AN ASSESSMENT OF RUNNING POWER AS A TRAINING METRIC FOR ELITE AND RECREATIONAL RUNNERS

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ABSTRACT

Aubry, RL, Power, GA, and Burr, JF. An assessment of running power as a training metric for elite and recreational runners. *J Strength Cond Res* XX(X): 000–000, 2018—Power, as a testing and training metric to quantify effort, is well accepted in cycling, but is not commonly used in running to quantify effort or performance. This study sought to investigate a novel training tool, the Stryd Running Power Meter, and the applicability of running power (and its individually calculated run mechanics) to be a useful surrogate of metabolic demand ($\dot{V}O_2$), across different running surfaces, within different caliber runners. Recreational ($n = 13$) and elite ($n = 11$) runners completed a test assessing $\dot{V}O_2$ at 3 different paces, while wearing a Stryd Power Meter on both an indoor treadmill and an outdoor track, to investigate relationships between estimated running power and metabolic demand. A weak but significant relationship was found between running power and $\dot{V}O_2$ considering all participants as a homogenous group ($r = 0.29$); however, when assessing each population individually, no significant relationship was found. Examination of the individual mechanical components of power revealed that a correlative decrease in $\dot{V}O_2$ representing improved efficiency was associated with decreased ground contact time ($r = 0.56$), vertical oscillation ($r = 0.46$), and cadence ($r = 0.37$) on the treadmill in the recreational group only. Although metabolic demand differed significantly between surfaces at most speeds, run power did not accurately reflect differences in metabolic cost between the 2 surfaces. Running power, calculated via the Stryd Power Meter, is not sufficiently accurate as a surrogate of metabolic demand, particularly in the elite population. However, in a recreational population, this training tool could be useful for feedback on several running dynamics known to influence running economy.

KEY WORDS running economy, performance, biomechanics, accelerometer, training tool

INTRODUCTION

There is a strong relationship between aerobic peak power (Watts) and maximum oxygen consumption ($\dot{V}O_2$) (9) in cycling, and power is well accepted as an accurate predictor of performance (9). As such, with the advent of portable power meters, this metric has become commonly used for training, testing, and competition among cyclists. In running, variations of running power have been established (21); however, this metric when applied to running is restricted to the laboratory and therefore not useful for training and performance testing outside of this setting. A newly developed device, the Stryd Running Power Meter (Pioneer model, Boulder, CO, USA), has been designed to similarly quantify "power" by using algorithmic computations. These calculations estimate the forces generated based on temporal patterns in triaxial accelerometry, with inclusion of the runner's body weight, GPS velocity tracked, and gradient (incline). The wearable Stryd Power Meter that can be used outside of a laboratory for running purposes is novel, and it is currently unknown whether power calculated through this device is a useful training or performance metric, or if it can be used as a surrogate for laboratory measures that are more difficult to obtain. Although it is logical that a tool capable of incorporating variables that directly influence the exercise load would be useful for running in a similar manner to cycling, it must be recognized that the computation of such variables is drastically different between sports. This is primarily owing to an inability to measure external force, such as mechanical tension or strain, given the absence of an intermediary between the engine (the athlete) and the propulsive application of force at the ground.

Metabolic demand of a physical task such as running is measured as the volume of oxygen for the specific task. Metabolic demand, or $\dot{V}O_2$, while running can be likened to running economy, which is the $\dot{V}O_2$ required specifically at a steady-state submaximal running pace (3,7,16). Running economy is recognized to have a strong relationship to endurance performance (5), as a runner with better running economy will, thus, consume less oxygen and use less energy

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at a given submaximal velocity owing to a more efficient application of used energy toward locomotion. Running economy has been shown to vary among runners with similar $\dot{V}O_2$max by up to 30%, making it a better predictor of performance than maximal aerobic power ($\dot{V}O_2$max) (6). Running form and technique have a direct influence on a runner's economy, and therefore small changes in specific running mechanics could be useful to reduce this metabolic demand at a given pace, thereby improving running economy and performance. A shorter ground contact time, for example, can be more economical as the force generated against the ground must be produced more quickly, leading to a shorter breaking phase (14). Cadence is the stride rate at which a runner is running and is measured in strides per minute (spm). There appears to be a specific range at which cadence is most metabolically efficient (12,15), and it is most likely related to an optimal ground contact time. Similarly, a smaller vertical oscillation has shown to reduce the metabolic demand at a given pace, as increased vertical displacement results in a greater metabolic cost to support and redirect one's body weight forward (3,12,20). The literature however is conflicting as to how much each biomechanical variable influence the metabolic demand of running, and typically such factors are measured only in an exercise laboratory using sophisticated sensors (8,12,22).

Running power is a novel metric that may be useful for economy assessment and could help drive targeted improvements in both run training and performance, but this is predicated on the assumption that running power is strongly related to metabolic demand. As Stryd estimated running power considers tri-axial forces generated while running and certain running mechanics that may influence metabolic efficiency, the primary objective of this study was to determine whether running power is strongly related to the metabolic demand of running through evaluation of the relationship of running power and $\dot{V}O_2$.

Given that energy expenditure and running mechanics are known to be influenced by running surface (10,18), a secondary purpose was to understand how the relationship between calculated running power and metabolic demand at varying paces differed when training on a treadmill or a world-class track. A final aim of this study was to determine whether any of these well-researched running mechanic outcomes of ground contact time, vertical oscillation, and cadence quantified using the Stryd Pioneer demonstrate a relationship to metabolic demand, and whether the relationships of these variables and metabolic demand differ between the 2 populations of elite and recreational runners, who are expected to have different running form.

METHODS

Experimental Approach to the Problem

This investigation was conducted as a validation study to determine the utility of the Stryd Power Meter and whether running power and running dynamics demonstrate relationships with the acute metabolic demand of running. Furthermore, we explored this relationship in different populations of runners while running on differing surfaces. To test these relationships, participants completed an assessment of their metabolic demand through the quantification of $\dot{V}O_2$ at a 3 given paces while simultaneously wearing a Stryd Power Meter to determine association between the measured outcomes of $\dot{V}O_2$ and power/running dynamics. Running power and the running dynamics of ground contact time, vertical oscillation, and cadence were measured using the Stryd to investigate both their applicability and relationship to metabolic demand. Comparisons between the relationships in the 2 populations of runners were conducted to determine whether the Stryd is more suitable for a certain level of runner.

Participants visited the laboratory on 2 separate occasions, completing a $\dot{V}O_2$ test, while wearing the Stryd Power Meter on the treadmill and the outdoor track. After the assessment of metabolic demand during the treadmill assessment visit, $\dot{V}O_2$max was measured as an indicator of maximal aerobic capacity using a standard graded exercise test on a treadmill. Participants completed a self-selected warm-up before beginning each test and the warm-up remained constant for each testing session.

Subjects

A total of 24 (13 recreational, 11 elite) male runners were recruited for this study. Elite runners were nationally ranked or national team members, and recreational runners were from the local community. Both groups competed in athletics distance events of 1500 m to the marathon or the Olympic distance triathlon (10k run). Baseline characteristics of the elite and recreational runners are presented in Table 1. All participants were provided written informed consent and were informed of the benefits and risks of the investigation before signing the informed consent and participating in the study. The study protocol was approved by the Research Ethics Committee at the University of Guelph.

Procedures

Treadmill $\dot{V}O_2$max & Metabolic $\dot{V}O_2$ Test. To assess metabolic demand at various paces on the treadmill, a $\dot{V}O_2$ test was conducted. Participants completed 3 consecutive paces for 2 minutes each, whereas $\dot{V}O_2$ was measured through expired gases collected and analyzed using a Cosmed Quark CPET system (Cosmed, Rome, Italy). Metabolic demand was quantified as the $\dot{V}O_2$ of the runner at a given speed in $ml \cdot min^{-1} \cdot kg^{-1}$ (3). Elite runners completed 3 standard paces of 14, 16, and 18 $km \cdot h^{-1}$. Recreational runners, whose race paces were (by design) slower than the elites, ran at 3 paces selected between 11 and 16 $km \cdot h^{-1}$, based upon their ability. To determine metabolic demand at each pace, breath-by-breath measures of $\dot{V}O_2$ were smoothed to a rolling 30 seconds average for analysis, and the highest rolling 30 seconds average $\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$) was taken from each interval. $\dot{V}O_2$max ($ml \cdot min^{-1} \cdot kg^{-1}$) was measured after the

TABLE 1. Baseline characteristics of elite and recreational runners used to assess the applicability of the Stryd Power Meter.*

	Elite ($n = 11$)	Recreational ($n = 13$)	p
Age (y)	26.0 ± 3.5	39.7 ± 9.3	<0.001
Body mass (kg)	67.6 ± 7.1	74.5 ± 7.8	0.03
$\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	67.9 ± 5.8	54.6 ± 4.9	<0.001
Training history (y)	11.2 ± 2.4	8.3 ± 8.1	0.30
Training volume ($days \cdot wk^{-1}$)	6.3 ± 0.5	3.5 ± 1.2	<0.001
Training volume ($km \cdot wk^{-1}$)	120 ± 32	33 ± 19	<0.001

*Values are mean ± *SD*.

completion of the 3 $\dot{V}O_2$ test paces. Runners maintained the highest speed achieved for a stage during the $\dot{V}O_2$ test, whereas there was a stepped increase in incline of 1% every-minute. Confirmation of $\dot{V}O_2max$ and subsequent test termination occurred when 2 out of 3 of the following criteria were met; $\dot{V}O_2$ did not increase by more than 150 ml with increasing workload, respiratory exchange ratio >1.15, and HR did not increase with increasing workload.

Outdoor Metabolic $\dot{V}O_2$ Test. Participants were instructed to run the 3 identical paces that they ran for the treadmill RE test for assessment of RE on the track. To ensure consistency, pacing feedback was given every 100 m and the pace was tracked and validated via concurrent GPS measures using the Stryd app (Boulder, CO, USA) on an iPhone 6 (Palo Alto, CA, USA) and the Cosmed K5 (Cosmed, Rome, Italy). Participants ran each pace for 4 minutes around the outdoor track with 1-minute rest. $\dot{V}O_2$ was measured using a portable metabolic computer (K5, Cosmed) worn on the back and strapped firmly around the chest and abdomen. $\dot{V}O_2$ measures ($ml \cdot min^{-1} \cdot kg^{-1}$) were similarly smoothed to a rolling 30 seconds average for analysis and the highest rolling 30 seconds average $\dot{V}O_2$ for each interval was used for analysis. The Cosmed K5 unit has been validated to be an accurate assessment of $\dot{V}O_2$ (2) and results are directly comparable to the $\dot{V}O_2$ measured with the validated Cosmed Quark CPET (13). To standardize for environmental conditions, tests were only conducted in the absence of precipitation when wind was minimal. The average temperature of the $\dot{V}O_2$ outdoor track tests was 15.9 ± 5° C, with a barometric pressure of 735.6 ± 6.5 mm Hg and the altitude of the track and treadmill was 335 m.

Stryd Power and Running Mechanics. The Stryd Pioneer uses tri-axial accelerometery, estimating forces in the horizontal, vertical and lateral directions, from a combined heart

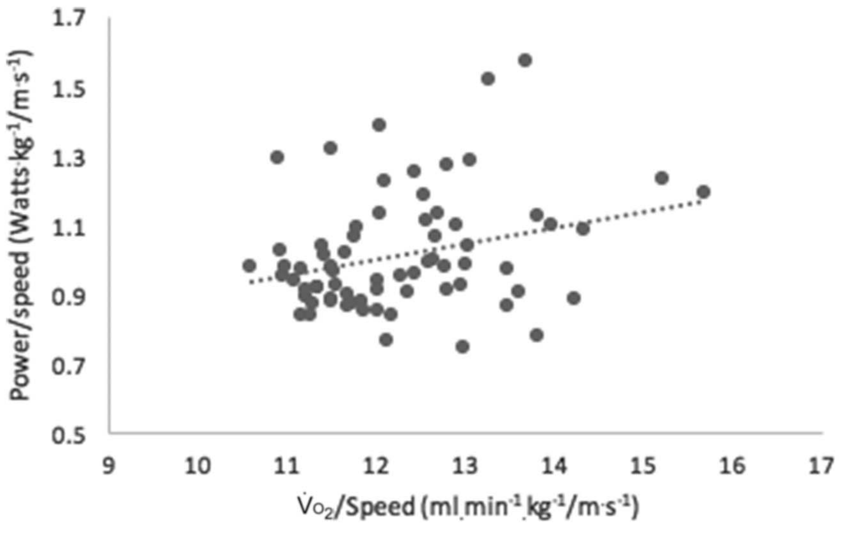

Figure 1. Relationship of metabolic demand ($\dot{V}O_2$/speed) with running power (power/speed) using both elite and recreational runners on a treadmill.

Table 2. Differences in average $\dot{V}O_2$ and running power while overground running on the track and treadmill running at various speeds in recreational and elite groups.*

		$\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$)						Power ($w \cdot kg^{-1}$)			
Over-ground speed ($km \cdot h^{-1}$)	Error measured vs. target (%)	Overground	% of max (overground)	Treadmill	% of max (treadmill)	Δ	p	Overground	Treadmill	Δ	p
Recreational											
11	2.0	41.2 ± 2.4	78.34 ± 5.3	41.7 ± 3.8	76.8 ± 8.5	0.5	0.5	2.94 ± 0.3	3.33 ± 0.5	0.39	0.4
12	2.5	45.0 ± 2.4	81.6 ± 6.9	43.7 ± 3.6	80.0 ± 8.1	1.3	0.13	3.42 ± 0.4	3.52 ± 0.6	0.01	0.5
14	2.8	51.6 ± 3.2	92.9 ± 5.8	47.9 ± 3.0	86.3 ± 5.7	3.7	0.007	3.90 ± 0.5	3.98 ± 0.7	0.08	0.6
16	3.3	59.1 ± 5.1	101.3 ± 3.2	54.0 ± 3.0	92.8 ± 3.1	5.1	0.01	4.56 ± 0.6	4.62 ± 0.5	0.06	0.7
Elite											
14	2.2	50.0 ± 4.0	73.6 ± 8.2	46.5 ± 2.6	68.4 ± 6.5	3.5	0.05	3.71 ± 0.3	3.72 ± 0.3	0.01	0.9
16	1.0	57.5 ± 4.1	84.5 ± 8.3	51.9 ± 2.4	76.2 ± 6.0	5.6	<0.001	4.18 ± 0.4	4.10 ± 0.4	0.02	0.3
18	0.8	64.8 ± 4.3	95.2 ± 9.1	58.6 ± 2.3	86.0 ± 6.3	6.2	<0.001	4.75 ± 0.4	4.65 ± 0.3	0.10	0.3

*Recreational runners were incapable of maintaining the same running speeds as elite runners. The variance of comfortable race pace, wherein metabolic demand is highest, differed more in recreational athletes, hence the inclusion of an additional category. Values are mean ± *SD*.

rate/accelerometer strap worn around the chest. A runner's cadence, ground contact time, and vertical oscillation are measured and used in conjunction with body weight, speed (tracked through GPS), incline, and running mechanics to calculate "running power," via a smart phone interface. For calculation of the running power measurement during the treadmill test, pace of the participant was manually imputed into the Stryd app for each interval. Ground contact time (ms), vertical oscillation (cm), and cadence (steps per min) were all obtained and can be accessed by the consumer using the "Power Center" on the Stryd application. Further analysis to determine the average over each interval using WKO4 program (WKO+ software, Training Peaks) was completed for study purposes. Running power (W) was taken as an average over the interval once a plateau was reached.

Statistical Analyses

Independent samples *t*-tests were used to compare baseline characteristics between the elite and recreational groups, and metabolic demand and running power between overground and treadmill running. To understand the relationship of metabolic demand with running power, ground contact time, vertical oscillation and cadence, bivariate Pearson correlations were performed and collinearity of predictor variables using stepwise linear regression to identify predictors of RE. Owing to the challenges associated with comparing across differing running speeds between elite and recreational runners, metabolic demand measured as $\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$) and the Stryd calculated outcomes of power, ground contact time, vertical oscillation, and cadence were divided by the speed in $m \cdot s^{-1}$ at which the given interval was run. All statistical analyses were completed using SPSS (version 24.0; IBM, Inc., Chicago, IL, USA) with an alpha of $p \leq 0.05$. Values are expressed as mean ± *SD*.

RESULTS

Metabolic Demand and the Relationship to Running Power

Metabolic demand, measured as $\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$), and power ($W \cdot kg^{-1}$) data were divided by the speed at which they were run to increase the number of comparable observations across the population of recreational and elite runners who were capable of different running speeds. With this, a weak but significant correlation was found between $\dot{V}O_2$ and running power (Figure 1. $r = 0.29$, $p = 0.02$).

Running Power and $\dot{V}O_2$ on Treadmill vs. Outdoor Track

Irrespective of pace and competitive running status, metabolic demand was significantly higher (as represented by a higher $\dot{V}O_2$) on the outdoor track compared with the treadmill, except at the 2 slowest speeds in recreational runners. As speed increased, the difference in $\dot{V}O_2$ between outdoor running and treadmill running increased. Contrary to this, running power did not differ between the 2 surfaces for either group at any speed (Table 2). The error in

TABLE 3. Relationships of treadmill metabolic demand ($\dot{V}O_2$/speed) and common run dynamic measures expected to affect efficiency in runners, expressed as an overall group and by competitive status.

	Metabolic demand		
	Combined participants	Elite runners only	Recreational runners only
Ground contact time ($ms/m\cdot s^{-1}$)	$r = 0.62$*	$r = 0.27$	$r = 0.56$*
Vertical oscillation ($cm/m\cdot s^{-1}$)	$r = 0.55$*	$r = 0.17$	$r = 0.46$*
Cadence ($spm/m\cdot s^{-1}$)	$r = 0.52$*	$r = 0.18$	$r = 0.37$*

*Significant correlation between metabolic demand and run mechanics at $p < 0.05$.

overground running speed, calculated by comparing target vs. GPS tracked pace can be seen in Table 2 Treadmill error, comparing set speed and actual belt speed, was found to be between 1 and 2%.

Relationship of Metabolic Demand and Running Mechanics

Moderate strength associations were apparent between metabolic demand and ground contact time, vertical oscillation, and cadence while on the treadmill in all participants. Division of the runners by competitive status demonstrated this relationship of metabolic demand and run mechanics to be driven by the recreational group with no significant relationship in the elites (Table 3).

Multivariable linear regression revealed that a combination of vertical oscillation and ground contact time was the best predictors for metabolic demand ($\dot{V}O_2$/speed) contributing approximately 36% of variance in the O_2 cost of running. The equation to predict $\dot{V}O_2$/speed was, thus, calculated as y = 9.61 + 0.21 (ground contact time) + 0.485 (vertical oscillation).

DISCUSSION

This was the first study to investigate the relationship between running power, as measured through a novel wearable power meter, and metabolic demand measured as $\dot{V}O_2$ in both elite and recreational runners on both a track and treadmill to understand the potential utility of this technology for quantifying metabolic demand representing running economy. Although a significant overall relationship between running power and metabolic demand was demonstrated, the relationship was weak ($r = 0.29$), suggesting that running power as assessed with the Styrd Power Meter is not a great reflection of the metabolic demand of running in a mixed ability population of runners. Considering the applicability and validity of power in cycling as a metric for effort and performance (9) and its demonstrated relationship with submaximal $\dot{V}O_2$ (23,24), it was believed by many that a power metric in running could be of similar use to assess effort through metabolic demand. Given the results of the current study, running power does not demonstrate to be as consistently or strongly associated with performance or effort outcomes in a diverse group of runners as it does in cyclists. A notable reason for this discrepancy between running and cycling power may relate to the way in which power is quantified. In cycling, power is measured internally through the stress applied to components of the cycle multiplied by the pedaling cadence and there are minimal external factors influencing this calculation. Running power measured through the Stryd, however, is mathematically estimated using GPS pace and factoring in accelerometer derived mechanics. Although these factors, and even gradient changes (hill inclination/declination), can be quantified and incorporated into this calculation, other variables that may have a direct impact on the efficiency of running (including running surface, coefficient of drag, or wind) cannot be captured or accounted for at present.

In assessing the cost of treadmill compared with overground running on the track, the results of the current study suggest that overground running was more metabolically costly than treadmill running for almost all speeds. Furthermore, in both populations, as the speed increased, the discrepancy in the cost of running between the 2 surfaces also increased. This was not observed with running power output measures, as no significant difference in running power between the 2 surfaces was noted at any pace in either population. It is likely that the difference in metabolic demand between the 2 surfaces relates to surface stiffness and elasticity, as it has been demonstrated that a more compliant surface of the treadmill provides a greater energy return (18) and the effects of this in adjusting power calculations is not certain. It has previously been suggested that running mechanics may also be affected depending on running surface owing to a more consistent stride timing and run mechanics on a treadmill compared with overground running (10). However, this did not seem to be reflected in the calculated running power and, thus, this is something to be considered when using the running power meter on varied terrains that may have different influences on the work of running.

Given the weak relationship between metabolic demand and estimated running power, a deeper analysis was performed to determine whether the individual mechanical running components given with the Stryd provided more valuable predictive information or had a stronger relationship with $\dot{V}O_2$. Through multiple linear regression analysis, vertical oscillation and ground contact time combined were found to better relate to $\dot{V}O_2$/speed than running power. The equation derived from this analysis, and the associated *beta* weights, may offer insight for developing a more accurate prediction of $\dot{V}O_2$/speed while running on flat ground.

When investigating accelerometer-derived mechanics of ground contact time, vertical oscillation, and cadence individually against running economy to determine the relationship of each mechanics specifically, significant relationships were found in the recreational runners, whereas no relationship was found in the elite runners. The discrepancy in the relationships between the 2 populations most likely suggests that more novice runners have greater variation in their running mechanics, therefore influencing the metabolic cost (efficiency). Elite runners, with cumulative years of training, coaching, and notable success in the sport, have developed far greater biomechanical and metabolic efficiency; thus, less variation will exist in factors such as ground contact time, vertical oscillation and cadence, demonstrating less influence of these factors on the elite runners' metabolic efficiency.

The current study found that recreational runners who demonstrated a reduced ground contact time demonstrated less of a metabolic demand, possibly due to a shorter braking phase, which is known to be metabolically costly (12). These results are consistent with previous literature demonstrating reduced ground contact time to be associated with better running economy (4,14). However, conflicting evidence has found both the opposite relationship (11,22) and no relationship whatsoever (19,22). It is possible that the caliber of runner may influence the relationship, and our results found that specifically in a population of recreational runners, a shorter ground contact time is beneficial for reducing the metabolic demand of running, whereas it does not influence the elite population.

The current study found a relationship of reduced vertical oscillation with reduced metabolic demand in the recreational group, but not in the elite group. The relationship found in the recreational group is consistent with literature as increases in vertical motion necessitate greater support of one's body weight, incurring a metabolic cost (1,12). It is likely that no relationship in the elite group was seen as the efficiency in $\dot{V}O_2$ of the elite runners is directly affected by their already reduced vertical oscillation compared with recreational runners (21). As mentioned, this may be an adaptive response that has occurred from years of training to limit impact and improve speed (17).

Lastly, the current study demonstrated a clear relationship between cadence and metabolic demand in the recreational group of runners, but not in the elite group, likely owing to the homogeneity (lack of variance) in observations in this group. Elite runners in the current study demonstrated an average cadence of 87.6 ± 3.6 spm, falling in the optimal economical range of 85–90 spm (15), whereas the recreational runners had an average of 86 spm ± 3.9 on the lower end of what is deemed economical. It is likely that elite runners in this study have all self-optimized their cadence (15), making variability across the elite runners too small to influence metabolic efficiency.

This study demonstrates that the novel metric of "running power," as measured with the Stryd Pioneer, has a relationship with metabolic demand quantified using $\dot{V}O_2$. The relationship, however, is weak, suggesting that a simple running power measure cannot be used as a surrogate of metabolic demand of running or assessing running economy, nor can it distinguish differences in a runner's metabolic demand that exists between surface types. Running mechanics of ground contact time, vertical oscillation, and cadence demonstrated relationships with $\dot{V}O_2$ in a recreationally competitive population on the treadmill, demonstrating the potential utility in this specific population of runners.

Practical Applications

Although running power does not appear to be an accurate assessment of the metabolic demand of running, running mechanics estimated through the Stryd Pioneer demonstrated important relationships and predictive value to $\dot{V}O_2$, specifically in recreational runners. Therefore, this training tool may be useful for novice runners looking to track and adjust their running mechanics, leading to potential improvements in the metabolic efficiency of running and therefore improved running economy. Although we controlled for the influence of the environment (i.e., wind, temperature) in the current study, a recognized limitation is the possibility of small variations in conditions between participant tests, which could have influenced comparisons in running economy between the outdoor track and treadmill. Further research on the ability of running power meters, and the component running mechanics, should be conducted using varying terrains, inclines, and environmental conditions to give further information on the use of power metrics in running.

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