Ruediger and Dombkowski. Int J Sports Exerc Med 2017, 3:049
DOI: 10.23937/2469-5718/1510049
Volume 3 | Issue 1

International Journal of
Sports and Exercise Medicine

ISSN: 2469-5718

Original Article: Open Access

Predicting $\dot{V}O_2$ Change from a Single Unidirectional Trial of Cadence Manipulation in Recreational Runners

Thomas Ruediger* and Ryan Dombkowski

Rinker-Ross School of Health Sciences, Trine University, USA

***Corresponding author:** *Thomas Ruediger, Associate Professor, Rinker-Ross School of Health Sciences, Trine University, 1819 Carew Street, Fort Wayne, IN46805, USA, Tel: +1-810-618-1897, E-mail: ruedigert@trine.edu*

Abstract

The purposes of the study were to describe $\dot{V}O_2$ among recreational runners under self-selected cadence (SS) and manipulated cadence 10 steps per minute faster (SS + 10) during a single treadmill running assessment, examine predictive ability of several variables on $\dot{V}O_2$, and compare estimates of energy expenditure from treadmill software with direct measure of $\dot{V}O_2$.

Airflow and percent of expired O_2 were used to calculate $\dot{V}O_2$ from thirteen (7 females and 6 males) runners at self-selected speed at both SS and SS + 10. Respiratory rates and mean tidal volumes were calculated from the collected data. Among all subjects there was no significant difference in $\dot{V}O_2$ between SS and SS + 10. There was a significant increase in $\dot{V}O_2$ from SS to SS + 10 in males, but not females. We observed several patterns of changes in respiratory variables at SS + 10.One pattern (N = 3, all female) was characterized by a modest increase in respiratory rate and large decrease in tidal volume, which resulted in a decrease in total ventilation and accompanied by increases in $\dot{V}O_2$ efficiency at SS + 10. Changes in tidal volume and ventilation were positively correlated with changes in $\dot{V}O_2$ between SS and SS + 10 conditions. None of the other potential predictor variables were significantly correlated with changes in $\dot{V}O_2$. Correlation of treadmill predicted energy expenditure of the Wood way Pro 27 with direct measure of $\dot{V}O_2$ was 0.81. It appears that a quarter of recreational runners may have large improvements in their running efficiency through an increase in cadence.

Keywords

Efficiency, Step rate, Respiratory pattern, Treadmill estimates

Introduction

Physiologically, oxygen consumption rate ($\dot{V}O_2$) increases as work increases. Changes in $\dot{V}O_2$ that occur at a fixed work load indicate relative levels of $\dot{V}O_2$ efficiency. $\dot{V}O_2$ may change under a fixed work load due to novelty of tasking, such as changes in gait [1-3]. It has been proposed that changes in $\dot{V}O_2$ efficiency under same load but different gait conditions may be partly explained by altered muscle activity [4]. It has also been proposed that these changes in efficiency may be due anxiety related changes in heart rate and respiration [5]. $\dot{V}O_2$ can be directly measured using commercially available physiological and metabolic equipment. Metabolic equivalents (METS) are often calculated by an algorithm and displayed on monitors on commercial aerobic fitness equipment such as treadmills, bicycles, rowing machines, and steppers.

Submaximal $\dot{V}O_2$ tests without direct measurement of $\dot{V}O_2$ are used to estimate $\dot{V}O_2$max. Although the use of submaximal tests is more efficient and less expensive than direct measure of $\dot{V}O_2$ in assessing $\dot{V}O_2$max and provide a measure of aerobic capability, this estimate of $\dot{V}O_2$max is not appropriate for a comparison of $\dot{V}O_2$ under different conditions [6]. Determining $\dot{V}O_2$ efficiency through a comparison of $\dot{V}O_2$ under different conditions such as cadence for running or gear selection for cycling, becomes increasingly more useful as the event becomes longer. $\dot{V}O_2$ efficiency is of interest to both competitive and recreational runners. Competitive runners are aiming to improve their finish times. Recreational athletes may be aiming to improve their time, but also in some cases to be able to finish.

Running more efficiently without direct measure of $\dot{V}O_2$ is done through repeated trial runs at different running paces and cadences. Direct measure on $\dot{V}O_2$ is available commercially in some markets for about $150-$300. Though relatively expensive compared to indirect estimates of $\dot{V}O_2$, these direct measures may be less costly than the time used to by iterative trial and error, and therefore a more efficient way to improve a completion time or to complete an endurance event. Competitive runners with access to direct assessment of $\dot{V}O_2$ are able to use this method to evaluate and modify training to improve performance.

In a study using direct measure of $\dot{V}O_2$ on ten high mileage (40 - 110 miles per week) runners, $\dot{V}O_2$ was collected under seven stride length conditions but a constant pace of 7 min/mile [1]. Based on the race results of a local half-marathon [7] with more than 2000 finishers, this study sample would represent the upper 3% of recreational runners. The self-selected stride length in that study group was 132 cm (143% of leg length) and was never the most efficient [1]. Seven of the runners became more efficient at a shorter stride length and three at a longer stride length [1]. Since running cadence varies inversely with stride length, seven of the runners became more efficient at a higher cadence, three at a lower cadence. When running at ventilatory threshold, self-selected stride frequency varied from optimal stride frequency more among novice recreational runners than among trained runners [8], with novice runners consistently below their optimal cadence based on $\dot{V}O_2$. Trained runners have also been shown to have better $\dot{V}O_2$ efficiency than untrained runners [9]. It is not known if a more efficient cadence can be determined by direct measure of $\dot{V}O_2$ with a single one directional manipulation of cadence.

ClinMed
International Library

Citation: Ruediger T, Dombkowski R (2017) Predicting $\dot{V}O_2$ Change from a Single Unidirectional Trial of Cadence Manipulation in Recreational Runners. Int J Sports Exerc Med 3:049. doi.org/10.23937/2469-5718/1510049

Received: September 30, 2016: **Accepted:** February 07, 2017: **Published:** February 10, 2017

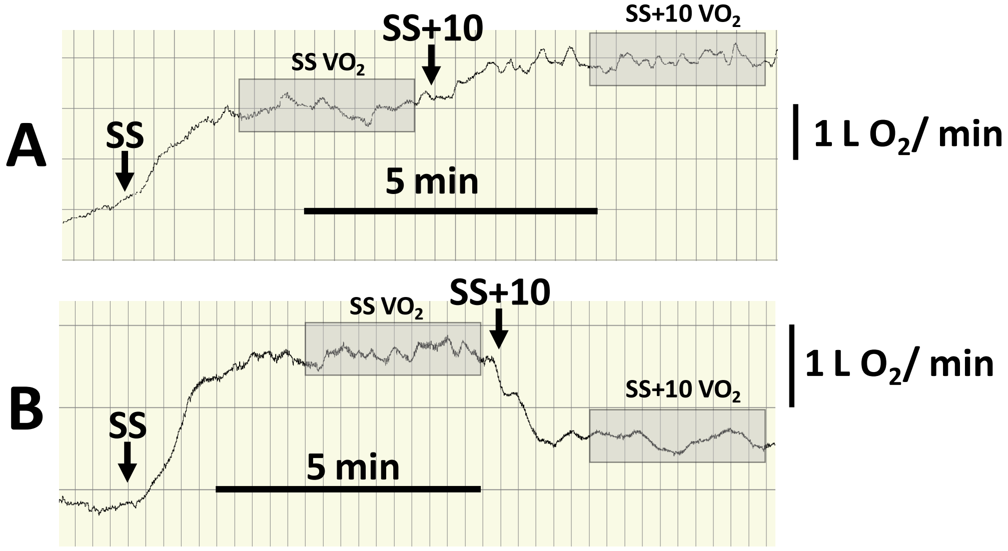

Figure 1: Typical tracings of oxygen consumption (L O_2/min) in two subjects. Arrows indicate the beginning of the two different cadence conditions. Grey boxes demonstrate the period used for data analysis. Panel A denotes a subject with a 29% increase in $\dot{V}O_2$ at SS + 10 while panel B demonstrates a subject with a 39% decrease in $\dot{V}O_2$ at SS + 10.

Purposes of the study were to report and compare $\dot{V}O_2$ and selected respiratory variables among healthy recreational runners at a self-selected cadence (SS) and single manipulated cadence 10 steps per minute faster than self-selected (SS + 10) during a single treadmill running assessment and to compare estimates of METS from treadmill software with direct measure of $\dot{V}O_2$.

Methods

Experimental approach to the problem

$\dot{V}O_2$ was collected from recreational runners running at SS and SS + 10 on a treadmill (Wood way PRO 27, Wood way, Waukesha, WI). Speed was self-selected by each subject but then kept constant for both cadence conditions. Comparisons of $\dot{V}O_2$ and changes in $\dot{V}O_2$ at SS + 10 were made in the entire cohort and dichotomized for gender, self-selected speed, and SS.

Subjects

The study protocol was approved by the University's Institutional Review Board. Subjects of either gender were recruited by convenience from a local cohort of graduate students or by direct association or relationship with this cohort. Subjects self-identified themselves as recreational runners logging at least 10 miles per week, free of any neuromuscular or neurological disorders, lacking any joint or limb pain or discomfort, and willing to sign the informed consent document. Subjects were excluded with any "YES" answer on the Physical Activity Readiness Questionnaire (PAR-Q). A total of 13 subjects (six male/seven female) volunteered and all 13 completed the study. Subjects were 23-26 years old, had a mean body mass of 78.5 ± 4.8 kg, with a range from 53.5 to 110.5 kg.

Procedures

Equipment and study familiarization: Each subject ran on two occasions. The first occasion was for familiarization with the treadmill and for fitting and familiarization with mask and tubing (BIOPAC, Goleta, CA). Subjects practiced running at their preferred SS and SS + 10 and also utilizing the Pro Metronome digital-audio metronome app to maintain their cadence (EUMLab, Berlin GE).No data, other than the appropriate mask size, were collected during the familiarization trial.

Experimental procedure and data collection: The gas analysis system was calibrated for airflow and room environmental conditions prior to each subject. Mask was fitted to subject; airflow and percentage of expired O_2 were collected throughout the entire experimental procedure. Airflow transducer (SS11LA, BIOPAC, Goleta, CA) and oxygen sensor as part of the expired gas analysis system (GASSYS2-EA, BIOPAC, Goleta, CA) were calibrated appropriately for each trial. Each subject was allowed to warm-up for several minutes with either brisk walking or jogging. When the subject was ready, they were allowed to set the treadmill to their own self-selected running speed and assume their preferred cadence. After $\dot{V}O_2$ reached a stable plateau, each subject was instructed to continue at this metronome assisted SS for three additional minutes. At the end of this period, cadence was increased by 10 steps per min. The subject was then asked to match this new cadence. Once the new cadence was established and $\dot{V}O_2$ again reached a stable plateau, the subject was instructed to continue at this metronome assisted SS + 10 for three additional minutes. At the end of this period the subject was allowed to cool down as desired. $\dot{V}O_2$ for SS and SS + 10 were averaged during the final three minutes of each stage for each subject. Respiratory rate and mean tidal volumes were also calculated from the data for each subject. Typical traces of $\dot{V}O_2$ data plateaus, as well as time periods utilized for data analysis are demonstrated in figure 1.

Table 1: Participant demographics and self-selected cadences (SS) and speeds (mean ± SE).

Subjects	n	mass (kg)	range	SS	range	SS speed (mph)	range
All	13	77.7 ± 5.6	53.5-110.5	166 ± 3	147-184	6.7 ± 0.4	5.0-8.0
Male	6	90.9 ± 6.7*	63.3-110.5	159 ± 3	147-166	7.0 ± 0.4	5.5-8.0
Females	7	67.8 ± 3.7*	53.5-84.4	167 ± 4	153-184	6.2 ± 0.4	5.0-7.8

* = significantly different.

Statistical analyses

Data were analyzed with IBM SPSS Statistics 23 (IBM Corp., Armonk, NY).Unless otherwise specified, all data are presented as mean ± standard error (SE); ranges are shown for descriptive data. Significance was assumed at $P \leq 0.05$. Subjects were dichotomized by gender (M, F), speed (≥ 7 mph, < 7 mph) and cadence (≥ 165, < 165 steps per min). Unpaired (Student's) t-tests were performed to examine differences between dichotomized groups. Paired t-tests were performed to examine differences in $\dot{V}O_2$ before and after cadence manipulation with each subject serving as their own control. Pearson's (scalar data) and Spearman's (nominal) correlations were calculated for potential predictor variables.

Results

Data for mass, SS, and self-selected running speed are summarized in table 1. Males (n = 6) were significantly heavier than females (n = 7). The mean SS and self-selected running speed of all subjects (n = 13) were 166 ± 3 steps per min (spm) and 6.7 ± 0.4 mph, respectively. Dichotomized by gender, there were no significant differences in SS or self-selected running speed. Dichotomized by speed, individuals who elected to run faster (n = 6) did not display any significant differences in either mass or SS than those who elected to run at a slower pace (n

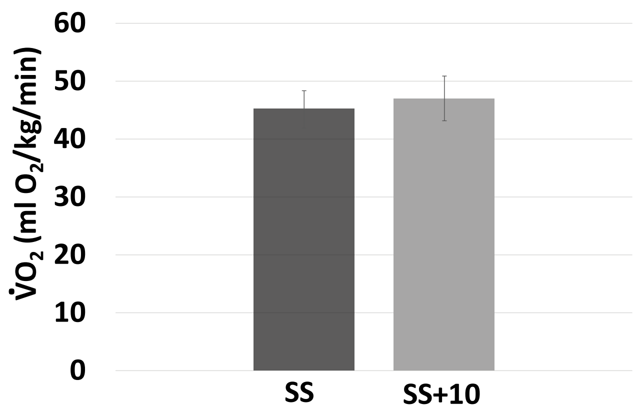

Figure 2: Mean $\dot{V}O_2$ (mean ± SE) at the two cadence conditions with no significant difference.

Table 2: Raw (cm) and relative (% leg length, %LL) characteristics of participants' stride during self-selected cadence (SS) and 10 steps per minute faster than SS (SS + 10) and including Pearson r-correlation values with respect to changes in $\dot{V}O_2$ are shown with P-values.

Parameter	Mean ± SE	Range	Correlation with Δ $\dot{V}O_2$
SS stride length (cm)	108 ± 5	83.3-131.5	0.355 (0.234)
SS stride length (%LL)	120 ± 5	93-144	0.162 (0.597)
SS cadence (spm)	163 ± 3	147-184	-0.171 (0.577)
SS + 10 stride length (cm)	102 ± 4	78.4-123.4	0.351 (0.240)
SS + 10 stride length (%LL)	113 ± 4	88-135	0.162 (0.596)
SS + 10 cadence (spm)	173 ± 3	157-194	-0.171 (0.577)
Δ stride length (cm)	-6.3 ± 0.3	-4.9--8.1	-0.381 (0.199)
Δ stride length (%LL)	-7.0 ± 0.3	-5.7--8.7	-0.232 (0.445)

= 7). Dichotomized by cadence, there were no significant differences in mass or self-selected running speed in those subjects who elected to run at either higher (n = 7) or lower (n = 6) cadences.

Overall (n = 13), there was no change in $\dot{V}O_2$ between SS (45.1 ± 3.2 L O_2/kg/min) and SS + 10 (46.8 ± 3.9 mL O_2/kg/min) (Figure 2). There were, however, large differences between individuals in the $\dot{V}O_2$ response to increased cadence. While the mean SS + 10 $\dot{V}O_2$ was 104 ± 5% of the SS $\dot{V}O_2$, the range was a 32% increase to a 39% decrease. Seven out of 13 subjects displayed decreased $\dot{V}O_2$ efficiency (> 5% *increase in* $\dot{V}O_2$) at SS + 10. A typical trace of this effect in presented in figure 1A. Three subjects exhibited < 2% *change* in $\dot{V}O_2$. Three subjects displayed increased $\dot{V}O_2$ efficiency (> 5% *decrease in* $\dot{V}O_2$) at SS + 10. $\dot{V}O_2$ tracing from the most extreme subject, a 39% $\dot{V}O_2$ decrease at SS + 10, is presented in figure 1B.

There were no significant differences in $\dot{V}O_2$ between individuals with a higher (> 165spm) or lower (≤ 165spm) cadence at SS or SS + 10, nor where there any changes in $\dot{V}O_2$ from SS to SS + 10 within these groups (data not shown).Individuals who ran faster displayed higher initial $\dot{V}O_2$ values (52.7 ± 3.5 mL O_2/kg/min) than those who ran slower (38.7 ± 3.7 mL O_2/kg/min, $P = 0.020$), but there were no significant changes in $\dot{V}O_2$ within these groups after transitioning from SS to SS + 10 (data not shown). Males demonstrated a higher $\dot{V}O_2$ than females at both SS and SS + 10 (Figure 3). Males displayed a significant increase in $\dot{V}O_2$ at SS + 10 compared to SS (52.8 ± 3.8 vs 56.9 ± 4.3 mL O_2/kg/min, respectively, $P = 0.047$) (Figure 3). When combined, females displayed no significant differences in $\dot{V}O_2$ at SS + 10 compared to SS (Figure 3).

We examined several potential predictor variables to explain the change in $\dot{V}O_2$. The potential predictor variables were: gender, mass, height, BMI, step length, leg length, self-selected speed, average weekly running distance, step length as a percentage of leg length, step length change from SS to SS + 10, and step length change from SS to SS + 10 as a percentage of leg length (Table 2). There were no significant correlations between any of the selected potential predictor variables with the change in $\dot{V}O_2$.

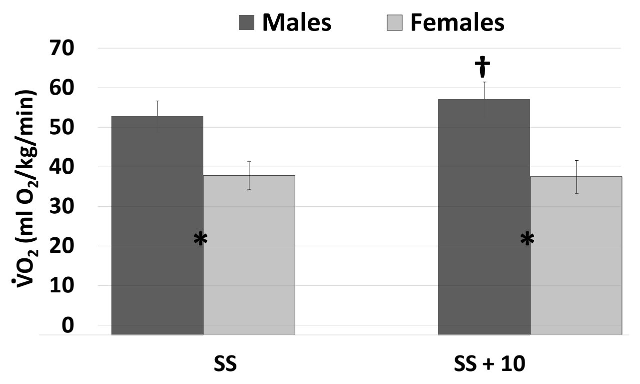

Figure 3: $\dot{V}O_2$ (mean ± SE) grouped by gender under the two cadence conditions. * indicates a significant difference between groups and † indicates a significant difference within male group.

Table 3: Differences in measured respiratory variables under two cadence conditions. bpm = breaths per minute. Pearson r-correlation values are shown P-values.

Respiratory variables	Mean ± SE	Range	Correlation with Δ $\dot{V}O_2$
Δ VO_2 (ml O_2/kg/min)	1.7 ± 2.0	-15.3-11.3	na
Δ FiO_2-FeO_2 (%O_2)	-0.33 ± 0.10	-0.82-0.59	0.271 (P = 0.370)
Δ V_E (L/min)	6.9 ± 3.7	-16.2-37.2	0.850 (P < 0.001)
Δ Respiration rate (bpm)	7.0 ± 1.4	0.0-16.0	0.316 (P = 0.294)
Δ Tidal volume (L/breath)	-0.20 ± 0.06	-0.54-0.17	0.655 (P = 0.015)

Changes in measured and calculated respiratory variables from SS to SS + 10 are presented in table 3. Combined subjects mean changes in $\dot{V}O_2$ were small, but did encompass a wide variety in individual respiratory compensation patterns. Mean respiration rate increased 7.0 breaths per minute at SS + 10. Mean pulmonary O_2 extraction decreased 0.33% at SS + 10. Mean tidal volume decreased 0.20 liters/breathe at SS + 10. Mean pulmonary ventilation (V_E) increased 6.9 liters/min. There were no significant correlations between changes in respiratory rate or pulmonary O_2 extraction with changes in $\dot{V}O_2$ from SS to SS + 10. Raw and percentage changes in V_E and tidal volume were positively correlated with changes in $\dot{V}O_2$ from SS to SS + 10.

Measured $\dot{V}O_2$ were converted to METS utilizing the common conversion of 1 MET = 3.5 mL O_2/kg/min. Under this assumption, measured METS at SS and SS + 10 were both positively correlated with the predicted METS from the treadmill software predicted value. Utilizing a linear best-fit model, measured MET versus predicted MET correlations for SS and SS + 10 were 0.81 and 0.80, respectively (data not shown). These models produce measured MET values which averaged 16% (SS) and 20% (SS + 10) above treadmill software predicted values. Both of these best-fit equations produce regression models which deviate more from treadmill software predicted values at higher METS.

Discussion

Subjects in the current study were similar with regard to age [8,10,11] and sample size [1,8,11] when compared to previous studies. BMI of subjects in the current study was 25.4 kg/m^2 which is higher than in previous studies which ranged from 21-22 kg/m^2 [6,10,11]. Mean weekly running mileage [6,11] and subjects' self-selected pace [1,10-12] were lower than in most of previous studies. Subjects in the current study ran a pace similar to Ruiter, et al. [8] and that is representative of a cross-section of recreational runners [7].

Mean $\dot{V}O_2$ did not change with a single cadence manipulation (Figure 2). Freely chosen running speed and cadence were not predictive of changes in $\dot{V}O_2$ with cadence manipulation. There was a significant difference in $\dot{V}O_2$ and changes in $\dot{V}O_2$ when dichotomized by gender (Figure 3). As a group, the six males were more efficient at SS. None had more than 5% increase in efficiency at SS + 10; four subjects had more than 5% decrease in efficiency at SS + 10; two showed no change at SS + 10. As a group, the seven females showed no change in running efficiency (Figure 3). Three had more than 5% increase in efficiency at SS + 10, three had more than 5% decrease in efficiency at SS + 10, and one showed no change at SS + 10.

$\dot{V}O_2$ is a product of V_E and O_2 extraction (FiO_2-FeO_2) and V_E is a product of respiratory rate and tidal volume. Changes in O_2 extraction were not correlated with changes in $\dot{V}O_2$ at increased cadence. Changes in V_E were correlated with increased VO_2 at increased cadence. Previous studies have not discussed which component of V_E, respiratory rate or tidal volume is responsible for this correlation. Twelve subjects had an increase in respiratory rate at SS + 10 compared to SS. This is expected and is consistent with locomotor-respiratory coupling previously reported (13). At constant work, this would be expected to be accompanied by a decrease in tidal volume, which was observed (Table 3). Overall, increases in respiratory rate outweighed the decrease in tidal volume with a resultant mean increase in V_E (Table 3). This increase in V_E would be expected to be accompanied by a decrease in O_2 extraction at constant work, which was observed.

Changes in $\dot{V}O_2$ may be explained by four observed respiratory pattern changes at SS + 10. The first pattern (N = 7) was a large increase in V_E dominated by an increase in respiratory rate. A second pattern (N = 2) produced little change in V_E due to the canceling effect of moderate increase in respiratory rate and moderate decrease in tidal volume. A third pattern was demonstrated by only one subject who had no change in respiratory rate and moderate decrease in tidal volume; the resultant decrease in V_E was accompanied by an increased O_2 extraction. The fourth pattern (N = 3) was characterized by a small increase in respiratory rate and large decrease in tidal volume resulting in decreased V_E and increase in efficiency.

The three subjects that were more efficient at SS + 10 were all female, representing 23% of subjects in this study is consistent with Morgan, et al. [11]. A decrease in tidal volume was the single best predictor of increased $\dot{V}O_2$ efficiency at higher cadence in this study (Table 3).

While shallower breathing alone may predict a slight decrease in $\dot{V}O_2$, a more plausible explanation for the large decrease in $\dot{V}O_2$ in this small group is increased running efficiency. Increasing cadence should result in a concomitant decrease in vertical oscillation and has been previously reported [14]. Gender differences in lower extremity running mechanics have been reported [15], which may partially explain the wider variability in $\dot{V}O_2$ changes in females with cadence manipulation.

It is not known if manipulating respiratory rate would be an independent predictor of change in $\dot{V}O_2$ while running. To our knowledge correlations between respiratory rates, tidal volumes, and total V_E with $\dot{V}O_2$ while running have not been reported in the peer-reviewed literature.

Recreational runners are not routinely measuring $\dot{V}O_2$ directly, but do have access to estimates of energy expenditure from treadmill software in METS or kilocalories. Sources of error include variance in consumption around accepted conventions of METS and consistency of actual treadmill belt speed with machine settings. Consistency of treadmill belt speeds may be influenced by drive, motor, temperature of belt, environment, subject mass, and selected speed. In our opinion, the current study demonstrates appropriate correlation of energy expenditure between Woodway PRO 27 treadmill software and direct measure of $\dot{V}O_2$ given the inherent variability of these estimates. Based on the results of this study, the treadmill software appears to be accurate with regards to energy expenditure near the lower end of vigorous exercise as defined by the American College of Sports Medicine (> 6 METS) [16].

Conclusions

An opportunity exists to improve performance in some recreational runners with cadence manipulation with direct measure of $\dot{V}O_2$. Given the short time commitment for direct $\dot{V}O_2$ measurement under different cadences and the ease of data analysis, this should be useful to coaches and runners to monitor performance increases within a given running season. Given the magnitude of improvement in three of our subjects, cadence manipulation may be the difference in finishing or not finishing a long distance running event. Similarly, there may be an opportunity to improve performance in competitive and recreational rowers, bicyclists, swimmers, cross-country skiers, and other extended length events.

Limitations

There are several limitations to this study. Sample size was appropriate for a pilot study but limited both power and generalizability. We did not collect heart rate and rating of perceived exertion and these measures of effort expenditure would provide support for changes in $\dot{V}O_2$ during cadence manipulation.

Future research will investigate the effects of cadence manipulation on $\dot{V}O_2$ in a larger group of runners with more age, body composition, and running speed diversity. We will also include both increase and decrease manipulation of cadence and assess reliability of $\dot{V}O_2$ measures.

Acknowledgement

The authors declare no conflicts of interest, and no external sources funded this research.

Ethical Statement

The study protocol was approved by the Trine University Institutional Research Review Board (approved 12 Feb 2016) and all participants provided their written informed consent.

Research was Conducted

Trine University Health Sciences Education Center, Trine University Rinker-Ross School of Health Sciences, Fort Wayne, IN.

References

1. Cavanagh PR, Williams KR (1982) The effect of stride length variation on oxygen uptake during distance running. Med Sci Sports Exerc 14: 30-35.
2. Flynn TW, Connery SM, Smutok MA, Zeballos RJ, Weisman IM (1994) Comparison of cardiopulmonary responses to forward and backward walking and running. Med Sci Sports Exerc 26: 89-94.
3. Hooper TL, Dunn DM, Props JE, Bruce BA, Sawyer SF, et al. (2004) The effects of graded forward and backward walking on heart rate and oxygen consumption. J Orthop Sports Phys Ther 34: 65-71.
4. Flynn TW, Soutas-Little RW (1993) Mechanical power and muscle action during forward and backward running. J Orthop Sports Phys Ther 17: 108-112.
5. Grossman P (1983) Respiration, stress, and cardiovascular function. Psychophysiology 20: 284-300.
6. McArdle WD, Katch FI, Katch VL (2015) Exercise Physiology: Nutrition, Energy, and Human Performance. (8th edn), Baltimore, MD: Lippincott, Williams, and Wilkins.
7. (2015) Fort 4 Fitness. Half-marathon results.
8. de Ruiter CJ, Verdijk PW, Werker W, Zuidema MJ, de Haan A (2014) Stride frequency in relation to oxygen consumption in experienced and novice runners. Eur J Sport Sci 14: 251-258.
9. Morgan DW, Bransford DR, Costill DL, Daniels JT, Howley ET, et al. (1995) Variation in the aerobic demand of running among trained and untrained subjects. Med Sci Sports Exerc 27: 404-409.
10. Högberg P (1952) How do stride length and stride frequency influence energy-output during running? Arbeitsphysiologie 14: 437-441.
11. Morgan D, Martin P, Craib M, Caruso C, Clifton R, et al. (1994) Effect of step length optimization on the aerobic demand of running. J Appl Physiol (1985) 77: 245-251.
12. Williams KR, Cavanagh PR (1987) Relationship between distance running mechanics, running economy, and performance. J Appl Physiol (1985) 63: 1236-1245.
13. Hoffmann CP, Bardy BG (2015) Dynamics of the locomotor-respiratory coupling at different frequencies. Exp Brain Res 233: 1551-1561.
14. Tseh W, Caputo JL, Morgan DW (2008) Influence of gait manipulation on running economy in female distance runners. J Sports Sci Med 7: 91-95.
15. Ferber R, Davis IM, Williams DS 3rd (2003) Gender differences in lower extremity mechanics during running. Clin Biomech (Bristol, Avon) 18: 350-357.
16. Pescatello LS, Arena R, Riebe D, Thompson PD (2014) ACSM's Guidelines for Exercise Testing and Prescription. (9th edn), J Can Chiropr Assoc 58: 328.