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Abstract: The sex difference in marathon performance increases with finishing place and age of the runner but whether this occurs among swimmers is unknown. The purpose was to compare sex differences in swimming velocity across world record place (1st–10th), age group (25–89 years), and event distance. We also compared sex differences between

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freestyle swimming and marathon running. The world's top 10 swimming times of both sexes for World Championship freestyle stroke, backstroke, breaststroke, and butterfly events and the world's top 10 marathon times in 5-year age groups were obtained. Men were faster than women for freestyle (12.4 ± 4.2%), backstroke (12.8 ± 3.0%), and breaststroke (14.5 ± 3.2%), with the greatest sex differences for butterfly (16.7 ± 5.5%). The sex difference in swimming velocity increased across world record place for freestyle ($P < 0.001$), breaststroke, and butterfly for all age groups and distances ($P < 0.001$) because of a greater relative drop-off between first and 10th place for women. The sex difference in marathon running increased with the world record place and the sex difference for marathon running was greater than for swimming ($P < 0.001$). The sex difference in swimming increased with world record place and age, but was less than for marathon running. Collectively, these results suggest more depth in women's swimming than marathon running.

In many sports, men outperform women because men have larger and more powerful muscle mass, and a higher maximal oxygen consumption compared with women (Sparling, 1980; Joyner, 1993; Cheuvront et al., 2005). Consequently, in the world's best running performances, men are faster than women by ~9–10% for sprint (100 m) and the marathon (42.2 km) (http://www.iaaf.org; e.g., Hunter et al., 2011). Even among elite runners however, the difference between men and women in velocity is greater than what would be expected because of physiological sex differences alone. For example, in elite marathon runners, the sex difference in velocity progressively widens between first and fifth place for the world's best runners (Hunter et al., 2011) and the same trend was observed between first and 10th place among elite runners in the New York City marathon across all age groups (Hunter & Stevens, 2013) suggesting less depth in women's running relative to men. Accordingly, the greater sex difference in running velocity was associated with lower participation rates of women compared with men that occurred in most age 5-year groups (20–79 years; Hunter & Stevens, 2013).

Historically, women have had less opportunity to participate in most sports and with lesser incentives than those provided to men, especially prior to the 1972 USA Title IX amendment in U.S. congress: legislating equal opportunity for women in educational settings including athletic scholarships. Consequently, these differences in opportunity may contribute to the lack of depth among women for some sports and might contribute to the larger sex differences in performance between men and women (Joyner, 1993; Hunter &

Stevens, 2013) demonstrated in running (Ransdell et al., 2009; Hunter et al., 2011; Hunter & Stevens, 2013; Stevenson et al., 2013) and triathlons (Lepers & Maffiuletti, 2011; Stevenson et al., 2013). For some swimming events however, participation rates of men and women approach greater equality than, for example, marathon running (Smith & Wrynn, 2013). In the Olympics, women have competed in swimming since 1912 (Stockholm) and the marathon (running) since 1984 (Los Angeles). U.S. Master's swimming records indicate similar participation rates between the sexes (Tanaka & Seals, 1997, 2008; Donato et al., 2003; Fairbrother, 2007) and 47.5% of Olympic swimmers in the London 2012 games were women (Smith & Wrynn, 2013). Despite some evidence of more equitable participation of men and women participating in swimming, open-water ultra-endurance swimming events have lower numbers of women than men competing (Knechtle et al., 2010; Eichenberger et al., 2012a,b, 2013).

Sex differences in physiology may affect swimming performance of men and women differently. For example, women are more energy efficient than men during swimming because of less drag (Pendergast et al., 1977). The sex difference in performance because of physiology therefore, may be less than that during weight-bearing exercise (e.g., running) and the sex difference may decrease in longer distance events (Tanaka, 2002; Tanaka & Seals, 2003; Rust et al., 2014; Wild et al., 2014). The purpose of the present study was to examine sex differences among world record holders 40 years post-Title IX and determine whether the sex difference widens among lower placed world record holders in young and older adults.

Therefore, the primary hypothesis of this study was that the sex difference in swimming performance would be less than marathon running particularly among the younger swimmers who were subject to Title IX. We also hypothesized the sex difference would decrease with greater event distances for all strokes as had been observed in the U.S. best freestyle swimming times (Donato et al., 2003), and that the widening of the sex difference across world record place would be diminished relative to marathon running. We addressed these hypotheses by comparing the sex differences in velocity among the top 10 world record holders in swimming freestyle, backstroke, breaststroke, and butterfly events across world record place, age, and distance. We also compared the sex difference in swimming (freestyle) with marathon running for the top 10 world record holder in each age group.

Materials and methods

Finishing times of the top 10 men and women world record performances (1986–2011) in 13 5-year age brackets between 25 and 89 years of age were analyzed for freestyle, backstroke, breaststroke, and butterfly. Swimming times for men and women were downloaded from the online International Swimming Federation (FINA) database World Masters Top 10 All Time Long Course Meters Records between 1986 and 2011 (http://www.fina.org/H2O/index.php?option=com_wrapper&view=wrapper&Itemid=637) for six freestyle events ranging from 50 m to 1500 m (50, 100, 200, 400, 800, and 1500 m; Fédération Internationale de Natation (FINA), March 20, 2012). For backstroke, breaststroke, and butterfly, three event distances (50, 100, and 200 m) were downloaded from the same database. The freestyle stroke was analyzed across all distances between 50 m and 1500 m because it has more event distances than other strokes; it has also undergone the fewest number of rule changes over these years (Donato et al., 2003). A similar analysis was performed on the backstroke, breaststroke, and butterfly for the three Master's event distances. Swimming velocity was calculated from the finishing time of the performances for the top 10 world records in each of the following 13 5-year age groups: 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, and 85–89 years. Age groups of 90 years and above were excluded because of incomplete data sets up to 10 places. Average velocity (m/min) was calculated from the finishing times reported by FINA. Sex differences in velocity were calculated as [(men's velocity)-(women's velocity)]/(men's velocity) × 100% for each place in each age group and event.

To understand the sex differences in world record marathon running, the top 10 performances in the marathon of all time, from 12 5-year age groups (25–84 years), were extracted from the Association of Road Racing Statisticians database (http://www.arrs.net/VetRec.htm; Association of Road Racing Statisticians (ARRS), June 2014). Velocity and sex differences in marathon performance time were calculated as described for the swimming times.

Statistical analysis

Data were reported as means ± SD within the text and tables and displayed as means ± SEM in figures. Statistical analysis was performed using the Statistical Package for the Social Sciences (version 21.0; SPSS Inc., Chicago, Illinois, USA). Separate univariate analysis of variances (ANOVAs) were used to compare the swimming velocity of men and women (sex effect), across age groups (25–29 years up to 85–89 years, age effect), world record place (first through to 10th place, place effect) and event distance (50, 100, 200, 400, 800, and 1500 m, distance effect). For freestyle, the sex difference in the swimming velocities (women as % of men) were compared with univariate ANOVAs across age groups (25–29 years up to 85–89 years), world record place (first through to 10th place), and distance (50 m, 100 m, 200 m, 400 m, 800 m, and 1500 m). The change in swim velocities of men and women across world record place (between first and 10th place) by expressing the times relative to first place were compared using univariate ANOVAs. Similar analysis was used to compare changes across ages (25–29 years to 85–89 years relative to the velocities of the 25–29 years) and distance (50 m to 1500 m events relative to 50 m times). For backstroke, breaststroke, and butterfly, the sex difference (women as % of men) for the swimming velocities were compared using univariate ANOVAs across age groups (25–29 years up to 85–89 years), world record place (first through to 10th place), and distance (50 m, 100 m, and 200 m).

For the top 10 all-time best marathon performances, the sex difference in running velocity was compared using univariate ANOVAs across age groups (25–29 years up to 80–84 years) and world record place (first to 10th). Post-hoc analysis (pairwise comparisons) was used to test for differences among pairs within a data set when significant main effects were identified. The sex differences in swimming (freestyle only) and running velocities were compared across world record place with multivariate ANOVA (sport effect). Further, the change in velocity across world record place was compared for freestyle swimming and marathon running when velocity of each world record (second to 10th) was expressed relative to first place world record in each age group. For all analyses including swimming and marathon running results, a level of $P < 0.05$ was used to identify statistical significance.

Results

Freestyle: 50–1500 m

Men were faster than women in the freestyle stroke across all age groups ($P < 0.001$), world record places ($P < 0.001$) and event distances ($P < 0.001$, Table 1). The sex difference for all the data pooled (age groups and distances pooled) for freestyle was 10.7 ± 4.0% for first place ($n = 78$) and was 12.4 ± 4.2% for the top 10 world record places pooled ($n = 780$).

The remaining results in this section demonstrate how this sex difference in freestyle swimming velocity varied across the 5-year age groups (25–89 years), event distances (50–1500 m), and world record places (first–10th).

Age and sex differences in swimming

The 25–29 years and 30–34 years age brackets had the fastest velocities of all age groups (event distance and world record place pooled) for men and women (Table 1). From the 45–49 years age group and older, both men and women showed reductions in velocity at a rate of about 1.0 m/min loss every year for both men [velocity (m/min) = 127.8–0.98 × age, $r^2 = 0.98$, $P < 0.001$] and women [velocity (m/min) = 119.6–1.04 × age, $r^2 = 0.98$, $P < 0.001$]. By the 85–89 years age group, the fastest swimmers (first place) were 60% and 52% slower that of the 25–29-years-olds for men and women, respectively, and the top 10 (averaged) were 57% and 50% slower for men and women, respectively (Fig. 1(a)).

The sex difference in swimming velocity increased with advanced age from 8.5 ± 2.9% for the 25–29-year-olds to 20.3 ± 3.5% for the 85–89-year-olds (event distances and world record places collapsed; age effect, $P < 0.001$, Fig. 1(b)). Pairwise comparisons indicated that the sex difference for the 25–29 years group was less than the sex difference in the 30–34-year-old age group and older (i.e., 30–34 through 85–89-year-old age groups; $P < 0.05$). The average sex difference in velocity appeared to increase linearly with across the age groups until age 60, at which point the sex difference increased more rapidly between age groups. The increase in sex difference across the ages was a similar rate for all event distances ($P > 0.05$; Fig. 1(d)).

World record place and sex differences in swimming

Comparison of the relative reductions in velocity between first and 10th place (age groups and event distances pooled) showed that the women had greater reductions in velocity between first and 10th place compared with the men (sex × place interaction, $P = 0.014$, Fig. 2(a)). The average 10th place world record holder swam at 94.1 ± 3.1% the velocity of the first place world record holder for the men and 91.8 ± 4.2% for the women (age groups and event distances pooled). Thus, the sex difference in world-record swimming performance progressively increased with the world record place between first place (10.7 ± 4.0%) to 10th place (12.9 ± 4.2%) across all age groups and distances (place and age effects, $P < 0.001$, Fig. 2(b)).

Pairwise comparisons indicated that the sex difference in first place was less than the sex difference from second place and higher (i.e., second to 10th place, $P < 0.01$). The widening of the sex difference between first and 10th place was at a similar rate across age groups (age × place interaction, $P = 0.99$, Fig. 2(c)). Further, while the sex differences was greatest in the shorter distance events (50 m vs 1500 m, distance effect, $P < 0.001$, see below), the widening of the sex difference with increased world record place did not differ across the freestyle event distances (place × distance interaction, $P = 1.00$, Fig. 2(d)).

Event distance and sex differences in swimming

Velocity of swimming decreased as freestyle event distance increased (distance effect, $P < 0.001$) but men had greater reductions in velocity across event distance compared with women (sex × distance interaction, $P = 0.004$, Fig. 3(a)). Thus, the sex difference in velocity (%) decreased with longer event distances (distance effect, $P < 0.001$, Fig. 3(b)) such that the sex difference was greatest for the 50 m and the least for the 800 and 1500 m events. Pairwise comparisons indicated that the sex difference was significantly different ($P < 0.05$) between 50 m and all other distances (i.e., 100, 200, 400, and 800 and 1500 m). There was however, no difference between 800 and the 1500 m ($P = 1.00$).

Backstroke, breaststroke, and butterfly: 50–200 m

The average sex difference in swimming velocity for backstroke, breaststroke, and butterfly were 12.8 ± 3.1%, 14.5 ± 3.2%, and 16.7 ± 5.5%, respectively (place, age groups, and distances pooled for each stroke) with the greatest sex differences observed for the butterfly compared with backstroke and breaststroke ($P < 0.05$). The decrease in velocity of backstroke was similar for men and women across the world record place such that the sex difference in velocity did not differ across world record place (first place: 13.2 ± 4.6% to 10th place: 13.2 ± 2.3%; place effect, $P = 0.46$, Fig. 4(a)). However, the sex difference in velocity increased with world record place for breaststroke (first place: 12.5 ± 2.9% to 10th place: 15.3 ± 2.8%, place effect, $P < 0.001$ Fig. 4(b)) and butterfly (first place: 15.1 ± 4.6% to 10th place: 17.7 ± 6.1%, place effect, $P < 0.001$, Fig. 4(c)) similarly across age groups (place × age interactions, $P > 0.05$). The sex difference in swimming velocity also increased with age for backstroke, breaststroke, and butterfly (age effects, $P < 0.001$, Fig. 4(d)). The sex difference in performance decreased with longer distances in the backstroke, breaststroke, and butterfly (distance effects, $P < 0.001$) and this occurred across all the world record places (i.e., first to 10th place, distance × place interactions, $P > 0.05$).

Marathon running performance: comparison with swimming

The sex difference in marathon running for all the age groups pooled was 13.7 ± 4.8% for first place ($n = 12$) and 15.6 ± 4.9% for the average of the top 10 world record places ($n = 118$) (Fig. 5(b)). Hence, men were faster than women in the marathon running across all age groups (sex effect, $P < 0.001$) and world record places (1–10th place; place effect, $P < 0.001$). The 25–29-year and 30–34-year-olds had the fastest velocities of all age groups (world record place collapsed) for both men and women ($P < 0.001$). Velocity of running declined with age for both men and women (age effect, $P < 0.001$) and the sex difference increased across age groups from 10.6 ± 0.5% for the 25–29-year-olds to 23.3 ± 2.6% for the 80–84-year-olds (age effect, $P < 0.001$).

Marathon velocity decreased across world record place when expressed relative to first place for both men and women and for all age (place effect, $P < 0.001$, Fig. 5(a)). However, men's relative performance (% of first place) across all world record places was better than women's relative performance (sex effect, $P = 0.016$, Fig. 5(a)) so that the relative drop-off from first place was less for men than women.

When freestyle swimming and marathon running were compared, the sex difference was larger for the marathon than swimming across all age groups (sport effect, $P < 0.001$) and the increase in the sex difference across world record place was similar for freestyle swimming and marathon running (place × sport interaction, $P = 1.00$, Fig. 5(b)).

Discussion

Men were faster than women across all swimming event distances and ages among the top 10 world record holders for all strokes and distances, with the greatest sex differences in butterfly stroke. The unique findings were that the sex difference in swimming velocity among the top 10 world record holders: (a) showed modest increases with world record place from first to 10th place for freestyle, breaststroke, and butterfly, with no increase for backstroke; (b) increased among the older age groups for all strokes; and (c) decreased among longer event distances for all strokes. Despite the increase with age and world record place, the sex difference in swimming velocity was smaller than for marathon running, possibly because of physiological sex differences (e.g., more subcutaneous fat) that limit women's performance more in weight-bearing exercise than non-weightbearing exercise, and more equitable participation levels of men and women in elite swimming than marathon running. The greater drop-off in performance across world record place for women compared with men in the marathon and some but not all swimming strokes, suggests a greater depth in women's swimming than marathon running.

Sex differences and world record place

A notable finding was that the sex difference in swimming velocity increased modestly across world record place for freestyle, breaststroke, and butterfly but this was not observed for backstroke. For freestyle, breaststroke, and butterfly, the widening sex difference was due to a greater drop-off in the swimming velocity of the women relative to first place than the men (Figs. 2(a), 4(b), and 4(c)). The widening sex difference with increased world record place occurred at a similar rate across most age groups and event distances for freestyle, breaststroke and, butterfly. Notably, the sex difference in the 1500 m freestyle event in the current study (25 to 89 years) was 8.6% for first place and increased to a modest 10.4% by 10th place (Fig. 5(b)). However, widening of the sex difference across world record place in the freestyle, breaststroke, and butterfly suggests a lack of depth in some of the women's swimming events relative to men. However, this lack of depth is not universal to all swimming strokes.

While the widening of the sex difference across world record place for the swimming was modest in magnitude and did not occur for the backstroke, it was similar between freestyle swimming and marathon running. There was a similar magnitude in the sex difference of drop-off between first and 10th place for freestyle events and marathon running. This is contrary to the New York City marathon (Hunter & Stevens, 2013) and also contrary to our hypothesis that there would be a greater widening of the sex difference across world record place in the marathon than swimming. However, the similar drop-off was specific to the freestyle stroke, and the marathon times widened more so than for backstroke. These data suggest that for only some events and strokes in swimming, there is less depth among the women than the men as we consistently observe for marathon running (Hunter et al., 2011; Hunter & Stevens, 2013).

It has been suggested that the widening sex difference (i.e., a greater difference than expected because of physiology alone) is because men are more "competitive" than women (Deaner, 2013a,b), and therefore, they are more innately motivated to train and compete harder (Deaner, 2013a,b). To support the "competitive" hypothesis however, the widening sex difference in performance should be consistent across sports and independent of age and participation rates. We show here however, a diminished rate of increase of the sex difference in some swimming events (e.g., no increase with world record place in backstroke) and a greater sex difference with aging in both swimming and the marathon. Thus, the "competitive" hypothesis that men are more motivated than women cannot be a large contributor to the sex difference especially at the most elite level of swimming and running.

Sex differences with advanced age

World-record swimming times were fastest in those < 35 years old and the decrease in velocity across the age groups occurred for both men and women. The decrement in swimming performance has been observed before among elite swimmers (Tanaka & Seals, 1997; Donato et al., 2003) and seen to decline exponentially from 70 years onwards (Tanaka & Seals, 1997, 2003; Donato et al., 2003; Rubin & Rahe, 2010). Our data however shows a more precipitous decline from 80 years of age (e.g., Fig. 1(a)) and may reflect a greater depth of swimmers, both men and women, in the older age groups in more recent years especially as the average age of life continues to climb in the western world. The decrease in velocity with advanced age is likely attributable to age-related declines in VO_{2max} in both men and women primarily because of age-related reductions in maximum heart rate and modest reductions in stroke volume and arterio-venous O_2 difference (Tanaka & Seals, 2008).

The sex difference in world records however, increased with age and more rapidly after 60 years for all strokes and then exponentially after 80 years (Figs. 1(b) and 4(d)). Thus, the smallest sex difference was typically in the 25–29-year-olds and the greatest in the 85–89-year-olds for all the strokes. The increased sex difference with advanced age has been noted among elite triathletes (Lepers &

Maffiuletti, 2011; Stevenson et al., 2013), runners (Ransdell et al., 2009; Lepers & Cattagni, 2012; Hunter & Stevens, 2013), and elite swimmers (Tanaka & Seals, 1997; Ransdell et al., 2009) and we also showed it among the world record holders for the marathon running in this study. In all cases for the freestyle, for example, the sex difference doubled between the 25–29 and 85–89 years age groups, and for the 800 m and 1500 m, the sex difference more than tripled between the same age groups (see Tables 1 and 2). The age difference in performance increased more so with advanced age among the longer distance events as seen for elite U.S. swimmers (Donato et al., 2003).

The magnitude of the overall reduction in swimming performance with advancing age was smaller than the observed reduction in running performance for both men and women in this study and other studies (Tanaka & Seals, 2003; Ransdell et al., 2009; Hunter & Stevens, 2013). Lower participation levels of women explained much of the sex differences beyond the physiological sex differences in marathon running (Hunter & Stevens, 2013) and probably a lack of the talent competing especially among older women who predated Title IX (1972) and who were not exposed to the same competitive opportunities. Similarly, the widening sex differences across age groups in swimming reflects either physiological differences in the rate of aging of men and women, or social factors such as levels of participation and opportunities to train and compete.

Sex differences in swimming with stroke and distance

The sex difference in performance was greatest for short-axis strokes (breaststroke, 14.5% and butterfly, 16.7%) and least for the long-axis strokes (freestyle, 12.4% and backstroke, 12.8%) likely reflecting differences in energy expenditure and power between the strokes (Barbosa et al., 2006) and the greater muscular power of men relative to women (e.g., Senefeld et al., 2013). Performance of the long-axis strokes (freestyle and backstroke) is characterized by a pivot around the long axis of the body from the head to the feet, whereas performance of the short-axis strokes (breaststroke and butterfly) involves a pivot point in the hips and a constant undulation motion, which is more energy inefficient with greater reliance on power and anaerobic metabolism (Barbosa et al., 2006).

The sex difference in swimming velocity also decreased with increased event distance for all strokes. The sex difference in the youngest and also the fastest age group (25–29 years) was only 2.6% for the 1500 m event and for first place this progressively increased with the shorter distances to 50 m (10.3%; Table 1). Thus, women appear to have a physiological advantage in the longer swimming events relative to the shorter events, with the shorter events requiring greater power and reliance on anaerobic metabolism. This was also shown in elite swimmers for freestyle (Tanaka & Seals, 1997; Donato et al., 2003). Here, we show the sex differences decreases with event distance for freestyle but also for other strokes (backstroke, breaststroke, and butterfly) and was a large enough effect to be significant between 50 m to 200 m.

This decreased sex difference in longer distance events is likely because of the greater reliance on oxidative metabolism (Tarnopolsky, 2008) especially during longer distance events and a relatively lower oxygen cost of swimming in women (Pendergast et al., 1977; Tanaka & Seals, 2003). Women have a higher swimming economy than men because they have less drag in the water during swimming that men (Pendergast et al., 1977), which would prove advantageous over a longer distance. The lower oxygen cost of swimming for women appears to be driven by their of their smaller body size, greater proportion of body fat, and smaller body density relative to men (Tanaka & Seals, 2003). This result suggests that some factors limiting women more than men during weight-bearing sports such as running (i.e., greater body fat, smaller limb lengths, and smaller body density) may be advantageous to women in distance-oriented swimming events. Running economy on the other hand is similar between elite men and women runners (Bunc & Heller, 1989), and the sex differences in performance are relatively consistent across running distances (Tanaka & Seals, 1997; Cheuvront et al., 2005). Whether women consistently outperform men in ultra-endurance swimming events is debatable. Some studies report minimal sex difference in ultra-endurance swimming events (Eichenberger et al., 2012a,b) while other studies report men are faster than women by 11% (Eichenberger et al., 2013). Of note, however, a woman, Diane Nyad

(64 years) was the first person to complete the Cuba to Florida, USA, 180-km swim.

Other factors affecting sex differences

There are several factors that likely affect the sex and age differences of both swimming and running at the elite and recreational levels that we did not measure. Several possible contributors involve race and ethnicity. For example, East African runners represent 70% of the world's fastest marathon times for men and women since 2011; however, prior to 1990, East African runners represented less than 20% of the world's fastest times (Hunter et al., 2014). Although, the rise of dominance of the East African runners is about 10 years more advanced for men than women (Hunter et al., 2014). Overall however, there is little empirical evidence to understand the role of race and ethnicity in the sex differences of elite performance.

Societal factors (e.g., child rearing and societal expectations) as well as pregnancy in women may also affect the observed sex differences in sport performance. Certainly, increased opportunity for women in sport can affect sex differences in performance. For example, the legal entrance of women into the marathon in the early 1970s was accompanied by a precipitous decline in the women's world record times relative to men over a ~15-year time span (Hunter et al., 2014). This example demonstrates that a lack of depth in women's running and the widening of the sex difference with age can be influenced by lower participation rates of women (Hunter & Stevens, 2013). Societal pressures of childrearing as well as the physical limitations of pregnancy reduce opportunity for women to train and be physically active at all levels in running and swimming. For example, ~70% of women had lower physical activity levels in pregnancy, and even more women (~80%) had lower physical activity levels postpartum (Gutke et al., 2011). These results suggest that societal factors can affect sex differences in performance across the life span, although much less empirical data exists regarding elite level of performance.

Perspectives

The sex difference in world-record swimming was less than for the marathon possibly because of more equitable participation over the last century and physiological sex differences that can limit women's performance more in weight-bearing exercise than non-weightbearing exercise. The sex difference in swimming decreased as event distance increased for all strokes and likely reflects greater swimming economy for women compared with men. We also showed that the sex differences in the world-record swimming increased with advanced age in the women who predated Title IX in the United States and even more so from 80 years, possibly reflecting a lack of exposure to the same opportunities/incentives as men, physiological differences in aging between men and women, or both. Women however, had a greater drop-off than men in velocity of swimming between the first and 10th placed world record holder for all age groups and distances for freestyle, breaststroke, and butterfly but not for backstroke. Although the widening of the sex difference across world record place occurred for marathon running, it was not universal to all swimming strokes suggesting greater depth in women's swimming than running.

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Table 1. Men and women world record holders in 2011 (first place) for freestyle swimming in each 5-year age groups (between 25 and 89 years) for events between 50 m and 1500 m

	Age (years)	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89
50 m	Men's velocity (m/min)	131.6	133.2	131.8	128.8	123.7	124.6	120.0	118.9	113.9	105.8	99.1	92.9	88.4
	Women's velocity (m/min)	118.0	116.6	115.5	116.8	112.8	106.3	104.6	102.4	94.2	89.4	86.1	80.1	67.1
	Sex difference (%)	10.3	12.5	12.4	9.3	8.8	14.7	12.8	13.9	17.3	15.5	13.1	13.8	24.1
100 m	Men's velocity (m/min)	118.2	118.0	118.2	116.0	111.6	109.9	107.0	102.4	99.4	91.7	90.0	82.1	72.1
	Women's velocity (m/min)	105.5	108.6	101.9	102.7	100.4	98.2	96.7	94.0	83.3	80.8	74.9	71.3	56.5
	Sex difference (%)	10.8	8.0	13.7	11.5	10.1	10.7	9.6	8.2	16.1	12.0	16.9	13.1	21.6
200 m	Men's velocity (m/min)	108.1	106.1	106.3	105.6	101.8	99.7	96.8	90.5	86.6	82.1	82.4	71.1	61.9
	Women's velocity (m/min)	98.3	96.7	94.8	93.0	92.2	88.9	88.1	84.0	75.4	71.4	68.0	64.0	50.8
	Sex difference (%)	9.1	8.8	10.9	11.9	9.4	10.9	9.0	7.2	12.9	13.0	17.5	9.9	17.9
400 m	Men's velocity (m/min)	99.6	100.7	97.3	97.3	96.3	93.5	91.4	85.6	79.9	76.9	75.5	65.1	56.7
	Women's velocity (m/min)	94.9	92.8	90.3	91.3	87.0	85.4	82.7	79.0	70.0	67.6	64.3	59.6	48.6
	Sex difference (%)	4.8	7.8	7.1	6.1	9.7	8.7	9.5	7.7	12.5	12.1	14.9	8.4	14.4
800 m	Men's velocity (m/min)	95.1	96.7	93.2	92.7	91.8	89.7	88.9	80.6	76.7	74.3	71.9	62.1	54.7
	Women's velocity (m/min)	91.0	91.2	88.0	89.0	85.1	83.0	79.3	76.5	67.3	65.5	61.6	57.7	46.6
	Sex difference (%)	4.3	5.7	5.5	3.9	7.3	7.4	10.8	5.2	12.2	11.9	14.3	7.1	14.8
1500 m	Men's velocity (m/min)	92.4	90.9	90.7	90.3	90.1	87.5	86.3	82.4	74.9	72.8	71.3	60.8	52.5
	Women's velocity (m/min)	90.0	87.3	85.4	83.6	83.7	81.1	77.9	75.4	66.1	62.2	60.7	56.6	46.6

1. Velocity is in meters per minute (m/min) and the sex difference as a percent (% difference relative to the men's velocity). Men are faster than the women in each age group and event distance ($P < 0.05$). The velocity for both men and women decreases with increased event distance and advanced age.

Age (years)	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89
Sex difference (%)	2.6	4.0	5.8	7.4	7.2	7.3	9.7	8.4	11.7	14.5	14.8	6.9	11.2

Velocity is in meters per minute (m/min) and the sex difference as a percent (% difference relative to the men's velocity). Men are faster than the women in each age group and event distance ($P < 0.05$). The velocity for both men and women decreases with increased event distance and advanced age

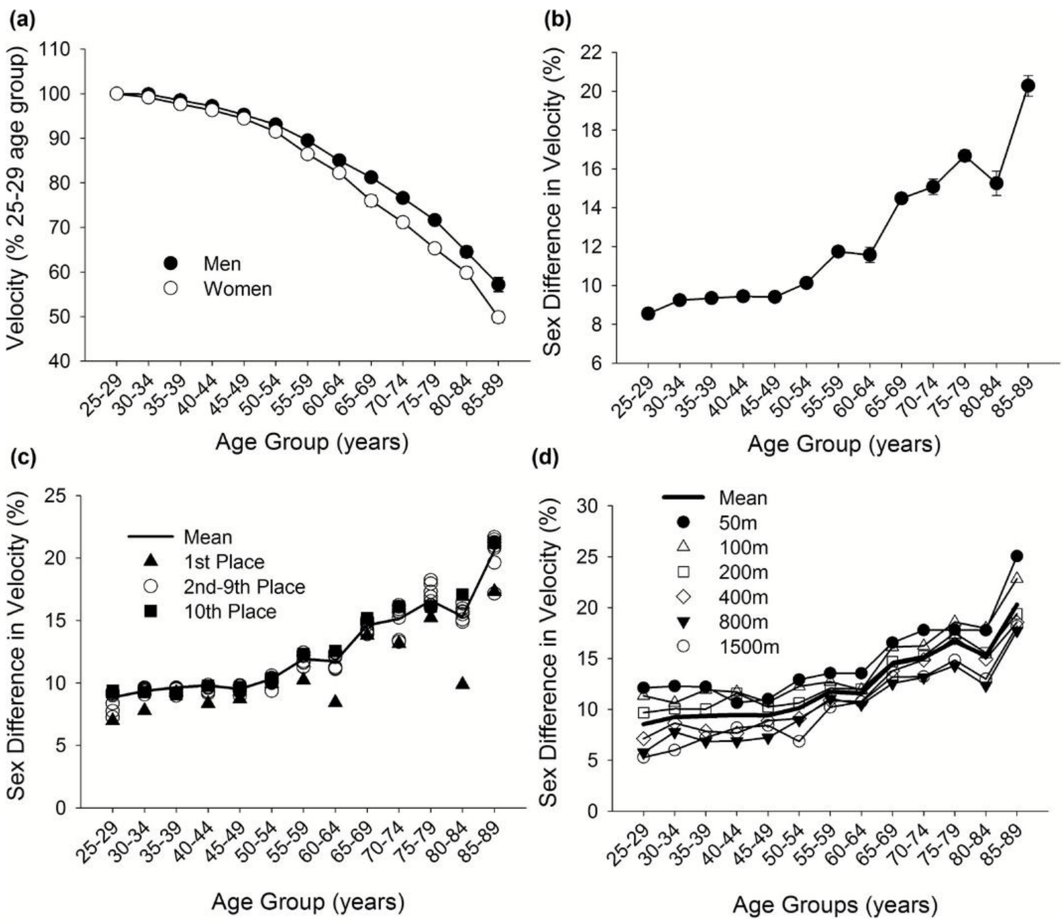

Figure 1. World's fastest freestyle swimming times for men and women in the 5-year age groups 25 to 89 years. (a) Average velocity (±SEM) across the age groups for men (filled circle) and women (open circle) relative to velocity of the 25–29 years age group for each sex (top 10 world records and all distances pooled). (b) Average (±SEM) sex difference in velocity (% of men's velocity) across age groups (distance and place pooled). (c) Sex difference in velocity (% of men's velocity) across the ages, stratifying the average as a line, first place world record holders (filled triangle), world record places 2–9 (open circles), and 10th place world record holders (filled square). (d) Sex difference in velocity (%, mean as thickest line) across age groups, for event distance between 50 m to 1500 m (world record place pooled).

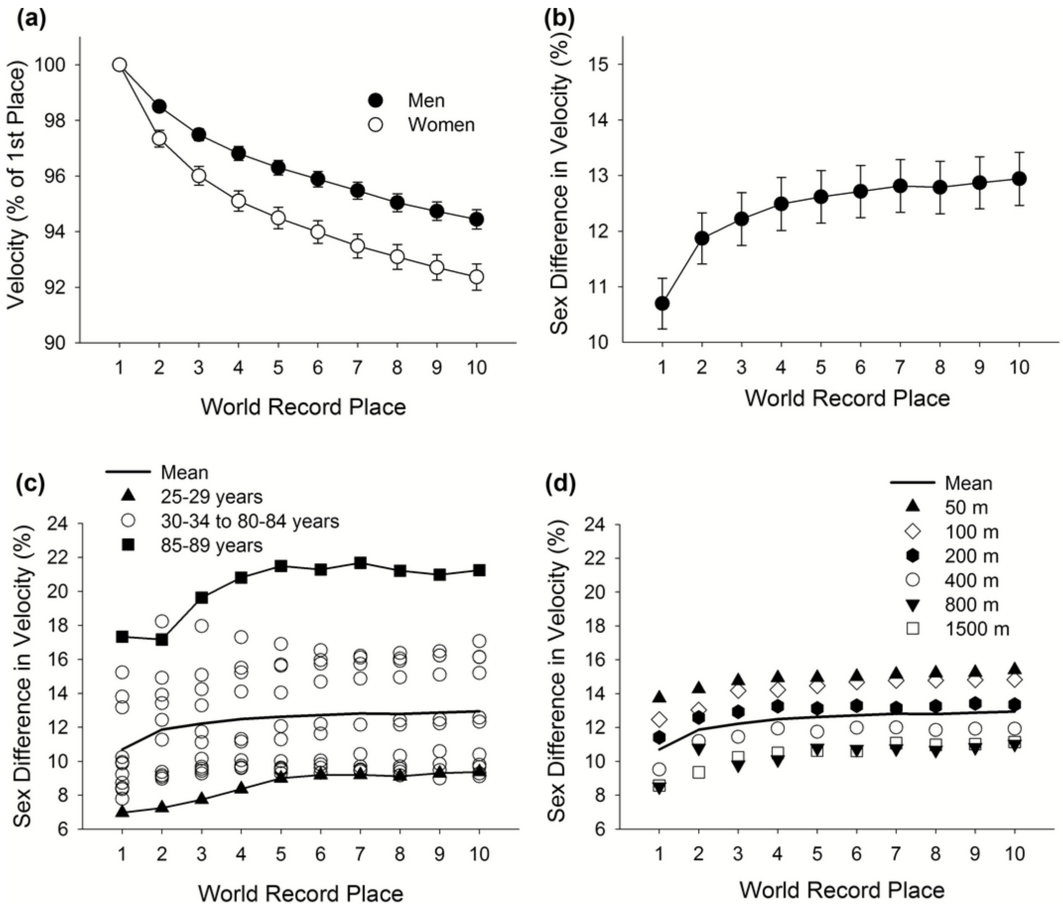

Figure 2. World's fastest freestyle swimming times for men and women across the top 10 world record places. (a) Average velocity (±SEM) across the world record for men (filled circle) and women (open circle) relative to the velocity of the world record (first place) for each sex (all age groups and distances pooled). (b) Average (±SEM) sex difference in velocity (% of men's velocity) across the top 10 world record places (all age groups and distances pooled). (c) Sex difference in velocity (% of men's velocity) across world record places (distances pooled), stratifying the average as a line, first place world record holders (filled triangle), world record places 2–9 (open circle), and 10th place world record holders (filled square). (d) Sex difference in velocity (%, mean as thick line) across world record place, for event distance between 50 m and 1500 m (ages pooled).

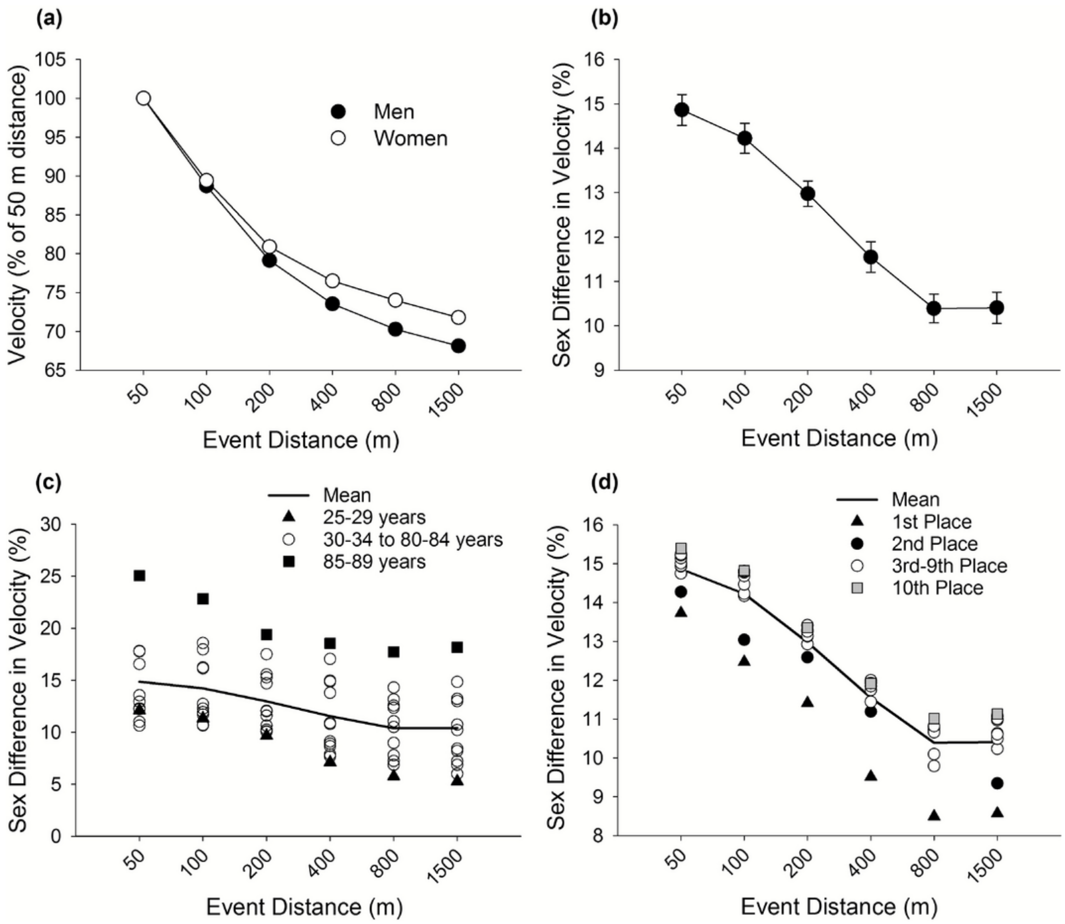

Figure 3. World's fastest freestyle swimming times for men and women for distances between 50 m and 1500 m. (a) Average velocity (± SEM) across the world record for men (filled circle) and women (open circle) relative to the velocity of the world record (first place) for each sex (all age groups and world record places pooled). (b) Average (±SEM) sex difference in velocity (% of men's velocity) for each event distance (all age groups and world record places pooled). (c) Sex difference in velocity (% of men's velocity) across distances (world record places pooled), stratifying the average as a line, 25–29 years age group (filled triangle), 30–84 years age groups (open circles), and 85–89 years age groups (filled square). (d) Sex difference in velocity (%, mean as thick line) across event distance between 50 m to 1500 m for world record places (ages pooled).

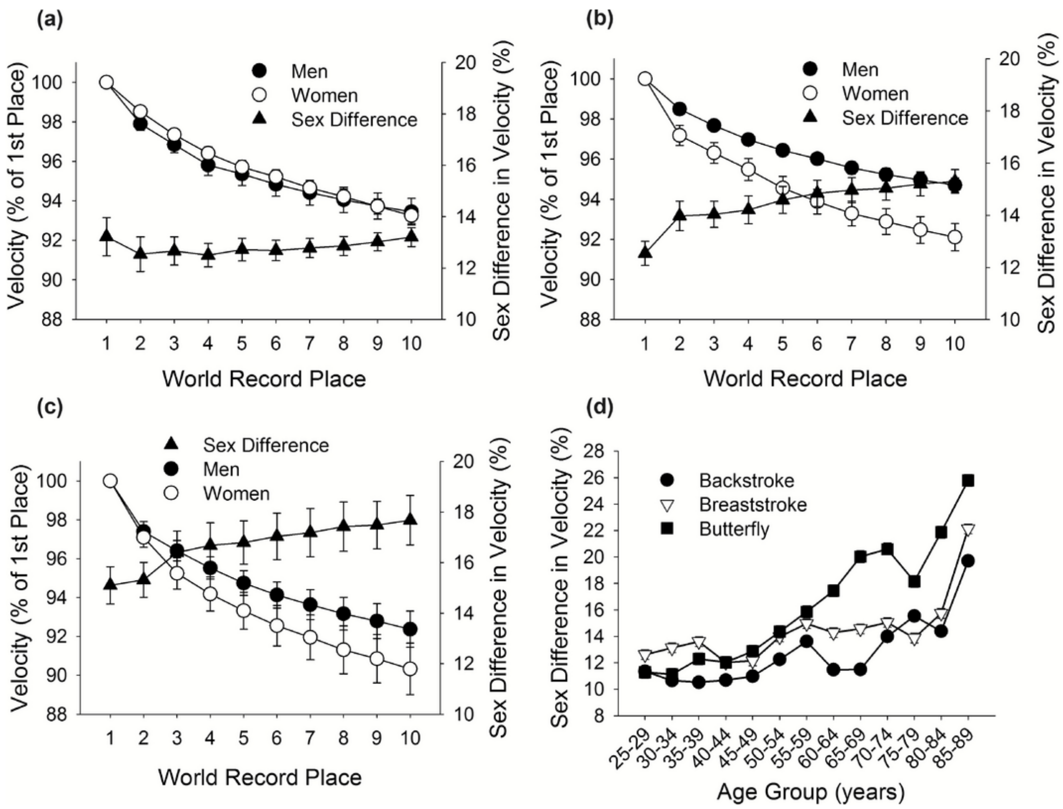

Figure 4. World's fastest swimming times for men and women (50–200 m) in backstroke (a), breaststroke (b), and butterfly (c). (a) For panels a, b, and c, the left axis shows the average velocity (±SEM) across the world record place for men (filled circle) and women (open circle) relative to the velocity of the world record (first place) for each sex (all age groups and distances pooled). The right axis indicates the average (±SEM) sex difference in velocity (% of men's velocity) across the top 10 world record places (all age groups and distances pooled). (d) The average (±SEM) sex difference in velocity (% of men's velocity) across the 5-year age groups (25–89 years) for backstroke, breaststroke, and butterfly (world record place and distances pooled).

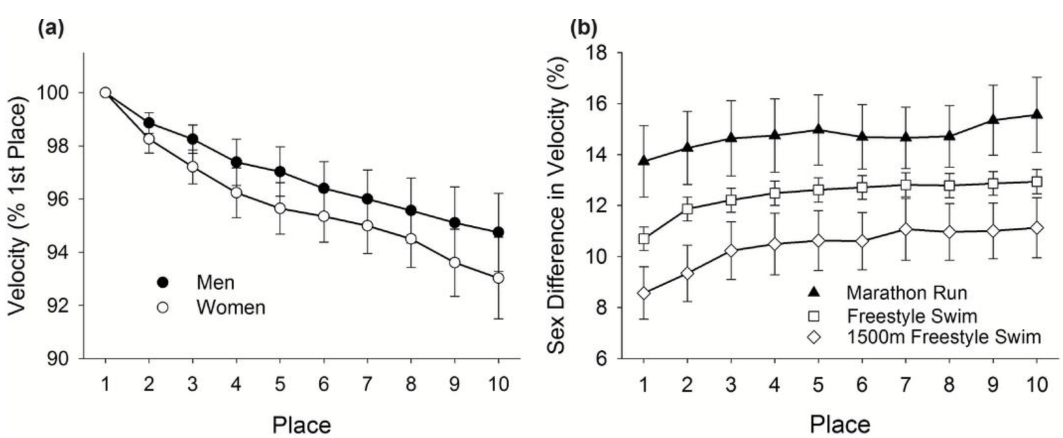

Figure 5. Top 10 world's fastest marathon running performances and freestyle swimming performances for men and women. (a) The mean (±SEM) velocity of men

and women (relative to first place) across the top 10 world record places for marathon running (all age groups pooled). (b) The average (±SEM) sex difference in velocity (% of men's velocity) across world record place (all age groups pooled) for marathon running (filled triangles), freestyle swimming (open squares, all event distances pooled), and 1500 m freestyle swimming (open diamonds).

Table 2. The average (±SD) velocity for the top 10 men and women world record holders for freestyle swimming in each 5-year age groups (between 25 and 89 years) for events between 50 m and 1500 m

	Age (years)	**25–29**	**30–34**	**35–39**	**40–44**	**45–49**	**50–54**	**55–59**
50 m	Men's velocity (m/min)	128.6 (1.2)	129.5 (1.8)	127.6 (1.8)	124.4 (1.7)	122.2 (1.0)	120.6 (1.9)	116.6 (1.7)
	Women's velocity (m/min)	113.0 (2.2)	113.6 (1.7)	112.1 (1.5)	111.2 (2.4)	108.7 (1.7)	105.0 (1.0)	100.8 (1.7)
	Sex difference (% men)	12.1	12.3	12.2	10.6	11.0	12.9	13.6
100 m	Men's velocity (m/min)	116.3 (0.9)	116.4 (1.1)	115.0 (1.5)	113.0 (1.7)	109.8 (1.2)	108.4 (1.0)	103.9 (1.3)
	Women's velocity (m/min)	103.1 (1.1)	104.0 (2.5)	101.3 (0.4)	99.7 (1.4)	98.1 (1.3)	95.1 (1.3)	90.7 (2.6)
	Sex difference (% men)	11.3	10.6	11.9	11.7	10.7	12.3	12.7
200 m	Men's velocity (m/min)	105.6 (1.2)	104.6 (0.9)	103.5 (1.4)	102.5 (1.8)	99.9 (1.0)	97.1 (1.4)	93.3 (1.6)
	Women's velocity (m/min)	95.4 (1.6)	94.1 (1.4)	93.1 (0.8)	90.6 (1.1)	89.7 (1.2)	86.8 (1.6)	82 (2.3)
	Sex difference (% men)	9.7	10.1	10.0	11.6	10.2	10.6	12.1
400 m	Men's velocity (m/min)	97.9 (1.2)	97.6 (1.6)	95.5 (1.0)	94.6 (1.1)	93.3 (1.6)	91.2 (1.4)	87.0 (2.2)
	Women's velocity (m/min)	91.0 (2.1)	89.1 (1.5)	88 (1.3)	87.3 (1.8)	85 (1.1)	82.9 (1.5)	77.5 (2.1)
	Sex difference (% men)	7.1	8.7	7.9	7.7	8.9	9.1	10.9

	Age (years)	**60–64**	**65–69**	**70–74**	**75–79**	**80–84**	**85–89**
50 m	Men's velocity (m/min)	112.3 (2.9)	109.4 (1.9)	104.0 (1.5)	96.7 (1.2)	89.5 (1.9)	82.1 (2.8)
	Women's velocity (m/min)	97.1 (2.6)	91.3 (1.5)	85.5 (2.3)	79.5 (2.6)	73.7 (3.0)	61.6 (2.4)
	Sex difference (% men)	13.5	16.6	17.8	17.8	17.8	25.1
100 m	Men's velocity (m/min)	99.1 (1.5)	96.3 (1.6)	89.8 (1.3)	83.7 (2.7)	77.3 (2.0)	69.2 (2.1)
	Women's velocity (m/min)	87.3 (3.0)	80.8 (1.6)	75.3 (3.0)	68.2 (2.5)	63.5 (3.6)	53.4 (2.2)
	Sex difference (% men)	11.9	16.1	16.2	18.6	18.0	22.8
200 m	Men's velocity (m/min)	88.4 (1.6)	84.3 (1.1)	79.4 (1.4)	74.4 (3.5)	66.3 (2.2)	58.8 (2.5)
	Women's velocity (m/min)	77.8 (2.8)	72 (2.1)	67.3 (2.6)	61.3 (2.5)	56 (3.1)	47.4 (2.1)
	Sex difference (% men)	12.0	14.7	15.3	17.5	15.6	19.4
400 m	Men's velocity (m/min)	82.1 (1.6)	78.1 (1.3)	73.6 (1.5)	69.7 (3.0)	61.5 (2.0)	54.3 (1.9)
	Women's velocity (m/min)	73.2 (2.2)	67.3 (1.7)	62.7 (2.5)	57.8 (2.5)	52.3 (2.9)	44.3 (2.5)
	Sex difference (% men)	10.8	13.8	14.9	17.0	15.0	18.5

1. Velocity is in meters per minute (m/min) and the sex difference as a percent (% difference relative to the men's velocity). The top 10 men were faster than the women in each age group and event distance ($P < 0.05$). The velocity for both men and women generally decreased with increased event distance and advanced age.

	Age (years)	**25–29**	**30–34**	**35–39**	**40–44**	**45–49**	**50–54**	**55–59**	**60–64**	**65–69**	**70–74**	**75–79**	**80–84**	**85–89**
800 m	Men's velocity (m/min)	93.1 (1.0)	93.5 (1.9)	91.7 (1.0)	90.9 (1.0)	89.2 (1.5)	87.2 (1.1)	83.9 (2.6)	78.9 (0.8)	74.5 (1.4)	70.3 (2.2)	65.9 (2.9)	58.3 (2.1)	51.1 (2.2)
	Women's velocity (m/min)	87.7 (2.3)	86.2 (1.8)	85.4 (1.3)	84.7 (1.7)	82.7 (1.4)	79.4 (1.9)	74.6 (2.0)	70.6 (2.2)	65.1 (1.4)	61.1 (2.5)	56.5 (1.9)	51.1 (2.6)	42.1 (3.1)
	Sex difference (% men)	5.8	7.8	6.9	6.9	7.2	9.0	11.0	10.5	12.6	13.1	14.3	12.4	17.7
1500 m	Men's velocity (m/min)	90.5 (0.9)	89.8 (0.8)	89.3 (1.1)	88.7 (1.1)	87.2 (1.4)	83.8 (1.7)	81.3 (2.4)	77.1 (2.2)	72.1 (1.8)	68.3 (2.2)	63.6 (3.2)	56.7 (2.0)	48.6 (2.5)
	Women's velocity (m/min)	85.7 (2.1)	84.5 (1.3)	82.9 (1.2)	81.4 (1.4)	79.9 (2.2)	78.0 (1.8)	73.0 (2.5)	68.8 (2.8)	62.6 (1.8)	59.3 (1.7)	54.2 (2.6)	49.4 (3.1)	39.8 (3.7)
	Sex difference (% men)	5.3	6.0	7.2	8.2	8.4	6.9	10.2	10.7	13.2	13.2	14.8	13.0	18.2

Velocity is in meters per minute (m/min) and the sex difference as a percent (% difference relative to the men's velocity). The top 10 men were faster than the women in each age group and event distance ($P < 0.05$). The velocity for both men and women generally decreased with increased event distance and advanced age.

