ORIGINAL ARTICLE

Effect of aging on the stride pattern of veteran marathon runners

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Objective: To investigate the stride pattern of different age groups of veteran runners in a marathon road race.

Methods: This kinematic study investigated the stride pattern (stride length, stride period, velocity, stance time, and non-stance time) for 151 runners (78 men aged up to 75–80, 73 women aged up to 60–64) at the 7 mile point.

Results: Significant declines for men with aging were found for mean stride length (from 2.4 m at age 40–49 to 2.0 m at age 60+), velocity, and non-stance time ($p < 0.05$), whereas stride period changed little. The findings indicate that the lower velocities of older runners are associated with shorter strides whereas cadence changes little. However, when a statistical adjustment was made for the variation in runners' velocity, it was found that older runners did not have a significantly shorter stride length at any given velocity.

Conclusion: Although a shorter stride is the mechanical route by which older runners lose velocity, the shorter stride may not be the fundamental cause of the velocity reduction with age. This has implications for researchers and coaches when investigating and training veteran distance runners.

There will be increasing interest in the causes of the age related decline in running velocity as substantial numbers of the post-war "baby-boom" generation seek to continue running into old age. Participation in marathons has increased at a higher rate in the older age groups: one study of the New York City Marathon over the period 1983–1999 found that the participation of both men and women aged 50+ rose more than twice as fast as younger age groups.¹ This trend covers not only recreational but also competitive running in the form of masters or veterans events with their competitive five year age categories.² It should be noted that the term "veteran" is used henceforth although "masters" is now also used to describe the same age groups.

The relatively few biomechanical studies of older runners have focused mainly on elite veteran runners. The two main kinematic studies looking at the effect of age in over-ground running^{3–4} both used elite sprinters in veteran championship track sprint events. Korhonen *et al*⁴ concluded that stride length was a decisive factor in the age related decline in running velocity. It would be expected that the relation between stride pattern and velocity would be different at slower (distance running) velocities when economy of energy is important.³

Many biomechanical research studies of running have used laboratory treadmills.^{5–7} Such approaches may modify biomechanical performance because of the imposition of treadmill conditions, such as belt velocity, which modify stride patterns. For example, one study⁸ found that eight of the 22 subjects changed from their normal heel strike to a midfoot landing when they moved from running over-ground to a treadmill. Although research on over-ground running presents more problems of controls and methodology, it is worth knowing fundamental criteria that apply to the activity of interest, as they may provide insights into performance and investigative criteria. A popular marathon road race was believed to be an appropriate platform for this research as it would allow consideration of the range of velocities applicable to both elite and recreational veterans.

The difficulty of controlling velocity in over-ground running is a particular problem for investigations into how

factors such as age, sex, performance level, or running surface affect stride variables. It can be difficult to determine whether observed changes in stride variables are due to these factors or whether they are the result of a change in running velocity. One suggested approach to this problem is to use statistical covariance.⁹ This approach is used in this investigative study of veteran marathon performance. The research question was therefore to investigate how the stride pattern of veteran runners in a marathon road race varied between runners in different age/sex groups both before and after adjustment in the analysis for the different velocities of the runners.

METHODS

The event chosen was the 2003 British Veterans Athletic Club national marathon championship.¹⁰ Having been notified in advance, the race organiser consented to filming of the event for the research which would aggregate data and preserve anonymity for the participants. The college ethics committee approved the procedures.

Altogether, over 1000 runners were filmed. The stride patterns of 78 men and 73 women were analysed. It was not possible to capture the stride pattern of all runners in each age/sex group. The main reason for a runner being excluded from the data analysis was the race number or stride pattern being obscured by other runners. The data (age group and sex) relating to each subject was taken from the published results.¹¹ These data would have originally been copied from the race entry forms completed by each subject.

The stride data were captured shortly before the 7 mile point using a JVC GR-FX1EKT VHS camcorder on a tripod at a height of 1.2 m above the ground located 10 m from the edge of the road so as to give a field of view of at least two strides of both feet for most runners (about 12 m). Partly because of oncoming traffic, most subjects ran within a narrow line no more than 0.5 m either side of the calibration pole position. A maximum possible error of $\pm 5\%$ in a stride length of 2 m due to "out of plane" motion was calculated.¹² The data were recorded at a fast shutter of 1/1000 second and a rate of 50 fields per second. This location was chosen for

Figure 1 Relation between stride length and velocity for men at 7 miles ($n = 78$).

convenience, to obtain a clear view of the runners on a wide, approximately flat stretch of road away from spectators. The road was approximately flat for at least 200 m either side of the camera point. The use of the 7 mile point was judged to be a sufficient distance to allow runners to have "got into their stride" without undue fatigue. It was also a sufficient distance from the start so that the field was sufficiently spread and most competitors could run unimpeded by other runners. Filming took place between 1000 and 1130. During that time, the air temperature rose from 16°C to 20°C. The wind velocity was described by the Meteorological Office as a "gentle breeze" from the south west. A second camcorder was positioned to record the runners' race numbers.

The video playback using a Panasonic AG MD830 VHS Player and Sony Triniton TV Monitor sampled at a rate of 50 fields per second. Motus 32 (version 2000) Peak Performance Motion Measurement System software was used to store, digitise, and analyse the video data. The video recording was digitised manually field by field using a simple "one point" model (the heel of the nearside left shoe). The raw coordinates were filtered using a cubic spline with five passes.

To estimate intraoperator reliability, we repeated the digitisation process on one runner several times. This produced a mean difference between the original and repeat measurements of stride length of 0.035 m.^{13 14} As a check on stride variability, two successive strides were measured on 10 runners: the mean difference between the two measures was 0.016 m.

For each runner the following (dependent) variables were calculated:

- Stride length was measured as the horizontal displacement of one foot (the nearside, left foot) from the point of footstrike to the next point of contact of that same foot.
- The stride period was calculated by multiplying the number of fields elapsed between same foot contact by the field time. (Stride period was therefore the reciprocal of the stride rate.) This produced a margin of error of 0.02 second—that is, the elapsed time of each field.
- Velocity—that is, mean horizontal velocity—over the stride was calculated by dividing stride length by stride period.
- Stance time was measured as the elapsed time (number of fields multiplied by the field rate) from first contact of the nearside left foot to toe-off in the same foot.
- Non-stance time was measured as the time from toe-off in the nearside left foot to the first contact of this foot again. Thus stride period = stance time + non-stance time.

The independent variables were sex and age group, bearing in mind the different ages at which veteran status occurs—that is, 40 years for men and 35 years for women. The statistical analysis was performed using SPSS for Windows

11.0 analysis of variance with a Bonferroni adjustment. The level of statistical significance was set at 0.05. The effect size and power (observed power) were calculated as part of the analysis of variance. Power was calculated using a significance level of 0.05. Analysis of covariance, with velocity as the covariate, was used to adjust statistically for different velocities in the analysis of stride length.

RESULTS AND DISCUSSION

The recorded velocity range was large at 1.8–4.5 m/s for women and 2 m/s to nearly 5 m/s for men. Stride length range was 1.4–2.7 m for women and 1.5–3.3 m for men. There was a strong linear relation between stride length and velocity for both men and women. This is shown in figs 1 and 2, with the (Pearson) correlation determined as 0.96 for men and 0.92 for women ($p < 0.01$).

The strong linear relation found between stride length and velocity is in agreement with other researchers,^{5 15 16} who concluded that the relation is approximately linear up to velocities of 6–7 m/s. The stride length of male runners showed a significant reduction with age (table 1), with subsequent post hoc tests (Bonferroni and Tukey HSD) showing a significant reduction in stride length and non-stance time from the under 40 to over 60 age groups. For the men, when the non-veteran under 40 age group was removed from the test, stride length, non-stance time, velocity, and relative stance time showed reductions with age, with subsequent post hoc tests (Tukey HSD and Bonferroni) identifying significant differences between the 40–49 and over 60 age groups ($p < 0.05$).

The decline in the stride length of women with advancing age (table 2) was less than for men with no significant difference between age groups. For women, the notable difference within the veteran age groups was increased stance time in the 55+ age group. For men and women, stride period varied little with age, a finding consistent with that of the two previous studies of veteran sprinters.^{3 4} The older age groups tended to run at a slower velocity with the age effect significant in the case of men between the 40–49 and 60+ age groups.

One problem for previous studies of the effect of age, sex, performance level, or terrain on stride patterns in over-ground running has been controlling for velocity. One study¹⁷ used a cyclist to try to enforce a constant pace on nine female club runners, when comparing the kinematics of running on different terrain. In the present study, the relatively large number of subjects allowed velocity to be taken into account statistically. This approach was facilitated by the strong linear correlation found between stride length and velocity. The purpose of the statistical adjustment was to determine whether differences in stride length between groups of runners were due to age and sex or due to their different running velocities.

The results show a significant difference between the stride length of men and women both before and after the adjustment for velocity, suggesting that sex is a significant

Figure 2 Relation between stride length and velocity for women at 7 miles ($n = 73$).

Table 1 Age related stride kinematics of men at 7 miles

	Age under 40 (n = 29)	Age 40–49 (n = 24)	Age 50–59 (n = 14)	Age 60+ (n = 11)	Effect size	Power
Stride length (m)	2.40 (0.48)*	2.44 (0.38)†	2.27 (0.51)	1.99 (0.25)*†	0.11	0.70
Stride period (s)	0.69 (0.04)	0.68 (0.04)	0.69 (0.04)	0.68 (0.25)	0.03	0.18
Stance time (s)	0.29 (0.04)	0.28 (0.04)	0.30 (0.04)	0.32 (0.05)	0.07	0.47
Non-stance time (s)	0.40 (0.03)*	0.40 (0.03)†	0.39 (0.04)	0.36 (0.04)*†	0.11	0.69
Velocity (m/s)	3.48 (0.74)	3.61 (0.66)†	3.29 (0.76)	2.95 (0.37)†	0.10	0.70
Stance time % in stride period	42.5 (4.44)	41.7 (4.87)*†	43.7 (5.78)	46.9 (5.46)*†	0.11	0.69

Values are mean (SD).

*Significant difference between age groups at the 0.05 level.

†Significant difference between age groups at the 0.05 level when the under 40 age group removed.

factor regardless of velocity. Men had a significantly ($p < 0.001$) longer mean (SD) stride length (2.3 (0.45) m) and longer stride period (0.69 (0.04) s) than women (stride length 2.0 (0.25) m; stride period 0.67 (0.04) s). The difference in these stride parameters between men and women was still significant ($p < 0.001$) after controlling for velocity (effect size = 0.13; power > 0.999).

Whereas men had significantly longer strides than women at any given velocity, the same was not true of younger runners compared with older runners. When velocity was entered as the covariate in an analysis of covariance, there was no significant difference in stride length between male age groups (power = 0.3). The presumption and conclusion of earlier age related studies is that older runners lose stride length (perhaps because of muscular changes) and that this is the cause of their slower pace. An alternative hypothesis is that, at submaximal velocities, older runners choose a slower pace and they do so by adopting a shorter stride. A similar question of cause/effect has been posed about the slower walking gait of the elderly.^{18–19} The coach (like the therapist) has the difficult task of distinguishing between cause and effect.²⁰ It is possible that both propositions are correct—that the first might be the case for sprinters and maximal velocities, and the second could be true for distance runners and submaximal, distance running velocities.

If controlling for velocity in this study had shown that older runners still had a shorter stride at any given velocity, then this would have tended to support the first hypothesis above. The fact that, after adjustment for velocity, there was no substantial or significant age related difference in stride length leaves open the possibility that, at submaximal velocities, the slower pace of older runners was self selected or had other causes rather than being forced on them because of an age related shorter stride.

One possibility is that the longer stance time of older runners was a cause of their slower pace. The mean stance time of older runners was longer than for younger runners, although the difference was only statistically significant for women aged 55+ (table 2). Older men aged 60 years plus spent a higher proportion of their stride period in the stance

phase (46.9%) compared with younger (40–49 years) runners (41.7%). It should be noted that there was no strong linear correlation between runners' stance time and velocity; and the increase in stance time with age for men was not statistically significant. This suggests that stance time could have explained only a minor part of the slower pace of older runners and that there may have been other (perhaps physiological) limiting factors.

The distinction between cause and effect is important because the researcher, when observing the association between the slower pace and shorter stride of an older runner, might look for the underlying biological age related causes of the shorter stride. The coach might conclude that, if the shortening stride is age driven, the runner would have to increase stride rate (shorten stride period) in order to maintain velocity. If the shorter stride is an effect rather than cause, then the researcher or coach might best look for other age related changes (perhaps cardiorespiratory or training intensity) as the limiting factor. Longitudinal studies into the biomechanical factors that limit running velocity as we age would be informative.²¹

CONCLUSIONS

The simple (unadjusted) changes in stride variables with age and sex found in this particular marathon are broadly consistent with those of earlier laboratory and track running studies. The more interesting findings arise when account is taken of the variation in the velocity of the runners. Although a shorter stride is the mechanical route by which older runners lose velocity, this leaves open the question of whether it is the cause or effect of their slower pace. One approach to this question is to adjust statistically for the slower pace of older runners: this suggested that older runners did not have a substantially or significantly shorter stride length at any given velocity, and that the shorter stride may not be the fundamental cause of the velocity reduction with age. This has implications for researchers and coaches when investigating the age related limiting factors in the velocity of distance runners.

Table 2 Age related stride kinematics of women at 7 miles

	Age under 35 (n = 14)	Age 35–39 (n = 15)	Age 40–44 (n = 19)	Age 45–49 (n = 11)	Age 50–54 (n = 7)	Age 55+ (n = 7)	Effect size	Power
Stride length (m)	2.03 (0.25)	2.09 (0.26)	2.09 (0.26)	1.88 (0.19)	2.04 (0.17)	1.88 (0.17)	0.12	0.58
Stride period (s)	0.66 (0.05)	0.66 (0.03)	0.67 (0.03)	0.67 (0.03)	0.65 (0.03)	0.69 (0.05)	0.10	0.47
Stance time (s)	0.30 (0.04)	0.29 (0.04)*	0.30 (0.03)	0.31 (0.02)	0.27 (0.03)*	0.34 (0.05)*	0.19	0.85
Non-stance time (s)	0.36 (0.03)	0.39 (0.03)	0.37 (0.03)	0.35 (0.02)	0.37 (0.04)	0.36 (0.03)	0.11	0.56
Velocity (m/s)	3.09 (0.50)	3.16 (0.50)	3.12 (0.42)	2.83 (0.33)	3.15 (0.18)	2.73 (0.45)	0.12	0.58
Stance time % in stride period	44.7 (4.92)	41.9 (4.94)	44.7 (4.90)	46.9 (3.98)	42.5 (2.33)	48.4 (4.39)	0.19	0.84

Values are mean (SD).

*Significant difference at the 0.05 level.

What is already known on this topic

- Stride patterns of runners on a treadmill and veteran sprinters on the track have been determined
- Veteran runners have a shorter stride as their pace slows up

What this study adds

- Stride patterns of men and women in a marathon road race are determined
- There may be fundamental reasons, other than a shorter stride, for the age related decline in running velocity

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COMMENTARY 1

This paper is based on a large group design and looks at the initiative area of veteran runners. It highlights the need for further scientific investigation on the gait of veteran runners, as it shows that it is different from younger gait patterns. The measurement of variables such as stance time, non-stance time, and gait velocity are susceptible to fairly large errors as a result of the two dimensional video analysis used in this study. Out of plane motion, sample rate, digitising, and subject variability are the cause of such unknowns. A different kind of research design would be required to study finite changes that occur to running gait as a function of age.

C Diss

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COMMENTARY 2

This paper supports findings of previous studies regarding differences in stride biomechanics not only between male and female veteran (or masters) runners, but also across age groups. A major strength of this study is the large number of subjects, which allowed the authors to control for velocity differences. Furthermore, the use of a competitive setting enhances the utility of the findings for the masters athlete.

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