other words, the later AaM in athletes is not the result of a training-induced delay; but rather, there are advantages associated with late maturation (e.g., height, body shape, lean body mass), and thus, athletes with later AaM are being selected for on the basis of these physical characteristics. We were able to test this hypothesis by analyzing the self-reported height and weight data from our questionnaire. In doing so, we found that self-reported height and weight were not significantly related. We used height and weight to calculate BMI, and then found significant relationship between AaM and BMI and between swim performance and BMI. This provides evidence for the hypothesis that late maturers are being selected for continued athletic participation based on physical traits common to both late maturers and better performers.

In summary, we can conclude that (1) collegiate swimmers are older at menarche than the general population and (2) swim performance is associated with later ages at menarche. However, it remains unclear as to why athletes are older at menarche than the general population and why the best swimmers tend to be older at menarche than their lower-performing counterparts. Is it because pre-menarcheal training delays menarche in these athletes? Is it because later-maturers are being selected for continued participation? Both? Neither? Something else entirely? In order to settle these questions, we recommend that future research observe training intensity and volume, swimming performance, growth, and maturational pace throughout childhood and adolescence and into early adulthood.

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APPENDICES

Appendix A: IRB Approval

RESEARCH @ EMU

UHSRC Determination: EXPEDITED INITIAL APPROVAL

DATE: February 20, 2016

TO: Alan Duski
Eastern Michigan University

Re: UHSRC: # 866843-1
Category: Expedited categories 5 & 7
Approval Date: February 19, 2016
Expiration Date: February 18, 2017

Title: Age at Menarche and Swimming Performance

Your research project, entitled **Age at Menarche and Swimming Performance**, has been approved in accordance with all applicable federal regulations.

This approval included the following:

1. Enrollment of 2000 subjects to participate in the approved protocol.

2. Use of the following study measures: Questionnaire

3. Use of the following stamped recruitment materials: Recruitment script for coaches; recruitment script for prospective participants

4. Use of the stamped: Informed consent form

Renewals: This approval is valid for one year and expires on February 18, 2017. If you plan to continue your study beyond February 18, 2017, you must submit a Continuing Review Form by January 19, 2017 to ensure the approval does not lapse.

Modifications: All changes must be approved prior to implementation. If you plan to make any minor changes, you must submit a **Minor Modification Form**. For any changes that alter study design or any study instruments, you must submit a **Human Subjects Approval Request Form**. These forms are available through IRBNet on the UHSRC website.

Problems: All major deviations from the reviewed protocol, unanticipated problems, adverse events, subject complaints, or other problems that may increase the risk to human subjects or change the category of review must be reported to the UHSRC via an **Event Report** form, available through IRBNet on the UHSRC website

Follow-up: If your Expedited research project is not completed and closed after **three years**, the UHSRC office requires a new **Human Subjects Approval Request Form** prior to approving a continuation beyond three years.

Please use the UHSRC number listed above on any forms submitted that relate to this project, or on any correspondence with the UHSRC office.

Good luck in your research. If we can be of further assistance, please contact us at 734-487-3090 or via e-mail at human.subjects@emich.edu. Thank you for your cooperation.

Sincerely,
Joan Cowdery, PhD
Vice Chair
University Human Subjects Review Committee

RESEARCH @ EMU

UHSRC Determination: EXPEDITED MODIFICATION APPROVAL

DATE: March 10, 2016

TO: Alan Duski
Eastern Michigan University

Re: UHSRC: # 866843-2
Category: Expedited
Approval Date: March 10, 2016
Expiration Date: February 18, 2017

Title: Age at Menarche and Swimming Performance

Your requested modifications for the project entitled Age at Menarche and Swimming Performance have been approved in accordance with all applicable federal regulations.

This approval includes the following:

1. Use of the modified study measures: Developmental Pace and Swim Performance

2. Use of the modified stamped Informed consent form.

Renewals: This approval does not change the original expiration date. This study expires on February 18, 2017. If you plan to continue your study beyond February 18, 2017, you must submit a Continuing Review Form by January 19, 2017 to ensure the approval does not lapse.

Modifications: All additional changes must be approved prior to implementation. If you plan to make any minor changes, you must submit a **Minor Modification Form**. For any changes that alter study design or any study instruments, you must submit a **Human Subjects Approval Request Form**. These forms are available through IRBNet on the UHSRC website.

Problems: All major deviations from the reviewed protocol, unanticipated problems, adverse events, subject complaints, or other problems that may increase the risk to human subjects or change the category of review must be reported to the UHSRC via an **Event Report** form, available through IRBNet on the UHSRC website

Follow-up: If your Expedited research project is not completed and closed after **three years**, the UHSRC office requires a new **Human Subjects Approval Request Form** prior to approving a continuation beyond three years.

Please use the UHSRC number listed above on any forms submitted that relate to this project, or on any correspondence with the UHSRC office.

Good luck in your research. If we can be of further assistance, please contact us at 734-487-3090 or via e-mail at human.subjects@emich.edu. Thank you for your cooperation.

Sincerely,
Joan Cowdery, PhD
Vice Chair
University Human Subjects Review Committee

Appendix B: Informed Consent Form

Purpose: The purpose of this research study is to gain a better understanding of the relationship between developmental pace and swimming performance.

Study Procedures: Participation in this study involves completing an online survey. It should take between 5 and 10 minutes to complete the survey.

Risks: The primary risk of participation in this study is a potential loss of confidentiality. Some of the survey questions are personal in nature and may make you feel uncomfortable. You do not have to answer any questions that make you uncomfortable or that you do not want to answer.

Benefits: You will not directly benefit from participating in this research. Benefits to society include better understanding of the relationship between developmental pace and swimming performance.

Confidentiality: We will keep your information confidential by using a code to identify your information. The code will be linked to your name using a separate key. Your information will be stored in a password-protected computer file.

We may share your information with other researchers outside of Eastern Michigan University. If we share your information, we will remove any and all identifiable information so that you cannot reasonably be identified.

The results of this research may be published or used for teaching. Identifiable information will not be used for these purposes.

Funding: This research is unfunded.

Contact Information: If you have any questions about the research, you can contact the Principal Investigator, Alan Duski at aduski@emich.edu or by phone at 734-262-3127. You can also contact Alan's faculty sponsor, Dr. Andrew Cornett at acornet2@emich.edu or by phone at 734-487-2810.

For questions about your rights as a research subject, you can contact the Eastern Michigan University Office of Research Compliance at human.subjects@emich.edu or by phone at 734-487-3090.

Voluntary participation: Participation in this research study is your choice. You may refuse to participate at any time, even after signing this form, with no penalty or loss of benefits to which you are otherwise entitled. You may choose to leave the study at any time with no loss of benefits to which you are otherwise entitled. If you leave the study, the information you provided will be kept confidential. You may request, in writing, that your identifiable information be destroyed. However, we cannot destroy any information that has already been published.

Statement of Consent: By clicking on the "Next" button below, I am indicating that (1) I have read this form; (2) I am at least 18 years of age; and (3) I give my consent to participate in this research study.

Approved by the Eastern Michigan University Human Subjects Review Committee
UHSRC Protocol Number: 866843-2
Study Approval Dates: 03/10/16 – 02/18/17

Appendix C: Participant Screening Questionnaire

General Information

1. Please enter your name below:
(This will only be used to look up your swim performance history in the USA Swimming database. If you've never competed at a USA Swimming competition, your name will be deleted. If you have competed at USA Swimming competitions, your name will be deleted after we've recorded your best performances.)

First Name:
Middle Name:
Last Name:

2. When were you born?
Date MM DD YYYY //

3. Which race/ethnicity best describes you? (Please choose only one.)
American Indian or Alaskan Native
Asian / Pacific Islander
Black or African American
Hispanic
White / Caucasian
Multiple ethnicity / Other (please specify)

4. What is your height in feet and inches? (Remove shoes before measuring.)
Feet
Inches

5. What is your current weight in pounds?

Menstruation Information

6. Have you begun your monthly periods (menstruating)?
Yes
No

7. At what age (in years) did your monthly periods (menstruating) begin?

8. What was the season of the year when your monthly periods began?
Spring (March, April, May)
Summer (June, July, August)
Fall (September, October, November)
Winter (December, January, February)

9. What was the month when your monthly periods began?
March
April
May

10. What was the month when your monthly periods began?
June
July
August

11. What was the month when your monthly periods began?
September
October
November

12. What was the month when your monthly periods began?
December
January
February

Swimming Participation History: Pre-High School

13. Did you begin swimming competitively before high school?
Yes
No

14. At what age (in years) did you begin swimming competitively?

15. Did you begin swimming competitively before or after your monthly periods began?
Before
After

16. On average, how many swim practices did you attend per week before high school?

17. Did you swim for a USA Swimming registered club before high school?
Yes
No

18. What was the name of the USA Swimming club or clubs on which you swam before high school?

Swimming Participation History: High School

19. Did you swim competitively when you were in high school?
Yes
No

20. How many years did you swim competitively during high school?

21. On average, how many swim practices did you attend per week during high school?

22. Did you swim for a USA Swimming registered club during high school?
Yes
No

23. What was the name of the USA Swimming club or clubs on which you swam during high school?

Swimming Participation History: College

24. Do you (or did you) swim for your university's varsity swim team?
Yes
No

25. What is the name of the university you compete (or competed) for?

26. In which association and division does your university's swim team compete?
NCAA Division I
NCAA Division II
NCAA Division III
NAIA

27. On average, how many swim practices do you (or did you) attend per week while swimming in college?

28. Do you (or did you) also swim for a USA Swimming registered club during college?
Yes
No

29. What was the name of the USA Swimming club or clubs on which you swim (or swam) during college?

30. Do you (or did you) swim for your university's club/intramural swim team?
Yes
No

31. On average, how many swim practices do you (or did you) attend per week while swimming on your university's club team?