Invited Paper

MASTERS ATHLETES: AN ANALYSIS OF RUNNING, SWIMMING AND CYCLING PERFORMANCE BY AGE AND GENDER

Lynda B. Ransdell[1], Jamie Vener[2], Jennifer Huberty[3]

[1]*Department of Kinesiology, Boise State University, Boise, Idaho, USA*
[2]*Department of Physical Education, Health and Leadership, Southern Oregon University, Ashland, Oregon, USA*
[3]*Physical Activity in Health Promotion, University of Nebraska at Omaha, Omaha, Nebraska, USA*

Given the growth in sport participation by masters athletes, the purposes of this paper are to: (1) describe record-level performances of masters athletes in running, swimming and cycling; (2) delineate the age- and gender-related performance decline that occurs in masters athletes in these sports; (3) explain how physiological, sociological and psychological factors affect masters level performance; and (4) provide some tips for continued healthy participation of the masters athlete. World and USA records (criterion and age-group) were plotted by age and gender for masters competitors in running, swimming and cycling. Percent difference was calculated for age-related performance [(age group record – criterion record/criterion record) × 100] and for gender [(women's record – men's record/men's record) × 100]. The smallest performance differences existed between world record performances and records for the youngest masters level competitors (e.g. 35–49 years old). The largest performance differences existed between world record performances and the oldest masters level competitors (e.g. ≥ 80 years old). The slope in declining performances increased notably after the age of 55 years, and women's performances tended to decline faster than those of men, especially in running. In the ≥ 80 years old group, performance declined at a rate that approached or exceeded 100%. Gender differences in middle-distance swimming performance were small compared to gender differences in running and cycling. Although younger athletes still have the advantage with regard to overall performance, masters athletes can continue to compete effectively in a variety of events until late in life. [*J Exerc Sci Fit* • Vol 7 • No 2 (Suppl) • S61–S73 • 2009]

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Introduction

The number of aging individuals is increasing worldwide at a staggering rate. When studying optimal aging, older athletes (also known as masters athletes) should be considered as one example of "ideal" subjects. Compared to the average sedentary aging person, masters athletes spend more time training, have better health indicators, and records from masters athletes provide cross-sectional data for analysis (Rittwager et al. 2009). Dionigi (2006) suggested that older people who compete in sport are "resisting the dominant negative stereotypes associated with aging and feeling empowered to live a fulfilled and healthy life". By competing in sport, masters athletes present an image that is powerful, vital and active compared to passive, disabled and dependent (Dionigi 2006).

Sport participation for masters level competitions has increased concurrent with the increase in our aging population. The World Masters Games, a venue for world class competition for seniors, started in 1975 in Toronto, Canada (World Masters Athletics 2009). From

Corresponding Author
Lynda B. Ransdell, Department of Kinesiology,
Boise State University, 1910 University Drive,
Boise, ID 83725-1710, USA.
Tel: (1) 208-426-1798
Fax: (1) 208-426-1894
E-mail: LyndaRansdell@boisestate.edu

1977 to 1991, the games experienced steady growth from approximately 2750 competitors to a peak of 12,000 in 1993. The number of competitors declined from 1995 to 1999 and dipped significantly in 2003 (due to the SARS scare), but the numbers rebounded to 9000 competitors in 2007. While the number of competitors for worldwide competitions has fluctuated, participation at the local and national levels has risen. In 1987, the first annual U.S. Senior Games in St. Louis, Missouri, hosted 2500 athletes; by 2007, at an event held in Louisville, Kentucky, those numbers had swelled to 12,100 (National Senior Games Association 2009).

Masters athletes are typically 35–40 years of age or older—although this age cutoff varies significantly by sport. Sport governing bodies determine the age of masters athletes, with the goal of providing events for athletes who exceed the age requisite for success in open, elite, or any other age-level competition. The age of the typical masters athlete exceeds the age range in which world records are typically established. For example, for a sport such as swimming, masters age group classifications begin at 20 years of age because world records are typically established by very young competitors. In contrast, masters classification starts at age 55 for the sports of curling and sailing. Of the 39 Olympic sports, 28 hold age-graded competitions.

Given the tremendous growth in sport participation by masters athletes, and the interest that individuals have in healthy sport participation with advancing age, the purposes of this paper are to: (1) describe world-record performances of masters athletes in running and swimming, and USA record performances of masters athletes in cycling; (2) delineate the typical age- and gender-related performance decline that occurs in masters athletes in these sports; (3) explain how physiological, sociological and psychological factors might affect masters level performance; and (4) provide some tips for the continued healthy participation of the masters athlete. It is our hope that, through this research, we will spur future interest in understanding the life circumstances that surround and encourage sport participation among these active and accomplished individuals.

Methods: Analyses of Performances

To examine age-related performances in running and swimming, world records were analyzed starting with the world record and continuing through the age groups beginning at the age of 35 years and increasing in 5-year increments until at least 50 years (with some comparisons occurring until the age of 90 years if data were available). For example, within masters running and swimming records, data are available up to the age of 90 years for most events for men and women. In comparison, data for masters track cycling are only available up to the age of 50 years, probably because fewer individuals have competed in those events.

Masters athlete world-record performances in running were examined for outdoor venues at sprint distances (100 m and 200 m), middle distances (400–1500 m) and longer distances (5000 m–marathon). Records were obtained on July 9, 2009 from http://www.mastersathletics.net/World-Masters-Athletics-Records-Women.78.0.html and http://www.mastersathletics.net/Records-Masters-Athletics-Masters-Trac.3.0.html. Outdoor records were used rather than indoor records because there are typically more outdoor events than indoor events, and outdoor events include longer distances such as the marathon (World Masters Athletics 2009).

To examine swimming performance, masters world record times for short course (25 m pools) freestyle stroke were examined for distances including 100 m, 200 m, 400 m, 800 m, and 1500 m. Swimming records were obtained on July 9, 2009 from http://www.fina.org/project/. Short course (25 m) swimming records were used rather than long course records (50 m) because they are typically faster, due to the swimmers' ability to push off the wall and glide more frequently (Thompson Swimming 2009). In addition, FINA World Swimming Championships are held in 25 m pools every 2 years (Wikipedia 2009). Freestyle stroke was used because it is representative of the swimming strokes and competitions are held for distances from 50 m to 1500 m (Wikipedia 2009).

To examine cycling performance, U.S. cycling records for masters athletes were examined for track cycling (flying start) for 200 m and 500 m distances and for road time-trialing (40 km). Cycling records were obtained on July 9, 2009 from http://www.usacycling.org/forms/records.pdf. Track racing events were selected for analysis because it is assumed that track cycling is less affected by aerodynamics and course differences (e.g. elevation, heat, terrain, weather) compared to other types of cycling events. Time trialing for 40 km was used because that event typically attracts large numbers of participants and it is representative of a long-distance cycling event.

Each age group record was compared with the corresponding world or USA record time, also known as the criterion record. The criterion record typically came from the open or elite divisions of competition. Tables 1–7 depict performance differences by age and gender.

Percent difference for the comparison of the criterion or world record to the age-group record was calculated using the following formula:

Percent difference for age-group record *vs.* criterion record
= [(age group record − criterion record/criterion record) × 100]

Percent difference for the comparison of male and female record-setting performances in the same age categories was calculated using the following formula:

Percent gender difference
= [(women's record − men's record/men's record) × 100]

In cases where times had to be converted to a proportion of an hour or minute, the appropriate conversion was conducted prior to the calculation of the percentage difference. For example, the world record for the women's 800 m freestyle was 8:04.53 and the record for masters women 35–39 years of age was 9:12.97. To facilitate a comparison of the criterion record to the record for 35–39 year olds, it was first necessary to convert the seconds to a proportion of a minute. Therefore, 8:04.53 was converted to 8.08 (e.g. 4.53 was rounded up to 5 seconds and the conversion was 5/60 seconds or 0.08, resulting in a proportional time of 8.08). The 35–39-year-old age group record for that same event was 9:12.97. Seconds (12.97 rounded up to 13) were converted to a proportion of a minute (i.e. 13/60 = 0.22) so the comparative value was 9.22.

To estimate percentage difference between the criterion record and the record for 35–39 year olds, 8.08 (world record) was subtracted from 9.22 (world record for 35–39 year olds), and this value (1.14) was divided by the criterion value (8.08). The value of 0.141 was then multiplied by 100 to obtain the percentage difference between the values (e.g. 14.1%).

Results

Running

Table 1 presents masters athlete running records for the 100 m and 200 m events of athletes between the ages of 35 and 90 years. For the 100 m sprint, between the ages of 35 and 45 years, performance declined from 2% to 9%. At age 50 years, performance declined 12.5% for men and 19% for women. By the age of 90 years, performance declined 79% for men and 121% for women. After age 50, women's performances declined at a much faster rate than men's. Overall gender differences in 100 m performance were only 13–28% in the oldest age group (80–90 years). In the 200 m sprint, performance declined 3–13% between the ages of 35

Table 1. World records, percent differences between world records and age group records, and percent differences between sexes for each age group for sprint running events (100 m and 200 m) in masters athletes 35–90 years of age*

	Age group (yr)											
	35	40	45	50	55	60	65	70	75	80	85	90
100 m — world records (sec): 9.78 (men); 10.5 (women)												
Men's records (sec)	9.97	10.3	10.7	11.0	11.4	11.7	12.0	12.7	13.6	14.4	16.1	17.5
Women's records (sec)	10.7	11.0	11.3	12.5	13.3	13.9	14.1	15.2	15.9	18.4	21.0	23.2
Age difference (%)												
Men	1.9	5.3	9.4	12.5	16.6	19.6	22.7	29.9	39.1	47.2	64.6	78.9
Women	1.9	4.8	7.6	19.0	26.7	32.4	34.3	44.8	51.4	75.2	100.0	121.0
Gender difference (%)	7.3	7.8	5.6	13.6	16.7	18.8	13.7	18.8	16.9	27.8	22.2	13.1
200 m — world records (sec): 19.3 (men); 21.3 (women)												
Men's records (sec)	20.1	20.6	21.8	22.5	23.4	24.0	24.7	26.7	28.0	30.8	34.2	38.6
Women's records (sec)	21.9	22.7	23.8	25.7	27.3	28.5	29.4	31.5	34.4	40.0	48.4	82.3
Age difference (%)												
Men	4.1	6.7	13.0	16.6	21.2	24.4	28.0	38.3	45.1	60.1	77.2	100
Women	2.8	6.6	11.7	17.4	28.2	33.8	38.0	47.9	61.5	87.8	127.2	286.4
Gender difference (%)	8.9	10.2	9.2	14.2	16.7	18.8	16.7	18.0	22.9	32.0	33.6	113.2

*Data obtained from http://www.mastersathletics.net/World-Masters-Athletics-Records-Women.78.0.html (women) and http://www.mastersathletics.net/Records-Masters-Athletics-Masters-Trac.3.0.html

Table 2. World records, percent differences between world records and age group records, and percent differences between sexes for each age group for middle-distance running events (400 m, 800 m and 1500 m) in masters athletes 35–90 years of age*

	Age group (yr)											
	35	40	45	50	55	60	65	70	75	80	85	90
400 m — world records (sec): 43.2 (men); 47.6 (women)												
Men's records (sec)	45.8	47.8	49.9	51.4	52.2	53.9	56.4	60.8	65.5	72.9	84.2	98.7
Women's records (sec)	50.3	53.1	56.2	58.5	62.4	66.7	68.2	78.3	87.7	100.5	134.0	182.1
Age difference (%)												
Men	6.0	10.6	15.5	19.0	20.8	24.8	30.6	40.7	51.2	68.8	94.9	128.5
Women	5.7	11.6	18.1	22.9	31.1	40.1	43.3	64.5	84.2	110.1	181.5	282.6
Gender difference (%)	10.5	12.3	12.0	12.3	19.5	23.7	20.9	26.3	34.3	41.6	59.1	89.5
800 m — world records (min): 1.68 (men); 1.88 (women)												
Men's records (min)	1.72	1.83	1.90	1.97	2.06	2.18	2.24	2.34	2.55	2.82	3.40	4.47
Women's records (min)	1.94	1.98	2.04	2.27	2.36	2.61	2.68	2.99	3.48	3.75	5.01	6.98
Age difference (%)												
Men	2.4	8.9	13.1	17.3	22.6	29.8	33.3	39.3	51.8	67.9	102.4	166.1
Women	3.2	5.3	8.5	20.7	25.5	38.8	42.6	59.0	85.1	99.5	166.5	271.3
Gender difference (%)	12.8	8.2	7.4	15.2	14.6	19.7	19.6	27.8	33.0	30.2	47.4	56.2
1500 m — world records (min): 3.43 (men); 3.85 (women)												
Men's records (min)	3.57	3.73	3.82	4.08	4.22	4.47	4.67	4.97	5.33	5.92	6.65	8.67
Women's records (min)	3.97	3.99	4.10	4.68	4.95	5.30	5.73	6.20	6.68	7.53	10.20	
Age difference (%)												
Men	4.1	8.7	11.4	19.0	23.0	30.3	36.2	44.9	55.4	72.6	93.9	152.8
Women	3.1	3.6	6.5	21.6	28.6	37.7	48.8	61.0	73.5	95.6	164.9	
Gender difference (%)	11.2	7.0	3.6	14.7	17.3	18.6	22.7	24.7	24.4	25.9	50.4	

*Data obtained from http://www.mastersathletics.net/World-Masters-Athletics-Records-Women.78.0.html (women) and http://www.mastersathletics.net/Records-Masters-Athletics-Masters-Trac.3.0.html

and 45 years. Similar to the 100 m sprint results, at the age of 55 years, women's performances declined at a faster rate than men's. By the age of 90 years, performance declined 100% for men and 286% for women. Compared to gender differences in the 100 m event for the oldest age groups (≥75 years), differences in the 200 m event were much larger (e.g. 9–113%).

Table 2 presents masters athlete running records for the 400 m, 800 m and 1500 m (middle distance) events between the ages of 35 and 90 years. For the 400 m run, between the ages of 35 and 45 years, performance declined 6–18%. By the age of 90 years, performance had declined 129% for men and 283% for women. Overall gender differences in 400 m performance were smallest between the ages of 35 and 50 years (11–12%), and they increased drastically in the oldest age group (42–90% for the 80–90-year-old group). In the 800 m run, performance declined 2–13% between the ages of 35 and 45 years. By the age of 90 years, performance had declined 166% for men and 271% for women. Gender differences in the 800 m event ranged from 7% to 56%; the largest gender differences occurred in the oldest age groups (≥75 years). When 1500 m performances were examined, there was a decline of 3–11% between the ages of 35 and 45 years. By 85 years, the last age group for which records are listed for women, performance had declined by 94% for men and 165% for women. Gender differences in the 1500 m event ranged from 4% to 50%, with the largest difference occurring in the ≥85-year-old group and the smallest difference occurring in the 45–49-year-old group. Similar to what occurred in the sprint events (i.e. 100 m and 200 m), at the age of 55 years, women's performances in middle-distance running events declined at a faster rate than men's performances.

Table 3 presents masters athlete running records for the 5000 m, 10,000 m, and marathon (long distance) for athletes between the ages of 35 and 90 years. For the 5000 m run, performance declined in the youngest age group (35–45 years) by 1–14%. By the age of 85 years, performance had declined by 98% for men and 157% for women. Overall gender differences in 5000 m performance were smallest between ages 35 and

Table 3. World records, percent differences between world records and age group records, and percent differences between sexes for each age group for long-distance running events (5000 m, 10,000 m and marathon) in masters athletes 35–90 years of age*

	Age group (yr)											
	35	40	45	50	55	60	65	70	75	80	85	90
5000 m — world records (min): 12.60 (men); 14.42 (women)												
Men's records (min)	13.02	13.72	14.40	14.88	15.62	16.22	16.65	18.55	19.12	21.78	24.87	31.43
Women's records (min)	14.57	15.35	15.93	17.17	17.97	18.98	20.45	22.87	23.90	26.93	37.03	
Age difference (%)												
Men	4.0	8.7	14.3	18.3	23.8	28.6	32.5	47.6	51.6	74.6	97.6	149.2
Women	1.2	6.6	10.6	19.2	24.8	31.8	42.0	58.8	66.0	87.0	157.2	
Gender difference (%)	11.5	12.4	10.4	16.1	15.4	19.1	22.8	23.1	28.8	22.3	49.0	
10,000 m — world records (min): 26.4 (men); 29.5 (women)												
Men's records (min)	26.85	28.52	30.05	30.93	32.47	34.25	34.70	38.07	39.42	44.48	52.85	62.37
Women's records (min)	30.50	31.52	32.57	35.62	37.37	39.35	42.12	47.38	50.02	58.42	86.93	
Age difference (%)												
Men	1.7	8.0	14.0	17.0	23.1	29.9	31.4	44.3	49.2	68.6	100.4	136.3
Women	3.4	6.8	10.4	20.7	26.7	33.4	42.8	60.6	69.6	98.0	194.7	
Gender difference (%)	13.9	13.0	8.3	18.4	15.1	14.9	21.3	24.4	26.9	31.2	64.3	
Marathon — world records (hr): 2.08 (men); 2.25 (women)												
Men's records (hr)	2.12	2.15	2.27	2.33	2.43	2.62	2.70	2.92	3.08	3.65	4.58	5.67
Women's records (hr)	2.35	2.45	2.48	2.60	2.87	3.20	3.47	3.77	4.15	4.53	6.90	8.88
Age difference (%)												
Men	1.9	3.4	9.1	12.0	16.8	26.0	29.8	40.4	48.1	75.5	120.2	172.6
Women	4.4	8.9	10.2	15.6	27.6	42.2	54.2	67.6	84.4	101.3	206.7	294.7
Gender difference (%)	10.8	14.0	9.3	21.0	18.1	24.0	28.5	29.1	35.4	32.3	50.7	56.6

*Data obtained from http://www.mastersathletics.net/World-Masters-Athletics-Records-Women.78.0.html (women) and http://www.mastersathletics.net/Records-Masters-Athletics-Masters-Trac.3.0.html

45 years (10–12%), and increased gradually (15–29%) until the oldest age group (49% at 85 years). In the 10,000 m run, compared to world record time, times of 35–45 year olds declined 2–14%. By the age of 85 years, performance had declined by 100% for men and 195% for women. Gender differences in the 10,000 m event ranged from 8% to 64%, with the largest gender difference (64%) occurring in the oldest age group (≥85 years). Marathon performance declined 2–10% between the ages of 35 and 45 years when compared to world record performances. By 90 years, performance had declined by 172% for men and 294% for women. Gender differences in the marathon event ranged from 9% to 57%, with the smallest gender difference in the 45–49-year-old group (9%) and the largest difference in the 90-year-old group (57%). Similar to what occurred in the sprint and middle-distance running events (i.e. 100–1500 m), starting at the age of 55 years, women's performances in long-distance running events declined at a faster rate than men's performances.

Swimming

Table 4 depicts masters athlete (35–90 years old) swimming records for sprint events (100 m and 200 m). For the 100 m sprint, performance in the youngest masters age categories (35–45 years) declined at a rate of 6–17%. At the age of 90 years, the decline had increased to 121% for men and 148% for women. In the 200 m sprint, performance declined by 9–14% between the ages of 35 and 45 years; in the oldest age group (≥90 years), performance had declined by 119% for men and 136% for women. Gender differences in sprint swimming performance ranged from 11% to 35% in the 100 m distance and from 9% to 21% in the 200 m distance.

Table 5 delineates masters swimming records for middle-distance events (400 m, 800 m, 1500 m). Declining performances between the ages of 35 and 45 years were fairly consistent among the middle-distance swim events. Between the ages of 35 and 45 years, performance declined 9–14% in the 400 m swim, 13–18% in the 800 m swim, and 12–16% in the 1500 m swim.

Table 4. World records, percent differences between world records and age group records, and percent differences between sexes for each age group for sprint freestyle swimming events (100 m and 200 m, short course) in masters athletes 35–90 years of age*

	Age group (yr)											
	35	40	45	50	55	60	65	70	75	80	85	90
100 m — world records (sec): 44.9 (men); 51.7 (women)												
Men's records (sec)	49.5	50.4	52.5	54.6	54.5	56.6	59.6	63.3	65.1	76.1	79.4	99.3
Women's records (sec)	55.0	57.6	58.6	61.5	61.4	70.0	71.0	73.7	78.6	86.2	107.0	128.0
Age difference (%)												
Men	10.2	12.2	16.9	21.6	21.4	26.1	32.7	41.0	45.0	69.5	76.8	121.2
Women	6.4	11.4	13.3	19.0	18.8	35.4	37.3	42.6	52.0	66.7	107.0	147.6
Gender difference (%)	11.1	14.3	11.6	12.6	12.7	23.7	19.1	16.4	20.7	13.3	34.8	28.9
200 m — world records (min): 1.68 (men); 1.87 (women)												
Men's records (min)	1.87	1.83	1.92	1.97	2.06	2.17	2.27	2.42	2.47	2.98	3.22	3.67
Women's records (min)	2.07	2.08	2.10	2.25	2.25	2.63	2.70	2.75	2.95	3.32	3.90	4.42
Age difference (%)												
Men	11.3	8.9	14.3	17.3	22.6	29.2	35.1	44.0	47.0	77.4	91.7	118.5
Women	10.7	11.2	12.3	20.3	20.3	40.6	44.4	47.0	57.8	77.5	108.6	136.4
Gender difference (%)	10.7	13.7	9.3	14.2	9.2	21.2	18.9	13.6	19.4	11.4	21.1	20.4

*Data for men and women masters swimmers obtained from http://www.fina.org/project/ (via masters and world record links from 5/2009).

Table 5. World records, percent differences between world records and age group records, and percent differences between sexes for each age group for middle-distance swimming events (400 m, 800 m and 1500 m) in masters athletes 35–90 years of age*

	Age group (yr)											
	35	40	45	50	55	60	65	70	75	80	85	90
400 m — world records (min): 3.58 (men); 3.93 (women)												
Men's records (min)	3.97	4.02	4.10	4.13	4.42	4.68	4.93	5.17	5.25	6.33	7.30	8.85
Women's records (min)	4.38	4.37	4.48	4.73	4.78	5.47	5.60	5.85	6.17	7.35	7.98	9.03
Age difference (%)												
Men	10.9	12.3	14.5	15.4	23.5	30.7	37.7	44.4	46.6	76.8	104.0	147.2
Women	11.5	11.2	14.0	20.4	21.6	28.2	42.5	48.9	57.0	87.0	103.1	129.8
Gender difference (%)	10.3	8.7	9.3	14.5	8.1	16.9	13.6	13.2	17.5	16.1	9.3	2.0
800 m — world records (min): 7.40 (men); 8.08 (women)												
Men's records (min)	8.38	8.53	8.72	8.75	9.05	9.73	10.30	10.90	11.00	12.90	14.10	18.60
Women's records (min)	9.22	9.17	9.33	9.85	9.92	11.30	11.40	12.60	12.70	15.20	16.80	18.70
Age difference (%)												
Men	13.2	15.3	17.8	18.2	22.3	31.5	39.2	37.8	48.6	74.3	90.5	151.4
Women	14.1	13.5	15.5	21.9	22.8	39.9	41.1	55.9	55.9	88.1	107.9	131.4
Gender difference (%)	10.0	7.5	7.0	12.6	9.6	16.1	10.7	15.6	15.5	17.8	19.1	0.5
1500 m — world records (min): 14.2 (men); 15.6 (women)												
Men's records (min)	16.0	16.2	16.5	16.6	17.2	18.9	19.6	20.9	20.7	25.6	28.3	35.3
Women's records (min)	17.5	17.6	17.8	18.9	18.9	21.5	21.7	23.9	24.1	28.9	31.8	35.7
Age difference (%)												
Men	12.7	14.1	16.2	16.9	21.1	33.1	31.0	47.2	45.8	80.3	99.3	148.6
Women	12.2	12.8	14.1	21.2	21.2	37.8	39.1	53.2	54.5	85.3	103.8	128.8
Gender difference (%)	9.4	8.6	7.9	13.9	9.9	13.8	10.7	14.4	16.4	12.9	12.4	1.1

*Data for men and women masters swimmers obtained from http://www.fina.org/project/ (via masters and world record links from 5/2009).

In the swimming events, gender differences were not as pronounced as they were in the running events. For example, gender differences in running events at the age of 90 years in the 200 m, 400 m and 800 m were 113%, 90% and 56%, respectively. In swimming, gender differences in events of comparable distance of 200 m, 400 m and 800 m were only 20%, 2% and 0.5%, respectively. Interestingly, middle-distance swimming is one event where women's performances did not decline as much as men's performances in the ≥ 90-year-old age category. Specifically, in the 400 m swim, women ≥ 90 years old demonstrated a 130% decline in performance, whereas men's performance declined by 147%. In the 800 m swim, women's performance in the oldest age category declined by 131%, whereas men's performance declined by 151%. Finally, in the 1500 m event, compared to world-record performances of much younger athletes, women in their 90s slowed down by 129% while men slowed by 149%.

Cycling

Table 6 presents masters athlete cycling records for flying start sprint track events (200 m and 500 m). Between the ages of 35 and 45 years, track cycling performance declined by 3–12% for 200 m and 19–36% for 500 m. Gender differences ranged from 8% to 22% across the age groups, but the oldest comparative age category for which records exist is 55 years in the 200 m and 60 years in the 500 m.

Table 7 presents data from long-distance (40 km) masters athlete time trial cycling events. Between the ages of 35 and 45 years, 40 km time trial performance decreased by 0.5–11%. Gender differences ranged from 10% to 17%. The largest differences existing between

Table 6. USA records, percent differences between world records and age group records, and percent differences between sexes for each age group for sprint track cycling events (200 m and 500 m, flying start) in masters athletes 35–70 years of age*

	Age group (yr)							
	35	40	45	50	55	60	65	70
200 m — track, flying start, USA records (sec): 10.1 (men); 11.1 (women)								
Men's records (sec)	10.6	10.5	11.1	11.1	11.4	11.5	11.9	12.8
Women's records (sec)	11.4	12.2	12.5	13.0	14.0			
Age difference (%)								
Men	5.0	4.0	9.9	9.9	12.9	13.9	17.8	26.7
Women	2.7	9.9	12.6	17.1	26.1			
Gender difference (%)	7.5	16.2	12.6	17.1	22.8			
500 m — track, flying start, USA records (sec): 26.49 (men); 29.66 (women)								
Men's records (sec)	34.90	35.95	34.83	35.51	35.65	37.24	40.10	
Women's records (sec)	35.40	38.25	39.07	39.86	41.56	42.52		
Age difference (%)								
Men	31.7	35.7	31.5	34.1	34.6	40.6	51.4	
Women	19.4	29.0	31.7	34.4	40.1	43.4		
Gender difference (%)	9.6	8.7	14.4	17.0	19.3			

*Data obtained from http://www.usacycling.org/forms/records.pdf

Table 7. USA records, percent differences between USA record and age group records, and percent differences between sexes for each age group for a road cycling time trial distance event (40 km) in masters athletes 35–60 years of age*

	Age group (yr)					
	35	40	45	50	55	60
40 km — road, time trial, USA records (min): 47.58 (men); 51.60 (women)						
Men's records (sec)	47.82	48.43	49.97	50.60	51.95	52.72
Women's records (sec)	51.60	53.03	53.03	57.03	59.02	
Age difference (%)						
Men	0.5	1.8	5.0	6.3	9.2	10.8
Women	2.8	2.8	10.5	14.4		
Gender difference (%)	10.9	9.5	14.1	16.6		

*Data obtained from http://www.usacycling.org/forms/records.pdf male and female competitors were observed in the ≥50 years age category—the oldest age category for which U.S. cycling women's records are kept.

Discussion

The primary purpose of this paper was to examine age and gender differences in world-record performances of masters athletes in running and swimming, and U.S. record performances of masters athletes in cycling. Not surprisingly, in all running, swimming and cycling events covered in this paper, the smallest age-related percentage differences existed between the criterion or world records and the records for the youngest masters level competitors (e.g. the 35–49-year-old age group). The largest age-related percentage differences existed between the criterion records and the records for oldest masters level competitors (e.g. the ≥80 years age group). Interesting findings were that: (a) after the age of 55 years, the decline in athletic performance increases exponentially in both sexes, but this decline is typically more pronounced in women than in men, and it is more pronounced in running events than in swimming or cycling events; (b) near the age of 85 years, performance declines at a rate that approaches or exceeds 100%; (c) gender differences in middle-distance swimming performance are less drastic than in all running events across the age spectrum; (d) in some events, gender differences are smallest for ages 45–49 years (not in the younger age groups); and (e) cycling results should be interpreted with caution due to the lack of available data, especially for competitors >50 years old.

It is not surprising that athletic performance declines with age in both sexes. Spirduso and colleagues (2005) suggested that performance declines approximate 1% per year, a value that parallels the loss in $\dot{V}O_{2max}$ during the same period. Interestingly, women's performances seem to decline at a faster rate than those of men after the age of 55 years. These findings are in agreement with previous researchers who also found that women's performances decline at a faster rate than men's (Spirduso et al. 2005; Tanaka & Seals 2003). It is likely that, compared to men, there are fewer women competing in athletic events—especially in the older age categories. It is also possible that biological and sociological factors affect women's participation in sport as they age. It will be interesting to see if more and more women will compete at higher levels as the "Title IX" generation ages. Compared to previous generations, the generation of women who benefited from Title IX (post 1972) has had more access to coaching, training techniques, nutritional strategies, facilities, and equipment (Priest 2003).

Performance decrements with age were more evident in running events compared to cycling or swimming events. These findings are in agreement with Reaburn and Dascombe (2008) who also suggested that running performance declines faster than swimming performance. It is logical that running performance declines faster than swimming and cycling performance because swimming and cycling events typically require less "pounding" and "wear-and-tear" than running. Thus, it may be possible to continue to compete at a high level in activities that do not require directly carrying one's body weight. There are fewer injuries in swimming than in running or cycling (Spirduso et al. 2005), so it is possible that swim athletes can perform injury-free longer. Age-related increases in percent body fat may be less detrimental to swimmers compared to runners, as it may add a competitive buoyancy advantage for older swimmers (Spirduso et al. 2005). Advances in cycling aerodynamics and technology may provide a competitive advantage for the older cyclist (Neptune et al. 2009).

A second important finding is that the decline in athletic performance exceeded or approached 100% in most events for both men and women after the age of 85 years. Although they did not quantify the percent decline in performance, Ransdell and Wells (1998) also reported a significant decline in the performance of masters women runners after the age of 80 years. Significant changes in performance are to be expected due to several physiological, sociological and psychological changes that occur with aging. A brief summary of these changes is included later in the discussion section of this paper.

A third important finding is that gender differences increase consistently with age in all events except middle-distance swimming. This finding is in agreement with Spirduso and colleagues (2005) who suggested that the energy cost of middle-distance swimming is lower in women than in men because women have shorter legs and a smaller body size (resulting in less drag), lower body density, and a higher percent body fat. It is also true that there are similar numbers of male and female competitors in swimming, whereas there are significantly fewer female than male competitors in running and cycling (Spirduso et al. 2005). Older individuals who have solid stroke mechanics and who can minimize drag can compete at a high level of intensity in swimming (Spirduso et al. 2005). In addition, the increase in percent body fat that typically occurs with age may give swimmers a hydrodynamic advantage compared to runners and cyclists who have to carry around the extra body weight.

An interesting and unexpected finding was that gender differences were lowest for competitors in the 45–49 years age group in certain events (e.g. running 100 m, 800 m, 1500 m, 5 km, 10 km, marathon; swimming 200 m, 800 m, 1500 m; and track cycling 500 m). This finding has not been previously reported. It is possible that women are gaining more competitive opportunities as they age, or that they are seeking out competition later in life (post childbirth or later in a career). It is also possible that the first generation to benefit from Title IX, women who were ≤ 18 years old in 1972, are now between the ages of 37 and 55 years. In the future, it would be interesting to examine whether there are more competitors in this age group than in younger age categories.

Finally, it is unfortunate that there is so little cycling data from which to comparatively examine age- and gender-related performance. More data are needed to make compelling comparisons between competitors from the older age groups. Of the data that do exist, it was interesting that there was only an 11% decline in men's track cycling performance from the world record to the record of a 60-year-old competitor. This is especially compelling given that the decline in performance for swimmers and runners in this age group ranged between 20% and 44%. It is likely that cycling results in less wear-and-tear on the body and that technological advances continue to result in improved performances in all age groups (Neptune et al. 2009).

Age- and gender-related differences in record-setting performances in running, swimming and cycling result from physiological, sociological and psychological changes that occur. Although there are many physiological factors that affect running, swimming and cycling performance with aging, it is likely that the best predictors of changes in anaerobic (sprint) performance result from speed determinants or neuromuscular characteristics. Physiological factors that best predict changes in aerobic (distance) performance include determinants of maximal aerobic capacity ($\dot{V}O_{2max}$) and lactate threshold. Age-related changes in body composition (i.e. increase in percent body fat and loss of muscle mass), hormonal changes, and fluid balance changes (e.g. a decline in the thirst mechanism) can also affect athletic performance. A discussion of the physiological, sociological and psychological factors that affect age-related differences in performance is presented in the paragraphs that follow.

Speed

Speed, the ability to move from one place to another as quickly as possible, is a major determinant of anaerobic performance. In a variety of sports, speed is likely determined by reaction time, muscle size and strength, type II muscle fiber area (i.e. fast twitch muscle fibers), and the maximal and rapid force generating capacity of various important or involved muscles (Korhonen et al. 2009). Related to the aforementioned muscle characteristics, the most likely determinants of speed are stride/stroke/pedal frequency, stride/stroke length, and, for running, ground contact time. The ability to generate power is also a significant predictor of speed (Neptune et al. 2009; Hawley et al. 1992).

Korhonen et al. (2009) compared factors related to running speed in younger and older Finnish male athletes ($n = 77$). They reported that the age-related decline in sprint speed was related to a 4% per decade decline in stride length and an increase in ground contact time (caused by an age-related decrease in push off). Changes in stride frequency with aging were minor. To our knowledge, changes in swim stroke and/or pedal frequency (also known as cadence) that occur with age, and how those changes relate to changes in performance, have not been frequently studied.

Muscle characteristics

Between the ages of 20 and 80 years, muscle area decreases 40% (Lemmer et al. 2003). Muscle tissue analysis shows that both slow and fast twitch fibers decline with age, although the loss of fast twitch fibers is greater (Korhonen et al. 2009); this is probably due to atrophy as opposed to loss of inherent force production of the myofibrils (Lemmer et al. 2003). In addition, the pumping of calcium ions through the sarcoplasmic reticulum slows with age. Combined, these factors result in lower force production (decreased power) and less efficient agonist-antagonist muscle group coordination. Because muscle cross-section is related to overall muscular force production (i.e. larger muscles are typically stronger), it makes sense that strength declines with age in conjunction with smaller muscle size. With aging, women tend to lose muscle more rapidly than men (Spirduso et al. 2005). This may help explain the faster performance decline observed in women around the age of 55 years.

The age-related decline in muscle mass may also be related to decreased levels of estrogen, growth hormone (GH), insulin-like growth factor (IGF-I) and respective binding proteins for IGF with aging (Waters et al. 2003). It has been shown that postmenopausal women on estrogen replacement therapy may have increased lean body mass and decreased IGF-I when compared with controls (Waters et al. 2003). These hormonal changes may be related to increased GH levels (Waters et al. 2003). Growth hormone is a powerful hypertrophic agent that facilitates increased muscle mass. Estrogen replacement therapy may stimulate GH release, which in turn stimulates protein synthesis and promotes muscle mass maintenance. On the other hand, menopause-related decreases in estrogen may have the opposite effect, resulting in decreased muscle mass, strength, and performance with age.

The "estrogen effect" in women

Just as testosterone declines in aging men (and may be related to a host of negative effects on athletic performance), estrogen may play a role in declining athletic performance in women. As was discussed in the previous section, estrogen may stimulate GH, which may prevent loss of muscle mass and facilitate the maintenance of athletic performance—especially in events requiring fast, strong muscular action. In addition, estrogen may have a host of effects on endurance performance. First, human and animal studies have shown that glycogen uptake and storage in liver and muscle is facilitated by estrogen (Hackney et al. 2000; Hackney 1999; Ramamani et al. 1999). GH, which enhances the use of free fatty acids (*vs.* glycogen) as fuel, may be enhanced in the presence of estrogen (Veldhuis et al. 2004). If it is true that the presence of estrogen enhances glycogen uptake and storage and enhances GH, then athletic performances that require glycogen and/or GH (which facilitates glycogen sparing) should be enhanced in women when estrogen is present.

Other positive effects of estrogen that might provide some performance benefits are that ventilatory response (Haggerty et al. 2004; de Jonge 2003) and water retention (Stachenfeld & Keefe 2002) are enhanced in the presence of estrogen. This would enable women to have better oxygen exchange during aerobic exercise and it would enable them to preserve water during long-distance events. It may also enhance cardiac output by adding to blood volume. Each of these effects should enhance long-distance performance (Charkoudian & Joyner 2004; Fortney et al. 1981). However, a potential downside to water retention (in extravascular spaces) is increased body weight, which could negatively impact running performance.

A final positive effect of estrogen is that it lessens free radical damage that sometimes occurs with exercise (Persky et al. 2000; Tiidus 1995). Free radicals are molecules with an unpaired electron. They are highly reactive in that they will attempt to steal an electron from other sources, which can cause cell damage in the process. A common site for free radical production is the electron transport chain where electron and proton transport are coupled with aerobic ATP production. When electron transport activity is increased, as with endurance exercise, free radical (reactive oxygen species) production and oxidative stress are increased. Exposure to ultraviolet radiation (sunlight) and smog during outdoor training sessions also increase free radical production (Dillard et al. 1978). Fortunately, in response to this phenomenon, endurance athletes increase the capacity to neutralize or "quench" free radicals through the activity of specific endogenous enzymes (i.e. superoxide dismutase, catalase, glutathione peroxidase) that protect them from increased free radical production associated with endurance exercise (Mena et al. 1991; Jenkins et al. 1984). It is intriguing that in women, estrogen may provide some anti-aging and ergogenic properties.

$\dot{V}O_{2max}$ and body composition

$\dot{V}O_{2max}$ is defined as the maximal amount of oxygen that can be delivered to working muscles during exercise. It can be measured in a laboratory or using any number of field tests that have been developed. Wiswell and colleagues (2000) proposed that $\dot{V}O_{2max}$ is the most significant predictor of performance in masters level runners. Hawkins et al. (2001) proposed a rate of decline in $\dot{V}O_{2max}$ of 0.5% per year from age 40 to 59 years, and 2.4% per year beyond the age of 60. This decline in $\dot{V}O_{2max}$ is due to a combination of factors—primarily changes in body composition and cardiovascular function. Regardless of age, changes in body composition, including an increase in percent body fat and a decrease in lean body mass, can contribute to a lower $\dot{V}O_{2max}$ (Korhonen et al. 2009; Plowman et al. 1979). Cardiovascular factors that explain this decline in $\dot{V}O_{2max}$ (and performance) may be related to decrements in oxygen delivery to the working muscle. Reduced delivery (cardiac output) is largely a function of decreased cardiac contractility and a lower maximal heart rate associated with aging (Reaburn & Dascombe 2008; Hawkins et al. 2001). Athletes between the ages of 40 and 49 years may lose 0.5 beats per year from their maximum heart rate, and from the ages of 50 and 70 years, they may lose 1 to 1.6 beats per year (Hawkins et al. 2001). The combined reductions in maximal heart rate and contractility result in a decreased maximal cardiac output and concomitant reduction in $\dot{V}O_{2max}$ (Hawkins et al. 2001). Although it is not likely that competitive masters athletes can avoid this age-related decline in maximal heart rate, it does appear that continued training can attenuate the decline.

Several studies have reported that male masters athletes who maintained a consistent training regimen over ≥20-year follow-up periods had approximately half the decline in maximal heart rate seen in non-athletes (Pollock et al. 1997; Trappe et al. 1996; Kasch et al. 1995). In one of the few studies with masters women runners, Wells et al. (1992), using a cross-sectional design, reported that regular physical training (mean, $42\,\text{km} \cdot \text{week}^{-1}$) appeared to prevent age-related changes in maximal heart rate. Considering longitudinal research with men and cross-sectional research with women, it appears that reductions in *volume* and *intensity* of training are critical factors that contribute to a decline in maximal heart rate, $\dot{V}O_{2max}$, and ultimately performance (Young et al. 2008; Hawkins & Wiswell 2003; Hawkins et al. 2001; Wiswell et al. 2000).

Lactate threshold

In addition to $\dot{V}O_{2max}$, lactate threshold (the exercise intensity at which blood lactate rises significantly above baseline) is an important predictor of endurance performance. In other words, high-performance athletes are able to maintain a faster pace at lactate threshold. Surprisingly, performance decrements associated with reduced $\dot{V}O_{2max}$ may be offset by an increase in lactate threshold in masters athletes. Evidence suggests that compared to younger athletes, the blood lactate threshold of masters athletes—especially those competing in endurance events—occurs at a higher percentage of their $\dot{V}O_{2max}$ (Allen et al. 1985). This has been attributed to peripheral adaptations at the skeletal muscle level. Coggan et al. (1990) reported increased oxidative enzyme activity (succinate dehydrogenase and β-hydroxyacetyl-CoA dehydrogenase) and decreased lactate dehydrogenase enzyme activity in elite masters runners compared with young runners matched for performance. These adaptations imply decreased lactate production and increased reliance on fatty acid oxidation in masters endurance athletes and may explain (in part) the increased lactate threshold relative to $\dot{V}O_{2max}$ (Coggan et al. 1990).

Decline in thirst mechanism

A final factor that potentially contributes to the decline in athletic performance in masters athletes is that with age, water output by the kidneys is greater and individuals become less sensitive to their thirst mechanism—especially in warm environments (Luckey & Parsa 2003; Ainslie et al. 2002; Kenney & Chiu 2001). Older individuals typically have higher baseline osmolality and lower response to loading and unloading baroreceptors; thus, their thirst mechanism is less sensitive. If older individuals are less sensitive to the thirst mechanism, they may be at increased risk of dehydration, impaired performance, and heat injury (Morgan et al. 2002; Sawka et al. 1984; Fortney et al. 1981).

Psychological effects of aging

Just as physiological factors can significantly affect the performance of athletes, so can psychological factors. Because older athletes "just can't do what they used to do", some become depressed (Gallo et al. 2003; Karim & Burns 2003). In addition, many older athletes do not have the same intrinsic drive to train that they had when they were younger (Korhonen et al. 2009; Reaburn & Dascombe 2008; Spirduso et al. 2005). Reaburn & Dascombe (2008) reported gender-based differences in motivation with aging. Initially, men were more motivated by achievement and women were more motivated by health, social interaction, and enjoyment; over time, both men and women ranked social interaction as the most important motivator for participation in masters athletic events.

As a result of this change in intrinsic drive to train hard, many masters athletes change their training habits. Some cross train because they do not recover as quickly; others spend fewer hours training because they have new or additional life or career responsibilities; still others spend less time on speed and strength training and more time on cross-training (Korhonen et al. 2009; Reaburn & Dascombe 2008; Spirduso et al. 2005; Okonek 1996).

Recommendations for continued training

Despite the fact that performance declines with increasing age, individuals who train and compete in running, swimming, and cycling events are typically healthier than similarly-aged sedentary individuals. So the key question becomes, "How can you maintain a level of training that will enable you to perform at a high level as a masters competitor?" This next section will provide information that will enable masters athletes to continue training for a prolonged period of time.

First, masters athletes should accept that aging will cause some changes in the body and its ability to perform. Most masters women athletes will not be able to perform at the same level they did when they were younger. To deal with this concept, athletes should set realistic goals for their training and competition based on past performances and the typical performances of other age-group competitors in each event. Second, because masters athletes are often "busier" than high school or college-age athletes, they should focus on *quality* of training rather than *quantity* of training. Third, allowing for adequate recovery after strenuous workouts or competitions is especially important for masters athletes. With age, most athletes need to allow adequate time for recovery before resuming their regular training regimen. If athletes do not "listen to their body" and take adequate rest time, they are at higher risk of injury. When injuries do occur, masters athletes need to take care of them. It is harder to heal from injuries as one ages because tendons, ligaments, cartilage and muscle break down easier and scar tissue forms faster (Nichols et al. 2000; Kallinen & Markku 1995; Shephard & Pacelli 1990). Therefore, gradual increases in volume or intensity of training as well as stretching and rest become very important. Fourth, masters athletes should participate in some weight training to prevent the typical loss of lean body mass and subsequent decline in strength that occurs with aging. Fifth, masters athletes need to watch their diet (Casadesus et al. 2002). Unless they have unusually high metabolism, they probably cannot eat as much as they could when they were younger. Nutritious foods should be chosen such that caloric intake will be balanced with expenditure and nutrient density will be maximized. Lastly, masters athletes should not rely on their thirst mechanism to remind them to drink. Because the thirst mechanism does not function as well as one ages, masters athletes need to drink water throughout the day. Hydration recommendations for athletes depend on the athlete's sweat rate, type of sport, environmental factors, duration and intensity of activity. Fluid replacement during activity should approximate sweat and urine losses (Casa et al. 2000). This generally requires 200–300 mL (7–10 oz) of fluid every 10–20 minutes, especially during distance events lasting longer than 60–90 minutes (Casa et al. 2000). Fluid replacement drinks that contain electrolytes become more important as the length of an event increases.

Conclusion

Improved coaching and training techniques have benefited older athletes just as they have benefited young competitors. As more knowledge is gained concerning the training and recovery of older athletes, it is likely that we will change our thinking about what is normal for the aging of the older athlete compared to the aging process of a sedentary individual. The benefits of physical activity and competition across the life span have yet to be realized for most of the aging population. The effects of regular training on the parameters associated with training (e.g. $\dot{V}O_{2max}$) enable the trained older individual to perform far better than the decades younger, sedentary individual. Although younger athletes still have the advantage with regard to overall record performance, declines in age group records indicate that we have yet to determine the limits to performance among masters athletes.

References

Ainslie PN, Campbell IT, Frayn KN, Humphreys SM, MacLaren DP, Reilly T, Westerterp KR (2002). Energy balance, metabolism, hydration, and performance during strenuous hill walking: the effect of age. *J Appl Physiol* 9:714–23.

Allen WK, Seals DR, Hurley BF, Ehsani AA, Hagberg JM (1985). Lactate threshold and distance-running performance in young and older endurance athletes. *J Appl Physiol* 58:1281–4.

Casa DJ, Armstrong LE, Hillman SK, Montain SJ, Reiff BS, Roberts WO, Stone JA (2000). National Athletic Trainers' Association Position Statement: fluid replacement for athletes. *J Appl Physiol* 35:212–24.

Casadesus G, Shukitt-Hale B, Joseph JA (2002). Qualitative versus quantitative caloric intake: are they equivalent paths to successful aging? *Neurobiol Aging* 23:747–69.

Charkoudian N, Joyner MJ (2004). Physiologic considerations for exercise performance in women. *Clin Chest Med* 25:247–55.

Coggan AR, Spina RJ, Rogers MA, King DS, Brown M, Nemeth PM, Holloszy JO (1990). Histochemical and enzymatic characteristics of skeletal muscle in master athletes. *J Appl Physiol* 68:1896–901.

de Jonge J (2003). Effects of the menstrual cycle on exercise performance. *Sports Med* 33:833–51.

Dillard CJ, Litov RE, Savin WM, Dumelin EE, Tappel AL (1978). Effects of exercise, vitamin E, and ozone on pulmonary function and lipid peroxidation. *J Appl Physiol* 45:927–32.

Dionigi R (2006). Competitive sport as leisure in later life: negotiations, discourse, and aging. *Leis Sci* 28:181–96.

Fortney SM, Nadel ER, Wenger CB, Bove JR (1981). Effect of acute alterations of blood volume on circulatory performance in humans. *J Appl Physiol* 50:292–8.

Gallo JJ, Rebok GW, Tennstedt S, Wadley VG, Horgas A (2003). Linking depressive symptoms and functional disability in late life. *Aging Ment Health* 7:469–80.

Hackney AC (1999). Influence of oestrogen on muscle glycogen utilization during exercise. *Acta Physiol Scand* 167:273–4.

Hackney AC, Muoio D, Meyer WR (2000). The effect of sex steroid hormones on substrate oxidation during prolonged submaximal exercise in women. *Jpn J Physiol* 50:489–94.

Haggerty CL, Ness RB, Kelsey S, Waterer GW (2004). The impact of estrogen and progesterone on asthma. *Ann Allergy Asthma Immunol* 90:284–91.

Hawkins SA, Marcell TJ, Jaque SV, Wiswell RA (2001). A longitudinal assessment of change in $\dot{V}O_{2max}$ and maximal heart rate in master athletes. *Med Sci Sports Exerc* 33:1744–50.

Hawkins SA, Wiswell RA (2003). Rate and mechanism of maximal oxygen consumption decline with aging: implications for exercise training. *Sports Med* 33:877–88.

Hawley JA, Williams MM, Vickovic MM, Handcock PJ (1992). Muscle power predicts freestyle swimming performance. *Br J Sports Med* 26:151–5.

Jenkins RR, Friedland R, Howald H (1984). The relationship of oxygen uptake to superoxide dismutase and catalase activity in human skeletal muscle. *Int J Sports Med* 5:11–4.

Kallinen M, Markku A (1995). Aging, physical activity and sports injuries. An overview of common sports injuries in the elderly. *Sports Med* 20:41–52.

Karim S, Burns A (2003). The biology of psychosis in older people. *J Geriatr Psychiatry Neurol* 16:207–12.

Kasch FW, Boyer JL, VanCamp S, Nettl F, Verity LS, Wallace JP (1995). Cardiovascular changes with age and exercise: a 28 year longitudinal study. *Scand J Med Sci Sports* 5:147–51.

Kenney WL, Chiu P (2001). Influence of age on thirst and fluid intake. *Med Sci Sports Exerc* 33:1524–32.

Korhonen MT, Mero AA, Alén M, Sipilä S, Häkkinen K, Liikavainio T, Viitasalo JT, Haverinen MT, Suominen H (2009). Biomechanical and skeletal muscle determinants of maximal running speed with aging. *Med Sci Sports Exerc* 41:844–56.

Lemmer JT, Hurlbut DE, Martel TBL, Ivey FM, Metter EJ, Fozard JL, Fleg JL, Hurley BF (2003). Age and gender responses to strength training and detraining. *Med Sci Sports Exerc* 32:1505–12.

Luckey AE, Parsa CJ (2003). Fluid and electrolytes in the aged. *Arch Surg* 138:1055–60.

Mena P, Maynar M, Gutierrez JM, Maynor J, Timon J, Campillo JE (1991). Erythrocyte free radical scavenger enzymes in bicycle professional racers. Adaptation to training. *Int J Sports Med* 12:563–6.

Morgan AL, Sinning WE, Weldy DW (2002). Age effects on body fluid distribution during exercise in the heat. *Aviat Space Environ Med* 73:750–7.

National Senior Games Association (2009). *History of NSGA*. Available at http://www.nsga.com/DesktopDefault.aspx?tabname=&sidebarname=History%20of%20NSGA&Params=454b04071756557a401a0c0b7b625a000000037f [Date accessed: July 30, 2009]

Neptune RR, McGowan CP, Fiandt JM (2009). The influence of muscle physiology and technology on sports performance. *Annu Rev Biomed Eng* 11:81–107.

Nichols JF, Robinson D, Douglass D, Anthony J (2000). Retraining of a competitive master athlete following traumatic injury: a case study. *Med Sci Sports Exerc* 32:1037–42.

Okonek CC (1996). Longitudinal analysis of change in sports performance of women between the ages of 30 and 75: a comparison between peak and leisure sports participation. *Z Gerontol Geriatr* 29:127–35.

Persky AM, Green PS, Stubbley L, Howell CO, Zaulyanov L, Brazeau GA, Simpkins JW (2000). Protective effect of estrogens against oxidative damage to the heart and skeletal muscle *in vivo* and *in vitro*. *Proc Soc Exp Biol Med* 223:59–66.

Plowman SA, Drinkwater BL, Horvath SM (1979). Age and aerobic power in women: a longitudinal study. *J Gerontol* 34:512–20.

Pollock ML, Mengelkoch LJ, Graves JE, Lowenthal DT, Limacher ML, Foster C, Wilmore JH (1997). Twenty-year follow-up of aerobic power and body composition of older track athletes. *J Appl Physiol* 82: 1508–16.

Priest L (2003). The whole IX yards: the impact of Title IX: the good, the bad, and the ugly. *Women Sport Phys Act J* 12:27–43.

Ramamani A, Aruldhas MM, Govindarajulu P (1999). Impact of testosterone and oestradiol on region specificity of skeletal muscle-ATP, creatine phosphokinase and myokinase in male and female Wistar rats. *Acta Physiol Scand* 166:91–7.

Ransdell LB, Wells CL (1998). Masters women runners. *Women Sport Phys Act J* 7:53–76.

Reaburn P, Dascombe B (2008). Endurance performance in masters athletes. *Eur Rev Aging Phys Act* 5:31–42.

Rittwager J, di Prampero PE, Maffulli N, Narici MV (2009). Sprint and endurance power and aging: an analysis of master athletic world records. *Proc R Soc B* 276:683–9.

Sawka MN, Francesconi RP, Young AJ, Pandolf KB (1984). Influence of hydration level and body fluids on exercise performance in the heat. *JAMA* 252:1165–9.

Shephard J, Pacelli L (1990). Why your patients shouldn't take aging sitting down. *Phys Sportsmed* 18:83–90.

Spirduso WW, Francis KL, MacRae PG (2005). *Physical Dimensions of Aging*, 2nd edition. Human Kinetics, Champaign, IL, pp 287–316.

Stachenfeld NS, Keefe DL (2002). Estrogen effects on osmotic regulation of AVP and fluid balance. *Am J Physiol Endocrinol Metab* 283:E711–21.

Tanaka H, Seals DR (2003). Invited Review: Dynamic exercise performance in masters athletes: insight into the effects of primary human aging on physiological functional capacity. *J Appl Physiol* 95:2152–62.

Thompson Swimming (2009). *25 m Versus 50 m Pool Lengths.* Available at http://www.thompsonswimming.com.au [Date accessed: July 29, 2009]

Tiidus PM (1995). Can estrogen diminish exercise induced muscle damage? *Can J Appl Physiol* 20:26–38.

Trappe SW, Costill DL, Vukovich MD, Jones J, Melham T (1996). Aging among elite distance runners: a 22-year longitudinal study. *J Appl Physiol* 80:285–90.

Veldhuis JD, Anderson SM, Patrie JT, Bowers CY (2004). Estradiol supplementation in postmenopausal women doubles rebound-like release of growth hormone (GH) triggered by sequential infusion and withdrawal of somatostatin: evidence that estrogen facilitates endogenous GH-releasing hormone drive. *J Clin Endocrinol Metab* 89:121–7.

Waters DL, Yau CL, Montoya GD, Baumgartner RN (2003). Serum sex hormones, IGF-I, and IGFBP3 exert dimorphic effect on lean body mass in aging. *J Gerontol A Biol Sci Med Sci* 58:648–52.

Wells CL, Boorman MA, Riggs DM (1992). Effect of age and menopausal status on cardiorespiratory fitness in masters women runners. *Med Sci Sports Exerc* 24:1147–54.

Wikipedia (2009). *FINA World Swimming Championships (25 m).* Available at http://en.wikipedia.org/wiki/FINA_World_Swimming_Championships_(25_m) [Date accessed: July 29, 2009]

Wiswell RA, Jaque V, Marcell TJ, Hawkins SA, Tarpenning KM, Constantino N, Hyslop DM (2000). Maximal aerobic power, lactate threshold, and running performance in master athletes. *Med Sci Sports Exerc* 32:1165–70.

World Masters Athletics (2009). Available at http://www.world-masters-athletics.org/index.php?content=about_us/history&title=title/about_us&bild=about_us_balken.jpg#1 [Date accessed: July 29, 2009]

Young BW, Medic N, Weir PL, Starkes JL (2008). Explaining performance in elite middle-aged runners: contributions from age and from ongoing and past training factors. *J Sport Exer Psychol* 30:737–54.