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Analyses of Elite Swimming Performances and Their Respective Between-Gender Differences over Time

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Abstract

The current study analyzed historical performance data in order to contribute to the understanding of the development of elite athletes. Data for elite adult and youth swimmers from 1962 to 2007 were employed to identify changes in American swimming records and in the performances of elite American youth swimmers. Over this period, 11 of the 12 men's and women's American records analyzed are improving at an ever slowing rate. This trend parallels the resultant analyses herein from elite youth swimmers, suggesting a possible limit to reaching elite athletic performance. Unique gender differences by event for both elite adult and youth swimmers were also revealed. Results imply that genotype plays a role in elite athletic performance. Additionally, possible reasons and ramifications of these findings are proffered.

KEYWORDS: sport psychology, physiology, biomechanics, athlete development, environmental factors, genotype

Performance improvements over time and the changes in the gender gap in elite athletic performance have been addressed in the literature. Conclusions proposed within these range from elite women and men will perform equally in the future (e.g., Tatem et al., 2004; Whipp & Ward, 1992), to men's world records will always be faster than women's (e.g., Cheuvront et al., 2005; Nevill & Whyte, 2005; Seiler et al., 2007; Sharp, 2004). A plurality of these analyses have specifically addressed running, while some have included sports such as speed skating and swimming. The current article contributes to this knowledge base by analyzing changes in objective performance data from elite male and female swimmers, both adult and youth, over a four decade timeframe and by identifying the respective gender differences.

In addition to the time series analyses performed on data from elite adult swimmers, we also accepted the novel mission of analyzing objective performance data from elite youth male and female swimmers. Identifying performance changes, and any associated gender differences during a 40 year timeframe, could evoke additional questions and aid future areas of exploration regarding the developmental patterns of athletes, and why those patterns manifest themselves. The analyses illustrated herein will provide concrete evidence of elite swimmers' performance trends over time. Additionally, this study will provide evidence supporting some previous researchers' contentions, while refuting others, regarding trends in between-gender athletic performance. However, the current study is not designed to predict future outcomes as is the case in many situations, past performances are not argued herein to predict future performances.

When considered in conjunction with studies addressing other aspects of elite athletes' experiences, analyses of performance data over time can be an asset to scientific inquiry. Previous cross-sectional analyses have identified that elite athletes tend to be born earlier, rather than later, in the calendar cycle that is used to group them during their youth sport experiences (i.e., the relative age effect: Barnsley et al., 1985; Baxter-Jones & Helms, 1994; Dundink, 1994). Additionally, a birthplace effect has been identified (Côté et al., 2006). Some (e.g., Cheuvront et al., 2005) have proposed factors such as social influences as the likely reasons for these effects, which also has been proffered as a possible explanation for the narrowing of between-gender performance differences in elite athletes.

Non-athletic domains also have experienced performance changes over time. One example is the Flynn effect (Flynn, 1987), which notes that average IQ scores have steadily risen approximately 3-5 points per decade over the past century. Reasons for this increase typically have been attributed to biological, social, educational, and nutritional factors (Neisser, 1998). However, Mingroni (2007) recently criticized these hypotheses as implausible or difficult to test and offered an alternative hypothesis that the Flynn effect is likely a consequence of what he terms *hybrid vigor*, that is, “A genetic effect that results from matings between members of genetically distinct subpopulations, such as has been occurring in human populations through the breakup of small, relatively isolated communities owing to urbanization and greater population mobility” (p. 806). This perspective augments the traditional paradigm that improvements in technology and training methods are the sole or primary contributors to improvements in human performance (i.e., there is a genetic influence on human performance; Brutsaert & Parra, 2006). The interactionist relationship among genetic and social factors relative to human performance, as suggested by Mingroni, likely generalizes to athletic performance. The present investigation supports this.

The two related analyses performed in the current study are presented individually. In the first study we analyzed the progression of American swimming records from 1962 to 2007, with special attention paid to gender differences over that time frame. In Study 2 we present an analysis of elite youth swimmers’ performances from 1962 to 2002.

Over the time period analyzed (i.e., 1962 to 2007) it was anticipated that performance improvements would be found for both elite adults and youths (e.g., Flynn, 1987; Seiler et al., 2007; Whipp & Ward, 1992). Additionally, it was hypothesized that performance improvements evidenced by elite adult and youth females would exceed those of their male counterparts. This second hypothesis was based on the fact that competitive opportunities for women in American schools and colleges between 1962 and 2007 have increased far more than they have for men. That is, more females participate in athletics at the high school level (NFSHSA, 2007), American collegiate level (NCAA, 2003), and at the Olympics (Cheuvront et al., 2002) in numbers relatively greater than for males over the past half century. If this second hypothesis is accurate, then the performance gap between males and females will be narrowing. And finally, it was conjectured that there will be similar trends in between-gender performance differences over time regardless of event distance or stroke, as nothing in the current literature indicates otherwise.

The sport of swimming was selected to test these hypotheses primarily for the following reasons. First, the data is readily available for both American records and the performances of elite youths since at least 1962. Second, there are fewer confounding factors in the sport of swimming than in most other sports. That is, (a) many high level swimming competitions are conducted indoors thereby reducing the effects of the weather; (b) strategy rarely, if ever, plays a role in swim racing other than the strategy to cover the competitive distance in the shortest time possible; (c) there are no team, or other, interpersonal dynamics (i.e., each swimmer has her or his own discrete lane within which to compete); (d) there is a clear and objective metric evaluating performance (i.e., time); and (e) changes in pool technology, racing apparel, and training principles are consistent between-genders and among ages over time (e.g., males and females both have access to the same training knowledge, experiences, coaching, and competitive facilities). Additionally, competitive swimming has the unique ability to illuminate performance trends and gender differences not only at discrete competitive distances (i.e., to analyze possible differences attributable to aerobic and anaerobic physiology), but also for different strokes at the same distance as the sport of swimming is partitioned into four (i.e., butterfly, backstroke, breaststroke, and freestyle). Uncovering any such performance trends and gender differences may assist future research that investigates the various psychological, physiological, and biomechanical factors involved in athletic performances.

STUDY 1

METHOD

Historical performance data was drawn from the USA Swimming, Inc. (USAS) Web site (USAS, 2009). USAS is the governing body for the sport of club swimming in the United States and is charged with, among other responsibilities, selecting the United States Olympic Swimming Team and verifying American swimming records.

American swimming records were compiled every year from 1962 to 2007 for both males and females in the following events: the 100 m freestyle, backstroke, breaststroke, and butterfly, and the 200 m freestyle. Additionally, American records for the 50 m freestyle were recorded from 1980 to 2007, because 1980 was the first year that this event was officially recognized for American record purposes. Therefore, 12 competitive events comprised the data set for Study 1. Furthermore, in order to effectively analyze this data, if a record was set on more than one occasion during a discrete year, then only the fastest time recorded in that year was utilized herein. Additionally, a record set in one year is identified as the American record repeatedly in subsequent years until that time was improved upon.

The decision to analyze only the aforementioned competitive events was primarily due to the ability of this data to provide comparisons within (a) one stroke at three different distances (i.e., freestyle) and (b) one distance (i.e., 100 m) in four different strokes. Data from the 2008 Olympics, the 2009 World Championships, or any performance from either 2008 or 2009 is excluded from the current analyses. The reason for this is that the racing suits worn beginning in 2008 have dramatically decreased drag coefficients when compared to 2007 and earlier. Additionally, these suits have been shown to increase the swimmers' buoyancy, which also contribute inordinately to increases in velocity. Although technology changes in the past have helped swimming speeds increase, nothing has improved racing velocity to the degree that these suits have. Further analyses that address any significant gender differences or differences among strokes and distances solely due to the suits are needed prior to including competitive times from 2008 and later. Using the data identified herein, two analyses were conducted. First, trends over time were evaluated for each of these 12 events. Second, data were evaluated for between-gender differences and their trends for each stroke and distance.

DATA ANALYSIS

In order to initiate data analyses, each American swimming record was converted to velocity in terms of meters per second (m/s). Regression equation coefficients for each of the 12 competitive events were calculated. First, a standardized linear regression equation was computed, which was followed by the calculation of a second-order polynomial regression equation. If the ΔR^2 for the second-order analysis was at least .02, which was an a priori decision, then the second-order polynomial was retained as a better fit with the data. Additionally, if the performance trend over time for an event was better fit with a second-order regression equation, then a third-order polynomial calculation was performed. This step was carried out in order to uncover if a third-order polynomial would be a superior fit with the data than the second-order polynomial. Furthermore, a ΔR^2 of at least .02 also was used here as the criterion by which a third-order polynomial was retained or not.

A linear relationship between velocity and year (i.e., $Y = \beta_0 + \beta_1 X + \text{error}$) indicates that the respective American record was improving at a continuous rate (i.e., at the rate of β_1). A second-order polynomial equation would be a superior fit with the data when the velocity increase over time was slowing. And finally, a third-order regression equation indicates a slowing of progression, followed by a subsequent increase.

Following these performance trend calculations by event, regression analyses were performed on each stroke and distance in order to discern the existence of any between-gender velocity differences over time. First, the between-gender velocity difference was calculated (e.g., the velocity of the women's 200 m freestyle was subtracted from the velocity of the men's 200 m freestyle) for each event. The data were then used to compute a linear regression equation, which was followed by both a second-order estimation and a third-order estimation. The process used to select the regression equation of best fit was identical to that used in the previous analyses on American swimming-record trends.

RESULTS

AMERICAN SWIMMING RECORDS

Table 1 presents the results of the regression analyses conducted on American swimming-record progression. Additionally, Table 2 provides the results of the regression analyses conducted on the male-female velocity differential in American swimming records. The time frame for both is 1962 to 2007.

AMERICAN SWIMMING-RECORD PROGRESSION

Table 1 provides the standardized beta coefficients for the regression equation of best fit with the data, and the resultant F-statistic, R^2, ΔR^2, and p values. Based on the magnitude of the correlation coefficients, we can conclude that the resultant beta coefficients strongly fit their respective event's model of change in velocity over time. That is, $p < .01$, and the $R^2 \geq .94$, for each of the 12 events analyzed.

	Standardized beta coefficients					
Event	β_1	β_2	β_3	F-test	R^2	ΔR^2
50 m Free						
Men	2.548	-1.723		$F(2, 25) = 198.64$*	.94	.17
Women	0.978			$F(1, 26) = 573.83$*	.96	
100 m Free						
Men	2.417	-1.547		$F(2, 43) = 1391.82$*	.99	.14
Women	2.035	-1.123		$F(2, 43) = 710.08$*	.97	.08
200 m Free						
Men	3.895	-5.950	2.949	$F(3, 42) = 1391.82$*	.99	.03
Women	4.392	-6.111	2.589	$F(3, 42) = 687.91$*	.98	.03
100 m Back						
Men	2.087	-1.179		$F(2, 43) = 805.38$*	.97	.03
Women	1.983	-1.061		$F(2, 43) = 981.38$*	.98	.07
100 m Breast						
Men	1.810	-0.881		$F(2, 43) = 511.78$*	.96	.05
Women	2.036	-1.138		$F(2, 43) = 389.59$*	.95	.06
100 m Fly						
Men	4.141	-7.187	4.096	$F(3, 42) = 468{,}87$*	.97	.07
Women	2.465	-1.626		$F(2, 43) = 383.85$*	.95	.16

* $p < .01$.

Table 1: Regression equation coefficients, F-test, R^2 values, ΔR^2 values and p values for the progression of 12 American swimming records (i.e., gender x 6 events) from 1962 to 2007.

Of the 12 races analyzed, only the women's 50 m freestyle resulted in a linear regression as the best fit ($R^2 = .96$, $p < .01$). When a second-order regression equation was attempted to improve this fit, the ΔR^2 for this new equation was less than .02, thereby providing evidence that the linear regression equation provided the best fit with the data. American swimming record progression for the remaining events recorded a ΔR^2 of at least .02 when a second-order polynomial regression equation was applied. This is indicative of a “slowing of improvement” over time in these events. Additionally, the men’s and women’s 200 m freestyle and the men’s 100 m butterfly recorded a ΔR^2 of at least .02 when a third-order polynomial regression equation was applied, revealing periods of slowing of improvement, followed by later hastening. For example, in the 100 m butterfly the American record gradually progressed at an ever-slowing rate to 52.76 s in the year 2000, and then was followed by a noticeable improvement over the next 5 years (i.e., in 2005 the record was 50.40 s).

	Standardized beta coefficients						
Event	β_1	β_2	β_3	*F*-test	R^2	ΔR^2	*p*
50 m Free	4.668	-8.560	3.619	$F(3, 24) = 11.69$	.59	.05	< .01
100 m Free	.745	1.832	-2.720	$F(3, 42) = 9.49$	.40	.03	< .01
200 m Free	-3.069	3.207		$F(2, 43) = 34.79$	.62	.62	< .01
100 m Back	1.062	-0.947		$F(2, 43) = 1.73$	.07	.05	.19
100 m Breast	-1.114	.894		$F(2, 43) = 2.62$	.11	.05	.08
100 m Fly	1.985	-9.351	7.284	$F(3, 42) = 26.91$	.66	.23	< .01

Table 2: Regression equation coefficients, *F*-test, R^2 values, ΔR^2 values, and *p* values for the gender difference in American record swimming velocity from 1962 to 2007.

GENDER VELOCITY DIFFERENTIAL

Between-gender differences in American swimming record performances were computed for each year available. Over the time frame analyzed, the between-gender velocity differentials for all six events were significantly better fit with at least a second-order polynomial than they were with a linear regression equation. In three cases (i.e., 50 m Free, 100 m Free, and 100 m fly) a third-order equation significantly better fit the data. Additionally, statistical significance finds support for four of the regression calculations (i.e., the three freestyle races and the 100 m butterfly). The data for the 100 m backstroke and breaststroke both fit poorly with regression analyses (i.e., $p > .05$). A visual inspection of the data in these latter two cases indicated a likely violation of the assumption of homoscedasticity.

DISCUSSION

Results from the data analyses performed herein provide additional lines of evidence that athletic performance is neither improving in a linear fashion nor accelerating at the elite level for (a) swimming events with a range of anaerobic and aerobic emphases or (b) any of the swimming strokes. Additionally, females do not appear to be closing the performance gap with males in elite competitive swimming. That is, in none of the six events analyzed did a linear relationship exist between year and gender velocity difference. In these events the women are clearly not catching the men and the men are not increasing the between-gender performance gap.

Limits to human performance clearly exist. The fact that competitive track and swimming employ a ratio scale (i.e., time to complete a prescribed distance) to evaluate an athlete's performance implies that eventual performances are limited to 0.0 s. Because the likelihood of this occurring is nonexistent, as is the likelihood of the 200 m freestyle American record ever being faster than the concurrent 100 m record, the actual limit to human performance must lie somewhere between its current state and 0.0 s. Ever-slowing rates of improvement in elite performance are currently being realized.

The current literature supports the argument that genetics plays a role in athletic performance as gender is possibly the most apparent genetically mediated trait. This fact strongly implies that ideal training cannot increase one's potential, rather only performance level. Additional examples exist. Data support the existence of functional asymmetries in the control of goal-directed movements that favor the left hemisphere of the brain/right-hand system, which are independent of the athlete's preferred hand (Boulinguez & Nougier, 1999). This suggests that an athlete's ability to control his or her movement is a function of his or her dominant hand. Supporting this includes the fact that there are statistically more right-handed saber fencers and, at the same time, more left-handed foil and sword fencers at the most elite level (Azemar & Stein, 1994).

It is known that athletic performance depends on the relationship between an individual's dispositional and situational thoughts, feelings, and behaviors, and his or her environment. Specifically, athletic development tends to advocate that environmental factors differentiate between elite and non-elite performers (Bloom, 1985). However, it is difficult to substantiate the existence of any differences between typical male and female training regimens in elite swimming. The fact that these elite male and female athletes likely spend the same amount of time-on-task yet achieve differing levels of performance quality infers that there are nonenvironmental factors involved in athletic performance. As support for this possibility, research that compares elite and subelite swimmers has uncovered sub-elites who trained equal to or more than a matched elite pair, and elite athletes who trained for less than (a) a matched pair sub-elite or (b) the requisite 10,000 hours as espoused as necessary by the theory of deliberate practice (Johnson et al., 2006). This research, which embraces a systemic view of the nature-nurture interplay and athlete development, has advocates (see Baker & Davids, 2007, for an overview). Only a few studies to date have performed comparisons that emphasize individuals' differences and similarities (Law et al., 2007).

Gender differences in American swimming records for the six events analyzed herein provide additional documentation of patterns similar to those found in previous research (Seiler et al., 2007). Seiler and colleagues identified a narrowing gender differential in the 1980s that since has drifted back to pre-1980s levels. The gender differences in the events analyzed in the present study appear to be stabilizing or fluctuating. In none of these cases is the between-gender performance difference consistently expanding or contracting. That is, gender differences in American swimming records appear to wax and wane over time (e.g., the largest of the six R^2 herein is .66). Furthermore, due to the fact that there was not a single case where a linear regression equation best fit the between-gender data trend (i.e., the difference in male and female American swimming records) and its progression over a span of 45 years, it appears highly unlikely that elite female and male swimmers will perform at similar levels in the future.

Although the limits of athletic performance are apparently being approached at a slower rate than in past decades, in some situations psychological factors likely play a role in pushing toward these limits. As an example, in the first decade of the 21st century the fastest two male 100 m butterfly swimmers in history were both citizens of and lived in the United States. These two athletes were relatively close in age and both made efforts for the two spots on the U.S. Olympic team. Moreover, only one could swim the butterfly leg on the U.S. 4 x 100 medley relay in the Olympic final, likely providing a great deal of incentive for each to be the fastest. This competitive environment may be a contributing factor resulting in the third-order regression curve witnessed for the American swimming record in this event. It is highly possible that two individuals who possess idiosyncratic and advantageous genotypes, when coupled with hard work guided by expert coaches within a supportive and efficacious social environment, can experience truly exceptional performances.

STUDY 2

METHOD

Performance data for Study 2 also was drawn from the USA Swimming, Inc. website (USAS, 2009). USAS annually identifies elite youth swimmers in the country (i.e., Top-16 performers from the following age-groups: 10 & under, 11-12, 13-14, 15-16, and 17-18). However, not every year yielded 16 data points as procedures utilized by USAS to collect this data periodically resulted in fewer than 16 athletes appearing on the Top-16 list for a discrete event. Table 3 identifies the events used for Study 2 and the years from which the data was culled. Additionally, Table 3 recognizes the extant gaps in this data as well as one manipulation, as some events and age-groups were not available. Originally, the current study planned to analyze data from each decade between 1962 and 2002 (i.e., 1962, 1972, 1982, 1992, and 2002). However, there is a gap in the available

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data, so the 1969 data was used in lieu of 1972, as these were the closest available to 1972. The final data set included 3,614 entries.

The decision to analyze the competitive events in Table 3 was made because these data would provide a comparison of three different distances within a single stroke (i.e., the 50 m, 100 m, and 200 m freestyle), and among the 100 m competitive distances in all four strokes. Moreover, these six are the only events that are consistently competed among the ages analyzed. An initial analysis was conducted to evaluate any performance trends over time for each event. A second analysis then was conducted to evaluate between-gender velocity differences over time. And finally, between-gender analyses were performed using a common rubric (i.e., effect sizes; *ES*).

	Age-Group				
Year	10 & under	11-12	13-14	15-16	17-18
1962	50 m free 100 m free	50 m free 100 m free 200 m free	50 m free 100 m free 200 m free		50 m free 100 m free 200 m free
1969	50 m free 100 m free 200 m free	50 m free 100 m free 200 m free	50 m free 100 m free 200 m free		50 m free 100 m free 200 m free
1982	All 6 events	All 6 events	All 6 events	All 6 events	All 6 events
1992	All 6 events	All 6 events	All 6 events	All 6 events	All 6 events
2002	All 6 events	All 6 events	All 6 events	All 6 events	All 6 events

Note. In 1962 and 1969, the USAS compiled performance data for the 15-17 age group. This data is considered as part of the 17-18 age group for the comparisons and trends analyses made herein.

Table 3: Age-group competitive swimming races' data parameters for the six races analyzed (i.e., the 50 m, 100 m, and 200 m freestyle, and the 100 m backstroke, breaststroke, and butterfly).

DATA ANALYSIS

First, regression equations for each year's average Top-16 age-group performers for the six competitive distances and disciplines over the 40 year timeframe used in the present study were calculated. Second, the gender differential over time was analyzed using the same procedures as in Study 1. Third, *ESs* were calculated for each event's between-gender difference. This final analysis was performed in order to evaluate the significance of any between-gender performance differences by event.

RESULTS

ELITE YOUTH SWIMMERS' PERFORMANCES

Table 4 presents the results of the multiple regression analyses conducted on elite American youth swimmers' performance progressions (i.e., velocity by year). These analyses were done in order to evaluate the velocity trends of six competitive swimming events over a four decade period for six competitive races by age-group and gender, resulting in 60 unique polynomial regression equations. Respective polynomial regression equation levels of best fit, *F*-statistic, R^2, ΔR^2, and *p* values are provided in Table 4. Additionally, Table 5 presents the resultant *ES* and associated *p* values when between-gender comparisons of elite youth males' and females' swimming velocities are calculated for each racing distance and stroke, by age-group. ESs were used in this final analysis in order to identify the significance of any between-gender differences using a rubric common to both data sets (i.e., standard deviation).

Age-group and event	Polynomial level	*F*-test	R^2	ΔR^2	*p*
10 & under girls					
50 m Free	3rd	$F(3, 59) = 28.309$	.590	.04	$< .0$
100 m Free	3rd	$F(3, 53) = 17.907$	.503	.04	$< .0$
200 m Free	3rd	$F(3, 49) = 21.292$	.566	.26	$< .0$
100 m Back	3rd	$F(3, 44) = 7.350$	.334	.13	$< .0$
100 m Breast	3rd	$F(3, 44) = 4.478$	.234	.16	$< .0$
100 m Fly	3rd	$F(3, 44) = 4.556$	.237	.21	$< .0$
10 & under boys					
50 m Free	2nd	$F(2, 57) = 11.267$	.283	.07	$< .0$
100 m Free	2nd	$F(2, 57) = 17.254$	.377	.03	$< .0$
200 m Free	3rd	$F(3, 49) = 14.031$	.462	.21	$< .0$
100 m Back	3rd	$F(3, 44) = 3.442$	.190	.11	.03
100 m Breast	3rd	$F(3, 44) = 2.414$	.141	.13	.08
100 m Fly	3rd	$F(3, 44) = 4.990$	.254	.20	$< .0$
11-12 girls					
50 m Free	3rd	$F(3, 60) = 32.163$	.617	.05	$< .0$
100 m Free	3rd	$F(3, 56) = 16.093$	.463	.04	$< .0$
200 m Free	3rd	$F(3, 56) = 19.517$	.511	.03	$< .0$
100 m Back	3rd	$F(3, 43) = 7.627$	.347	.28	$< .0$
100 m Breast	3rd	$F(3, 44) = 7.311$	.333	.09	$< .0$
100 m Fly	3rd	$F(3, 45) = 5.794$	.279	.18	$< .0$
11-12 boys					
50 m Free	3rd	$F(3, 57) = 15.191$	.444	.10	$< .0$
100 m Free	3rd	$F(3, 56) = 8.489$	.313	.09	$< .0$
200 m Free	2nd	$F(2, 56) = 13.204$	.320	.06	$< .0$
100 m Back	3rd	$F(3, 44) = 13.820$	.485	.12	$< .0$
100 m Breast	3rd	$F(3, 44) = 6.268$	.299	.12	$< .0$
100 m Fly	3rd	$F(3, 44) = 3.123$	.176	.14	.04

13-14 girls					
50 m Free	3rd	$F(3, 61) = 35.197$	.634	.03	< .0
100 m Free	3rd	$F(3, 56) = 27.278$	.594	.09	< .0
200 m Free	3rd	$F(3, 54) = 18.256$	.504	.04	< .0
100 m Back	3rd	$F(3, 43) = 6.590$	.315	.15	< .0
100 m Breast	3rd	$F(3, 44) = 10.900$	.426	.05	< .0
100 m Fly	3rd	$F(3, 39) = 3.340$	.204	.17	.03
13-14 boys					
50 m Free	2nd	$F(2, 55) = 20.492$	.427	.28	< .0
100 m Free	3rd	$F(3, 55) = 15.149$	.452	.05	< .0
200 m Free	2nd	$F(2, 57) = 15.320$	.350	.11	< .0
100 m Back	3rd	$F(3, 44) = 6.330$	.301	.17	< .0
100 m Breast	3rd	$F(3, 44) = 13.492$	.479	.27	< .0
15-16 girls					
50 m Free	3rd	$F(3, 44) = 7.614$	.342	.19	< .0
100 m Free	3rd	$F(3, 44) = 4.278$	.226	.12	.01
200 m Free	3rd	$F(3, 44) = 4.373$	.230	.10	< .0
100 m Back	3rd	$F(3, 44) = 3.882$	.209	.16	.02
100 m Breast	3rd	$F(3, 44) = 4.766$	.245	.16	< .0
100 m Fly	3rd	$F(3, 44) = 12.611$	.462	.22	< .0
15-16 boys					
50 m Free	3rd	$F(3, 44) = 3.205$	.179	.15	.03
100 m Free	3rd	$F(3, 45) = 2.854$	.160	.10	.05
200 m Free	3rd	$F(3, 44) = 5.148$	.270	.11	< .0
100 m Back	3rd	$F(3, 44) = 6.428$	.305	.16	< .0
100 m Breast	3rd	$F(3, 44) = 7.305$	.332	.12	< .0
100 m Fly	3rd	$F(3, 45) = 13.013$	.465	.36	< .0
17-18 girls					
50 m Free	2nd	$F(2, 61) = 88.628$	.744	.19	< .0
100 m Free	2nd	$F(2, 56) = 45.292$	.618	.13	< .0
200 m Free	2nd	$F(2, 47) = 22.799$	.492	.08	< .0
100 m Back	3rd	$F(3, 40) = 3.429$	.205	.16	.03
100 m Breast	3rd	$F(3, 40) = 4.915$	.269	.23	< .0
100 m Fly	3rd	$F(3, 37) = 2.248$	.154	.12	.10
17-18 boys					
50 m Free	3rd	$F(3, 67) = 33.517$	.600	.02	< .0
100 m Free	3rd	$F(3, 56) = 23.579$	.558	.02	< .0
200 m Free	3rd	$F(3, 54) = 12.779$	.415	.02	< .0
100 m Back	3rd	$F(3, 44) = 4.557$	.237	.20	< .0
100 m Breast	3rd	$F(3, 44) = 5.953$	.289	.22	< .0
100 m Fly	3rd	$F(3, 40) = 6.679$	.334	.22	< .0

Table 4: Regression equation coefficients, F-test, R^2 values, ΔR^2 values, and p values for the progression of elite American youth swimming performances from 1962 to 2002.

ELITE YOUTH SWIMMERS' PERFORMANCE PROGRESSION

Table 4 shows that 52 of the 60 events were best fit with a third-order polynomial regression equation, providing support that a unidirectional pattern of improvement or deterioration over time (i.e., 1962-2002) does not exist for these events. The remaining eight events were best fit with a second-order regression equation, reflecting a "slowing of progress over time." Additionally, of the 60 F tests performed only three were not statistically significant (i.e., $p > .05$).

GENDER VELOCITY DIFFERENTIAL

When analyzing the 30 between-gender velocity difference trends over time for each age-group and competitive event (i.e., 6 events x 5 age-groups), only three relationships were found to have data that resulted in a good fit with a regression line at $p < .05$. These three events all were best fit with a linear regression equation and include the 10 & under 50 m freestyle ($F(1, 3) = 28.502$, $R^2 = .905$, $p < .05$); 13-14 200 m freestyle ($F(1, 3) = 10.680$; $R^2 = .781$, $p < .05$); and 15-16 100 m backstroke ($F(1, 1) = 410.301$, $R^2 = .998$, $p < .05$).

VARIATION IN ELITE YOUTH SWIMMERS' PERFORMANCES DUE TO GENDER

Table 5 provides the resultant *ES* for between-gender velocity differences for the objective performances addressed in Study 2. *ES*s were statistically significant (i.e., $p < .01$) for 28 of the 30 intergroup comparisons. The two exceptions were the 10 & under 100 m back and 100 m breast. Trends of note highlighted in Table 5 include the increases, by event, in *ES* as the age-group increases in all but two cases, the exceptions being the larger *ES* in the (a) 50 m Free for 13-14 year olds compared with 15-16 year olds, and (b) 200 m Free for 15-16 year olds compared with 17-18 year olds. Additionally, at each age-group there is a noticeable heterogeneity among events' *ES*s with the 100 m breaststroke consistently having the smallest *ES* and the largest *ES* appearing in the freestyle events.

	Age-group				
Event	10 & under	11-12	13-14	15-16	17-18
50 m Free	0.63**	2.44**	5.97**	5.33**	8.14**
100 m Free	1.00**	2.00**	5.08**	5.51**	7.36**
200 m Free	0.81**	1.64**	3.60**	6.49**	6.21**
100 m Back	0.39	1.30**	3.29**	4.81**	5.36**
100 m Breast	0.18	1.14**	2.37**	3.94**	5.01**
100 m Fly	0.60**	2.08**	3.09**	4.99**	5.22**

Note. Effect sizes were calculated as follows: $(\mu_{\text{male}} - \mu_{\text{female}})/\text{standard deviation}_{\text{male}}$
* $p < .05$. ** $p < .01$.

Table 5: Effect size differences and associated p values for the between-gender comparison of elite youth American swimmers by age, stroke, and distance from 1962 to 2002.

DISCUSSION

The majority of performances from elite youth swimmers over approximately the last four decades of the 20th century presented no distinguishable trend in performance changes. That is, only five of the 60 events' $R^2 \geq .60$, and only 12 of the $R^2 \geq .50$. This supports the argument that the data for at least 48 or the 60 events do not show a strong trend toward improvement. Additionally, when testing for the possibility of any between-gender performance trends very little significance was found as only three events identified that the performance gap between boys and girls was narrowing. Just as with the American swimming record analyses, between-gender differences do not, for the vast majority of events, appear to be narrowing or growing. They ebb and flow. Future research that includes data from every year available will undoubtedly provide stronger associations than those presented here. However, it is clear that overall, between-gender performances of elite youth swimmers over time have remained relatively unchanged.

In the final analyses performed there emerged a large range of between-gender by event *ESs* (see Table 5). Although it was hypothesized that there would be increases in between-gender *ESs* as athletes mature from ages 10 to 18 years, it was not hypothesized that these *ESs* would expose such divergences within each age-group. For example, performances for elite male and female 10 & under freestyle and butterfly swimmers are statistically different, while such significance is lacking in both backstroke and breaststroke for this age-group. And, while between-gender differences are consistently smallest for breaststroke regardless of age-group, by the 13-14 age-group between-gender differences for backstroke are more similar to those found in butterfly than they are to those in breaststroke.

Although gender differences in elite sport performance may be the result of uniquely expressed functions of power output and drag coefficients (Seiler et al., 2007), the question remains to be answered as to why unique gender differences in objective performance data at age 10 exist among competitive strokes. This is exemplified by freestyle and backstroke events as both have been acknowledged as having highly similar drag parameters. If the phenotypes of gender and height are the only genetic influences on performance, as espoused by the concepts such as deliberate practice (Ericsson, Krampe, & Tesch-Römer, 1993), then one could reasonably anticipate at least somewhat consistent gender differences for the performances of elite youth swimmers regardless of competitive stroke, and perhaps also distance, particularly at ages prior to puberty. Similar drag parameters being imposed on pre-pubescent athletes who express differing performance outcomes based on stroke strongly implies the existence of some non-environmental mediating factor that is psychological, physiological, biomechanical, or a systemic interaction among the three. Additionally, the fact that the training opportunities and technological advancements provided to both genders in the sport of swimming are highly uniform reinforces the idea that non-environmental factors mediate elite athletic performance at the youngest of ages, and perhaps throughout development.

CONCLUSION: STUDIES 1 AND 2

Unlike the results from Monte Carlo methods that revealed relative age and birthplace effects, the data utilized in the current study essentially controls for competitive and training environmental factors and exposes differences in objective performances due to other factors. That is, males and females involved in the sport of competitive swimming in the U.S. commonly train simultaneously under the tutelage of a single coach, or group of coaches. Future examinations could investigate the demographic backgrounds of those who achieve at the highest levels in various sports' subdomains (e.g., the different strokes of swimming) in order to aid the identification of possible reasons for and causes of the results evidenced in Table 5. A number of rationales for the relative age effect have been offered (Musch & Grondin, 2001), including greater coaching support to those who appear bigger and stronger at a young age. However, unless coaching support differs (e.g., high levels for elite youth female breaststrokers and simultaneous lower levels for elite youth female freestylers) this cannot explain the differences in *ES* unearthed in the present study. In addition to the relative age effect, factors involved in the birthplace effect may mediate eventual elite performance achievement. Côté et al. (2006) hypothesized that this is due in part to the greater affordance of salient resources, such as exposure to high level coaching, facilitative community pride, and social support. For reasons similar to those provided herein regarding the relative age effect this is also not likely to play a role in the results identified in Table 5.

Explanations for the *ES*s in Table 5 that complement one another may include that deliberate play (Côté, 1999) is known to be an effective 'training regimen' for young athletes who later develop into elites and that deliberate play may vary significantly between males and females (Côté et al., 2003; Côté & Hay, 2002). For example, the ages at which males and females reach puberty varies. This variability can mediate positive or negative interpersonal and intrapersonal experiences in relation to training and these transactions may carry consequences into adulthood (Caspi et al., 1993; Duke et al., 1982; Ge, Conger, & Elder, 1996; Jones, 1965), which likely affect eventual athletic performance level.

It also is possible that there exists an interaction among psychological, physiological, and biomechanical factors resulting in the *ES* uncovered in the present study, as well as the elite performance asymptotes and between-gender differences discussed herein. As an athlete matures there is possibly an interplay among his or her (a) environment, which includes factors such as culture, social norms, physical environment, socioeconomic status, historical events, random events, and other people in his or her life; (b) intrapersonal experiences, that is, one’s thoughts, feelings, and actions; (c) genotype, which is inherited from the athlete’s biological parents; and (d) feedback from previous athletic performances (Johnson, Edmonds, Jain, & Cavazos, in press). Future research that examines these factors and recognizes the interplay among them will aid the understanding of why the *ES* presented in Table 5 exist.

Implications of the results uncovered in the present analyses for those interested in the development of elite athletes include (a) investigating specifically why the heterogeneous gender differences (i.e., those in Table 5) identified in the current study exist, as well as any ramifications this has for adult elite athletes, and (b) recognizing that there may be optimal training and teaching methods that are more efficacious for one gender than the other, and for one swimming stroke more so than the others. It is suggested that those who work with young athletes and have an interest in developing elite competitors, include concepts such as those identified by Nicholls (1976, 1978, 1980) who reported that children under the age of 12 are not adept at differentiating among luck, task difficulty, effort, and ability. If it is true that idiosyncratic performance ceilings exist then it may be advisable for athletes and significant others in their lives to focus on training and social interactions that increase athletes’ motivation and feelings of accomplishment (Vallerand, 2007) rather than focusing on their objective performances. Strategies such as these will lead to athletes more closely adhering to efficacious training and behavioral patterns, resulting in maximized performances.

Future studies that effectively investigate gene-environment interactions and correlations will undoubtedly also aid the understanding of elite athlete development. Research designed to evaluate human athletic potential is encouraged to identify the systemic psychological, physiological, and biomechanical parameters that limit such potential. Research addressing only one of these domains, while ignoring the others is likely flawed. Gene-environment interactions exist (Brutsaert & Parra, 2006), as do gene-environment correlations similar to those described by Mingroni (2007). Addressing this interplay will further impact the understanding of elite athletic potential and its development.

SUMMARY

The primary objective of the current study is to contribute to the discussion regarding trends in elite athletes’ performances over time. The resultant trends and gender comparisons herein do just that with ecologically valid data. First, the current article adds to the existing literature base that addresses elite athletes' performance trends (e.g., Seiler et al., 2007; Tatem et al., 2004), by analyzing trends over time for (a) discrete events and (b) between-gender performance differences involving those same events. Second, the present article reviews various aspects of the performance trends of elite youth athletes both over time and at various ages, while also conducting (a) between-gender comparisons over time by event and (b) between-gender comparisons over five discrete age-groups by event. This latter goal is accomplished by identifying between-gender *ES* for six swimming events.

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