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AGING PERFORMANCE FOR MASTERS RECORDS IN ATHLETICS, SWIMMING, ROWING, CYCLING, TRIATHLON, AND WEIGHTLIFTING

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Record performances for Masters sporting events for swimming, cycling, triathlon, rowing, and weightlifting were analyzed and then compared with the authors' previously published results for Masters running, walking, and jumping sports events. Records were normalized using the 30s age records as a baseline, and studied through the various age ranges to the 90s. A curvilinear mathematical model $[y = 1 - exp((T - T_0)/\tau)]$ *was again used for the major comparisons, along with slope changes using a linear model* $[y = \alpha(T - T_0')]$ *across the age groupings. All sports declined with increasing age, with rowing showing the least deterioration. Performances in running, swimming, and walking were reasonably well maintained, followed by greater decline with age for cycling, triathlon, and jumping events. Weightlifting showed the fastest and greatest decline with increasing age. The relative performances for women, when compared with men's performances for these Masters events, was approximately 80% to 85%, with jumping at 73% and weightlifting at 52%. These relative performances compared with World Record comparisons of approximately 90% (with weightlifting at approximately 75%). All these results show no greater decline with age for endurance events over the sprint events, though there was a greater decline for the strength events of weightlifting and jumping. There may be real*

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physiological differences for these strength events, or there may be other explanations such as training or competitive considerations or smaller numbers participating.

In many countries the total number of elderly people (>65 years) is increasing each decade, and along with this increase there is a change in the age demographic from the "pyramid" to the "coffin" shape, as there is a simultaneous decrease in the birth rate. These elderly and old (>80 years) people are exercising more energetically, as there is a coexistent improvement in medical care and appreciation of lifestyle factors that enhance longevity. Along with this improved life expectancy and increased interest in exercise, the aspirations of many have turned to Masters games and thence to attempting to better their own and ultimately World Records for different age groupings in a wide range of Masters sports.

Previously we reviewed the performance with aging in Masters sporting activity for track and field events (Baker, Tang, & Turner, 2003). As noted in that article such records document the gradual detrimental change in physical performance that occurs with increasing age. Kennelley (1906) and Hill (1925) were the first to note that "in the study of the physiology of muscular exercise there is a vast store of accurate information, ... in the records of athletic sports and racing" (Hill, 1925), and Moore (1975) was the first to use these records to investigate the aging process. Masters athletes must be very motivated, extensively trained, and well practiced at the particular sporting activity they undertake. There is a degree of healthy self-selection, as those with acute or chronic diseases, chronic disability, obesity, etc., will not be contenders for the records. Nevertheless the study of these fit and dedicated individuals gives a good indication of the best possible performance for the age group concerned, and demonstrates how that best performance decreases with aging. Using such world's best performance records within each age range for Masters sports removes the inconsistencies inherent in following individuals on a longitudinal time basis where health, motivation, environmental conditions, etc., all play a part in the resultant performance measured at a set time, though such longitudinal studies taken over many individuals may well provide a better indication of the average aging potential rather than the best aging potential.

There have been many studies of athletic records as a means of investigating normal physiology, including the effects of age on athletic performance, particularly for track-running records (Kennelly, 1906, 1926; Meade, 1916, 1956; Hill, 1925, 1926; Allen, 1936; Francis, 1943; Lietzke, 1954; Henry, 1954, 1955; Keller, 1973; Moore, 1975; Salthouse, 1976; Stones & Kozma, 1980, 1981, 1982, 1984, 1985, 1986a, 1986b; Riegel, 1981; Fair, 1994, 2006; Fung & Ha, 1994; Trappe, Costill, Vukovich, Jones, & Melham, 1996; Baker et al., 2003; Young & Starkes, 2005; Tanaka & Seals, 2008; Wright & Perricelli, 2008). There have been fewer studies for sports other than track and field (Rahe & Arthur, 1974, 1975; Hartley & Hartley, 1984, 1986; Meltzer, 1994, 1996; Tanaka & Seals, 1997; Tanaka & Higuchi, 1998; Seiler, Spirduso, & Martin, 1998; Starkes, Weir, Singh, Hodges, & Kerr, 1999; Pearson et al., 2002; Weir, Kerr, Hodges, McKay, & Starkes, 2002; Donato et al., 2003; Fair, 2006; Fairbrother, 2007; Balmer, Bird, & Davison, 2008). Comparisons between different sports of the effects of aging on the world's best performances has not been undertaken, though such a study would indicate whether or not the effects of aging were similar across different sports and hence likely to be caused by similar physiological effects. In order to investigate the response to aging, we now compare the age-related deterioration for a number of other sports in a similar manner to our previous study for track and field athletic events, where we demonstrated that the decline in performance was exponential (Baker et al., 2003). The present study was undertaken to test the hypothesis that the world's best performance for these Masters sports decremented with age in an exponential fashion for all sports, and that there were no differences between "strength" and "stamina" events.

We normalized these individual performances for swimming, rowing, cycling, triathlon, and weightlifting using as the baseline performance the world's best performances at the mature age range of 30 to 35 years (or 30 to 40 years depending on the recording age range) (Baker et al., 2003). This normalization allows for a better comparison across the various sports as well as within the sports, such as different swimming strokes and distances or different weightlifting techniques. Again we have chosen to use this baseline rather than the World Record performance because the population from whom the World Records was recorded is much wider than the population for Masters records, though this situation is changing rapidly with more countries and competitors participating in Masters events, and with increasing professionalization within many of these sports.

METHODS

World Masters performance-versus-age data for the individual World Records at that age range were obtained from Fédération

Internationale de Natation for swimming with age ranges for men of 30–95 and women of 30–100 (http://www.fina.org/project/index.php?option=com_content&task=view&id=708&Itemid=332); from Triathlon.org (the official triathlon resource) for the full-distance triathlon with age ranges for men of 30–70 and women of 30–60 (http://www.triathlon.org/); from Union Cycliste Internationale for cycling with age ranges for men of 30–65 and women of 30–55 (http://www.cyclingmasters.com.au/index.php?id=49); from International Weightlifting Federation for weightlifting with age ranges for men of 30–80 and women of 30–65 (http://www.mastersweightlifting.org/records.htm); and from Concept 2 Rowing for rowing using the standard indoor rowing ergometer (the Concept II for 2000 m) with age ranges for men of 30–90 and women of 30–90 (http://www.concept2.com/sranking/rankings.asp). The results for running, walking, and jumping were taken from our previous article (Baker et al., 2003) where the age ranges for running were 30–95 for men and 30–90 for women, for walking were 30–95 for men and 30–85 for women, and for jumping were 30–95 for men and 30–85 for women.

Performance data for timed events were calculated as the reciprocal of time as previously (Baker et al., 2003). For example, if the baseline time was 10 s and the next age range time was 10.1, then the second performance was $(1/10.1)/(1/10) = 0.99$ of the baseline performance. For the weightlifting events the calculation was simply as a function of the baseline performance, as were the data previously obtained for the field athletic events particularly the jumping events used for comparisons.

Where possible, data were current records for September, 1999 (or as near to that date as possible). Data from this period were specifically chosen to enable direct comparison to our previous article (Baker et al., 2003), which used results obtained from Niemi and Dunkel (1999), and to avoid any possible differences engendered in the results because there were many more active participants who might also be training more effectively.

The individual swimming events (50 m Free; 100 m Free; 200 m Free; 400 m Free; 1500 m Free; 50 m Back; 100 m Back; 200 m Back; 50 m Breast; 100 m Breast; 200 m Breast; 50 m Fly; 100 m Fly; 200 m Fly; 200 m Medley; and 400 m Medley) were included, and then an averaged combined result was used to compare with the combined track athletic results from Baker et al. (2003). Similarly, the weightlifting, and heavy- and light-weight rowing, results were independently listed and their combined results used for comparisons. For cycling, the only results that we able to locate for Masters results were for the 200 m Sprint, as other distances were not consistent (at that time) across the age range, and thus these were the only results used for cycling in this study. The triathlon results were for the full-distance triathlon of 3.8 km swim, 180 km cycle, and 42.2 km run, and were analyzed as a complete triathlon and not broken down within individual sections of the triathlon.

Deterioration in performance with age was assessed as previously (Baker et al., 2003) by fitting a curvilinear model of the form:

$$y = 1 - \exp((T - T_0)/\tau)$$

where y = functional performance; T = age; T_0 = age when performance equated to a fractional performance of zero; τ = time constant of the curvilinear decline.

And by fitting a straight line model of the form:

$$y = \alpha(T - T_0')$$

where y = fractional performance; T = age; T_0' = age when performance equated with a fractional performance of zero; α = slope of linear decline.

The slope of the line indicates the rapidity of the deterioration with age (although the type of mathematical model also affects the slope). Straight-line slopes were compared between the ages of 35–50, 50–65, 65–80, and 80–95. Events were compared using the values T_0 and τ as a measure of the rate of performance deterioration for that event. GraphPad Prism 3 was used for statistical analysis. One-way analysis of variance (ANOVA) was performed to examine differences in fractional performance and slope amongst age groups. When overall significance was obtained, Tukey's method for multiple comparisons was used to compare the individual differences. For the grouped age comparisons, Kruskal-Wallis analysis was performed with Dunn's multiple comparison used for correction. Statistical significance was accepted for comparison when $p < .05$.

RESULTS

These Masters record performances for swimming, cycling, rowing, weightlifting, and triathlon declined with age in a similar fashion to that for Masters running performances for both men and women (Figures 1 and 2). From these figures it is obvious that there are no major differences in declining sports performance for males (Figure 1) when comparisons are made between rowing (which is the best

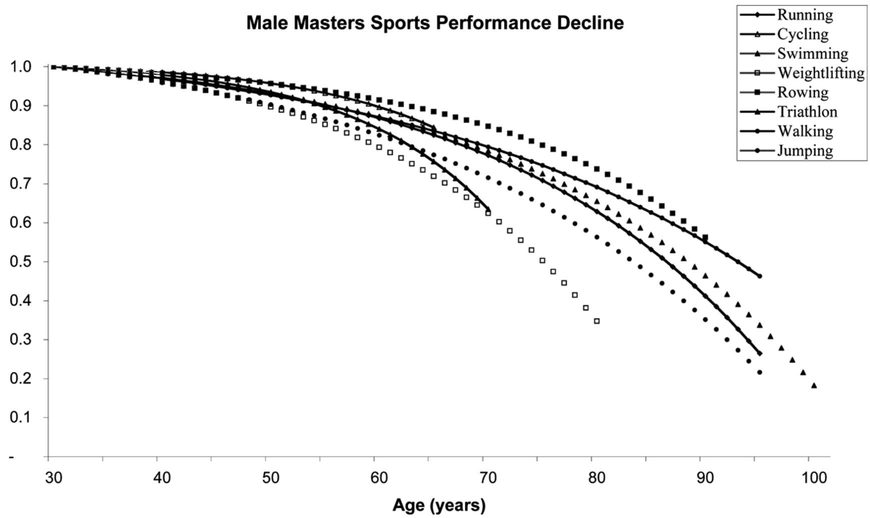

Figure 1. Fractional performance decline with age for male Masters sports.

maintained sport with aging), walking, swimming, running, and jumping, and possibly cycling (though the age range is not as wide). For females (Figure 2) there are similar results except that cycling is

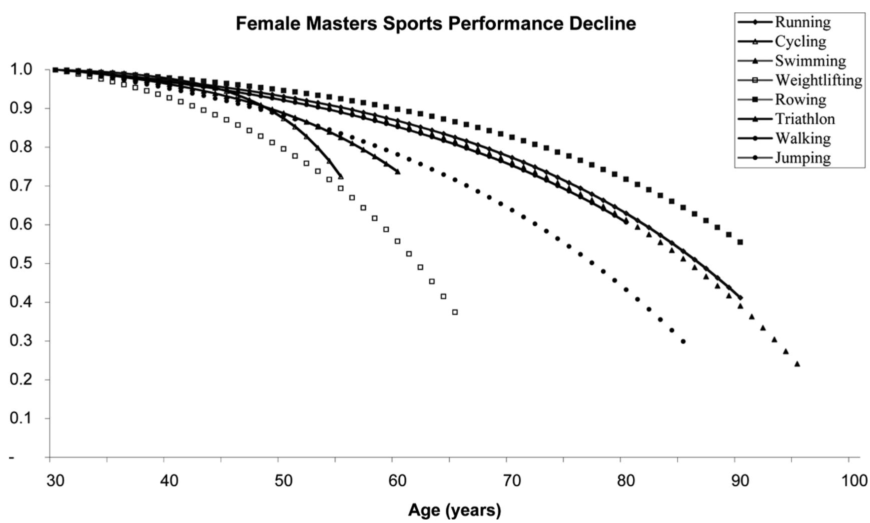

Figure 2. Fractional performance decline with age for female Masters sports.

Table 1. Decremental parameters for the different sports events over the age ranges studied

	Men			Women		
Events	R^2	τ	T_0	R^2	τ	T_0
Combined Running	.9905	24.18	101.8	.9803	23.64	95.98
Combined Walking	.936	32.92	113.3	.9351	26.39	102.1
Combined Jumping	.9582	30.22	101.6	.9468	27.9	93.72
Swimming						
50 m Free	.9907	22.53	105.4	.989	21.94	101.8
100 m Free	.9939	23.55	104.8	.9801	22.22	100.8
200 m Free	.9812	25.06	105.1	.9681	22.87	100.6
400 m Free	.978	24.68	104.4	.9697	23.04	99.87
800 m Free	.9761	24.65	104.7	.9743	21.43	98.46
1500 m Free	.9792	23.87	104	.9742	22.54	99.28
50 m Back	.9813	25	106	.9839	22.5	102.6
100 m Back	.9749	27.54	106.1	.9758	24.12	101.6
200 m Back	.9534	26.9	105.2	.9533	26.79	103.3
50 m Breast	.9829	23.07	104.1	.9879	23.99	100.5
100 m Breast	.9863	24.2	103.3	.9732	22.74	99.44
200 m Breast	.9736	23.61	103.3	.9787	19.93	96.42
50 m Fly	.9937	19.43	97.74	.9842	18.64	92.35
100 m Fly	.9726	20.33	94.51	.9296	20.38	93.1
200 m Fly	.9669	23.09	96.09	.9355	23.65	94.54
200 m IM	.9857	23.42	99.68	.982	21.87	95.66
400 m IM	.9859	24.22	99.66	.9618	23.18	97.92
Combined Swimming	.9888	25.78	104.9	.9875	24.81	101.4
Rowing, 2000 m						
Heavy weight	.9913	19.52	102.2	.9704	26.03	108.4
Light weight	.9867	23.14	112.9	.9668	23.43	109.2
Combined Rowing	.9952	21.04	106.7	.97	24.77	108.8
Cycling						
200 m Sprint	.9583	13.34	89.01	.9246	6.609	63.42
Triathlon	.9524	12.99	82.71	.6344	14.38	77.82
Weightlifting						
Snatch	.9718	20.77	88.38	.8221	16.37	71.46
Clean and jerk	.9758	19.96	87.79	.8187	17.52	72.68
Total	.9744	20.38	88.08	.8139	16.97	72.25
Combined Weightlifting	.9745	20.37	88.08	.819	16.94	72.11

Note. R^2 = coefficient of determination; τ = time constant of curvilinear decline; T_0 = age at which performance has declined by 100%.

See Baker et al., 2003, for individual events within the fields of Running, Walking, and Jumping.

not in the group that maintains sporting performance. The group that declines fastest for both males and females is weightlifting where the decline is evident from an early age. Triathletes seem to maintain their

Table 2. Ages (years) at which sports event performance declines to set levels of 75%, 50%, or 25% of the maximum performance at 30–35 years of age

	Men fractional performance			Women fractional performance		
Events	75%	50%	25%	75%	50%	25%
Combined Running	68	85	95	63	80	89
Combined Walking	68	90	104	65	84	94
Combined Jumping	56.5	78	100	53	72	92
Swimming						
50 m Free	74	90	99	71	87	95
100 m Free	72	88	98	70	85	94
200 m Free	70	88	98	69	85	94
400 m Free	70	87	97	68	84	93
800 m Free	71	88	98	69	84	92
1500 m Free	71	87	97	68	84	93
50 m Back	71	89	99	71	87	96
100 m Back	68	87	98	68	85	95
200 m Back	68	87	97	66	85	96
50 m Breast	72	88	97	67	84	94
100 m Breast	70	87	96	68	84	93
200 m Breast	71	87	97	69	83	91
50 m Fly	71	84	92	67	79	87
100 m Fly	66	80	89	65	79	87
200 m Fly	64	80	89	62	78	88
200 m IM	67	83	93	65	81	89
400 m IM	66	83	93	66	82	91
Combined Swimming	69	87	97	67	84	94
Rowing						
Heavy Weight	75	89	97	72	90	101
Light Weight	81	97	106	77	93	102
Combined Rowing	78	92	101	74	92	101
Cycling						
Sprint, 200 m	71	80	85	54	59	62
Triathlon	58	68	74	65	74	79
Weightlifting						
Snatch	60	74	82	49	60	67
Clean and jerk	60	74	82	48	61	68
Total	60	74	82	49	60	67
Combined Weightlifting	60	74	82	49	60	67

Note. See Baker et al., 2003, for individual events within the fields of Running, Walking, and Jumping.

ability but then decline rapidly after the age of 50–55 years in males and 45–50 years in females. Female sprint cyclists decline in ability from an even earlier age (40–45 years).

The values for the curvilinear decline (τ) and the theoretical age at which performance declines to zero for individual sports are listed

Table 3. Performance decline (linear) for each age range in the various sports

Age	M-Jump	F-Jump	M-Run	F-Run	M-Walk	F-Walk	M-WL	F-WL	M-Swim	F-Swim	M-Triath	F-Triath	M-Cycle	F-Cycle
35–40	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9772	0.9907	0.9731	0.9650	0.9940	1.0106
40–45	0.9473	0.8890	0.9437	0.9425	0.9505	0.9444	0.9516	0.9813	0.9473	0.9562	0.9733	0.9335	0.9799	0.9704
45–50	0.8767	0.8473	0.9073	0.9218	0.9107	0.9113	0.8699	0.7785	0.9182	0.9165	0.9781	0.8790	0.9510	0.9205
50–55	0.8234	0.7832	0.8809	0.8521	0.8578	0.8504	0.8538	0.6963	0.8997	0.8981	0.9589	0.9779	0.9282	0.8745
55–60	0.7812	0.7045	0.8515	0.8058	0.8144	0.8215	0.7822	0.4924	0.8506	0.8324	0.9003	0.8625	0.9258	
60–65	0.7090	0.6717	0.8153	0.7505	0.7788	0.7667	0.7234	0.4559	0.8060	0.7887	0.8681	0.7737	0.8973	
65–70	0.6701	0.5954	0.7802	0.6922	0.7307	0.7381	0.6509	0.4335	0.7738	0.7404	0.8780		0.8312	
70–75	0.6047	0.5724	0.7190	0.6457	0.6925	0.6846	0.5738		0.7272	0.7065	0.6911			
75–80	0.5512	0.4672	0.6611	0.5810	0.6744	0.6174	0.4744		0.6615	0.6397	0.6410			
80–85	0.4966	0.3729	0.5977	0.5080	0.6143	0.5233	0.3497		0.6020	0.5547				
85–90	0.4165	0.3174	0.4800	0.3788	0.5354	0.5398			0.5366	0.4701				
90–95	0.3035		0.3768	0.2297	0.5340				0.4023	0.3559				
95–100	0.2529		0.2685		0.4678				0.3427	0.2299				
100–105									0.1942	0.0843				

Age	M-Row	F-Row
19–30	1.0000	1.0000
30–40	0.9684	1.0379
40–50	0.9930	0.9852
50–60	0.9616	0.9441
60–70	0.8999	0.9272
70–80	0.8406	

Note. These results show a steady increase in the declining slope with increasing age for all sports. Rowing is separated because of the different age ranges used in this sport.

Table 4. Performance decline slopes (linear) for each age range in the various sports

	35–50 years			50–65 years			65–80 years			>80 years		
Sport	Slope	*SD*		Slope	*SD*		Slope	*SD*		Slope	*SD*	
M-Jumping	0.0120	0.0005	S	0.0106	0.0009	S	0.0115	0.0004	S	0.0169	0.0016	S
F-Jumping	0.0138	0.0020	S	0.0119	0.0013	S	0.0155	0.0026	S	—	—	
M-Running	0.0079	0.0010	S	0.0068	0.0002	S	0.0121	0.0001	S	0.0218	0.0004	S
F-Running	0.0093	0.0013	S	0.0107	0.0004	S	0.0124	0.0008	S	0.0278	0.0011	S
M-Walking	0.0093	0.0003	S	0.0083	0.0003	S	0.0073	0.0011	S	0.0088	0.0021	NS
F-Walking	0.0096	0.0007	S	0.0078	0.0007	S	0.0142	0.0013	S	—	—	
M-Weightlifting	0.0104	0.0017	S	0.0134	0.0004	S	0.0201	0.0015	S	—	—	
F-Weightlifting	0.0223	0.0048	S	0.0165	0.0061	NS	—	—		—	—	
M-Swimming	0.0052	0.0004	S	0.0084	0.0005	S	0.0116	0.0005	S	0.0182	0.0020	S
F-Swimming	0.0064	0.0006	S	0.0103	0.0007	S	0.0125	0.0016	S	0.0218	0.0013	S
M-Triathlon	0.0008	0.0007	NS	0.0055	0.0022	NS	0.0237	0.0079	NS	—	—	
F-Triathlon	0.0003	0.0048	NS	0.0204	0.0015	S	—	—		—	—	
M-Cycling	0.0045	0.0004	S	0.0064	0.0020	NS	—	—		—	—	
F-Cycling	0.0092	0.0003	S	—	—		—	—		—	—	

Note. S = statistically significant, $p < .05$; NS = statistically nonsignificant.

Table 5. Statistically significant performance decline with age (linear slope between age ranges) when compared to other sports at the different age ranges for men (M) and women (W)[a]

Sport where the performance declines faster	Compared sport: Running	Walking	Swimming	Cycling	Triathlon	W-L	Jumping
Running					F30		
		M80	M80 F80				M80
Walking					M30 F30		
Swimming					F30		
		M80					
Cycling					F30		
Triathlon							
	F50 M65	F50 M65	F50 M65				F50 M65
W-L	F30 M50 F50 M65	F30 F50 M65	F30 M30 F50 M65	M30 F30 M50	M30 F30 M50		F30 M65
Jumping			M30 F30	M30	M30 F30 M50		
		M80					

Note. W-L = Weightlifting; 30 = 30–39 years; 50 = 50–64 years; 65 = 65–79 years; 80 = >80 years.

Note that rowing cannot be compared with the other sports because of the different age ranges used in Master's rowing.

[a]For instance, swimming performance only declines faster than walking for males >80 years and faster than triathlon for females 30–39 years of age, whereas weightlifting performance declines faster for most sports for both males and females.

in Table 1, and the age at which performance declined to 75%, 50%, and 25% of maximum performance is listed in Table 2. Both Tables 1 and 2 indicate that performance is very well maintained into later life for running, walking, jumping, swimming, and rowing. The other sports have smaller numbers participating and this may have a statistical effect or it may indicate other influences. These elite athletes show remarkably well-maintained performance into their mid-50s for all sports for both males and females with the exception of female weightlifters. Rowing performances are exceptional for both men and women who maintain very good performances well into their 70s.

The coefficients of determination for the exponential curve fitting show a very close fit for most of the results, with 10 out of 16 showing >0.95 and 14 out of 16 showing >0.90. Only one result, that for female triathlon, showed a poor fit, and the data were no better fit with either a linear or polynomial model. This latter result almost certainly indicates that better performances are possible in many age ranges for this sport for females.

When the linear slopes, for declining performance between ages, were compared at the various age ranges, the majority of the sports had statistically significant slopes, demonstrating a decline in performance over that age range (Tables 3 and 4), except for the male triathlon results, which were not significantly different from zero for all age ranges studied (though there were no results for the >80 years band). Other statistically nonsignificant results were for female triathlon (30–49 years band), male cycling (50–64 years band) and male walking (>80 years band). Most of these nonsignificant statistical relationships are probably influenced by the small number of data points (within the age bands) that were used for the comparisons. Despite these statistics, Figures 1 and 2 both show an exponential decline in performance for both males and females in the triathlon, which suggests that there is a marked decline in performance over these age ranges. This is confirmed by the results in Table 1 (which includes the results for athletics from our previous article [Baker et al., 2003]) where the decline to zero performance is estimated for the triathlon as being the fastest for males of all the sports, and amongst the fastest for females; and in Table 2 where the results for triathlon also show an early decline in performance, along with weightlifting, jumping and female cycling.

The short-intensity power sport of weightlifting showed the greatest decline (Figures 1 and 2), and when the linear age bands were compared between sports (Table 5), weightlifting, and the combined jumping events and triathlon between them, accounted for the steepest slope differences over 5-year increments from 40 to 90 years.

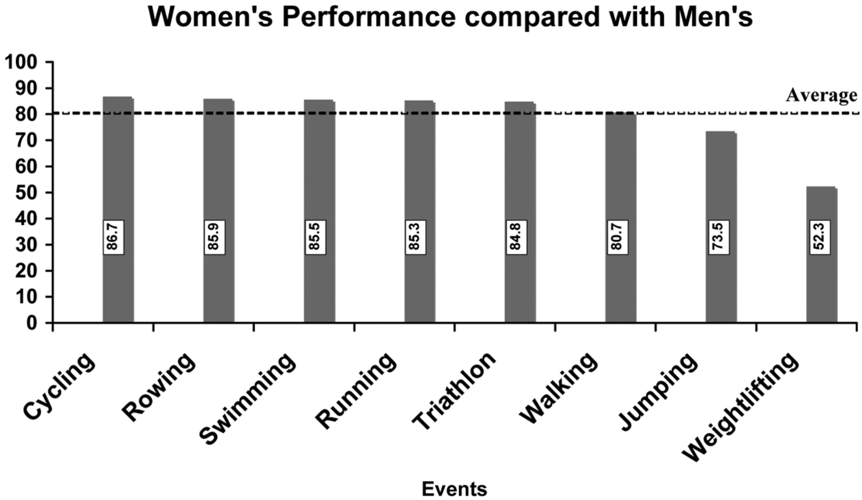

Figure 3. Female sports performance compared with male performance.

Though it was not possible to compare rowing with these other sports because of the different age bands used for Masters events in that sport, the linear decline over 10-year bands for rowing was very well maintained, and the best (i.e., slowest decline) for all sports studied, until at least 80 years (Table 3).

When women's records were compared to the men's (Figure 3) they were all greater than 80% of the men's records for each sport except weightlifting and the field jumping events.

DISCUSSION

These data have all been normalized in the same fashion as for the track and field data in our previous article (Baker et al., 2003). Normalization of the individual Masters records allows all the sports to be compared equally because widely divergent unit values of different magnitude are thus excluded. The baseline age for this normalization procedure was again taken as the 30s age performance level for the same reason as given in that article, viz. there was in general a greater sudden deterioration in performance between the world record and the 30s age performance than for the 30s performance versus later age performances. As we noted then, it is likely, with increasing professionalization of sport, that the discrepancy between World Records and the 30s age record performances will decrease as the intensity of training and competition increases, and as professionalism, with longevity at the elite level, increases into the 30s and 40s age groups in some of these sports. At such a time, it would be appropriate to carry out these age comparisons starting with the 20s age group and World Records as the baseline for comparison, as Schulz and Curnow (1988) have noted that peak performance for most sports is in the 20s age group. This effect of improving performances in the 30s may already be affecting some of the sports, and thus skewing the proportional decline for these sports, which will then flow on to affect the results we have obtained, with a greater decline evident due to substantially better performances for the 30s baseline performances when compared to later age groupings. However, it is equally likely that this increased professionalism will not be transferred to the older age ranges, past about 40 years of age, because of lifestyle issues and possibly age-related decline as well. Older athletes train less than younger ones (Starkes, Weir, & Young, 2003; Weir et al., 2002) both in the number of days per week and the time spent at each session. Masters athletes also differ in the type of training, concentrating more on the sporting activity itself, and less on other associated and varied exercise training to build general strength and aerobic capacity, than do the younger competitors. Other physiological factors that potentially affect these Masters performances are reviewed by us (Baker et al., 2003) and by Maharam, Bauman, Kalman, and Skolnik (1999). These include slowed reaction time, decreased coordination and joint mobility, decreased skeletal size and muscle bulk, decreased type 2 fast-twitch muscle fibers, changed body fat composition, and decreased cardiovascular and respiratory functions. Using data from 1999 instead of more recent data may have meant that for sports where there has been a marked increase in participation levels across the age ranges, our results may have been subject to a greater decrement in performance with age or that females may have exhibited lower levels of performance when compared to males for those sports. The increase in participation levels in Masters sports and the increasing professionalism in sports generally will inevitably increase the best performance levels at all ages.

We have again used an exponential curvilinear mathematical fit for the data to provide a comparison with our athletic data (Baker et al., 2003), and because we consider it the most valid model to use. Such a model is supported by others (Moore, 1975; Stones & Kozma, 1980), and harks back to the classic assumption by Gompertz in 1825 who hypothesized that deterioration with age would be exponential (Rossolini & Piantanelli, 2001; Gompertz, 1825). Morton (1983) also supports this exponential approach, though his study was directed at the ultimate value of World track records. Many other authors have used power mathematical models, particularly for improvement of sports performance and comparison of speeds against distances (Buchanan, 1997; Katz & Katz, 1999; Young & Starkes, 2005; Fairbrother, 2007), but such models overemphasize the curvilinear nature of the performance decline with age. Recently Fair (2006) has used a linear percentage decline model to an estimated transition age, and then a quadratic decline thereafter; and Donato et al. (2003) used a similar model using linear declines to, and then from, a nominated transition age of 70 years, which was endorsed by Tanaka and Seals (2003). Some authors (Rittweger, Kwiet, & Felsenberg, 2004) have argued for a linear decline with age, and we (Baker et al., 2003) found that there were linear relationships with age for walking and field sports, though these sports could also be represented exponentially almost equally as well as using a linear model, and in this present comparison we are using the exponential model for these sports for comparison. Because we consider that the decline in performance is most likely to be a continuum, the use of a continuous mathematical exponential model is preferred, rather than a discontinuous one, which has to be forced together, often at different ages even within the one sport, as in Fair (2006). A recent publication on Masters triathlon has confirmed our approach showing an almost perfect fit for performance decline with age using an exponential approach based on our model (Bernard, Sultana, Lepers, Hausswirth, & Brisswalter, 2010).

Our study demonstrates that a normalized comparison of the decline in the world's best performance with increasing age across these sports is valid, and that all fit the exponential model well. Similar to our previous results for running (Baker et al., 2003), these results confirm that for most sports there is a well-maintained but declining sports performance well into the 60s years of age, though the strength-dependent sports of weightlifting and jumping show the earliest declines for both men and women—during the 50s. Male triathlon performances also decline at an earlier age (late 50s), though each of the individual component sports that comprise triathlon events (swimming, cycling, and running) is well maintained in Masters competitions until the late 60s. Female sprint cyclists show a fall off in the mid-50s, though for the women triathlon the results are maintained into the mid-60s. These seeming inconsistencies may be contributed to by the fact that we were able to use only sprint cycling records, as longer race records were not used because of inconsistency of distances cycled (at that time). The best maintained performances were for rowing, which showed well-maintained performances into the 70s. It is interesting that rowers maintain their performance with aging best of all the sports studied here, when it is considered by some tests to be the most physiologically strenuous, with the greatest falls in arterial pH and oxygen saturation, and increases in blood lactate, during maximum exercise (Nielsen, 2003; Secher, 2003). Some sports had very good data into old age, whereas a few ceased in mid-life. Inferences from these latter sports would obviously be less sound than from sports where there were more participants into old age. The trends were still present, however, though the causes of the decline in performance are likely to be complex and to be caused more by social, economic, and lifestyle factors than physiological, particularly when there were marked gender differences.

There is no evidence from our studies that the endurance distance records decline faster with age than the shorter or sprint-type distance records in those sports where comparisons may be made. This finding is in contra-distinction to many statements in the literature, including a recent review by Tanaka and Seals (2008). Previously we showed that there was no difference between the "strength" and "stamina" aspects of running events (Baker et al., 2003), and our current results confirm that finding for Masters swimming records. We found no differences between the longer duration and short duration swimming events, nor any differences in general terms between other short- and long-duration sporting events. Other studies, however, have found such differences (Donato et al., 2003; Tanaka and Seals, 1997; Weir et al., 2002), but these studies did not normalize the data, which allows a more accurate comparison. As Carbone and Savaglio (2001; and Savaglio & Carbone, 2000) have shown, there is a transition time at 130–150 s (for males) and 140–170 s (for females) for both running and swimming where the scaling exponent ("n") changes in their mathematical power model ($\tau = cd^n$). In running, this is equivalent to approximately 1000 m (and for swimming to approximately 200–400 m). This is thought to be "the transition time between anaerobic and aerobic energy expenditure" (Savaglio & Carbone, 2000). Whether or not there is a significant change in this critical "scaling time" ("τ") of $\sim$2.3 s (Carbone & Savaglio, 2001) with aging would be interesting to study, as there are changes in both anaerobic and aerobic metabolism with aging. Chamari, Ahmaidi, Fabre, Massé-Biron, and Préfaut (1995) showed a fall in peak aerobic power of 35.4% and in peak anaerobic power of 42.7%, with a fall in the ratio of anaerobic to aerobic power of 11.3% when comparing young (18–33 years) and Masters (59–72 years) athletes. These results suggest that the scaling time might be reduced with aging, with a reduction in the transition time for mean speed of racing, and thus a decrease in the distances run or swum during this reduced time.

It is of interest that in a recent article (Bernard et al., 2010), where the individual sections of the Olympic-style triathlon performance decline with age were dissected, there was a significant difference in the rates of decline, with swimming having the greatest decline and cycling being the best maintained with age. As cycling represents approximately 50% of the relative time for the full-distance triathlon, and for the Olympic-style triathlon, this may reflect the relative training time spent cycling versus running or swimming. Alternatively, it may be a real effect of physiological difference in this demanding sport where a succession of different locomotion modes follow each other rapidly in sequence requiring major muscle and joint adaptation. The swim section of the triathlon is also the section where there is the most potential "interference" from other competitors, and this may also be a contributing cause.

Although there may not be a difference between "strength" and "stamina" events, there may be a difference between "strength" and "power" sports. The high-intensity, very-short-duration explosive muscle movement sports, such as weightlifting and jumping, optimally recruit type 2 muscle fibers. It is these type 2 muscle fibers that are preferentially reduced in number and size with aging (Lexell & Downham, 1992; Hawkins, Wiswell, & Marcell, 2003). Also Macaluso and De Vito (2004) have suggested that there may be a relative enzymatic change with age of type 2b fibers to type 2a fibers following the report from Häkkinen et al. (1998), and this would additionally decrease the fast-response anaerobic fibers, and possibly the ability to produce an explosive "power" response. As Meltzer (1994) points out, "maximal strength as a function of age is much better studied than is the age dependence of maximal muscle power," where strength is the magnitude of force exertion and power is the magnitude of force exertion times the velocity of the object moved. There is good evidence in our study that performances in power/strength sports such as weightlifting do decline faster with age, and this may be related to a real physiological aging effect (such as changes with aging in the high-intensity short-action phosphate anaerobic system and increased intracellular phosphate, which decreases muscle force production in high-intensity short-burst activity [Westerblad & Allen, 2002]), or due to constitutional aging factors such as reduction and enzymatic changes in type 2 muscle fibers, decreased joint mobility and body flexibility (Wright & Perricelli, 2008), increased tendon stiffness (Eyre, 1984), decreased disc compressibility, etc. The explanation could equally be related to the motivational aspects for weightlifting when compared to such other strength sports as rowing that show well-maintained performances well into the 70s, and many more competitors continuing to compete. Anton and colleagues (Anton, Spirduso, & Tanaka, 2004), who based their research on U.S. Masters records, found a greater decline with age for weightlifting when compared with powerlifting. As they point out, "The snatch and clean and jerk in weightlifting events require quickness and explosive power as well as more complex and exquisite neuromuscular coordination . . . In In contrast, speed is not a critical factor for bench press, squat, and deadlift in powerlifting." This result (Anton et al., 2004) demonstrates the differences with aging between the "strength" (powerlifting) and "power" (weightlifting) sports alluded to by Meltzer (1994) even when the sports are superficially very similar.

Once again we have shown that most of the results for women are approximately 80% to 85% of those for men, with the exceptions being weightlifting and jumping, which might be considered the "power" sports. We have made no attempt to allow for the difference in body size (Sinclair correction: http://www.qwa.org/Liftstats/2005.Sinclair.pdf) when comparing the relative weightlifting performances of men and women that will contribute partly to this difference when considering weightlifting. Within the jumping events, the pole vault is noteworthy at ~62%, with triple jump ~70%, long jump ~77%, and high jump ~83% (Baker et al., 2003). These exceptions may be real differences based on physiological differences in power, or may just indicate that there is a great opportunity for women to advance age records in these sports, possibly because there are fewer participants or because the training required is too arduous or inconvenient compared to other sports. However, Hill, back in 1925, showed that women were performing at a rate of 84% of the men for running, and even for jumping (when the square roots of the height and distance were compared, because of the required mechanical assumption that the squares of velocities of bodily projection are necessary, with 87% for the high jump and 81.5% for the long jump). Bird, Balmer, Olds, and Davison (2001) showed that British female orienteers were performing at approximately 70% of the orienteering times of their male counterparts, but at approximately 85% for 10 km cross-country racing. These results were similar to those by Gjerset, Johansen, and Moser (1997), who found Norwegian female orienteers to be performing at 68% of their male colleagues for orienteering, though at 79% for cross-country racing. A recent study of stride lengths with aging showed that although stride length shortened with age, when it was adjusted for velocity there was no change with aging (Conoboy &

Table 6. Female performance compared with male performance for current World Records (June, 2008)

Events	Men	Women	% (W/M)
Track and Field			
100 m	9.74	10.49	92.9
200 m	19.32	21.34	90.5
400 m	43.18	47.6	90.7
800 m	101.11	113.28	89.3
1500 m	206	230.46	89.4
5000 m	757.35	856.63	88.4
10000 m	1577.53	1771.78	89.0
Marathon	2:04:26	2:15:25	91.9
High jump	2.45	2.09	85.3
Long jump	8.95	7.52	84.0
Triple jump	18.29	15.5	84.7
Pole vault	6.14	5.01	81.6
20 km walk	1:17:16	1:25:11	90.7
Swimming			
50 m	21.28	23.97	88.8
100 m	47.5	52.88	89.8
200 m	103.86	115.52	89.9
400 m	220.08	241.53	91.1
800 m	458.65	496.67	92.3
1500 m	874.56	942.54	92.8
50 m back	24.47	27.67	88.4
100 m back	52.98	59.21	89.5
200 m back	114.32	126.39	90.5
50 m breast	27.18	30.31	89.7
100 m breast	59.13	65.09	90.8
200 m breast	128.5	140.54	91.4
50 m fly	22.96	25.46	90.2
100 m fly	50.4	56.61	89.0
200 m fly	112.09	125.4	89.4
Cycling			
200 m flying	9.865	10.831	91.1
500 m flying	25.85	29.655	87.2
1 h (km)	49.7	46.065	92.7
Rowing			
2000 m HW	336.6	388.4	86.7
2000 m LW	362.2	416.7	86.9
Weightlifting			
69 kg snatch	165	123	74.5
69 kg C&jerk	197	157	79.7
69 kg total	357	276	77.3
>75 kg snatch	195	139	71.3
>75 kg C&jerk	240	182	75.8
>75 kg total	430	319	74.2

Dyson, 2006). These authors also showed a significant difference in stride length (∼87%) between male and female runners even when adjusted for velocity. It is possible that stride length comparisons for women may be further affected by the rough ground over which orienteers traditionally run. Sparling, O'Donnell, and Snow (1998) and Grubb (1998) have shown that the gap for World distance running records between males and females has plateaued at ∼90%, which shows a closing of this performance gap over the last 30 to 40 years (Furlong & Szreter, 1975) after remaining fairly constant for the previous 50 years (Hill, 1925). Table 6 shows a comparison of the current World Records for a number of the sports we are considering and this table shows remarkable consistency for most sports around 90%. The exceptions being the jumping events and weightlifting, just as found in our current Masters study. It has been suggested, for ultra-marathon racing greater than 70 km, that women might have greater fatigue resistance and their performances might equal or better those for men (Bam, Noakes, Juritz, & Dennis, 1997; Speechly, Taylor, & Rogers, 1996). Our results again confirm that there is no increased decline with aging in the longer endurance events for female performances when compared to males, a finding that differs from statements to the contrary in many publications (Joyner, 1993; Tanaka & Seals, 1997; Tanaka & Seals, 2008), although in the Tanaka and Seals (1997) article their conclusion is at odds with their figure (figure 4a), which demonstrates that for swimming the percentage difference between men and women became less for the longer distances (ranging down from ∼19% for 50 m to ∼10% for 1500 m). Savaglio and Carbone (2000) showed that the slope of the ratio of speed versus time was the same for men and for women when both the anaerobic and aerobic events in running and swimming were considered using world record performances. As Khosla has shown (1968, 1974), on average, the greater the size of the athlete, the better the result for most events, with possible exceptions being 10,000 m and marathon events. Therefore, possibly comparisons between men and women should apply a correction factor based on body size such as the 0.872 (or ∼7/8) power of body mass ($kg^{0.872}$) (Weibel & Hoppeler, 2005).

In our previous article (Baker et al., 2003) we discussed the many physiological, psychological, and social (including economic) factors that impinge on the very strong commitment to training that is required over many years, and any of which might induce a decline in sports performance with age, and these are also relevant to all the other sports considered here. Such factors will limit the numbers of competitors, and thus potentially affect the overall best performance due to smaller numbers of really elite athletes. The smaller numbers of competitors in the older ages will, of course, affect the best performances for those age ranges, and is one of the inherent statistical limitations for all the studies using sports records. Most recent reviews (e.g., Tanaka & Seals, 2008) reaffirm that the most likely major physiological factor in this decline in performance with age, at least for the endurance events, is the deterioration in maximal oxygen consumption ($\dot{V}_{O_2max}$) that occurs with aging, because the other major physiological factors (lactate threshold and exercise economy) do not appear to change with aging. However, there is a study by Chamari et al. (1995), discussed above, that suggests that anaerobic power shows greater change with advancing age than does aerobic power, and this might be caused, at least in part, by reduction in numbers of type 2 muscle fibers and by type 2b fibers morphing into type 2a fibers (Macaluso & De Vito, 2004).

This study confirms, similarly to our previous study for track and field (Baker et al., 2003), that when normalized the performance decline with age is remarkably similar for all sports, and where there are differences it is not clear whether these differences are due to real physiological or other factors, due to specific training or lifestyle issues such as motivation, or just due to statistical issues inherent in the small numbers of participants. Whereas aerobic power changes have been well studied against aging, anaerobic power has not been as well studied. In particular, there has been no investigation with aging of the part played by the high-energy short-duration phosphate part of the anaerobic power pathway, and very little investigation of the glycolytic part of the anaerobic power pathway. Such investigation may prove useful to the consideration of performance decline in the "power" sports such as weightlifting.

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