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Running Economy Changes Alter Predicted Running Speed and Performance in Collegiate Runners

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ABSTRACT

International Journal of Exercise Science 17(1): 965-974, 2024. The goal of the study was to determine the effect of altering running strategy on predicted running performance in distance runners through application of a novel prediction model. Fifteen male (n = 10; Age: 22.2 ± 4.9 years; Height: 177.7 ± 7.4 cm; Mass: 68.6 ± 6.7 kg) and female (n = 5; Age: 21.8 ± 4.1 years; Height: 167.4 ± 7.8 cm; Mass: 59.3 ± 8.1 kg) long distance runners were recruited to participate in the study. Participants' oxygen consumption (VO_2) and carbon dioxide (VCO_2) were measured by a metabolic cart using a face mask. After a brief warm-up, participants rested for the initial five minutes then ran at their preferred speed for five minutes. Participants rested for another five minutes while their oxygen consumption returned to baseline measurements and ran for five minutes while increasing step rate by 7.5%. There was no significant difference between conditions for VO_2 measurements and energetic cost ($p > 0.05$). There was also no significant difference in the baseline, self-selected speed and predicted speed resulting from the increase in step rate ($p > 0.05$). Increasing stride rate 7.5% resulted in an average decrease in predicted running speed of 1%. While statistically insignificant, small decrements in running speed can accrue over time and negatively impact running performance.

KEY WORDS: Gait, running economy, speed

INTRODUCTION

Running event popularity has increased by 57% over the last decade (2). In 2021, running became the biggest fitness trend with 28% new runners beginning to run for physical activity during the pandemic (41). This dramatic uptake was likely a result of lockdowns and indoor restrictions causing many people to turn to running due to its numerous health benefits associated with cardiovascular exercise (19, 21, 32) and lack of access to other facilities.

While the increase in the number of individuals running to maintain health is beneficial to rising chronic illness-related healthcare costs, it can lead to high rates of running injuries. Nearly 80% of runners get injured each year (52, 53) with the majority being novice and recreational runners (10, 49). Therefore, to treat and prevent many of the injuries, clinicians and runners have turned to many different strategies, including gait retraining.

Gait retraining, or modifying an individual's running mechanics, has the potential to treat several running-related injuries, including patellofemoral pain (6, 17, 38, 43, 56) and anterior compartment syndrome (22). Gait retraining can include manipulating step rate, reducing tibial acceleration, reducing hip adduction or altering foot strike pattern. While the clinical benefits are well documented and accepted (1, 7, 23), the effects of gait retraining on performance are less clear (23, 35).

There is minimal evidence to support implementation of gait retraining for the explicit reason of improving performance (3, 35). Based on prior research, the key determinants of running performance are measured maximal aerobic capacity (9), lactate threshold (47), and running economy, often known as the steady-state oxygen consumption at a given running velocity (13), which is the key component in predicting endurance running performance and success due to its variability in runners with similar aerobic capacities (20). However, both acute and long-term gait retraining studies have not provided definitive results regarding its effect on performance. Acute gait retraining interventions have demonstrated worsening (11, 14, 15, 27, 34, 50) and no change (4, 27, 34, 54) in running economy. Long-term gait retraining has also yielded equivocal results. Only one study has demonstrated an improvement (36) and one a worsening (18) in running economy. Otherwise, long-term retraining yielded no change in running economy (5, 12, 16, 25, 28, 33, 39, 42, 54). Given the lack of *significant* effect on running economy that gait retraining elicits, clinicians and coaches will continue to turn to gait retraining to treat and prevent running-related injuries. However, many of these studies do report a small change in running economy that, while not statistically significant, can still potentially worsen endurance running performance based on a novel performance prediction model.

Hoogkamer and colleagues (29) developed a model that can predict endurance running performance based on the curvilinear relationship between running velocity and energy cost (the amount of energy the body expends while running at specific velocities) established by Tam et al. (46) They have since refined the model to account for the impact air resistance has on running performance (31). Because of the curvilinear relationship between changes in running economy and running performance, a change in running economy can yield a larger or smaller proportionate effect on running performance. For example, based on their model, the researchers demonstrated that a 4% improvement in running economy predicted a 3.4% improvement in running velocity (29). Much of this group's research has focus on footwear and running performance (29). This model has yet to be applied under gait altering conditions to further understand the implications gait retraining has on predicted endurance running performance. Therefore, the purpose of this study was to determine the impact an acute gait retraining session has on predicted running performance in high-level endurance runners employing the novel model developed by Hoogkamer and colleagues (29).

METHODS

Participants

Fifteen male (n = 10) and female (n = 5) healthy long-distance runners completed the testing protocol. All runners were currently running at least 20 miles per week as part of their normal training schedule for at least the past 3 months and run at a velocity of at least 3 m/s. Participants were excluded if they had a history of cardiopulmonary disease or events within the past year and if they had sustained a lower extremity injury within the past six months. The study was approved by the Institutional Review Board and participants provided written informed consent prior to participation. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (37). Participant characteristics are reported in Table 1.

Table 1. Participant characteristics.

Age (yrs)	Height (cm)	Weight (kg)	Sex (M/F)	Speed (m/s)	Baseline VO_2 (ml/kg/min)
22 ± 4	174.28 ± 8.5	65.54 ± 7.97	10/5	3.44 ± 0.41	40.44 ± 5.39

Data presented as mean ± SD; yrs: years

Protocol

Upon arrival to the laboratory, participants filled out a health history questionnaire and subsequently were measured for height and mass using a calibrated stadiometer and scale (Health o meter, Model 500KL, McCook IL, USA). Participants then were asked to warm up on a treadmill (Woodway 4Front, Woodway USA, Inc., Waukesha, WI, USA) for approximately 5 minutes reaching a self-selected speed that they would use for a 30-minute run. This speed was used throughout all of the testing protocol.

Participants then rested approximately five minutes while being equipped with a face mask for the collection of expired gases via a metabolic cart (Quark CPET, COSMED Srl, Rome, Italia). Once equipped with the mask and head gear, participants stood quietly while resting energy expenditure was being collected. After resting data were collected, participants ran at their baseline, self-selected speed for approximately five minutes while expired gases were collected and analyzed. During the 4^{th} minute of data collection, step rate was measured via a metronome (DMT-1 Digital Metronome, DeltaLab, Thousand Oaks, CA, USA) and recorded. At the end of five minutes, runners stood quietly for five minutes while VO_2 measurements returned to within 2% of baseline.

Once VO_2 returned to near resting values, participants were asked to run again at their baseline, self-selected speed with 7.5% increase in step rate for five minutes. Researchers calculated their new step rate and set the metronome to the new rate. Participants were then asked to match their footfalls with the increased cadence while they ran. If participants did not match footfalls to the tone of the metronome, researchers provided a brief reminder to do so. At the end of the five minutes, participants stood quietly while recovery VO_2 data was collected.

Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) at the exercise steady state was determined by a metabolic cart during each running condition. Steady state was defined as a plateau in oxygen consumption. The system was calibrated prior to each measurement following the manufacturer's guidelines. The average of the breath-by-breath values were measured during the last 30 seconds of each running condition.

Energy cost of running per unit of distance (Cr) was calculated similar to Schena et al. (45). The difference between VO_2 at steady state (VO_{2ss}) and VO_2 at rest was calculated. Then the net energy expenditure was calculated as:

VO_2 (J/kg/min) = [(VO_2 (L/min) x calorie equivalent of O_2 (kcal/L O_2) • 4186 J/kcal/min)]/kg considering the corresponding respiratory exchange ratio (RER) and with the calorie equivalent of O_2 = 3.941 + (1.106 • RER) (55). C_r in J/m/kg was finally calculated by dividing the net energy expenditure by the speed maintained during each running condition.

Similar to Hoogkamer et al. (29), estimated changes in running performance were predicted based on changes in energetic cost using a curvilinear relationship between running velocity and energetic cost, while accounting for surface area, projected frontal area (A_p), and the individual's coefficient for overcoming air resistance. Briefly, body surface area was calculated from height (cm) and mass (kg) based on the Du Bois and Du Bois' formula (24):

$$\text{Surface Area} = 0.007184 \bullet \text{height}^{0.725} \bullet \text{mass}^{0.425}$$

The A_p was then calculated as 26.6% of the runner's body surface area per Pugh (40). From there an individualized coefficient for overcoming air resistance was determined:

$$VO_2(\text{ml/kg/min}) = (3.54/\ \text{mass} \bullet A_p) \bullet v^3$$
$$VO_2(\text{ml/kg/min}) = \text{Pugh coefficient} \bullet v^3$$

Subsequently, the Pugh coefficient for overcoming air resistance was combined with the curvilinear relationship between VO_2 and velocity to extrapolate changes in RE to changes in performance as described by Batliner et al. (8):

$$VO_2\text{base}(\text{ml/kg/min}) = \text{Pugh coefficient} \bullet v^3 + 1.5355 \bullet v^2 + 1.5374 \bullet v + 15.661$$

The new predicted VO2 was calculated as:

$$VO_2\text{new} = VO_2\text{base}/(100\text{-RE\%})$$

where RE is the % change in running economy. From here the new VO_2 was set equal to the VO_2base equation to solve for the new velocity (v).

$$VO_2\text{new} = \text{Pugh coefficient} \bullet v^3 + 1.5355 \bullet v^2 + 1.5374 \bullet v + 15.661$$

The % change in velocity was calculated as:

$$(vVO_2\text{new} - vVO_2\text{base})/vVO_2\text{new} \bullet 100$$

where vVO_2new is the new predicted velocity at the new VO_2.

Statistical Analysis
Data are presented as mean ± SD. The effect of increased cadence on the measured variables was evaluated by paired *t*-tests. Correlation between the variables was evaluated by means of the Pearson's correlation coefficient. The Cohen *d* effect size (ES) was calculated. All statistical analyses were performed with IBM SPSS Statistics Version 27 (IBM Corp., New York, NY) with significance set at $p < 0.05$.

RESULTS

There were no significant differences between participant's baseline running trial and the trial with increased cadence in VO_2 and C_r ($p > 0.05$) (Table 2).

Table 2. Running economy.

	Baseline	SR +7.5%	*p*-value	Effect Size
VO_2 (ml/kg/min)	41.59 (5.88)	42.07 (5.72)	0.16	0.38
C_r (J/m/kg)	3.55 (0.42)	3.53 (0.22)	0.84	0.05

Data presented are mean (SD); SR: stride rate; C_r: energetic cost

There was no significant difference between baseline, self-selected speed and predicted speed as a result of altered cadence ($p > 0.05$; $d = 0.38$) (Figure 1).

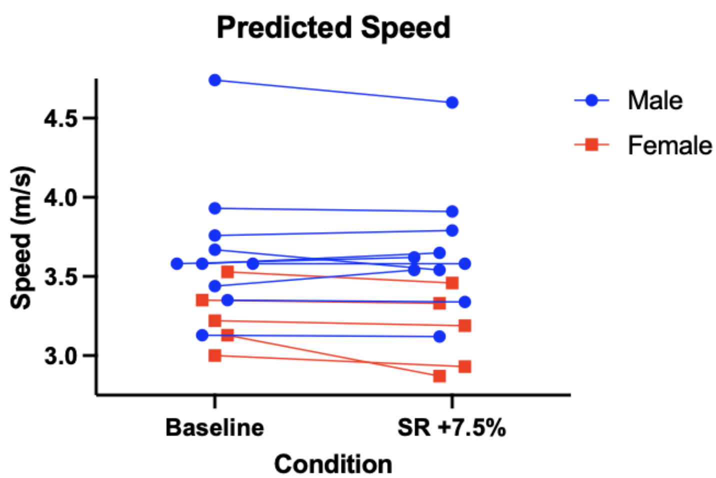

Figure 1. Predicted running speed pre- and post- gait alterations based on running economy changes; SR: stride rate.

DISCUSSION

The purpose of the study was to understand the impact of increasing cadence on predicted running performance using a novel performance prediction model. Increasing cadence by 7.5% did not significantly change VO_2, running economy, or predicted running speed. However, despite the insignificant, statistical changes in running economy and energetic cost, increasing running cadence *decreased* predicted running speed based on the performance prediction model. The resulting decreased predicted speed can have significant real-world implications on overall running performance and is a novel finding of the study.

The present study demonstrated that there was no significant difference in running economy and energetic cost as a result of increasing cadence. This finding is similar to previous studies. Warne et al. (54) demonstrated that a 10% increase in cadence did not significantly change running economy in recreational runners. The present study and that of Warne and colleagues is similar to that of Connick and Li (14) who demonstrated similar results when transitioning participants to 4% and 8% increased cadence. Each study demonstrated insignificant changes in running economy. While these findings are specific to altered cadence, changing stride length (11) or foot strike pattern (4, 27, 34) have also demonstrated similar results.

Perhaps the primary novel outcome of the present study is the decrease in predicted running speed using the performance prediction model as a result of altering running gait mechanics. On average, increasing cadence by 7.5% decreased predicted top running speed by 1% based on a 1% average change in VO_2, which was a small to moderate effect based on Cohen's *d*. For context, the same performance prediction model determined that a 4% average energetic savings from racing shoes should translate to ~3.4% improvement in running velocity at world record pace (29) and was critical in breaking the 2-hour marathon barrier. In a real-world scenario, similar relative changes in energetic cost of running due to altered shoe mass translated to similar changes in 3000-m running performance (30). However, it is worth noting that the 1% average change in predicted running velocity was likely influenced by a small subset of runners. When examining the data, some runners exhibited decreases in predicted running speed from 1% to 9% while others had no change or even increases in predicted running speed up to 3%. Therefore, despite the insignificant average change in predicted running velocity, one should examine the individual responses presented (Figure 1) for a better interpretation of the potential impact gait retraining can have on running performance.

While statistically insignificant, it is important to highlight the real-world implications for such a small change in predicted running speed resulting from altered gait mechanics. In the 2020 Tokyo Olympics, the times between first and third place runners for the 1,500-m, 5,000-m, and 10,000-m were separated by 0.73 s, 0.90 s, and 0.66 s, respectively. This translates to roughly 0.004%, 0.001%, and 0.0004% differences in running performance among the top three runners in their respective races. Therefore, an acute 1% reduction in running performance by the top runners, as observed here, would have led to disastrous performance in their respective races. So, while there may only be small reductions in predicted running performance due to altering gait mechanics, the predicted small reductions in running speed accrue over time and ultimately are more harmful to the runners' performance than inconsequential.

It should be noted that four of the male runners (40%) were able to *improve* (i.e. decrease) their running economy resulting in improved predicted running performance by up to 3% with the smallest improvement measured at 1%. In prior studies, there were no reported individual improvements in running economy because of altering cadence (14, 54), but this does not mean that individual improvements cannot be found. Previously, it has been determined that there is a negative correlation between running economy and step rate ($r = -0.61$) in male endurance runners (48). Therefore, particularly with changing cadence, it's possible that some male runners become more efficient by increasing step rate while simultaneously reducing injury risk because of altered mechanics (28). Taken together, this suggests that clinicians and coaches should take an individualized approach to gait retraining. Improvements based on individualization has already been shown during walking where individual selection of gait retraining strategies were believed to optimally reduce dynamic knee load during gait (26, 51). We speculate the concept of individualization applies to running gait retraining and its impact on mechanics and running performance. More research on individualized strategy selection for gait retraining in running is warranted.

This study is not without limitations. The runners only performed an acute retraining transition in a single session and could possibly not be habituated to the new running gait pattern. However, even long-term retraining studies showed similar results of no significant changes in running economy, suggesting these results would hold true even if runners were chronically habituated. Diet was not controlled prior to data collection; however, participants were instructed to not eat or drink anything that would artificially inflate oxygen consumption prior to testing. Lastly, testing was completed on a treadmill with no incline; therefore, caution should be used when applying to overground running (20, 36, 44), although the running performance prediction model does account for potential air resistance at the different speeds.

Lastly, it is important to highlight the practical applications of this study. Because gait retraining is a popular method by which runners correct harmful mechanics to reduce injury risk, clinicians, sport scientists and strength coaches can use these findings to make informed decisions regarding altering running mechanics. Important practical considerations include (a) measurement of running economy after gait retraining may not accurately reflect the impact it has on future running performance due to potential lack of significant changes measured pre- and post-retraining; (b) reductions in predicted running speed of even 1% can significantly impact race performance, particularly for more experienced runners; and (c) coaches may want to take an individualized approach to gait retraining (i.e. retraining strategy) to minimize the impact of retraining on future running performance as some runners may ultimately become less proficient while some runners may become more efficient post-retraining and indeed benefit from such changes.

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