Effects of Stride Length Alteration on Racewalking Economy

by
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MORGAN, D. W. and MARTIN, P. E., Effects of Stride Length Alteration on Racewalking Economy. Can. J. Appl. Spt. Sci. 11(4): 211-217, 1986. This study investigated the effects of stride length (SL) manipulation on racewalking economy in 7 competitive racewalkers. Following two test sessions in which VO₂ max and freely-chosen stride length (FCSL) were determined, each subject completed 6-min racewalking bouts at five randomly-ordered SL conditions (FCSL and -10%, -5%, +5%, and +10% of leg length from the FCSL) while walking at a velocity approximately equal to their 10 km training pace. Actual and predicted group mean VO₂ values for the five SL conditions indicated that the subjects were most economical walking at the FCSL, with progressively higher energy costs manifested at the +5% and -5% and the +10% and -10% leg length conditions, respectively. A mean absolute difference in VO₂ of 0.6 ml·kg⁻¹·min⁻¹ was observed between subjects' FCSL and optimal SL. Linked with this deviation in VO₂ was a mean absolute SL difference of 3.2 cm (3.6% of mean leg length). These data support the hypothesis that trained subjects select locomotion patterns that are nearly optimal in terms of the aerobic demands.

stride length, economy, racewalking, oxygen consumption

INTRODUCTION

Numerous walking and running studies have demonstrated that stride length and velocity are directly related to one another. (e.g., Mann, 1980; Murray, et al., 1966; Nelson, et al., 1972). Additional research has also shown that the steady-state oxygen uptake (VO₂) measured at a given submaximal speed (i.e., economy) is affected when stride length is manipulated. Högborg (1952) observed that a well-trained subject running at 14 and 16 km·hr⁻¹ was most economical at a freely-chosen stride length (FCSL) versus running at stride lengths shorter and longer than the FCSL. A comparison of the energy costs associated with these various stride length conditions also revealed that running at the long stride lengths elicited a higher VO₂ than running at the short stride lengths. Cavanagh and Williams (1982) also examined the relationship between stride length and running economy at a given submaximal velocity of 13.7 km·hr⁻¹ (7 min·mile⁻¹) in 10 well-trained recreational...
runners. Their results indicated that a curvilinear relationship existed between stride length and VO₂ as stride length was varied from the FCSL by as much as 20% of leg length. Similar to Högb erg's data, Cavanagh and Williams found that the VO₂ for a given submaximal speed was lowest at stride lengths close to the FCSL. Their data also demonstrated that the pattern of VO₂ response to stride length manipulation differed considerably among subjects. In contrast with the results of Högb erg, however, Cavanagh and Williams showed that similar increases in VO₂ resulted as stride length was increased and decreased from the FCSL. These investigators concluded, therefore, that there is usually little need to manipulate a distance runner's stride length since most runners naturally select a nearly optimal stride length for a given velocity of running.

While Cavanagh and Williams (1982) demonstrated that inter-subject variation in VO₂ at various stride length conditions exists for trained subjects running at a given submaximal velocity, the energy costs associated with a similar regimen of stride length manipulation in trained racewalkers has not yet been investigated. The purpose of this study, therefore, was to investigate the effects of stride length alteration on racewalking economy in a group of competitive racewalkers.

METHODS

Subjects

Seven competitive racewalkers (4 males and 3 females) volunteered to participate in this study. They averaged 32.4 ± 14.4 (SD) years in age, 59.9 ± 10.5 kg in body mass, and 169.1 ± 10.8 cm in height. The mean training duration and weekly mileage of the subjects were 27.0 ± 9.7 months and 34.4 ± 15.9 miles, respectively. All of the subjects had received racewalking awards (e.g., high overall and/or age-group finishes) in various local and/or national contests. Included in the subject pool were the 1984 male National Junior Olympic 3000 m and Arizona 10 km champions as well as the second-place female finisher (35-year-and-older age-group category) in the 1983 TAC National 15 km championships. Prior to their participation in the study, written informed consent was obtained from all subjects.

Data Collection Procedures

Each racewalker completed a series of three treadmill testing sessions over a 3 to 4-week period. The maximal oxygen consumption (VO₂ max) of each subject was measured in Session #1. During Sessions #2 and #3, stride length and economy measurements were obtained. Prior to the initial testing session, the subjects practiced racewalking on the treadmill at both a horizontal grade and at a variety of inclined grades.

Session #1: Measurement of VO₂ max. A constant-speed, grade-incremented racewalking protocol was used to determine VO₂ max. Treadmill speed was set slightly below the average 10 km training pace of each individual. A 3-min warmup and a subsequent 2-min rest period preceded the VO₂ max test. At the beginning of the test, the subjects racewalked at their pre-selected speed at a 0% grade. Treadmill grade was then increased by 2.5% at 2-min intervals until volitional exhaustion ensued.

An open-circuit system connected on-line to a Tektronix 4052 microcomputer was used to obtain and calculate metabolic data. Expired gas was sampled from a mixing chamber, passed through a drying tube, and analyzed for O₂ and CO₂ with Applied Electrochemistry S-3A and Beckman LB-2 analyzers, respectively. The analyzers were calibrated at the beginning of each test with standards verified for content by a Lloyd-Gallenkamp volumetric apparatus. Inspired ventilation was measured with a Parkinson-Cowan CD-4 dry gas meter previously calibrated against a 120-l Collins spirometer. VO₂ max was defined as the average of the two highest consecutive 30-sec values obtained for each subject. Five subjects attained a plateau in VO₂ with an increase in workload (Taylor, Henschel, and Buskirk, 1953). The remaining 2 subjects who did not reach a VO₂ plateau exhibited maximal respiratory exchange ratios of 1.09 and 1.17 and maximal heart rates which represented 98% and 89% of their age-adjusted predicted values, respectively. The mean VO₂ max of the sample was 46.9 ± 11.3 ml kg⁻¹ min⁻¹, indicating that the subjects were heterogeneous with regard to maximum aerobic power.

Session #2: Determination of the FCSL. A determination of each subject's FCSL at a given submaximal speed was made 1 week after Session #1. Following a 3-min warmup and a subsequent 2-min rest period, each subject performed three 10-min racewalking bouts on the treadmill at a speed approximating a 10 km training pace. Ten-min rest intervals separated each bout. In light of the wide difference in aerobic fitness levels exhibited by the subjects, three different walking speeds (126 m·min⁻¹, 140 m·min⁻¹, and 190 m·min⁻¹) were employed. The relative energy cost of racewalking at the FCSL at these various speeds, which was determined in Session #2, averaged 77.4 ± 4.0% of VO₂ max. The relative stress imposed on the
subjects, therefore, was similar, even though the subjects did not walk at the same absolute speed.

FCSL was calculated for two 30-sec intervals during the last 10-min walking bout (4:30 to 5:00 and 9:30 to 10:00) using a procedure described by Cavanagh and Williams (1982). With each foot contact on the treadmill belt, a slight change in belt speed occurred which was reflected by small fluctuations in the treadmill velocity meter. By amplifying and recording the voltage signal of the velocity meter with a speed-calibrated chart recorder, instants of foot contact were easily identified as a stylus deflection. From these records, the time required to complete a specific number of strides was measured to the nearest tenth of a sec. Because the walking speeds and stride rates were not the same for all subjects, the number of strides completed and analyzed for the 30-sec recording period varied slightly from subject to subject. On the average, however, the time required for approximately 80 strides (identified by 81 successive spikes on the chart record) was used to determine average stride time for each subject. This average value was calculated by dividing the time measurement by the number of strides completed. Walking velocity for each subject was assumed to be equal to treadmill speed. This value was determined from measures of the time required for 30 belt revolutions and treadmill belt length. Stride length was then calculated as the product of velocity and average stride time. The mean FCSL for each subject was determined by averaging stride length measures calculated for each of the two 30-sec intervals. For all subjects, these two measures were nearly identical to one another, suggesting that the racewalkers were in stable walking patterns between the recording periods. During this session, each subject's right leg length (LL), taken as the distance from the floor to the superior border of the greater trochanter during barefoot standing, was also determined. This measurement was obtained three times on each subject. An average value of the three measurements was then used to represent each subject's LL. The mean LL obtained for the subjects was 90.1 ± 5.3 cm.

Session #3: Measurement of $\dot{V}O_2$ at various stride lengths from the FCSL. One week after Session #2 was completed, the subjects performed a series of 6-min racewalking bouts at five randomly-ordered stride length conditions (FCSL and $-10\%$, $-5\%$, $+5\%$, and $+10\%$ of the LL from the FCSL). Following randomization, the orders of the stride length conditions were examined to ensure that a balanced presentation was used. The actual stride length measures (expressed in meters) desired for each condition were established for each individual by multiplying LL by $5\%$ and $10\%$ and either adding or subtracting the resultant value to or from the FCSL values obtained in Session #2. Treadmill velocity for each subject in Session #3 was adjusted prior to and checked twice during each walking bout to verify that it was the same as that used in Session #2. Since velocity was held constant, stride length was altered by manipulating stride rate. This was accomplished by having each subject walk in cadence to the audible beat of an electronic metronome. The metronome settings corresponding to each of the five walking conditions were checked against an electronic timer for accuracy and adjusted, if necessary, to obtain the desired stride rate.

Since it was assumed that the subjects would be unable to exactly match their stepping frequency with the metronome beat, a procedure similar to that employed in Session #2 was used to determine the average stride length for each subject during two 30-sec intervals (4:30 - 5:00 and 5:30 - 6:00) of each 6-min bout. Oxygen uptake was also measured during the last 2 min of each walking bout using the on-line system described previously. The mean absolute difference in $\dot{V}O_2$ between the two gas collection periods averaged across all SL conditions was 0.3 ml·kg$^{-1}$·min$^{-1}$ (37.6 vs 37.9). Hence, it was concluded that the subjects were in steady-state during the time that $\dot{V}O_2$ was measured.

Data Analysis

The $\dot{V}O_2$ and stride length values corresponding to the five stride length conditions were entered into a least-squares curve-fit routine to generate a polynomial equation that best expressed the relationship between the two variables. This procedure was performed on the data of each subject so that differences in individual response to stride length variation could be examined. Coefficient of determination and standard error of the estimate values were used to select the most appropriate polynomial equation for each individual. Using these equations, predicted $\dot{V}O_2$ values corresponding to the five desired stride lengths (FCSL, $-10\%$, $-5\%$, $+5\%$, and $+10\%$ of the LL from the FCSL) were calculated.

Based on the results of the curve-fit analysis, an optimal stride length (OSL) measure was determined for each subject. This value was derived from individual stride length-$\dot{V}O_2$ equations and represented the stride length at which the predicted $\dot{V}O_2$ was a minimum. The predicted $\dot{V}O_2$ associated with the OSL condition was also identified and was considered to be the optimal $\dot{V}O_2$.

The predicted $\dot{V}O_2$ measures for the five stride length conditions were analyzed using analysis of
variance with repeated measures (ANOVA) to determine whether there were statistical differences in oxygen consumption produced by stride length manipulation. Necessary post-hoc analyses were conducted using a simple t-test. Normally, a more conservative follow-up testing procedure would be recommended. The small sample size for the study, however, meant that resulting statistical power for the test was low. Consequently, it was felt that a simple t-test would be appropriate without dramatically inflating the potential for Type I statistical error. The 0.05 probability level was used for all tests to determine the presence or absence of significant mean differences.

RESULTS

Mean stride length and \( \dot{V}_O_2 \) data for the five walking conditions are shown in Table 1. Included in the table are values representing the actual stride lengths measured during Session #3, associated \( \dot{V}_O_2 \) values, and predicted \( \dot{V}_O_2 \) measures for each of the desired stride length conditions. Input of actual stride length and \( \dot{V}_O_2 \) measures into the least-squares curve-fit routine revealed that data for six of the seven subjects were best-fit by quadratic curves, while data for the remaining subject were best-fit by a cubic curve.

As expected, the subjects were unable to exactly match the desired stride length conditions. The results demonstrated that the absolute differences between actual and desired stride length values were smallest at the FCSL and \(-5\% \text{LL}\) conditions, greater at the \(+5\% \text{LL}\) condition, and largest at the two extreme stride length conditions. Sample means for actual and predicted \( \dot{V}_O_2 \) values indicated that the FCSL was the most economical of the five conditions, with progressively higher energy costs manifested at the \(-5\%\) and \(+5\%\) and \(-10\%\) and \(+10\% \text{LL}\) conditions, respectively.

The ANOVA procedure evaluating the influence of stride length manipulation on oxygen consumption resulted in a significant F statistic (\(F = 3.41\)). Results of post-hoc testing essentially revealed that manipulation of stride length by 5% did not produce significant differences in oxygen consumption from the freely-chosen condition. Only when stride length deviated from the freely-chosen stride length by 10% were the oxygen consumption values significantly different from the freely-chosen value. More specifically, post-hoc analyses demonstrated that the following stride length comparisons showed significantly different \( \dot{V}_O_2 \) values: \(-10\%\) vs \(-5\% \) (\(t = 2.82\)); \(-10\%\) vs FCSL (\(t = 3.28\)); \(-5\%\) vs \(+10\% \) (\(t = 3.85\)); FCSL vs \(+10\% \) (\(t = 4.32\)); and \(+5\%\) vs \(+10\% \) (\(t = 2.88\)).

Table 2 contains predicted values for stride length and \( \dot{V}_O_2 \) associated with the FCSL and OSL conditions for each subject. A mean absolute difference in \( \dot{V}_O_2 \) (\(\Delta \dot{V}_O_2\)) of 0.6 ml·kg\(^{-1}\)·min\(^{-1}\) was observed between the FCSL and OSL conditions, indicating that variation in \( \dot{V}_O_2 \) between the two conditions was minimal. Linked with this deviation in \( \dot{V}_O_2 \) was a mean absolute stride length difference (\(\Delta \text{SL}\)) of 3.2 cm. This difference was equivalent to 3.6% of the subjects’ mean LL.

Changes in \( \dot{V}_O_2 \) plotted as a function of stride length manipulation for 3 subjects. The squares represent the optimal stride length for each subject.

Changes in \( \dot{V}_O_2 \) plotted as a function of stride length manipulation for all subjects.


Mean stride length (SL) and \( \dot{V}O_2 \) values for the five SL conditions

<table>
<thead>
<tr>
<th>Actual SL (ASL)* (%LL)</th>
<th>Desired Stride Lengths (DSL)</th>
<th>-10%LL</th>
<th>-5%LL</th>
<th>FCSL</th>
<th>+5%LL</th>
<th>+10%LL</th>
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</thead>
<tbody>
<tr>
<td>( \bar{x} )</td>
<td>7.91</td>
<td>-4.71</td>
<td>-0.28</td>
<td>3.74</td>
<td>7.96</td>
<td></td>
</tr>
<tr>
<td>(SD)</td>
<td>2.23</td>
<td>0.86</td>
<td>1.22</td>
<td>2.07</td>
<td>3.32</td>
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</table>

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<thead>
<tr>
<th>Actual ( \dot{V}O_2 )b (ml·kg(^{-1})·min(^{-1}))</th>
<th>( \dot{V}O_2 )a (ml·kg(^{-1})·min(^{-1}))</th>
<th>( \bar{x} )</th>
<th>38.2</th>
<th>37.8</th>
<th>36.5</th>
<th>37.1</th>
<th>39.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{x} )</td>
<td>38.2</td>
<td>37.8</td>
<td>36.5</td>
<td>37.1</td>
<td>39.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(SD)</td>
<td>8.9</td>
<td>9.8</td>
<td>9.5</td>
<td>11.0</td>
<td>11.2</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Predicted ( \dot{V}O_2 )c (ml·kg(^{-1})·min(^{-1}))</th>
<th>( \dot{V}O_2 )a (ml·kg(^{-1})·min(^{-1}))</th>
<th>( \bar{x} )</th>
<th>40.1</th>
<th>37.4</th>
<th>36.9</th>
<th>38.3</th>
<th>41.0</th>
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</thead>
<tbody>
<tr>
<td>( \bar{x} )</td>
<td>40.1</td>
<td>37.4</td>
<td>36.9</td>
<td>38.3</td>
<td>41.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(SD)</td>
<td>9.5</td>
<td>9.2</td>
<td>9.9</td>
<td>11.0</td>
<td>12.4</td>
<td></td>
<td></td>
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</tbody>
</table>

*Measured from chart recordings obtained for each SL condition
bMeasured at each actual SL condition
Values obtained from individual SL-\( \dot{V}O_2 \) polynomial equations for each of the desired SL conditions

Even though mean values for the sample indicated that the FCSL was the most economical of the five conditions, the results of the study also demonstrated that the subjects displayed a wide range of individual responses to stride length manipulation. Typical stride length-\( \dot{V}O_2 \) curves for 3 subjects are shown in Figure 1 to illustrate the variation in subject responses. A fairly symmetrical \( \dot{V}O_2 \) response pattern across the five conditions was observed for Subject #1. This subject displayed similar increases in \( \dot{V}O_2 \) for equal increases and decreases in stride length from his FCSL. In addition, his OSL was quite close (-1.2%LL) to his FCSL. Subject #4, on the other hand, displayed a more economical walking pattern at the longer stride length conditions and had an OSL that was substantially longer (+5.1%LL) than her FCSL. In contrast to this response, Subject #3 was more economical when walking at the shorter stride length conditions. The OSL for this subject was also considerably less (-5.1%LL) than her FCSL. Individual stride length-\( \dot{V}O_2 \) curves for all subjects are displayed in Figure 2.
DISCUSSION

Results of this study support the hypothesis advocated by Cavanagh and Williams (1982) that trained subjects eventually adopt locomotion patterns that tend to minimize the energy cost at a particular speed. These data also indicated that slight alterations in stride length from the FCSL did not substantially increase the energy requirement needed to racewalk at various submaximal speeds. The FCSL selected by 5 of the 7 subjects were longer than their OSL, indicating a tendency to overstride. This finding does not appear to be significant, however, given the relatively small change in VO₂ observed between the FCSL and OSL conditions.

Although a wide variation in racewalking VO₂ max (range = 30.8 - 58.3 ml·kg⁻¹·min⁻¹) was present, the influence of stride length manipulation on energy cost at the five stride length conditions was generally the same across subjects (Figure 2). A similar pattern of metabolic response was also reported by Cavanagh and Williams (1982) in runners exhibiting a high level of aerobic training (mean VO₂ max = 64.7 ml·kg⁻¹·min⁻¹). Taken together, the results of the two studies imply that the curvilinear relationship between stride length manipulation and VO₂ is relatively independent of subject variation in VO₂ max. In addition, a comparison of the two studies indicates that the general pattern of VO₂ changes associated with stride length manipulation is similar for racewalking and running.

The advantage gained by altering the FCSL towards a more optimal setting depends upon the magnitude of the ΔVO₂ as well as the amount and importance of the improvement in racewalking time associated with such a change. In an attempt to assess the relative contribution of these variables from a theoretical perspective, the relationship between treadmill speed and VO₂ at the FCSL was determined by linear regression analysis. The result of this analysis, a VO₂ cost-curve, is shown in Figure 3. Within the range of paces examined herein, data from this figure suggests that a 2.7 m·min⁻¹ increase in walking speed could be sustained for every 1 ml·kg⁻¹·min⁻¹ increment in VO₂. Based on the mean ΔVO₂ of 0.6 ml·kg⁻¹·min⁻¹ found for the sample, optimizing stride length would result in a hypothetical improvement in racewalking speed of 1.6 m·min⁻¹ (2.7 x 0.6). The practical significance of this speed increase during sustained walking at the OSL is illustrated by the following example. A racewalker who was able to maintain a speed of 159.4 m·min⁻¹ (the mean treadmill speed utilized during the stride length manipulation portion of the present study) would cover 50 km in 313.7 minutes. By optimizing stride length (assuming a ΔVO₂ of 0.6 ml·kg⁻¹·min⁻¹), this subject would be able to racewalk 50 km at a speed of 161.0 m·min⁻¹ (159.4 + 1.6 m min). This faster speed would result in a reduction in total walking time to 310.6 minutes, thus producing a time savings of 3.1 minutes. While this improvement may seem trivial, as does the 0.6 ml·kg⁻¹·min⁻¹ ΔVO₂ mean difference between the FCSL and OSL conditions, it should be noted that finishing positions in racewalking competitions are often separated by only a few seconds. In particular, well-trained or elite racewalkers who deviate markedly from their OSL condition could realize a marked improvement in walking performance by optimizing their stride length. For instance, if subject #6 (who displayed a ΔVO₂ of 1.3 ml·kg⁻¹·min⁻¹) was fit enough to racewalk 50 km at his normal 10 km training pace (190 m·min⁻¹), he could potentially reduce his total walking time at this distance nearly 5 minutes by optimizing his stride length. In practical terms, this improvement in racewalking performance may be substantial enough to significantly raise his subject’s order of finish in a 50 km race.

![Diagram](image)

**FIGURE 3**

The relationship between walking velocity and VO₂ at the Freely-Chosen Stride Length (FCSL).

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

The relationship between stride length manipulation and racewalking economy was
determined in a group of 7 competitive racewalkers who racewalked at their individual 10 km training paces. Results of the study indicated that for most subjects, walking at the FCSL was more economical than walking at stride lengths longer and shorter than the FCSL. Individual differences in VO2 responses at the various stride length conditions, however, were manifested. The small differences in VO2 and stride length observed between the FCSL and OSL conditions supports the hypothesis that trained subjects adopt locomotion patterns that are nearly optimal in terms of the aerobic demands. From a performance standpoint, these data suggest that modification of the FCSL is not necessary for most racewalkers. The elite performer who exhibits a substantial deviation in ΔVO2, however, might particularly benefit by lengthening or shortening their FCSL towards more optimal conditions.

Data obtained from this study raise two interesting questions for future research. First, does the VO2 response to stride length manipulation in elite racewalkers vary at different submaximal speeds? And secondly, would a prolonged period of OSL training in subjects exhibiting uneconomical tendencies (e.g., a substantial ΔVO2) shift the FCSL towards a more optimal setting? Answers to these and other related questions should provide a more complete understanding of the physiological, biomechanical, and training components which influence stride length selection and racewalking economy.

REFERENCES

AUTHOR NOTES
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