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Percentage Decline in Masters Superathlete Track and Field Performance With Aging

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Masters athletic records in track and field events, published in September 1999, were analyzed to evaluate the percentage decline in maximum physiological performance with increasing age. Records were normalized using the 30s age records as the baseline and studied through to the 90s age range. Track running records declined with age in a curvilinear fashion [$y = 1 - \exp((T - T_0)/\tau)$*] whereas the walking and field events declined in a linear manner [*$y = \alpha(T - T'_0)$*]. There were significant differences in the rates of percentage decline in the running events over various distances for both males and females, and significant differences between males and females. Decline with aging was greater for females, and for the longer or endurance running events. There were no differences in the rates of declining function for any of the walking events, and the only jumping event to show a significant difference was the high jump performance, which showed the slowest decline. The walking events declined more slowly than the running events, which declined more slowly than the jumping events. Because of the changes in the weights, heights, and distances at different ages, for both males and females, it was not possible to directly compare rates of decline in the various throwing and hurdling events. The strength-dependent throwing events and the pole vault showed the greatest rates of decline with age. In general terms, men's performance declined to 75% of peak performance in sprint events by the early 70s, in the longer track distances by mid to late 60s, and in field events by mid to late 50s. Women's performance declined to a similar extent by their mid 60s in track events, and by late 40s to early 50s in field events. Some of these differences may be due to differences in training*

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effort and/or other competitive aspects, such as the numbers of athletes involved in the sport, and such differences may be reduced in the future with a more professional approach to these events.

Hill (1925) noted 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." In a similar manner, mature age athletic records document accurately the gradual detrimental change in physical ability that occurs with increasing age. Athletes who achieve mature age world records must overcome the debilitating problems of increasing age (decreasing strength, acute and chronic diseases, chronic disability, decreasing activity, obesity, etc.), and they must be well motivated, trained, and practiced at the sporting activity. These mature age record performances thus indicate the maximum physiological functional capacity possible for any individual in that particular age group. The very "old" (>80 years) records may be affected by sampling effects due to the smaller number of participants, but this in itself indicates one of the declining physiological attributes of age where general activity decreases for physical, pathophysiological, and psychosocial reasons.

A number of studies have compared athletic performance across events and with increasing age (Hill, 1926; Lietzke, 1954; Henry, 1955; Keller, 1973; Moore, 1975; Stones & Kozma, 1980, 1981, 1984, 1985, 1986a, 1986b; Riegel, 1981; Fung & Ha, 1994). These articles have compared performances either in terms of time, distance, height, etc., or in terms of speed (m/s, etc.). Some studies have compared percentage decrease in performance at various stated ages (Salthouse, 1976; Stones & Kozma, 1982). We wished to compare the deterioration with age across the different events. We therefore normalized all the events, using the best performance (in speed, height, distance, etc.) at the mature age range of 30 to 35 (or 30 to 40 depending on the recording age range) as the baseline performance, and considered older age record performances as a fraction of the baseline value. This technique has allowed us to compare performances across the different events in track and field. This baseline rather than a younger age range was chosen because Masters records start at 30 years of age, world records are held by athletes in the 20 to 30 age range, and the population of athletes from whom the world records come is much wider than the population for Masters records, which at present comes from a smaller range of countries.

METHODS

Performance-versus-age data were obtained from Niemi and Dunkel (1999) for World Masters Records for track and field events for mature age athletes over the age of 30 years by decade. Data were updated to

11 September 1999. Performance data for timed events were calculated as the reciprocal of time. The reciprocal at age 30–35 or 30–40 years was then used as the baseline measurement for that event. For example, if the time was 10 s for the 30–35 year age range, but 10.1 s for 35–40 years and 10.3 s for 40–45 years, then the 35–40 and 40–45 performances were respectively: (1/10.1)/(1/10) = 0.99 and (1/10.3)/(1/10) = 0.97.

For the field events where the performances decline in either distance or height, then the fraction was simply calculated as a fraction of the baseline performance.

In the throwing events, the weights of the objects are different at various ages, and in the hurdling events heights and distances are changed, which complicates these comparisons.

The track events were divided into the sprint events (100 m, 200 m, 400 m), middle distance events (800 m, 1500 m, 3000 m), long distance (5000 m, 10,000 m, marathon), hurdling events (110 m, 400 m, steeple chase), and walking events. The jumping events (long jump, high jump, triple jump, pole vault) were separated from the throwing events (shot put, discus, javelin, hammer). Linear and nonlinear regression analyses were performed to determine the decrement with age.

Deterioration in performance with age was assessed by fitting a curvilinear model of the form $y = 1 - \exp((T - T_0)/\tau)$ (where y = fractional performance; T = age; T_0 = age when performance equated with a fractional performance of zero; τ = time constant of the curvilinear decline), or 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, and events were compared using the values T_0 and τ (running) and T'_0 and α (jumping and walking) as a measure of the rate of performance deterioration for the event. 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. Significance was accepted when $p < .05$ for a comparison.

RESULTS

All of these Masters track and field performances declined with age and there was an increasing rate of decline with age for running particularly at great age (>80 years). In running events, the performance for longer distance events declined marginally faster than for shorter events, but the trends did overlap (Figures 1 and 2). For men's track performance, there were statistically significant differences between all age groups except for 35 versus 40, 40 versus 45, 45 versus 50 and 55, 50 versus 55, 60 versus 65, and 75 versus 80 (Table 1). For women's track performance, all age groups were statistically different except for 40 versus 45, 45 versus 50 and 55, 50 versus 55 and 60, 55 versus 60, 60 versus 65, 65 versus 70, and 80 versus 85 (Table 1). There were few statistically significant differences across the different running distances, though the greater deterioration for the men's marathon was statistically different from all other distances except 400 m and 1500 m. The 100 m and 200 m distance records showed the least deterioration with age, though there was statistical significance only for 100 m versus 1500 m and marathon, and 200 m versus 400 m, 1500 m, and marathon for men, and 100 m versus 3000 m, 10,000 m, and marathon for women. The 150 m records for men also showed more deterioration with age and were statistically different from those for 100 m, 200 m, 800 m, and 1500 m.

When all running events were pooled, the time constants for curvilinear decline for men ($\tau = 24.2$) and women ($\tau = 23.6$) were not statistically different. The ages, however, at which performance potentially fell to zero were statistically different ($p < .05$) with the men's performance prolonged to an older age (102 versus 96) (Figure 3). Linear regression analysis of running

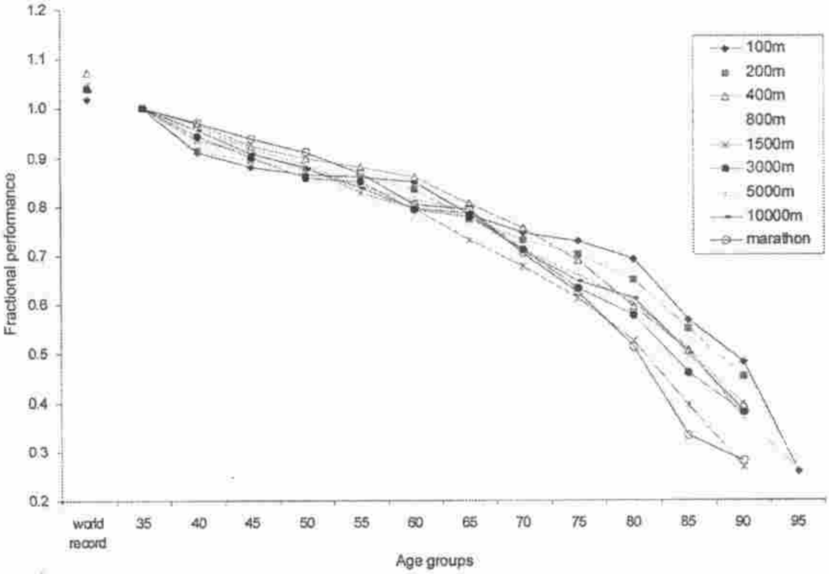

FIGURE 1 Men's Master track fractional records by age groups.

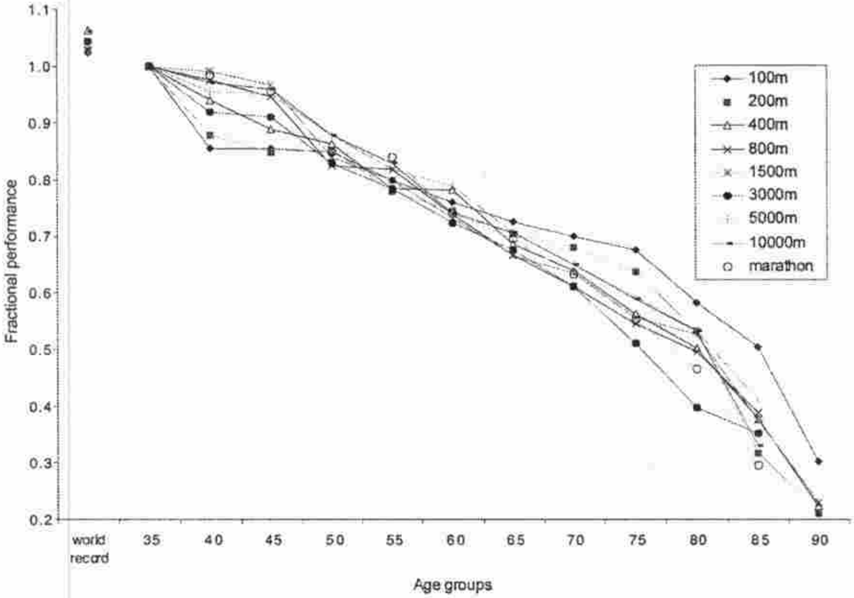

FIGURE 2 Women's Master track fractional records by age groups.

TABLE 1 Statistically Significant Comparisons (P < 0.05) Between Different Age Groups

Age		35	40	45	50	55	60	65	70	75	80
35 Men	Track										
	Jumping										
	Walking										
35 Women	Track										
	Jumping										
	Walking										
40 Men	Track										
	Jumping										
	Walking										
40 Women	Track	*									
	Jumping										
	Walking										
	Track	*									

(*Continued*)

TABLE 1 (Continued)

Age		35	40	45	50	55	60	65	70	75	80
45 Men	Jumping	*									
	Walking	*									
	Track	*									
45 Women	Jumping	*									
	Walking										
	Track	*	*								
50 Men	Jumping	*	*								
	Walking	*	*								
	Track	*	*								
50 Women	Jumping	*									
	Walking	*									
	Track	*	*								
55 Men	Jumping	*	*	*							
	Walking	*	*	*							
	Track	*	*								
55 Women	Jumping	*	*	*							
	Walking	*	*								
	Track	*	*	*	*						
60 Men	Jumping	*	*	*	*						
	Walking	*	*	*	*						
	Track	*	*	*							
60 Women	Jumping	*	*	*							
	Walking	*	*	*							
	Track	*	*	*	*	*					
65 Men	Jumping	*	*	*	*	*					
	Walking	*	*	*	*	*					
	Track	*	*	*	*	*					
65 Women	Jumping	*	*	*	*						
	Walking	*	*	*							
	Track	*	*	*	*	*	*				
70 Men	Jumping	*	*	*	*	*	*				
	Walking	*	*	*	*	*	*				
	Track	*	*	*	*	*	*				
70 Women	Jumping	*	*	*	*	*					
	Walking	*	*	*	*						
	Track	*	*	*	*	*	*	*			
75 Men	Jumping	*	*	*	*	*	*	*			
	Walking	*	*	*	*	*	*				
	Track	*	*	*	*	*	*	*			

(Continued)

TABLE 1 (Continued)

Age		35	40	45	50	55	60	65	70	75	80
75 Women	Jumping	*	*	*	*	*	*				
	Walking	*	*	*	*	*	*				
	Track		*	*	*	*	*	*	*	*	
80 Men	Jumping	*	*	*	*	*	*	*	*		
	Walking	*	*	*	*	*	*	*	*		
	Track	*	*	*	*	*	*	*	*		
80 Women	Jumping	*	*	*	*	*	*	*	*		
	Walking	*	*	*	*	*	*	*	*		
	Track	*	*	*	*	*	*	*	*	*	*
85 Men	Jumping	*	*	*	*	*	*	*	*	*	
	Walking	*	*	*	*	*	*	*	*	*	
	Track	*	*	*	*	*	*	*	*	*	
85 Women	Jumping										
	Walking	*	*	*	*	*	*	*			

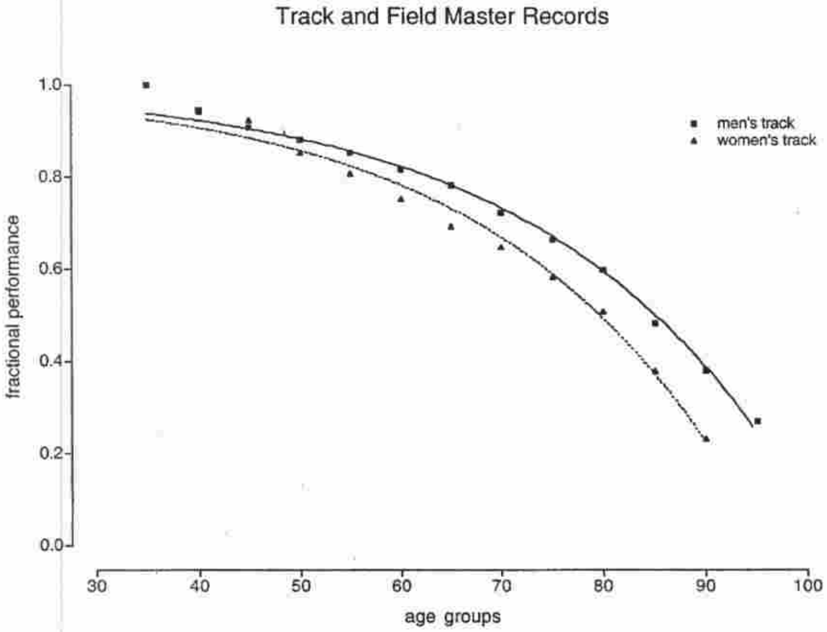

FIGURE 3 Combined fractional records for track results by age groups. Curves of best fit using the equation $y = (1 - \exp((T - T_0)/\tau))$ are shown.

events revealed a statistically significant difference between the men's and women's performances only for the 35–49 and 50–64 age ranges (Figure 4), and statistically significant differences for men and women as individual groups (and also when grouped together) when the over 80 years of age records were compared to the 35–49 and the 50–64 age groups (Figure 4).

Performance in the throwing and jumping field events declined linearly and more rapidly than in the running events, though there was no statistically significant difference in rates of declining performance for any age groupings between men and women. In the jumping events, the decline was fastest for the pole vault (Figures 5 and 6, Table 2), though this was not statistically significant. For jumping events, the high jump results declined the slowest. These results were statistically significant when compared to all the other jumping events for both men and women, except in the triple jump where the difference was significant only for women. For the throwing events, javelin (men and women) and discus (women) declined the most steeply (Figures 7 and 8). Statistical evaluation was not performed on the throwing and hurdling events because of the changes in weights and heights used at differing age groupings. There was no difference in the rate of decline in walking events between men and women (Figure 9). Running events were best fitted by the curvilinear model (Figures 1 and 2), whereas the field events (jumping and throwing) and walking were best fitted by the linear model (see Figures 5 to 9, Table 2). The results at great age (>80 years) show greater variability, which may be due to smaller numbers of competitors, and variable training opportunities and sporting interests.

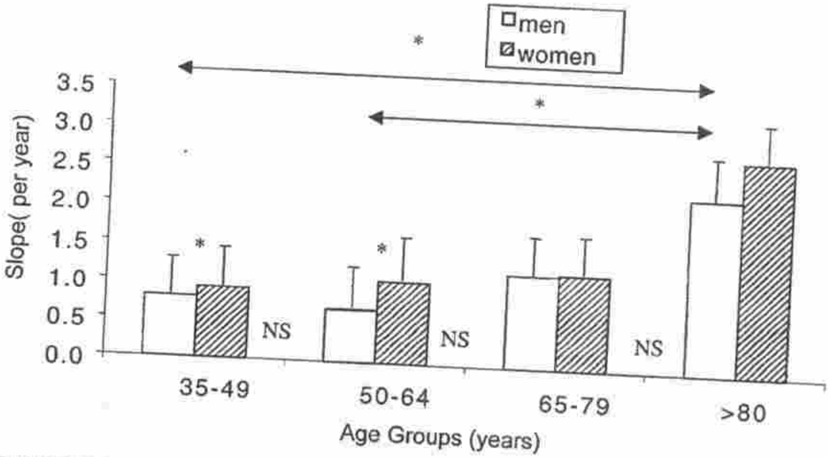

FIGURE 4 Linear slope changes for master track records by age groups between male and female at different age groupings. ($* = p < 0.05$, NS = not significant).

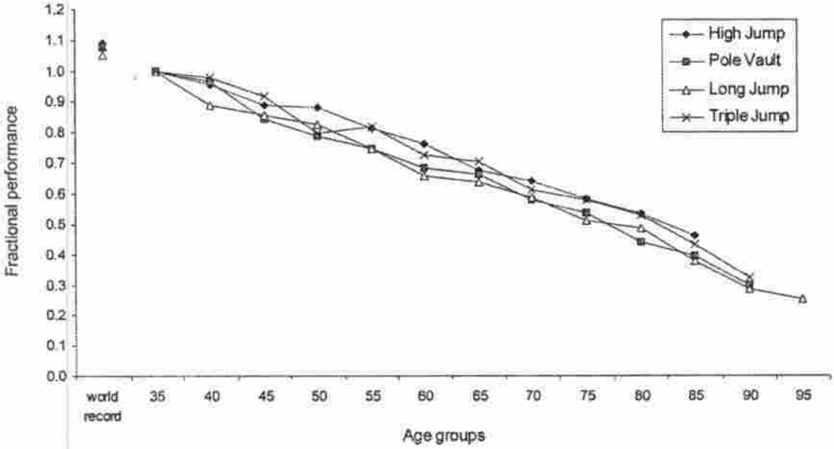

FIGURE 5 Men's Master jumping fractional records by age groups.

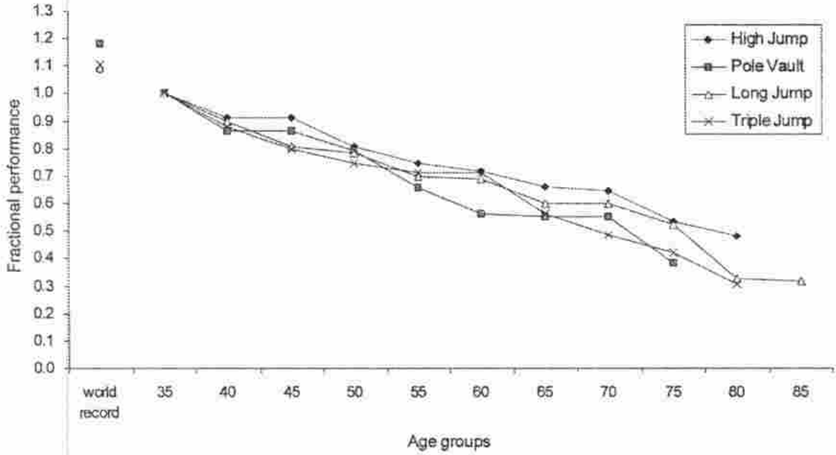

FIGURE 6 Women's Master jumping fractional records by age groups.

The age at which performance declined to 75%, 50%, and 25% of maximum performance is demonstrated in Table 3. Performance is remarkably well maintained amongst this group of elite athletes into at least the mid 50s and for running into the mid 60s. Figure 10 shows the women's performance decline for the individual events as a fraction at each age grouping of the men's performance across the complete age range.

TABLE 2 Decremental Parameters for the Different Events Over the Age Ranges Studied (R^2 = Coefficient of Determination; τ = Time Constant of Curvilinear Decline; T_0 = Age at Which Performance Has Declined by 100% for Running Events; α = Slope of Linear Decline (% per 5 yr); T_0' = Age at Which Performance Has Declined by 100% for Walking and Jumping Events)

Events	Men			Women		
Track	R^2	τ	T_0	R^2	τ	T_0
100 m	0.9700	23.06	104	0.9367	30.16	106
200 m	0.9806	25.48	106	0.9259	27.78	101
400 m	0.9909	20.88	100	0.9536	22.79	94
800 m	0.9857	26.12	103	0.9392	23.62	95
1500 m	0.9896	22.45	97	0.9281	23.13	95
3000 m	0.9829	24.01	101	0.9644	23.88	93
5000 m	0.9887	23.64	102	0.9623	22.22	96
10000 m	0.9811	23.80	101	0.9576	20.77	94
marathon	0.9806	19.97	95	0.9675	20.37	92
Field	R^2	α	T_0'	R^2	α	T_0'
High Jump	0.9928	− 5.38	129	0.9819	5.49	125
Pole Vault	0.9904	− 6.11	115	0.9533	7.09	104
Long Jump	0.9903	− 6.03	115	0.9611	6.38	112
Triple Jump	0.9804	− 5.88	120	0.9691	6.99	105
Walking						
5000 m	0.9879	− 4.10	158	0.9693	4.25	149
10 km	0.9424	− 4.40	146	0.9779	4.40	151
20 km	0.9852	− 4.40	153	0.9620	4.40	150
30 km	0.9702	− 4.65	127	0.8205	4.65	140
50 km	0.9514	− 4.40	159	0.8750	4.40	148

DISCUSSION

We normalized timed performance data using reciprocals to allow comparison against a baseline time. All performance data were then compared using fractional performance of the baseline performance, which was taken as the 30s age performance level. An alternate baseline, which could have been used, was the current world record for the sport, which is usually held by athletes in the 20–30 age range. Schulz and Curnow (1988) also note that peak performance for most sports is in the 20s. This world record baseline was not used because we found in general a greater sudden deterioration in performance between the world record and the 30s age

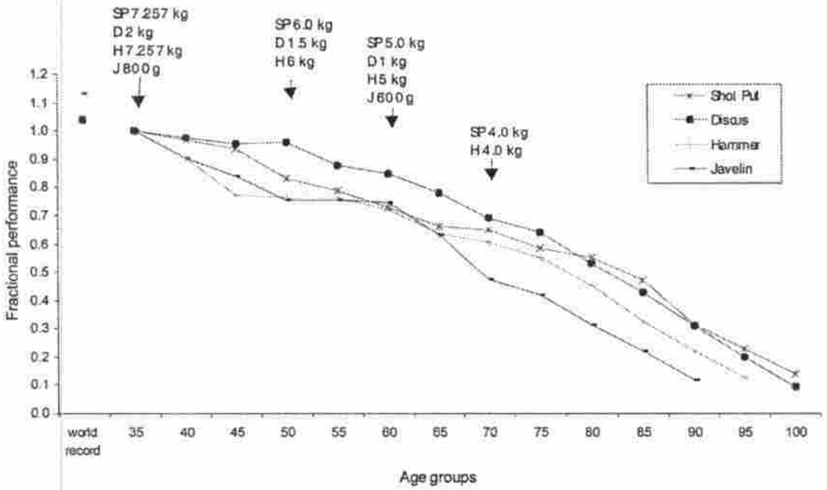

FIGURE 7 Men's Master throwing events fractional records by age groups.

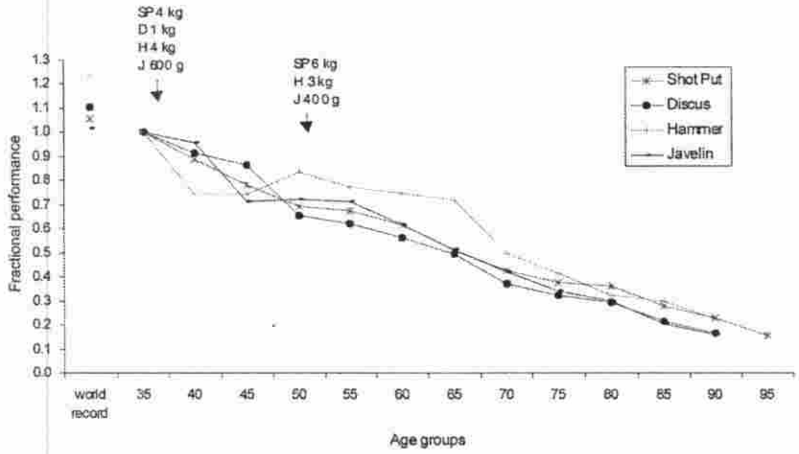

FIGURE 8 Women's Master throwing events fractional records by age groups.

performance than in the 30s age performance versus later age performances, and because the athletic populations that set these records are at present very different because Masters athletic events are less widespread around the world. There are exceptions to this generalization, particularly in the marathon, where there is the noteable exception of Carlos Lopez, who in 1984 at the age

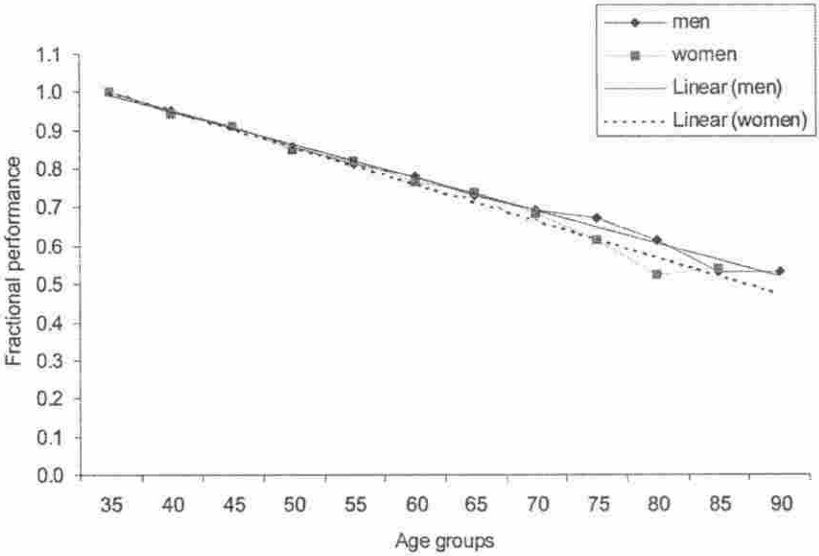

FIGURE 9 Masters walking fractional records by age groups.

of 42 won an Olympic Marathon, and a year later set a world record of 2 hr 7:12 min for the marathon and won the World Cross-Country Championship. With professional athletes remaining longer in the sport, it is possible that this discrepancy between the world records and the 30s age record performances will reduce, as the intensity of the training and competition increases. At that time, it may be appropriate to make comparisons using the world records as the baseline. Similarly, with better under-20 records, the improvement through youth and adolescence may then be compared with the world records as well. It is possible, with professionalism and prolonged individual duration in the sport, that the 30s versus 40s age performances may in the future show greater discrepancy.

The use of an exponential curvilinear mathematical fit for the running events is supported by Stokes and Kozma (1980), who found that an exponential fit was better than linear, logarithmic, or power models.

For running, Moore (1975) found that deterioration was more pronounced in the shorter distance events and postulated that decline would be greatest for events that taxed the body's energy resources more ("energy expenditure hypothesis"). On the other hand, Stones and Kozma (1980, 1981) found that deterioration was more pronounced in the longer distance events, postulating a difference in anaerobic/aerobic metabolism ("energy supply hypothesis"). There is a possibility that a combination hypothesis, the "energy expenditure-supply ratio," may explain the decline with age (Stones & Kozma 1981).

TABLE 3 Ages at Which Event Performance Declines to Set Levels of 75%, 50% or 25% of the Maximum Performance at 30–35 Years of Age

	Men's fractional performance			Women's fractional performance		
Events	75%	50%	25%	75%	50%	25%
Track						
100 m	72	88	97	65	83	94
200 m	70	88	98	63	79	89
400 m	71	85	94	63	79	89
800 m	67	85	96	63	79	88
1500 m	65	81	90	63	79	89
3000 m	67	84	94	60	77	87
5000 m	69	85	95	65	81	90
10000 m	68	85	94	65	79	88
marathon	67	78	89	64	78	86
Field						
High Jump	59	82	106	57	79	102
Pole Vault	55	76	96	51	69	86
Long Jump	54	75	96	53	72	92
Triple Jump	58	79	101	51	69	87
Shot Put	58	78	97	49	68	86
Discus	61	79	97	49	65	81
Hammer	54	73	92	52	71	91
Javelin	53	69	85	50	66	83

Fung and Ha (1994) agreed "that performance decline for events demanding maximal energy are greater than for those events that are associated with lower maximal energy expenditures . . . the 400 meter would be most affected since its demand on anaerobic reserve is greater." Our findings show no such correlation for 400 m; all events tended to show similar rates of decline in peak performance with age. Even though there was greater relative decline for the longer running events, there was much overlap and variability.

Women's average performance for each event was 82% to 91% of the men's performance (Figure 10). This ratio is in keeping with their relativities for world records, and is at least in part due to the slighter muscle bulk and general size of females compared to males. The women's performances decremented more with age than did the men's performance. The rates of change of deterioration for men and women were not statistically different, indicating that the rate of age-related performance deterioration was similar, even though the actual deterioration was greater for females. This difference

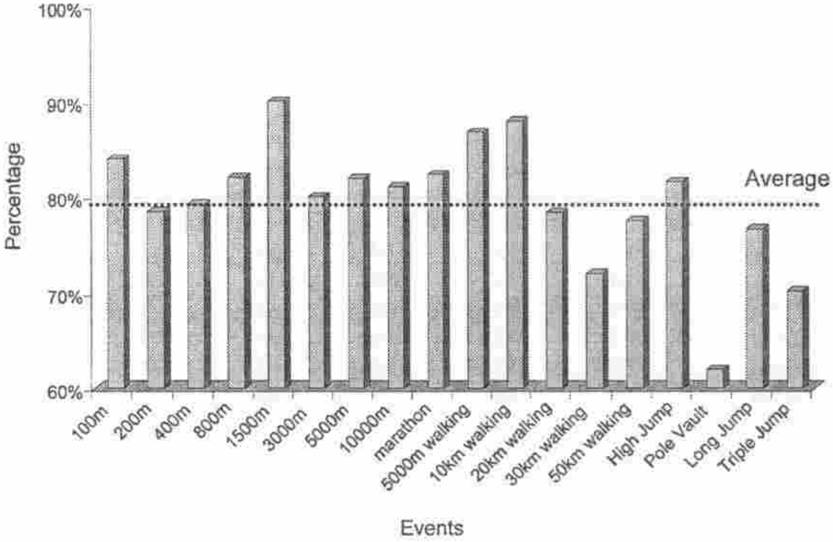

FIGURE 10 Women's performance compared with men's for different events.

may be due to the smaller number of women competing at the older age ranges and/or the shorter time that women have been competing at the Masters levels, or more fundamental differences between the sexes.

Moore (1975) suggested that "strength deteriorates faster than stamina" from the results based on his exponential model for the rate of decline in speed. This conclusion may be in error due to the choice of uncorrected speed results, which do not take into account the maximum speeds for the different distances. When Moore's data are normalized, the results are different to his postulates, as the 200 m results (in Moore's data) decline at ~0.91% per year and the marathon results at ~1.11% per year. In the percentage results, which he also published, there is no evident difference in percentage decline when the longer distance (marathon) is compared with the shorter (200 m).

A number of different factors, related to age, may influence the decline in function (Stones & Kozma, 1986b). These factors potentially have different weightings affecting the decline in different sports, and different events in the same sport.

Reaction time is a composite of neural response (e.g., to the starting gun), neuromuscular transmission, and muscular contraction by fast fibres. Hodgkins (1963) showed that in adult life reaction time slows with increasing age. Thus reaction time may contribute to the age-related decline in very short events (100 m) where the neuromuscular reaction time contributes a greater percentage to the total time for that event.

Coordination may contribute to the field events more than to running or walking events and may have an effect on the hurdling and steeplechase events.

Joint mobility, particularly spinal mobility, contributes to flexibility and the ability to use the muscles to their maximum efficiency. Flexibility may be partly influenced by cartilage fluid content, which is increased by warm-up and cartilage compression following joint stressing (Ingelmark & Ekholm, 1948), and which may decrease with age.

Skeletal size decreases with age (Büchi 1950; Rossman 1977). This decrease affects the potential of the athlete because it has been shown that, in general, the greater the size of the athlete, the better the result, particularly in throwing and jumping events (Khosla, 1968) and in speed events (Khosla, 1974). Athletes shrink with age, but there is a tendency in each generation for young elite athletes to be taller and more muscular in all events except the 10,000 m and marathon events (Astrand & Rodahl, 1986). Taller individuals tend to skew the aging effects as there is a delay in transference through the age ranges of these changing skeletal attributes.

Body fat composition increases with age even in the obsessively trained individuals (Dill et al., 1967; Heath et al., 1981; Pollock et al., 1987). This increase may partly contribute to decline in performance because of power-to-weight considerations as well as for metabolic reasons (Trappe, Costill, Vukovich, Jones and Melham, 1996).

Muscle strength potentially contributes more to the shorter running events and to the jumping field events, but is all important along with technique in the throwing field events. There is relatively a greater loss in Type II fast-twitch muscle cells with age (Tomonaga, 1977; Larsson, 1978), though others have not found this change (Aniansson, Grimby, Nygaard, & Saltin, 1980; Essen-Eustausson & Borees, 1986). Potentially the back and lower body muscle strength is affected more by age than upper body strength (Fisher & Birren 1947; McDonagh et al., 1984; Asmussen 1986). Our data suggest greater decline for javelin- and discus-throwing events, which disagreed with Stokes and Kozma (1981), who found greater decline in the hammer throw than in the javelin, but agreed with Fung and Ha (1994), who found javelin declined faster than other throwing events. Throwing events showed the greatest rates of decline in this study, which would suggest that strength, joint mobility, and coordination declined faster than endurance aspects. In the running events, however, there was a trend for greater rates of decline in endurance events. Moritani and deVries (1980) showed that increasing age did not interfere with the ability to increase muscle strength by training, though they found that in younger men both muscle hypertrophy and neural facilitation occurred, whereas in older men only neural facilitation occurred without muscle hypertrophy. However, the ability to train effectively was retained into extreme old age (Fiatarone et al., 1990).

Endurance for the longer running and walking events depends on a balance within the body between power output and power supply. Supply of power is either anaerobic or aerobic.

Anaerobic power supply is either from the ATP muscle store (readily available for short energy bursts for seconds of high power intensity) or the glycogen store, which metabolizes to lactic acid (less available and of lower power intensity but for longer times of 0.5 to 5 min).

Aerobic power supply is of lower power output than anaerobic but has a high capacity for renewal and therefore sustains muscular activity for much longer periods, up to hours. Astrand and Rodahl (1986) state that anaerobic and aerobic contributions are approximately equal when maximal athletic performances of about 2-min duration are considered—ranging through 85/15 for 100 m, 70/30 for 200 m, 60/40 for 400 m, 50/50 for 800 m, 30/70 for 1500 m, 20/80 for 3000 m, 15/85 for 5000 m, 5/95 for 10,000 m, and 1/99 for a marathon. The ability of the healthy body to supply oxygen for aerobic supply is dependent on maximum breathing capacity (oxygen diffusion, shortened capillary transit time, and increased a-v O_2 gradient are not usually a problem in normal lungs during maximal exercise), oxygen carriage by hemoglobin in blood, and cardiac output (which is itself partly dependent on maximum heart rate). The ability to mobilize free fatty acids for energy supply is also important (Saltin & Astrand, 1993) and may change with aging. The maximum oxygen consumption also plays a part in this supply chain when considered from the mitochondrial perspective. There are a large number of studies documenting decline in these latter cardiorespiratory parameters with age (Astrand 1968; Astrand & Rodahl, 1986, p 409) and in athletes over a 22-year period (Trappe et al., 1996). There is also a listing (Table 1 in Astrand, 1992) of the physiological improvements that are produced by "habitual physical activities." These individual "improvements" vary in their rates of decline with age.

Recovery/renewal ability of the athlete is enhanced by training, but little is known about the effect of ageing on this phenomenon, though the normal increase in mitochondria with training is possible in mature athletes (Sjödin & Jacobs, 1981). Conversion of lactate back to glycogen (Astrand, Hultman, Juhlin-Dannfelt, & Reynolds, 1986) may be important in repetitive anaerobic events, such as throwing and jumping, and in the ability to "kick" at the end of a long race.

With increasing age, the faster deterioration in maximum physiological performance or functional capacity represented by these mature age record performances is mirrored by a faster decline in many of the physiological functions, which probably plays a role in the overall limitation in exercise response. These factors are decreases in $\mathrm{Vo}_{2\max}$, maximum breathing capacity, heart rate, cardiac compliance and contractility, left ventricular ejection fraction, and sympathetic tone; increases in vascular stiffness, vagal tone, and A-a Po_2 gradient; and the increased tension required in respiratory muscles to expand the lungs. Our study has again confirmed that maximum physiological function as determined by mature age athletic records deteriorates with increasing age. It has demonstrated, using a fractional decrement model, that there are only relatively small differences between the different track and field events, though the running events decremented in an exponential fashion, whereas the other events (walking, jumping, and throwing) appeared to decrement in a linear fashion. These differences do not appear to be consistent with any specific physiological model of energy supply or demand, nor to depend strongly on any physiological age-dependent deterioration. Any differences may be due to the popularity of the event, the degree of training, the numbers of athletes and hence the competition, the commitment over many years by the athletes, and the necessary psychological competitive determination. It appears likely that there will continue to be improvements, particularly at the older middle age and old age ranges, especially as more competitors continue participating in their chosen sports, thus increasing the overall numbers competing and the possibility of an idiosyncratic extremely high-level performance (Ryder et al., 1976; Kleiner, 2000).

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