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THE PHYSIOLOGICAL IMPORTANCE OF PREFFERED STRIDE FREQUENCY DURING RUNNING AT DIFFERENT SPEEDS

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ABSTRACT

Mercer J, Dolgan J, Griffin J, Bestwick A. The physiological importance of preferred stride frequency during running at different speeds. ***JEP****online* 2008;11(3):26-32. The purpose of this study was to determine if rate of oxygen consumption (VO_2) during running is influenced by an interaction of stride frequency (SF) and running speed. Ten well-trained runners (66.3±8.8 kg; 23±5 yrs; 1.75±0.1 m) completed 3 15-minute runs. During each 15-minute run, subjects ran for 5 minutes at speeds of 3.13, 3.58, and 4.02 m/s. During the first 15-minute run, subjects were allowed to freely select a preferred stride frequency (PSF). The remaining two 15-minute runs consisted of running using SF that were ±15% of PSF at each speed. Using a repeated measures ANOVA, it was determined that VO_2 was different across speeds ($p<0.05$) and tended to be different between SF ($p=0.059$) with no interaction between speed and SF observed ($p>0.05$). VO_2 was less during running at PSF than when using the 15% lower SF at 3.13 m/s and 3.58 m/s ($p<0.05$). VO_2 was not different between other SF comparisons. PSF did change across speeds, but the change was subtle (about 4% per m/s increase in speed). It seems that there is an optimal SF range across speeds vs. a unique optimal SF at each speed that is important to maintain during distance running.

Key Words: Economy, Optimization, Locomotion, Energy Cost.

INTRODUCTION

A theory explaining the coordination of bipedal locomotion is that locomotion is accomplished in such a way that energy expenditure is minimized (1). Extending this to running, it has been shown that runners naturally adopt a running style that results in minimizing the rate of oxygen consumption (VO_2) for running a given speed (2, 3, 4). There are many ways to describe running style, but the basic kinematic descriptors are stride frequency (rate of right or left foot strikes) and stride length (distance covered between consecutive right or left foot strikes).

In general, it has been determined that runners will naturally select a stride frequency – stride length combination that results in the lowest VO_2 (2-4). Observations such as this seem to provide evidence that runners optimize running style on physiological criteria. The self-selected stride frequency – stride length combination is typically referred to as the preferred stride frequency (PSF) and preferred stride length (PSL). A general methodological approach that is used to compare VO_2 across stride frequencies is to set a treadmill speed and have runners naturally select their PSF for that speed. Additional experimental conditions would then consist of different stride frequencies while running the same speed (and therefore stride length also changes). This experimental model has been useful in understanding the relationship between VO_2 and stride frequency. However, very little is known about how this relationship is influenced by changes in running speed.

As running speed changes, runners naturally change PSF and PSL (5,6,7,8,9). In two early studies (10,11), VO_2 was compared while running at different stride frequencies and stride lengths at different speeds and it was suggested that the runners had the lowest VO_2 at the preferred stride frequency at different speeds. However, the number of subjects in these studies was low (Hogberg, 1952; (10) n = 1; Kaneko et al., 1987; (11) n = 4) and neither study presented a statistical comparison of VO_2 across stride frequency - speed conditions. Therefore, the purpose of this study was to basically replicate these studies and determine if VO_2 during running is influenced by an interaction of stride frequency and running speed. A second purpose of the study was to determine if VO_2 was different between a preferred running style and slightly different running styles as described by changes in stride frequency.

METHODS

Subjects

Ten well-trained runners (4 females, 6 males; 66.3 ±8.8 kg; 23 ±5 yr; 1.75 ±0.1 m) participated in the study after giving written informed consent according to a protocol approved by the Institutional Review Board at the University of Nevada, Las Vegas.

Instrumentation

Rate of oxygen consumption was recorded using either the Vista mini-CPX or Orca Diagnostic metabolic analysis system. During the course of the study, the laboratory changed metabolic instrumentation. Therefore, for the first six subjects, VO_2 was measured using a Vista mini-CPX (model 117670); for the last four subjects, VO_2 was measured using Orca Diagnostics. Both systems required subjects to breathe through a mask that was connected to metabolic cart so that expired gases could be analyzed. Prior to testing, the system used was calibrated following manufacturer directions. During testing, VO_2 data were recorded every 15 seconds. All running conditions were completed on a treadmill (Quinton Instruments, Seattle, WA).

Procedures

Prior to testing, time was allowed for subjects to complete a warm-up run on the treadmill. Following the warm-up session, subjects were asked to complete a total of 3 15-minute runs. During each 15-minute run, subjects ran for 5 minutes at speeds of 3.13, 3.58, and 4.02 m/s. These speeds were selected to represent typical training paces and it was thought that subjects would likely be able to complete all stride frequency conditions at these speeds. Speed was always increased from slow to fast and the 15-minute run was always continuous. During the first 15-minute run, subjects were allowed to freely select a stride frequency – stride length combination, with no instructions given to the subjects regarding stride frequency and stride length. This first condition was therefore called the Preferred Stride Frequency (PSF) condition.

Since stride frequency can change with increases in running speed (5-9), PSF was measured at each speed (i.e., $PSF_{3.13}$, $PSF_{3.58}$, $PSF_{4.02}$) by recording the time to complete 20-strides (i.e., right foot contact to right foot contact). This measurement was taken at the 2nd and 4th minutes of each 5-minute stage. The average of these two values was used to determine the stride frequency for the remaining two 15-minute conditions. In these conditions, runners ran at specific stride frequencies that were based upon a percentage of PSF at each speed. One 15-minute run required subjects to use a stride frequency that was 15% greater than the PSF at each speed ($PSF_{+15\%}$). The other 15-minute run required subjects to use a stride frequency that was 15% slower than the PSF at each speed ($PSF_{-15\%}$). During these conditions, a metronome attached to speakers was used to provide an auditory key the subject into using the prescribed stride frequency. During testing, stride frequency was recorded at the 2nd and 4th minute of each stage. The average of the two values per stage was used to check post-hoc that the target stride frequencies were achieved. The order of conditions was always PSF first with $PSF_{+15\%}$ and $PSF_{-15\%}$ counterbalanced. Subjects were allowed time between each 15-minute run to rest and recover before beginning the next condition.

Data Reduction

Rate of oxygen consumption data were analyzed by first plotting against time for each 15-minute run and calculating a line of best fit. Discrete VO_2 values corresponding to the third minute of each 5-minute stage were determined using the line of best fit and used for analysis. One subject was not able to complete one stage (the last 5-minute stage of the last 15-minute run). Another subject completed only two minutes of the last stage. In this case, the discrete VO_2 value was calculated for the start of the second minute of the stage (vs. third minute). In both cases, subjects voluntarily stopped and indicated that it was too difficult to maintain the cadence/speed combination. The statistical analyses were compared with and without these subjects and there was no change in the statistical outcome of the study and, therefore, we have presented only the statistical analyses with these subjects retained.

Statistical Analyses

Rate of oxygen consumption was compared across conditions using a 3 (Speed: 3.13, 3.58, and 4.02 m/s) x 3 (Target stride frequency: $PSF_{-15\%}$, PSF, $PSF_{+15\%}$) repeated measures ANOVA (SPSS Inc., version 11.5.2.1). Actual stride frequencies were also compared using a 3 (Speed: 3.13, 3.58, and 4.02 $m \cdot s^{-1}$) x 3 (Target stride frequency: 85%, 100%, 115%) repeated measures ANOVA in order to confirm that the stride frequency conditions were different from each other. It was planned to contrast PSF across speeds as well as VO_2 between stride frequencies at each speed. Alpha level was set to 0.05.

RESULTS

Stride frequencies achieved were different across speeds ($F_{2,16}$ = 17.37, p<0.001) and target stride frequencies ($F_{2,16}$ = 76.16, p<0.001) with no interaction between speed and target stride frequency observed ($F_{4,32}$=0.74, p=0.568). The PSF at 3.13 m/s was not different from the PSF during 3.58 m/s ($F_{1,9}$ = 4.09, p=0.074), but was different from 4.02 m/s ($F_{1,9}$ = 16.20, p=0.003). Rate of oxygen consumption was different across speeds ($F_{2,16}$ = 68.47; p<0.001), but not different between stride frequencies ($F_{2,18}$ = 3.40, p = 0.059; Table 1 and Figure 1) with no interaction between speed and stride frequency observed ($F_{4, 32}$ = 0.87, p = 0.495; Table 1). Using planned contrasts, it was determined that VO_2 was less during running at PSF compared to the VO_2 during $PSF_{-15\%}$ conditions while running 3.13 m/s ($F_{1,8}$ = 13.19, p = 0.007) and 3.58 m/s ($F_{1,9}$ = 18.15, p=0.002) but not different between PSF and $PSF_{-15\%}$ at 4.02 m/s ($F_{1,8}$ = 1.79, p = 0.213). Rate of oxygen consumption was not different between PSF and $PSF_{+15\%}$ at any speed (3.13 m/s: $F_{1,8}$=1.51, p=0.254; 3.58 m/s: $F_{1,8}$ = 0.98, p = 0.349; 4.02 m/s: $F_{1,8}$ = 0.14, p = 0.716).

Table 1: Group means and standard deviations for the stride frequencies (strides·min^{-1}) achieved during each target stride frequency condition and rate of oxygen consumption (ml·kg^{-1}·min^{-1}) per condition.

Speed (m/s)	Target Stride Frequency (% of PSF)	Observed Stride Frequency† (strides / minute)	Observed Stride Frequency (% PSF)	VO_2 (ml·kg^{-1}·min^{-1})
	85%	74.9 ±4.6	90.0 ±4.0	38.8 ±4.3*
3.13	100%	83.2 ±3.5	100.0 ±0.0	34.7 ±4.0*
	115%	92.7 ±5.2	111.4 ±4.2	35.9 ±6.8
	85%	76.4 ±3.9	90.0 ±4.4	42.8 ±6.3*
3.58	100%	84.9 ±2.4	100.0 ±0.0	39.7 ±5.0*
	115%	94.0 ±5.4	110.8 ±5.1	40.9 ±7.5
	85%	78.7 ±3.6	90.7 ±4.2	46.9 ±8.8
4.02	100%	86.8 ±2.4	100.0 ±0.0	45.3 ±6.0
	115%	96.1 ±5.5	110.7 ±4.6	45.8 ±8.7

. †Stride frequency was different between target conditions and speeds (p<0.05) with no interaction between speed and target condition (p>0.05). *Rate of oxygen consumption was different between PSF and $PSF_{-15\%}$ during running at 3.13 m/s and 3.58 m/s (p<0.05) but was not different between stride frequency conditions running at 4.02 m/s (p>0.05) nor was it different between PSF and $PSF_{+15\%}$ at any speed (p>0.05)

DISCUSSION

Rate of oxygen consumption increased with faster running speeds, as expected, but there was no interaction effect between VO_2 and stride frequency. Using planned comparisons of VO_2 between stride length conditions at each speed, it was determined that VO_2 was less when runners used their PSF compared to a lower stride frequency at the slower speeds but VO_2 was not influenced by stride frequency when using the faster stride frequency. It makes sense that changes in stride frequency had less influence on VO_2 at faster running speeds since there is a ceiling effect of VO_2 defined by the maximum rate of oxygen consumption (VO_{2max}). That is, when running at speeds that approach VO_{2max}, changes in stride frequency will not cause VO_2 to increase beyond that maximum rate.

Although subjects did not achieve the target stride frequencies of ±15%, the frequencies that were achieved were significantly different than the PSF at each speed. It is not clear why runners could not achieve the target stride frequencies. During data collection, a metronome was used to indicate the frequency and a research team member was dedicated to helping the subjects achieve the target frequency. Despite that effort, subjects simply seemed to want to drift towards the PSF, especially as running speed increased. Qualitatively, subjects often related that running at the stride frequencies other than the preferred was very difficult, especially at the faster speeds. A limitation of this study was that the novelty of maintaining a prescribed stride frequency combined with the increased physiological demand of running with a stride frequency other than PSF made achieving steady state difficult. For this study, we focused our analysis on VO_2. If markers of anaerobic energy production were measured, we would expect to see a greater amount of anaerobic energy production at the ±15% stride frequency conditions at the fast running speed and that type of analysis would further emphasize the importance of using the preferred running style. However, it is not known whether or not the results of this study would be different if subjects had trained at frequencies other than PSF.

Although it is accepted that changes in submaximal speeds are accomplished primarily through changes in stride length (vs. stride frequency), it is not entirely clear why little change in stride frequency occurs. In our study, there was only a 4% increase in stride frequency per $m \cdot s^{-1}$ increase in running speed. This change is similar to other studies that have reported a change in stride frequency ranging about 5-10% change in stride frequency per m/s increase in speed (5,7-9). Interestingly, there are other situations where challenges have been introduced to the runner and the preferred stride frequency does not change or changes very little. For example, preferred stride frequency does not change despite a change in ground-surface stiffness characteristics (12) or when running on sand (13). Likewise, there was no difference in preferred stride frequency between day testing (14) or across a 7-week training period (15) or when loads of up to 1.1 kg were added to the distal aspect of the leg (16). Only subtle changes in stride frequency have been observed when a runner becomes fatigued while required to run a set speed (17,18,19,20) or when subjects ran in springboots (a rollerblade type boot with a spring attached at the bottom surface) (21,22). These observations indicate that the PSF is quite stable despite challenges (e.g., speed, footwear, surface characteristics, and physiological state) imposed on the runner.

The observation that PSF is maintained under a variety of conditions is likely related to economy of locomotion. Nevertheless, further research is needed to better understand factors that influence the selection of PSF. The importance of only subtle changes in PSF across speeds (or other situations) may be that there is an optimal stride frequency range which runners try to work within for any speed as opposed to a unique optimal stride frequency for each speed situation. Although the relationship between VO_2 and stride frequency may be described as a U-shaped relationship such that VO_2 tends to increase as stride frequency is increased or decreased relative to the PSF, based upon our experiment it seems that there is a flat portion of the relationship around the PSF in which changes to stride frequencies do not negatively influence VO_2. Therefore,

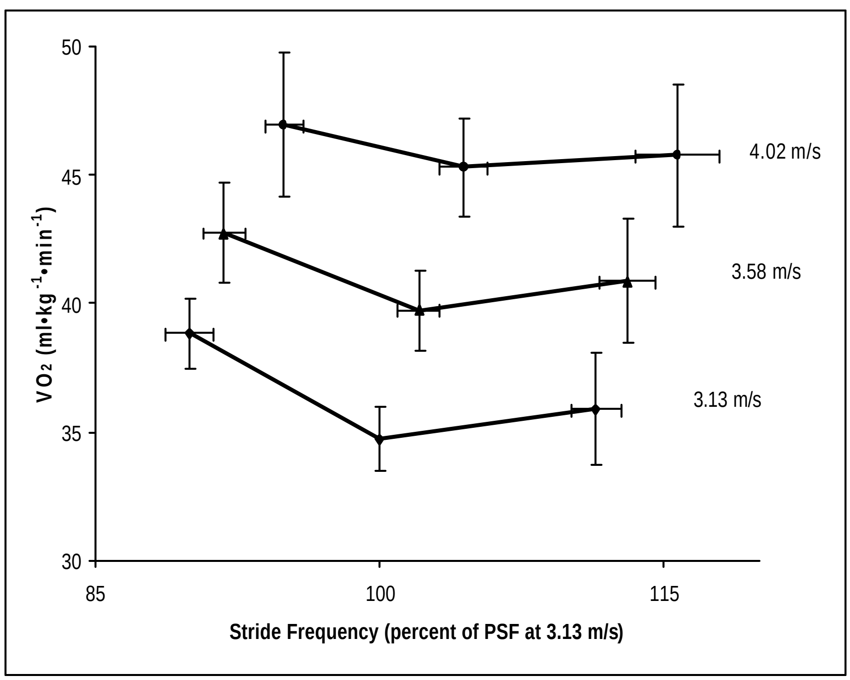

Figure 1: Group means and standard errors for rate of oxygen consumption (VO_2 $ml \cdot kg^{-1} \cdot min^{-1}$) vs. stride frequency ($strides \cdot min^{-1}$). For illustration purposes, all stride frequency conditions were normalized to the preferred stride frequency condition while

there are likely other factors (e.g., biomechanical, anthropometric) that influence the selection of PSF. For example, changes in stride frequency influence ground reaction forces (23) and there may be situations when PSF is determined by a need to modify the impact force.

Although running is achieved with seemingly little conscious thought, the runner must be able to integrate perception of salient features of the environment with pertinent physiological information in order to coordinate the contractions of many different muscle groups to achieve an appropriate running behavior. Minimizing VO_2 is clearly an important criterion driving running behavior and the ability to minimize VO_2 is linked to the chosen stride frequency. Despite the strong physiological reason for runners selecting a similar stride frequency during different running conditions it seems that there is some flexibility in the system and a runner can select from a range of frequencies that do not negatively influence VO_2.

CONCLUSIONS

At the speeds tested (3.13, 3.58, 4.02 m/s), VO_2 increased with speed and was lower only while running using the PSF than when using a slower stride frequency at the 3.13 m/s and 3.58 m/s speeds. Although VO_2 was not influenced by the interaction between stride frequency and speed, the magnitude of difference of VO_2 between the stride frequency conditions became smaller as speed increased, with no difference observed in VO_2 between stride frequency conditions at the fastest speed (4.02 m/s). Finally, PSF did change across speeds, but the change was subtle (about 4% per m/s increase in speed). We conclude that there is an optimal stride frequency range across speeds that is important for runners to work within during distance running but not a unique optimal stride frequency at each speed.

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