Effects of age and gender on physical performance

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Abstract Our purpose was to examine the effects of age and gender on physical performance. We assessed a one-hour swimming performance and participation of 4,271 presumably healthy men and women, aged 19–91 years, from the 2001–2003 United States Masters Swimming long-distance (1 h) national competition. The decline in performance with increasing age was found to be quadratic rather than linear. The equation which best fit variation in 1 h swimming distance in meters (m) according to variations in age in years (y) in men was: distance (m)=4058+2.18 age−0.29 age (http://www.acsmmsse.org/pt/re/msse/positionstandards.htm;jsessionid=DiRVACC7YS3mq27s5kV3vwpEVSokmmD1ZJLC7pdnol3KcfoSu0t!1096311956!-949856145!9001!-1), with the same equation for women except that 380 m needed to be subtracted from the calculated value at all ages (about a 10% difference). There was a large overlap in performance between men and women. The overall mean decline in performance with age was about 50% and was parallel in men and women. The mean difference in distance for a 1-year increment in age was −9.7 m at 21 y of age, −21.3 m at 40 y, and −44.5 m at 80 y. Far greater declines of about 96% in numbers participating with advanced age (80 y and over, 4% of peak numbers) were observed than in the 40–49 y age group. In conclusion, the declines in performance were parallel in men and women at all ages, and the 1-year age-related declines in performance were about twice as great at 40 y and more than four-times as great at 80 y than at 20 y of age, with even greater age-related declines in participation being noted for both men and women.

Keywords Aging · Physical performance · Physical activity · Exercise · Swimming

Introduction

Habitual exercise is able significantly and positively to impact on health, and the Centers for Disease Control and Prevention and the American College of Sports Medicine have actively worked to develop and disseminate exercise recommendations for different populations (National Center for Chronic Disease Prevention and Health Promotion 2006; American College of Sports Medicine 2006). Guidelines for healthy aging emphasize the daily inclusion of 30–90 min of moderate activity (150+kcal/day, for a total of 1,000+ kcal/week) (Department of Health and Human Services Centers for Disease Control and Prevention 2006). Very few individuals in the population actually meet these goals. While it is clear that exercise provides health benefit at any age (World Health Organization 2003), aging and cultural expectations can affect physical activity in different ways. First, there is an age-related decrease in engagement in physical activity (Department of Health and Human Services Centers for Disease Control and Prevention 2006) and a tendency to train at lower exercise intensities (DiPietro et al. 2006; Weir et al. 2005). Second, the physiological changes that accompany advancing age result in declines in both aerobic and anaerobic performance, with speed and power most affected (Westerkerp and Meijer 2001; Douglas and O'Toole 1992). Questions remain about gender-specific differences in decline. As science continues to influence training methods and techniques, sports performances have improved across all ages (Jokl et al. 2004). Finally, evolving cultural norms influence age-related expectations regarding athletics during 'middle age' and in the elderly. Changes in health status once attributed to 'normal aging' are now recognized as resulting in part from a sedentary lifestyle (Spiroduso and Cronin 2001). Increasing disease-related disabilities, such as cardiovascular disease, cancer, and osteoarthritis, also play an important role in this regard.

The number of older adults participating in organized sports, including distance events that require habitual training regimens, continues to grow. From 1983–1999, New York Marathon participation increased at a higher rate in athletes over 50 years of age than in younger athletes, and 54.7% (n=9,605) of runners who completed the 2005 Boston Marathon were ≥40 years (Boston Athletic Association 2005). Women's involvement in athletics, and competition specifically, is on the rise. In the 2005 Boston Marathon, women comprised 28% of the runners, and almost half (49.4%) of the younger runners (ages 18–39 years) were women. Environmental and training influences are evident, as the mean finishing times for distance runners of both genders at all ages continue to improve (Goldstein 2001).

The U.S. Masters Swimming (USMS) organization has responded to a growing interest in its sport by expanding membership beyond competitive athletes, encouraging participation by fitness and novice swimmers, and opening its program to a wider age-bracket (ages 19+ years). When asked to list the top five reasons for swimming, 76% of current Masters Swimmers consider fitness the primary motivator. Competitive swimming was ranked fifth and reported by only 19% (Goldstein 2001).

It is important to understand peak performance and its relationship to age in elite athletes, but equally important is uncovering information that reflects the changes experienced by adult fitness athletes within a wide performance range. Some information is available on running/track; however, less information is available on age-related swimming performance in women and on non-elite Masters athletes, and there is none available on longer distance swim events. The benefits of examining swimming performance is that, in USMS, men and women of a wide range of ages and abilities continue to measure their performance in 1 h swimming nationally each year. Our aim was to determine the age-related decline in this program in men and women ages 18 years to over 90 years of age and to ascertain the cross-sectional relationship between age and physical performance over a wide range of skill levels.

Methods

Study population and collected data

We studied subjects registered in United States Masters Swimming (USMS), an organization that promotes life-long swimming through workouts, competitions, clinics, and workshops for approximately 42,000 adults aged 18 years and over (United States Masters Swimming Organization 2006). Programs are open to all adult swimmers who are interested in improving their overall fitness, developing better technique, or training for any type of swimming competition. Annual registration fees and participation fees are nominal. Each January, a Long-Distance National Postal Championship (one-hour championship) is organized and open to all USMS members. The objective of the championship is to cover the greatest distance in a 1 h swim without assistance from drafting, flotation or propulsive devices. Swimmers can do the event in freestyle, which means virtually every stroke (crawl or freestyle, breaststroke, backstroke, or butterfly). Virtually all swimmers do the event in crawl or freestyle stroke. The swim can be done during the month in any pool 25 yards or longer. Each swimmer must have a verifier who counts lengths, times the individual with a stopwatch, records cumulative splits, and signs the official entry form. The 1 h swimming distance, the age and the gender of each participant are recorded. Swimmers are unaware of their standing until all entry forms have been received, and the standings are tabulated and then publicly posted (United States Masters Swimming Organization 2001, 2003, 2005).

USMS enrollment information in 2003, categorized by gender and age, was obtained in order to determine participation data. The number of USMS members who participated in the 2001–2003 one-hour championships and their results provide the performance data. Between 2001 and 2003, 6,167 times were recorded in one of the annual one-hour championships (1,926 in 2001, 2,005 in 2002, and 2,236 in 2003). Some individuals participated in several championships. Only the 4,271 first-year performances were included in the statistical analysis of the relationship between age and 1 h swimming performance. No informed consent was obtained since we analyzed publicly available data. The Tufts University Institutional Review Board granted exemption approval for these analyses. Even though the performance of each individual is recorded by name in the published USMS data set, we anonomized the data for this analysis. No information on the heath status of participants was available. Insurance for the facility is provided through USMS registration, and participation is self-determined.

Statistical analysis

SAS for Windows statistical software, release 8.2 (SAS Institute, Cary, NC) and SYSTAT software, version 10.2.01 (SYSTAT Software, Richmond, CA) were used to analyze the data. Registration rates in the USMS organization were estimated in 10-year-interval age groups, using the number of people registered as USMS members by 31 January 2003 (end date of the 2003 one-hour championship) for the numerator and the most recently available data from the US age-specific population census (2000 at the time of these analyses) for the denominator (http://www.census.gov). Rates were calculated per 100,000 US age-specific individuals. Participation rates (per 100 USMS members) in the 2003 one-hour championship were estimated in 10-year-interval age groups. Chi-square tests for homogeneity of proportions and logistic regression were used to compare rates for men and women at different ages. A one-way analysis of variance (ANOVA) was adopted to assess the effect of age on the total distance covered by participants.

Results

Table 1 shows USMS membership registration rates by the end date of the 2003 one-hour championship (31 January 2003), in 10-year-interval age groups. The rates increased in both men and women until it peaked between 40 years and 49 years old (20.96 male USMS members per 100,000 US men and 15.83 female USMS members per 100,000 US women) and decreased thereafter. Registration rates were significantly higher in men than in women in all age groups except in the youngest one. It is important to note that the number of individuals in the total population aged 80 years and over versus the peak decade (30–39 years of age) declined by 85.9% for men and 71.7% for women, while numbers of USMS swim members declined by 71.0% for men and by 87.4% for women.

Table 2 describes participation rates in the 2003 one-hour championship among registered USMS members, in 10-year-interval age groups. Participation rate peaked between 60 years and 69 years in men (10.02%) and 10 years later in women (13.18%). Women were more likely than men to participate, and there was no significant change in the relative male-to-female participation rates with age ($P=0.55$ for the age by gender interaction tested in a logistic regression model). However, in absolute numbers, total swimmers participating in the 1 h swim peaked in the 40–49 year age group and then declined very significantly thereafter, so that, in the 80 years and over age group, the decline was 95.2% for male participants in the 1 h swim and 95.8% for USMS membership, and 96.6% and 96.4% for women, respectively. These declines were even greater than the declines for the total population. The pattern was very similar for men and women. This decline presumably relates mainly increased death and disability with aging, although no health status information on participants was available.

The cross-sectional relationship between age and 1 h swimming performance was studied in the 4,271 subjects (2,173 men and 2,098 women) that participated in one of the annual USMS Long-Distance National Championships (one-hour swim) between

Table 1 USMS membership registration rates in 10-year-interval age groups

Age group	Men			Women			
	(n)	US age-specific population[a]	Rate per 100,000	(n)	US age-specific population[a]	Rate per 100,000	P[c]
20–29 years	1,156	19,486,574	5.93	1,770	18,858,763	9.39	<0.0001
30–39 years	3,150	21,640,465	14.56	2,930	21,576,587	13.58	<0.01
40–49 years	4,406	21,018,608	20.96	3,407	21,515,659	15.83	<0.0001
50–59 years	2,856	15,116,453	18.89	1,616	15,938,332	10.14	<0.0001
60–69 years	1,158	9,536,989	12.14	616	10,802,003	5.70	<0.0001
70–79 years	594	6,947,368	8.55	349	9,325,886	3.74	<0.0001
≥80 years	186	3,061,895[b]	6.07[b]	122	6,123,059[b]	1.99	<0.0001

[a] Estimated by the last US population census (2000) and in USMS as of 31 January 2003

[b] The percentage of individuals in the population 80 years and over was 14.2% in men and 28.4% in women as compared to the peak decade (age 30–39 years), while the participation rate per individuals in the population in the 80 years and over group was 29.0% for men and 12.6% for women of rates observed at the peak decade (40–49 years of age)

[c] Chi^2 test comparing rates between men and women in each age group

2001 and 2003. The mean age of the participants was 45.2 years for men (SD ±13.0, range 19–91 years) and 41.7 years for women (±13.1, range 19–89 years). Mean 1 h swim distance was 3,506.1 m (±687.5 m) and 3,207.9 m (±657.0 m) in men and women, respectively (3,834.4±751.9 yards and 3,508.2±718.5 yards, respectively). Age and 1 h swim distance were normally distributed both in men and women, and 1 h swimming distance was inversely related to age [Pearson correlation coefficient −0.48 (P<0.0001) for men and −0.53 (P<0.0001) for women]. Table 3 compares mean 1 h swimming distances between 10-year-interval age groups and shows a significant decrease in swimming distances from the youngest to the oldest age group for both men and women (P<0.0001). No age and gender interaction was noticed. Table 4 reports the regression analysis that examined variations in distance. The inclusion of a quadratic term (age x age) was highly

Table 2 Participation rates in the 2003 one hour championships in USMS members, as of 31 January 2003

Age group	Men			Women			
	(n)	USMS members	Rate/100	(n)	USMS members	Rate/100	P[a]
20–29 years	101	1,156	8.74	180	1,770	10.17	0.20
30–39 years	238	3,150	7.56	275	2,930	9.39	<0.05
40–49 years	371	4,406	8.42	350	3,407	10.27	<0.01
50–59 years	220	2,856	7.70	177	1,616	10.95	<0.001
60–69 years	116	1,158	10.02	77	616	12.50	0.11
70–79 years	46	594	7.74	46	349	13.18	<0.01
≥ 80 years	18[b]	186[b]	9.68	12[b]	122[b]	9.84	0.96

[a] Chi -square test comparing rates between men and women in each age group

[b] The percentage of swimmers in the 80 years and over age group was 4.8% for men and 3.4% for women as compared to the peak decade (40–49 years), while for USMS membership it was similar at 4.2% for men and 3.6% for women. In contrast, participation rates in the 1 h swim per 100 USMS members were reasonably constant, but somewhat higher in women, with significant differences in the 30–49 year old age groups and the 70–79 year age group

Table 3 Mean 1 h swimming distances (in meters) by gender and 10-year age groups

Men (n=2,173)			Women (n=2,098)	
Age group	(n)	Mean (SD) (m)	(n)	Mean (SD) (m)
19–29 years	222	3,913.5 (567.0)	394	3,586.4 (572.7)
30–39 years	558	3,728.8 (638.2)	599	3,385.0 (574.0)
40–49 years	702	3,579.4 (603.3)	621	3,217.7 (577.7)
50–59 years	385	3,361.9 (595.6)	277	2,863.7 (522.8)
60–69 years	182	3,000.1 (575.8)	118	2,595.5 (485.3)
70–79 years	101	2,649.0 (547.0)	72	2,251.5 (417.2)
≥80 years	23	2,118.4[a] (523.1)	17	1,745.2[a] (396.7)

The value for the F statistic was 110.96, with $P<0.0001$ for one-way ANOVA comparing mean 1 h swimming distances between the seven age groups in men, and the F value was 136.36, with $P<0.0001$ for one-way ANOVA for women. Two-way ANOVA showed a non-significant interaction between age and gender (F=1.58, P=0.15). For the two-way ANOVA model including main factors (age group and gender) without interaction, F=243.28, $P<0.0001$ for age group and F=441.28, $P<0.0001$ for gender. Conversion: 1 m= 1.0936 yards

[a] The mean distance percentage decrease from the youngest age group to the oldest age group was 45.9% for men and 51.3% for women

significant. The equation which best fit variations in 1 h swimming distance in meters according to variations in age in years was:

$$Men:\ Distance\ in\ meters\ (m) = 4058 + 2.18\,age - 0.29\,age^2$$

$$Women:\ Distance\ in\ meters\ (m) = 4058 + 2.18\ age - 0.29\ age^2 - 380$$

According to this equation, the mean difference in 1 h swimming distance for a 1-year increment in age was −9.7 m at 21 years of age, −21.3 m at 40 years, and −44.5 m at 80 years, and this explained 30% of the variability in performance. Figure 1 plots 1 h swimming distance with age in men and women. Curves for men and women were parallel. Therefore, no significant gender differences were noted except that 380 m needed to be subtracted from the calculated value for women. From the youngest decade to the oldest group the decline in mean performance was 45.9% for men and 51.3% for women.

Table 4 Ordinary least-squares regression analyses assessing variations in distance (in meters) according to change in age (in years)

	Parameter estimate (standard error)	P	R^2
Intercept	4058 (87)	<0.0001	
Gender (women versus men)	−380.0 (17.9)	<0.0001	0.30
Age (1 year increment)	2.18 (3.71)	0.56	
Age × Age	− 0.29 (0.04)	<0.0001	

Conversion: 1 m=1.0936 yards

Discussion

USMS is composed of adults interested in swimming for fitness, with enrollment being required by many local workout programs [44% of 2001 members (Goldstein 2001)], since registration provides insurance coverage during workouts and the one hour swim and reduces the aquatic facilities' liabilities. Participation in the nationwide 1 h event poses fewer barriers to swimmers than regional or national meets, since individuals can take part in the event at any time during the first month of the year at their local facility, unlike regional or national meets, which may require qualifying standards and may be associated with competition anxiety, access difficulties, and financial expense for travel. The one-hour swim is promoted as an annual personal assessment tool. Accurate times are reported through the use of verified split sheets recording each 50-yard/meter split, with the results publicly posted only after all swims have been entered and tabulated by gender and age. Therefore, one-hour

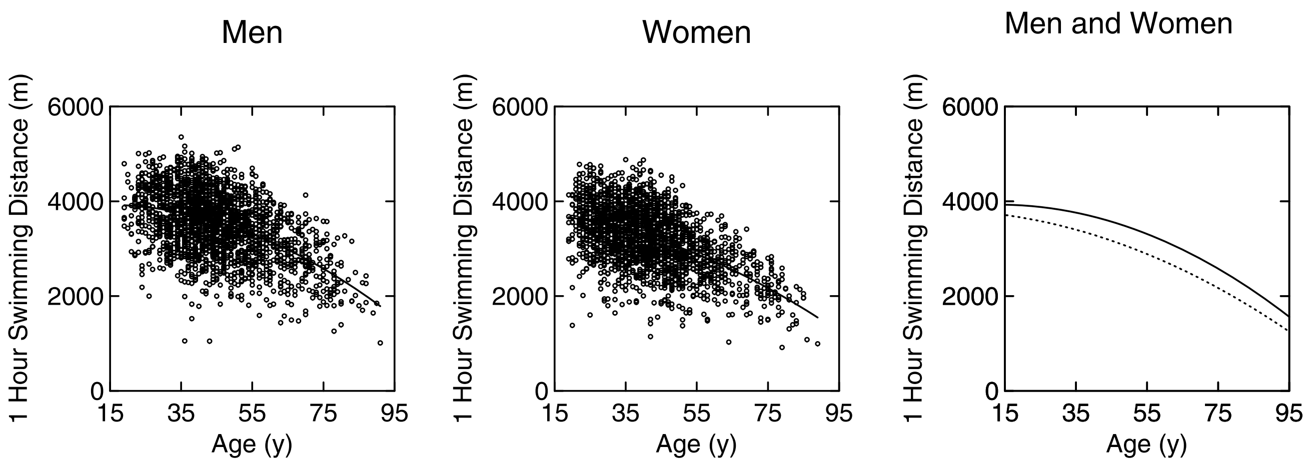

Fig. 1 Relationships between 1 h swimming distance (in meters) and age (in years) for men (*left*), women (*center*) and men vs women (*right*)

swim data reflect a wide range of abilities and training regimens and allow each swimmer to compare his or her own 1 h performance with the mean performance for the same age and gender category nationwide.

One of the characteristics of physical activity with advancing age is the lower engagement of elderly people in regular exercise (DiPietro 2001). In the present work we first describe the age-related patterns of participation in an organized physical activity program. These patterns may be highly dependent on the type of physical activity (Bijnen et al. 1998, DiPietro et al. 1989). Since swimming is not weight bearing, it may offer advantages over weight-bearing exercises such as running, walking, or being on a treadmill, especially for those individuals in the society that suffer from osteoarthritis. It should be noted that we have no health status information on participants. However; in 2002 we did assess overall health and cardiovascular risk status in 114 individuals (59 men and 55 women) participating in a regional competition of New England Masters Swimming held at Harvard University. We assessed height, weight, blood pressure, medication use, history of heart and vascular diseases, diabetes, and cardiovascular risk status as recommended by the third Adult Treatment Panel of the National Cholesterol Education Program (age, gender, systolic blood pressure, total cholesterol, and high density lipoprotein cholesterol by the fingerstick method) (Kaufman et al. 1990; Schaefer et al. 1994). Participation was voluntary, and only 20.8% of meet participants elected to take part. Their mean age was 57 years, with a standard deviation of 13 years. When these subjects were compared with age- and gender-matched participants in the Framingham Offspring Study we noted a 45% lower calculated 10-year risk of heart disease ($P<$ 0.01), associated with a lower prevalence of a history of heart disease and diabetes, elevated body mass index, hypertension, and decreased high-density lipoprotein (HDL) cholesterol (unpublished observations, EJ Schaefer, A McDermott) [Executive Summary of the Third Report of the National Cholesterol Education Program (NCEP) 2001; Schaefer et al. 1994]. These data suggest that Masters Swimmers as a group are quite healthy and have a substantially lower cardiovascular risk than their less physically active counterparts.

Our data distinguished three periods: before age 30 years, where the registration rates in USMS were low but higher in women than in men; between ages 30 years and 50 years, where the rates increased and became higher in men than in women; and after age 50 years, where the rates decreased, with consistently higher registration rates in men than in women. A similar trend in overall leisure-time physical activity has been described in the Baltimore Longitudinal Study on Aging (Verbrugge et al. 1996), where they report peak participation between the ages of 30 years and 49 years, with lower participation rates being observed in younger and older age groups. U.S. Census data (2006) also indicate that younger men have greater participation rates than older men and women across a number of sports, in addition to swimming. The drop in registration rates in the elderly may well reflect increased morbidity and mortality in this segment of the population, as well as less interest in fitness swimming. The higher USMS registration rates in older men than in older women observed in our study are consistent with previous reports suggesting that women have a lower probability of engaging in regular or vigorous physical activity (DiPietro 2001). Clearly, middle-aged women, granted access to collegiate sports as the result of Title IX (1972), have continued their involvement in sports-promoting organizations, but not to the same extent as men have.

Along with registration rates in USMS, we also studied the 2003 one-hour championship participation rates. Participation rates in the one hour swim as a percentage of registered USMS swimmers were significantly higher for women than for men. This may be due to differences in job-related time constraints, preferences for social interaction, goal-setting or objective external measures. The peak participation rate was shifted towards older age groups: between 60 years and 69 years in men and 10 years later in women, possibly reflecting more leisure time or less age-adjusted disability among women. However, when participation in the one hour swim is viewed in terms of absolute numbers, a different picture emerges. For both men and women, the greatest number of participants in the one hour swim was observed for the 40–49 year age group, with dramatic declines thereafter, with only about 4% of the number seen for the peak decade seen for number of swimmer in the 80 year and over age group. A very similar pattern was seen for both men and women. In our view this dramatic decline is mainly due to increasing death and disability associated with aging.

The most important feature of our data is the documentation of the relationship between age and distance physical performance throughout adulthood, from the twenties through the nineties, in a large cross-sectional sample of US male and female swimmers with a wide range of skill levels. The curvilinear decline of mean swimming distance with age did not significantly differ between men and women. The average difference in performance for a 1-year increment in age increased throughout the age groups. This difference was twice as great at 40 years as at age 20 years and 4.5-times greater at 80 years of age. However, this model explains only 30% of the variability in performance, so clearly other factors, such as increasing disability, and training and technique factors, may play an important role. Maximal oxygen consumption, habitual exercise training, technique and strength are considered to be the major determinants of endurance performance (Weir et al. 2005; Eskurza et al. 2002; Maharam et al. 1999). Masters swimmers who maintain rigorous training, unlike younger athletes, emphasize aerobic training at the cost of anaerobic speed and strength (Weir et al. 2005). Unlike in some other sports, biomechanical efficiency in swimming plays a major role in swim performance. In samples of 319 male and 321 female elite swimmers followed prospectively for 12 years, Tanaka et al. analyzed the effect of age on championship performance times in 50-m and 1500-m freestyle swimming races (Donato et al. 2003; Tanaka and Seals 1997). In their analysis (Donato et al. 2003), peak performance was maintained approximately until age 35 years, then a curvilinear decline similar to that in our study was observed. They found the magnitude of the decline was greater for women than for men in sprint races (50 m), where power and anaerobic capacity are most important, but this gender difference was not present for aerobic capacity, as demonstrated in the 1500 m event. Our results indicate that for longer distances (3,506.1 m and 3,207.9, m on average, for men and women, respectively), there was no substantial gender difference in the relationship between age and performance, in agreement with the results of Tanaka in the 1500-m swim.

Previous research has indicated that the physiologic systems in men respond to aging in different manners (Nair 2005; Croley et al. 2005; Kirkendall and Garrett 1998; Mattern et al. 2003; Short et al. 2005), and this is of interest to both athletes and physiologists. Cross-sectional examination of performance in a study of male U.S. Masters runners (100-yard sprint; ~10–16 s), rowers (2500-m Concept II; ~7–11 min) and swimmers (1500-m; ~17–42 min) suggested an annual 0.5% decline in maximal oxygen consumption (VO_2 max) in fit individuals from ages 35 years to 85 years in events lasting fewer than 45 min (Bortz and Bortz 1996), but data were lacking for the longer events. In addition, Bortz and Bortz reported that, regardless of the sport and competition length, that men > 65 years have a more rapid decline in performance than men younger than 65 years, and, at all ages, the VO_2 max values in athletes are much higher than in their sedentary counterparts. No data on women in this regard have been reported.

Longitudinal data in swimmers (Hartley and Hartley1984) and runners (Young and Starkes 2005) indicate that within-person performance changes are less than those reported in cross-sectional analyses, due to the removal of cohort variability in training, experience or technique. Therefore, our data may over-estimate the age-related decline in performance. While our data are cross-sectional, the fact that our sample includes more than 4,200 subjects with data collected within a 3-year period does reduce the impact of historical differences. Sport-specific assumptions as to what the aging body is capable of achieving are evolving. In a number of sports, record times across older age categories have been falling annually, as aging athletes adopt more efficient techniques and maintain cross-training regimens designed to promote speed, power, strength, flexibility and endurance (Jokl et al. 2004; "Swimmers enjoy long course nationals California style" 2005). In age categories ≥40 years, the 2005 one-hour swim record performances have improved since 1995 by, on average, 7.1% in men (ten age category records) and 8.3% in women (seven records) (Personal communication, Marcia Cleveland, USMS Long Distance Chair). At the 2005 USMS National Long Course Championship meet, swimmers aged ≥40 years constituted 68.6% of competitors (gender P=not significant) and set 84% of the newly established meet records (48 of 57 records) (personal communication, Barry Fasbender, USMS Championship Committee Chair).

The strength of the present study lies in the large sample size and the numbers of women and older participants. Its limitation resides in its cross-sectional design, which is sensitive to bias, especially selection bias. Indeed, USMS subjects may be healthier and more active than the general population, and this bias may have been particularly important among the oldest age groups. Therefore, even if our results are consistent with those in previous reports, they may not be generalizable to the entire population. Registration in USMS and participation in the annual USMS one-hour championship appear to be greatly affected by age and gender. Our cross-sectional data do provide information about decline in physical performance with aging. We have described the relationship between age and distance swimming performance throughout adulthood and documented a greater difference in performance for a 1-year increment in age in the older men and women, with a similar pattern of decline similar in men and women. However, while mean performance in the one hour swim declined by about 50% in both men and women between the youngest and the oldest decades examined, participation in numbers declined by a much greater extent, so that only about 4% of the peak number (40–49 year age group) of both men and women were still participating in the oldest decade examined. This decline was greater than the comparable declines in the general population, to 14.1% in men and 28.4% in women of the numbers observed at the peak decade (30–39 year old age group). It is anticipated that future longitudinal research on this cohort will add much to the understanding of age-related declines in both participation and performance. A shortcoming of our studies is the lack of health data on participants.

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