THE EFFECT OF STRIDE FREQUENCIES ON RUNNING PERFORMANCE AT THE VELOCITY OF VO_2MAX

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Abstract

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Running economy(RE) is considered to be a critical factor to improve running performance. Stride frequency(SF) is an important variable for determining RE. The importance of SF has gained more attention in recent years, especially for recreational runners. However, no previous research has investigated the interaction between running performance and SF at the velocity of VO_2max. **PURPOSE:** To investigate the effect of five different SF variations on running performance until volitional fatigue at the velocity of VO_2max. **METHODS:** Fourteen male recreational runners (Age = 25.8 ± 4.96 years, Height = 171 ± 6.2cm, Body Mass = 71.9 ± 7.5kg) measured VO_2max (54 ± 5.6 ml/kg/min) and preferred stride frequency (PSF; 89.3 ± 4 / min) through a graded exercise test (GXT) and running session, respectively. Running speed was determined based on each individual's VO_2max via the metabolic equation for gross VO_2 in metric units by ACSM. Participants ran on the treadmill (0% grade) with five SF conditions (PSF, ±5%, ±10%) until time to exhaustion. Data were analyzed using a one way ANOVA with repeated measures and Tukey HSD post hoc. **RESULTS:** The total running performance (time, distance), energy expenditures (kcal), and oxygen consumption (VO_2) were statistically significant among SF variations ($p<0.05$). Additionally, the respiratory exchange ratio

(RER), respiratory rate (RR), and ventilation (V_E) were no statistically significant ($p>0.05$). **CONCLUSION:** The SF variations have a significant influence on running performance. The relationship between SF variations and other variables (RER, RR, V_E) were possibly related to the central governor theory to delay the onset of fatigue. These results suggest that recreational runners could use a 105% of PSF to improve running performance with the better RE.

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Introduction

Running is an important and widespread exercise mode from all populations to professional athletes. The main reasons and motivations for running include: improving a general health and an athletic performance, as well as preventing several disease risk factors of coronary heart disease, diabetes, hypertension, and certain cancers (1,3,38). According to Blair et al. (1), the higher levels of measured cardiorespiratory fitness from the maximal treadmill test had relevance to reducing cardiovascular disease risk factors objectively. For these reasons, running performance is widely used to evaluate cardiorespiratory fitness levels (6,21).

One of the crucial components of classifying one's cardiorespiratory fitness level is to measure the maximum oxygen uptake (VO_2max) (5,7,9,10). However, even though the most accurate and ideal way of measuring VO_2max is in a laboratory setting, this method is not practical for measuring large groups of individuals as it requires expensive equipment, qualified technicians, and a considerable amount of time. Moreover, VO_2max is influenced by many physiological variables such as all energy systems (aerobic and anaerobic), hemoglobin mass, stroke volume, muscle fibers recruitment and body composition, and muscle capillary density (13,27).

For these limitations, running economy (RE) should be considered as a better prediction to determine one's running performance, while also including the measurement of VO2max (32,36). RE is considered to be a critical factor to improve running performance (24). There are a variety of variables that could influence RE and include as running environment, age, training status, stride length, stride frequency, weight, lactate and ventilate threshold and others (13,15,28,31,32). Among these variables to determine RE, stride frequency (SF) is closely related to RE (3).

Previous studies have concluded that humans tend to self-select a SF at a certain speed in order to be a better RE spontaneously (15,19). Specifically, running at 90 strides/min is considered to be an optimal SF to minimize oxygen consumption for elite runners (24,32,34). Other research has demonstrated that runners often choose 81-94 strides/min for lowest running cost (4,32) and self-selected SF showed the lowest energy cost compared to other SF conditions (15). Mercer et al. (19) explained that participants naturally increased their PSF by increasing speed, but oxygen consumption were not changed significantly. De Ruiter et al. (15) demonstrated the PSF in both novice and trained runners was lower than their optimal SF. In addition, increasing SF five to ten percent above PSF reduced joint pain, vertical impulse, energy absorption of lower limb muscles, and fatigue (3,13). Conversely, a lower SF condition from PSF increased O_2 consumption when compared to PSF (19,20). Overall, a considerable quantity of research has established the relationship between SF variations and RE. Previous studies examined the relationship between the different percentages of SF and oxygen consumption or biomechanical kinematics such as center of mass, joint angular velocity, and muscle activation via EMG (13,17,19,20,22,23). Furthermore, the running speed chosen in previous research was typically at submaximal intensities consisting of self-selected speed, or running below LT or VT (15,17,19,28,39).

Therefore, it was postulated that running performance will be significantly different depending upon SF variations while running at the velocity of VO2max. Even though VO_2 will not be significantly different at the velocity of VO_2max, conditions in which a higher SF is used compared to PSF will reveal better running performance in terms of distance and time. However, no previous research has investigated the interaction between running performance and SF while running to exhaustion at the velocity of VO_2max. The purpose of this study is to investigate the impact on running performance when using five different stride frequencies (PSF, ±5%, ±10%) during constant speed running at the velocity of VO_2max. Specifically, this study aims to determine the optimal SF for maximizing running performance at VO2max through five experimental sessions.

Methodology

Participants. Fourteen male recreational runners who were running at least three days a week volunteered to participate in the current study. Participants needed to be between the age of 18 - 44 years old in order to eliminate one positive risk factor of age according to CVD risk factor classification by providing ACSM. All participants must be qualified above good classifications on the "fitness categories for maximal aerobic power" (2) depending on their age groups and were free from lower and upper extremities injuries during running at least last six months. In addition, participants were excluded if they were currently taking any medication that altered the cardiovascular system (e.g., stimulants, β-blocker). They should not have more than two positive risk factors from the Physical Activity Readiness Questionnaire (PAR-Q) (Canadian Society for Exercise Physiology: CSEP) and medical history questionnaire. Participants were instructed to refrain from alcohol, coffee or any beverages containing caffeine, and intense exercise for 48 hours before the experimental trials. In addition, participants were instructed to intake food in 2 hours before each trial but maintain their normal diet routine. All participants provided written informed consent, and the experimental design and protocol for this study was approved by the Institutional Review Board of the Humboldt State University.

Graded Exercise Test (GXT). All participants performed a standard Bruce protocol on a motorized treadmill (TM55LXXRQE, Quinton, Cardiac Science Corp, Bothell, WA, USA) for determination of participant's VO_2max. Achievement of VO_2max will be based on meeting at least two of the following criteria: (a) a plateau in VO_2 less than 150 ml/min, (b) a respiratory exchange ratio above 1.15, (c) a heart rate within 10 beats per minute of age-predicted maximum heart rate, or (d) a rating of perceived exertion over 18 (5,23). During the graded exercise test, expired air was measured for oxygen, carbon dioxide, ventilation, and quantity contents using a metabolic cart (MMS-2400, Parvo Medics, UT, United States). Data collection was set to record gas analysis every 15 seconds because it is more difficult to detect a plateau in VO_2 with larger time averages than smaller time averages (5). Heart rate was recorded every second with a wearable transmitter (Polar 800CX, Polar, Finland); maximum heart rate was considered the highest value achieved during the testing duration. In addition, subjects reported their perceived exertion using the Borg's Rating of Perceived Exertion Scale (RPE) at the end of each 3-minute stage. From this GXT data, the actual metabolic data (VO_2max) was converted to the running pace and speed based on the "Fitness Categories for Maximal Aerobic Power" and a metabolic equation for gross VO_2 in metric units (2) in order to apply constant running speed practically to the experimental running sessions with controlling SF.

Table 1. Metabolic equation for gross VO2 in metric units

$$VO_2 = (0.2 \times \text{Speed}) + (0.9 \times \text{Speed} \times \text{Grade}) + 3.5$$

VO_2 is gross oxygen consumption in ml/kg/min
Speed is in m/min
Grade is the percent grade expressed as a fraction

The Constant Running Session without SF intervention. Participants completed a constant speed running session at the velocity of VO_2max on the treadmill to determine PSF without an intervention. According to Fletcher et al (31), running on a treadmill at constant speed is the fundamental way to measure of RE. The aim of running distance decided was 1.5-mile (2.4km) in accordance with the normative data (2,8,21). Previous research has shown that the 1.5-mile run test had a high correlation (r=0.87) with VO_2max (24). In addition, the minimum distance and duration to measure cardiorespiratory fitness level were 1.5-mile (2.4km) and 12 minutes (21). Participants were instructed to run with their self-selected SF with their maximum effort until reaching 1.5-mile. Since running pace during mid and long-distance endurance running was not the same due to pace strategy and fatigue (33), SF should be determined as a mean value. Therefore, the PSF was considered as a mean value of an observed SF in the 1st running session, then calculated target SF conditions (PSF, ±5%, ±10%) for each individual.

The Running Sessions with SF variations. Participants ran at the velocity of VO_2max with different SF conditions (90%, 95%, PSF;100%, 105%, and 110%) on the motorized treadmill (Platinum Club Series Treadmill, Life Fitness, Rosemont, IL) in five different trials. A minimum of 48 elapsed between sessions to avoid any muscle stiffness or discomfort of the lower limbs. The sequence of experimental sessions was determined randomly in a counterbalanced format. Participants ran to exhaustion, and exhaustion was determined as volitional fatigue or when the participant could not longer maintain the given SF. Prior to each experimental session, participants performed a warm-up running for five minutes at their self-selected speed to familize to the experimental session, followed by a dynamic stretching routine that included leg swing, high knees, etc. (8). During warm-up running, a computer based metanome was set to each participant's target SF in order to famarlize to the new SF. The treadmill was set to a constant speed which was equivalent to to the velocity at VO2max with a 0% percent grade of incline. Heart rate and SF were measured continuously using a wearable device (CX800 & S3+, Polar, Finland). RPE was asked every two minutes to correspond with their exertion level. In addition, the oxygen consumption (VO_2), ventilation (V_E), energy expenditure (kcal), respiratory exchange ratio (RER), and respiratory rate (RR; breaths/min) were also measured by a metabolic cart (MMS-2400, Parvo Medics, UT, United States).

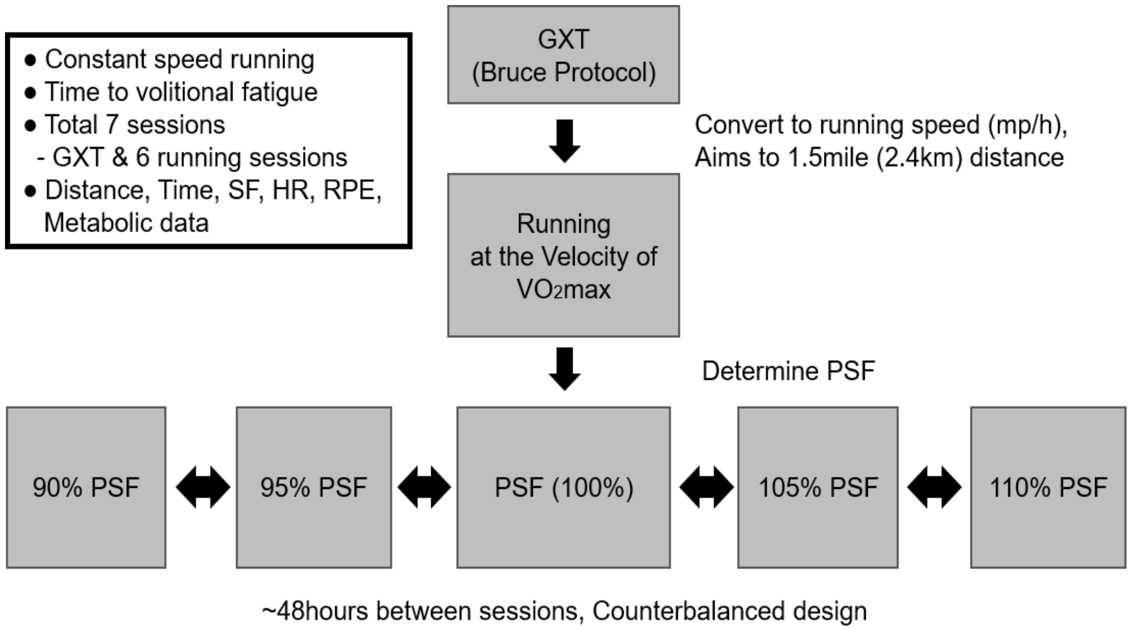

Figure 1. Experimental design

Statistical Analyses. Statistical analyses were performed using STATISTICA version 7.1 software (StatSoft, Inc., Tulsa, OK). A repeated-measures one-way ANOVA test was used for each of the following variables to examine the differences in running distance, oxygen consumption, respiratory rate, energy expenditure, ventilation, and RER among five different stride frequency variation. Normal distribution was checked and subsequently confirmed using Kolmogorov-Smirnov test. There were no violations of assumption of normality, linearity, and homogeneity. When an F-ratio obtained was statistically significant, post hoc comparisons were made using Tukey Honest Significant Difference (HSD) tests and a criterion for significant level was accepted at $p \leq 0.05$.

Results

Participants characteristics. The descriptive data of participants is represented in Table 2. Fourteen male recreational runners who run at least a total of 150 minutes per week, completed 7 experimental sessions. The age range of the participants was between 22 and 35 years old. Each participant met the criteria of taking part in this study via pre-assessment screening and the excellent classifications of GXT.

Body mass index (BMI) category was normal (healthy weight). Two subjects excluded from the study due to failure to keep at a given SF during the whole experimental sessions. Furthermore, running duration and distance converted from GXT were approximately 9.55 minutes, 1.84 miles (2.96km) based on the equations provided from ACSM (2). The environment conditions (temperature; C°, barometric pressure, and humidity) in the laboratory were maintained for all testing sessions.

Table 2. Descriptive characteristics of the participants (N = 14) †

Age(y)	Height(cm)	Weight(kg)	BMI(kg/m)	*VO_2max	Speed(km/h)
25.8 ± 4.9	171.4 ± 6.2	71.9 ± 7.5	24.4 ± 1.7	54.0 ± 5.6	15.1 ± 1.7

† Value are given as mean ± SD.
* Relative VO_2max value (ml/kg/min)

Running distance. Running distance was originally measured in miles, then converted to the universal distance unit in km. The total running distance was significantly different among SF variations. (F 4,52) = 18.78, $p < 0.01$. The tukey HSD post hoc test determined that running distance at the four SF conditions were significantly different when compared to 105% of PSF in terms of total distance covered while running to exhaustion ($p < 0.01$ at 90%, 95%, and 110% of PSF and $p < 0.05$ only between PSF and 105% of PSF). Furthermore, there were statitically significant difference between PSF and two SF conditions ($p < 0.01$, $p < 0.05$ respectively) at 90% and 95% of PSF. However, there were no significant differences between PSF and 110% of PSF ($p=0.22$). All participants ran the furthest distance (2.53 ± 0.89 km) at 105% of PSF when compared to all other SF conditions. By contrast, participants ran the shortest distance (1.46 ± 0.69 km) at 90% of PSF. Running distance covered during the other SF variations included: 1.69 ± 0.66, 2.12 ± 0.82, 1.83 ± 0.86 km at 95%, 100%, and 110% of PSF respectively.

Table 3. Relationship between SF variations and distance

SF variations	Target SF	Actual SF	Percentages (%)	Distance (km)
90%	79.1 ± 3.4	81.3 ± 2.8	102.8 ± 1.3	1.46 ± 0.69**Ψ Ψ
95%	83.7 ± 3.5	84.6 ± 3.5	101.1 ± 0.7	1.69 ± 0.66** Ψ
100%	88.5 ± 4.9	88.5 ± 4.4	100.0 ± 1.1	2.12 ± .082*
105%	92.5 ± 4.2	92.3 ± 3.7	99.8 ± 1.0	2.53 ± 0.89
110%	97.0 ± 4.4	96.9 ± 5.3	99.8 ± 1.4	1.83 ± 0.86**

All data represented by mean ± SD. The SF variations represented % of PSF.
The actual SF means measured SF (stride/min) during experimental sessions.
The percentages were calculated as [(Actual SF/Target SF) × 100].
The comparison of 105% PSF (*p<0.05, **p<0.01) and PSF (Ψ p<0.05, ΨΨ p<0.01)

Oxygen consumption (VO2). The mean VO_2max was 55.4 ± 6 ml/kg/min from the GXT, 52.2 ± 6.6 ml/kg/min from the 1st running session for determining PSF, 51.7 ± 0.5 ml/kg/min during the five experimental sessions with SF variations. The VO_2 values were

94.3 ± 4.4 % between the 1st running session and GXT, 93.3 ± 4.1 % between five running sessions with SF variations and GXT, and 100 ± 3.5 % between the 1st running session and five running sessions. The VO_2 values during five experimental sessions with different SF conditions were statistically significant (F 4, 36) = 3.91, $p < 0.05$. Through the Tukey's post hoc in comparison of 105% PSF, there was only statistically significant at 90% of PSF ($p < 0.05$). The mean VO_2 value at the 105% and 90% of PSF were 53.3 ± 6.5 and 50.1 ± 6.2 ml/kg/min. In addition, the mean VO_2 value at the 95%, 100%, and 110% of PSF were 50.9 ± 5.3, 52.6 ± 6.4, 51.54 ± 6 ml/kg/min, respectively.

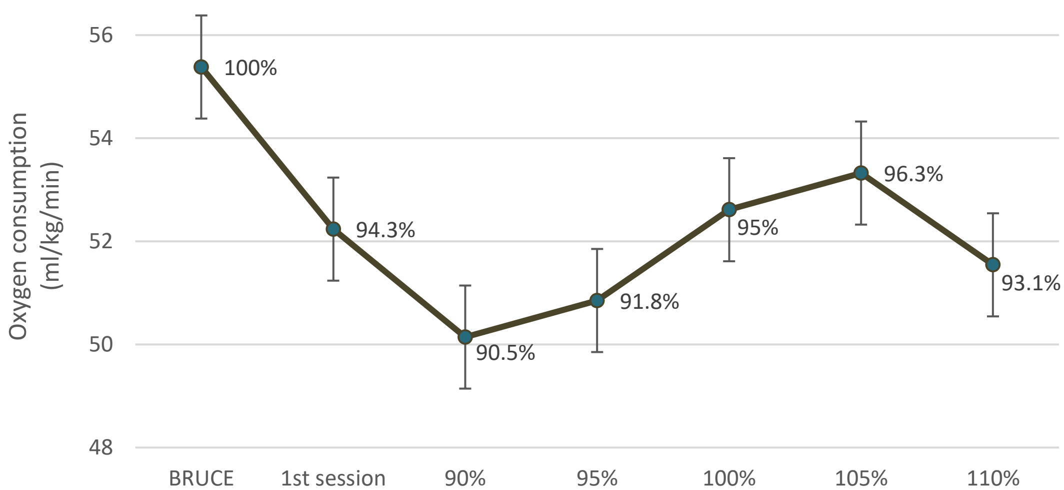

Figure 2. The relationship oxygen consumption (VO2) among experimental sessions Percentage (%) represented comparting GXT to each experimental session. (GXT/experimental session) × 100

Exercise time (min). Total exercise time were measured by a stopwatch and was converted from minutes and seconds to minutes only (second × 0.0166667). The longest exercise time was 10.4 ± 4.9 minutes at the 105% of PSF, and the shortest exercise time was 6.03 ± 3.3 minutes at the 90% of PSF. There were significant differenences between

SF variations and exercise time (F 4,52) = 13.71, p < 0.01. Follow up post hoc analyis determined there were significant differenences among three SF conditions; 90%, 95%, and 110% of PSF (p < 0.01) in comparison of 105% PSF. However, no statistic differences existed between PSF and 105% of PSF (p = 0.09). Furthermore, there was a significant difference between 90% of PSF and PSF (p < 0.01).

Energy expenditure (kcal). Statistically significant differences existed for energy expenditure (F 4,36) = 6.34, p < 0.001. Tukey HSD post hoc showed that three SF conditions (90%, 95%, and 110% of PSF) were significant different from 105% of PSF (p < 0.05). Specifically, there was significant different between 90% of PSF and 105% of PSF (p < 0.001). However, there was no difference between PSF and 105% of PSF (p = 0.42). The total kilocalories data elicit from metabolic data set. It doesn't consider either a proportion of utilizing aerobic and anaerobic metabolism or calculation method [kcal = absolute VO_2 × RER caloric equivalent × time (min)] due to RER above 1.0

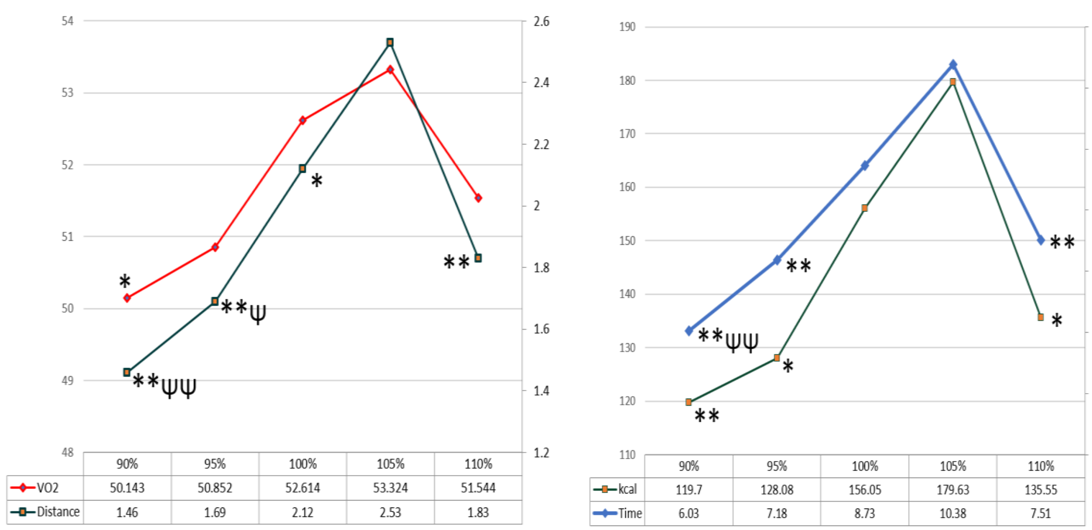

Figure 3. The relationship between SF variations and distance, VO2, kcal, and time
The comparison of 105% of PSF (* p<0.05, ** p<0.01) and PSF (Ψ p<0.05, Ψ Ψ p<0.01)

Other physiological variables; **Ventilation, RR, RER**. No significant differeneces bewtween the SF conditions were found for ventilation, RR and RER ($p = 0.09$, $p = 0.72$, and $p = 0.69$).

Discussion

This study demonstrated primarily the relationship between SF variations and running performance until time to exhaustion at the velocity of VO_2max. According to this study, 5% increases in SF from PSF elicited better running performance measured by total distance and time to exhaustion than other conditions. To our best knowledge, our research is the first study to measure running performance on the treadmill with SF variations until volitional fatigue at the velocity of VO_2max (2).

Participants were quite well-maintained at a target SF conditions in whole trials [Mean target SF/actual SF) × 100 = 100.7 ± 0.2%] beyond our expectation. An electric metronome was used which was loud enough via built-in speaker in the human performance lab and participants were encouraged verbally to kept maintaining a given SF. Participants performed most effectively under the 105% of PSF. The increased efficiency at 105% of PSF is thought to occur due to lessen central of gravity, joint impact on ankle and knee, muscle force (3,13,15,19,22). Conversely, the lowest SF condition (90% of PSF), it would be possible to recruit relatively higher force, more FT muscle fibers in running (5,13). Increasing the rate of recruitment of FT muscle fibers may be a cause of decreased efficiency during the 90% of PSF trial (30).

Tartaruga et al (33) has demonstrated the relationship between SF and upper body movement (shoulder, arm, elbow). It can be explained that when participants run with low SF (below PSF), longer SL employed could cause a decrease in economy due to additional upper body movement and increasing joint impact, muscle force. In the current study, more upper body movement was observed anecdotally during running with low SF comparing high SF conditions even though upper body movement was not measured during experimental sessions.

Despite no significantly difference in running distance between PSF and 105% of PSF participants ran at 105% of PSF about 0.4km more than running with their PSF in terms of reaching exhaustion. Furthermore, participants ran substantially longer distance (2.18 ± 0.5 km) at higher SF conditions than lower SF conditions (1.58 ± 0.7 km) when high (105% and 110% of PSF) or low SF (90% and 95% of PSF) conditions without comparing with PSF. Additionally, Jung (27) elucidated that an individual with improved RE will not merely run more distance at a fixed work rate but also decrease running duration at a given distance. Therefore, the current results in terms of the relationship between SF variations and distance display that the proposed hypotheses were accepted. In addition, it was anticipated that participants would be able to run for a greater distance at 105% of PSF on account of improving RE in result of increasing SF 5% more than PSF, and it was consistent with the former explanation of the study (27).

Previously, De Ruiter et al. demonstrated that running performance in distance could increase by almost 3.8% caused by increasing 5% of RE (25). De Ruiter et al. (15) addressed the self-selected SF in both novice and trained runners, and self-selected SF was lower approximately 8% and 3% respectively than their optimal SF. In the current study, the recreationally trained runners should possibly use 105% of PSF as an optimal SF for improving exercise time / distance with a better running economy while performing at the velocity of VO2max, and this is consistent with prior research mentioned above (15,25).

Myriad studies utilized that VO_2max measurement to measure cardiorespiratory fitness level as well as predict endurance performance. However, VO_2max does not explain entirely about the contribution of anaerobic metabolism, mitochondria enzyme sensitivity, training status, strength, percentages of VO_2max at the lactate threshold, arousal, and motivation level (16, 26,32). Energy provided from not only aerobic but also the anaerobic energy system should be considered when using high intensity running (6,11). Therefore, we measured running performance until time to volitional fatigue for a better prediction of endurance performance with measuring VO_2. However, our research could not explain which specific variables caused the differences between the SF variations.

In the current investigation, the VO_2max from the Bruce protocol did not correspond with the 1.5-mile run pace that ACSM shows through classifications; “Fitness categories for maximal aerobic power” (2). Theoretically, participants were supposed to run approximately the 1.5-mile distance (5,6). However, they ran more than 1.5-mile (2.4km) only at the 105% of PSF condition (2.53 ± 0.89 km). From our observation, they were hardly reach close to their VO_2max value during running sessions. It might be explained that the Bruce protocol is increasing work rates gradually, otherwise our experimental running sessions were set a constant speed based on participant’s VO_2max. In addition, the differences in VO_2 values does not account for whether more contribution of anaerobic metabolism among SF variations or not because the VO_2 value affected by running distance and duration in our research. In other words, achieving the highest value of VO_2 at 105% of PSF indicates that participants were able to run longer than all other SF conditions. However, we can assume that 105% of PSF could use relatively less anaerobic metabolism as well as less FT muscle fiber recruitment comparing other SF conditions.

Our research displayed approximately 6~7% lower VO_2 value during experimental running sessions in overall than VO_2max. Running at a constant speed with maximal effort might be harder than their expectation physiologically, even though running on the treadmill has an advantage of air, wind-resistance compare to track running (28) and because of the greater accumulated oxygen deficit (35) than during a GXT. Depending upon SF variations, fatigue occurred different at different time points. It was speculated that SF variations caused an imbalance of homeostasis, or participants might have felt discomfort physiological and psychologically depending upon certain SF conditions (30) assuming all participants performed every session until volitional fatigue.

Volitional fatigue at a certain moment during high intensity running can be explained as an aspect of peripheral fatigue that ATP regeneration must supply from anaerobic glycolysis and creatine phosphate hydrolysis during high intensity running (4,5,30). Typically, the increasing recruitment of FT muscle fibers increases lactate and proton (H^+) production due to the characteristic of FT when exercise intensity is greater than LT. Therefore, exercising muscles released more metabolic waste products (H^+) in the process of regeneration ATP from anaerobic metabolism during maximal effort running (4,5,10,22,37). Production of H^+ causes an imbalance in homeostasis due to the pH level decreasing both in blood and muscle as well as decreased redox potential because of increasing more NADH than NAD^+ in cytoplasm from step 6 of glycolysis (5,10,22). The accumulated H+ ions causes a decreasing cellular pH level that could affect negatively on several important enzymes such as adenosine monophosphate (AMP), phosphorylase, phosphofructokinase (PFK), and adenylate kinase (ATPase) for muscle contraction chemical pumps (Ca^+, Na^+/K^+) (5,36). The accumulated H^+ precluded supplying an appropriate amount of oxygen to exercising muscles creates a hypoxic environment (5,10,37).

According to Tucker (30), RPE generally increases linearly by increasing exercise intensity or the point of depletion of glycogen at the fixed work rate. The RPE reported from each participant were all above 19 in every experimental session because they ran until time to fatigue, and at a speed to elicit VO2max. The results of running performance were different depending on the SF variations despite no differences in RPE between the experimental trials. Therefore, presumably, it could explain that SF variations could impact self-anticipatory regulation to terminate before reaching at their actual maximal tolerance exercise bout based on their previous exercise experiences, motivation, and arousal level (30,37).

The central governor model (CGM) by Noakes (37) demonstrates that the brain and spinal cord regulate the exact amount of motor unit recruitment for exercise termination securely and anticipated exercise duration based on previous experience. Thus, fatigue can occur earlier than true exhaustion physiologically to prevent detrimental effect on muscle or brain in maximal or near maximal exercise intensity. The possible explanation of different running performance during experimental sessions in accordance with CGM was that brain could not regulate properly due to SF variations even though participants had experienced running at the velocity of VO_2max previously. The SF variations possibly caused an incongruity of “in anticipation” from the brain regardless of other variables such as RER, RR, V_E.

The practical application of the current research is that the 1.5-mile run test on treadmill can be used as a good estimation of measuring VO_2max without a metabolic cart for all populations. The 1.5-mile run test displayed a high correlation (r=.87) with VO_2max determined from a GXT (34). For more accurate ways to estimate VO_2max through the 1.5-mile run test, people should try 1.5-mile run test several trials (> 3 trials) until reaching their maximum running capacity, then measure PSF via wearable device and test again with increasing SF 5%. Therefore, running speed should be set as a maximal constant speed to both control SF and get more reliable estimation of VO_2max. Moreover, it is beneficial for an individual who want to lose body weight to burn more kilocalories due to running longer duration at 105% of PSF when performing until exhaustion. Running with 105% of PSF is also good pace strategy training for middle and long-distance runners due to constant speed running at their maximal speed. Furthermore, the best performance (constant running speed) of 1.5-mile run test will be using as a substitute of VO2max measurement to create high intensity interval training (HIIT), TABATA, and many other training protocols for running to improve performance and fitness.

Conclusions

In conclusion, SF variations have a significant influence on high intensity running performance. Therefore, recreationally trained runners could use a 105% of PSF when they run on the treadmill at the velocity of VO_2max for improving running performance in terms of duration and distance.

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