Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com

Full length article

Prediction of power output at different running velocities through the two-point method with the Stryd™ power meter

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ARTICLE INFO

Keywords:
Endurance runners
Linear regression
Power output
Two-Velocity method

ABSTRACT

Background: The force- and power-velocity (F–V and P–V, respectively) relationships have been extensively studied in recent years. However, its use and application in endurance running events is limited.
Research question: This study aimed to determine if the P–V relationship in endurance runners fits a linear model when running at submaximal velocities, as well as to examine the feasibility of the "two-point method" for estimating power values at different running velocities.
Methods: Eighteen endurance runners performed, on a motorized treadmill, an incremental running protocol to exhaustion. Power output was obtained at each stage with the Stryd™ power meter. The P–V relationship was determined from a multiple-point method (10, 12, 14, and 17 $km \cdot h^{-1}$) as well as from three two-point methods based on proximal (10 and 12 $km \cdot h^{-1}$), intermediate (10 and 14 $km \cdot h^{-1}$) and distal (10 and 17 $km \cdot h^{-1}$) velocities.
Results: The P–V relationship was highly linear ($r = 0.999$). The ANOVAs revealed significant, although generally trivial (effect size < 0.20), differences between measured and estimated power values at all the velocities tested. Very high correlations ($r = 0.92$) were observed between measured and estimated power values from the 4 methods, while only the multiple-point method ($r^2 = 0.091$) and two-point method distal ($r^2 = 0.092$) did not show heteroscedasticity of the error.
Significance: The two-point method based on distant velocities (i.e., 10 and 17 $km \cdot h^{-1}$) is able to provide power output with the same accuracy than the multiple-point method. Therefore, since the two-point method is quicker and less prone to fatigue, we recommend the assessment of power output under only two distant velocities to obtain an accurate estimation of power under a wide range of submaximal running velocities.

1. Introduction

Testing endurance athletes is essential for determining how they are adapting to their training program, understanding individual responses to training, assessing fatigue and the associated need for recovery, and minimizing the risk of nonfunctional overreaching, injury, and illness [1,2]. The use of incremental tests for detecting adaptations to training, predicting performance and determining training zones (i.e., thresholds) in endurance runners is quite extended [2]. The term 'threshold' refers to the level at which abrupt changes in the dynamic of any parameter occur in response to a stimulus. For instance, the blood lactate threshold concept has been used to define the exercise intensity at which there is a non-linear increase in lactate concentration [3]. Likewise, the heart rate during incremental exercise is sigmoidal, with a linear component in the middle and a plateau close to the maximal workloads [4]. The non-linear dynamic of these commonly used parameters makes difficult its prediction and utilization for prescribing training intensity. The identification of variables that change linearly together with the in-

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https://doi.org/10.1016/j.gaitpost.2018.11.037
Received 22 May 2018; Received in revised form 22 July 2018; Accepted 29 November 2018
Available online xxx
0966-6362/

crease in intensity might facilitate the prescription of training intensity.

The force-velocity (F–V) and load-V (L–V) are two important relationships that follow a linear fit (the higher the force and load, the lower the velocity) [5,6]. The assessment of the F–V relationship allows to determine the athletes force and velocity deficits [7,8], while the L–V relationship enables to estimate the one-repetition maximum [9,10]. Therefore, both relationships provide valuable information that can be used to prescribe individualized resistance training programs. The typical procedures used to determine the F–V and L–V relationships are based on the application of multiple loads (at least 4), which provide a wide range of force and velocity data that can be modelled through a linear regression [11,12]. However, since this procedure is time consuming and prone to fatigue, Jaric [13] proposed that, due to the high linearity of the F–V and L–V relationships, the application of only two loads could be enough to accurately determine these relationships. The name "two-point method" has been proposed to describe the testing procedure in which an individual linear relationship is modelled from only two data points (e.g., two different loads or velocities), while the name "multiple-point method" is used when more than two loads or velocities are applied [14].

Such a time-efficient method (i.e., 'two-point method') has been proved to be valid and accurate for determining the F–V and L–V relationships during a variety of resistance training exercises [9,15,16], cycling [17–19] and running [11,12,20]. Of note, in all the aforementioned studies subjects were required to exert maximum values of force against all the tested loads, obtaining a linear F–V relationship and a parabolic power-V (P–V) relationship. However, during an incremental running test (i.e. submaximal intensities), the resistance (i.e. runners´ body mass) is constant and, therefore, a linear P–V is expected. If this rationale is confirmed (i.e. the P–V relationship obtained from different treadmill velocities turns out to be approximately linear), a simplified method for its assessment might be used (i.e., 'two-point method' [20]), but no data is available regarding the feasibility of the two-point method during submaximal efforts.

Once discussed the importance of the information provided by the F–V and P–V relationships, now the point is how to measure them. Traditionally, force data during running has been obtained using specific instrumented treadmills [21]. Despite the high accuracy of instrumented treadmills, most coaches do not have easy access to such expensive equipment. In an attempt to provide an easier access to the F–V and P–V relationships, Samozino et al. [12] proposed a method to estimate them from only anthropometric and spatiotemporal data during an overground sprint acceleration, but this method is not applicable to submaximal velocities. Fortunately, the development of inertial motion units to quantify performance have been considerably developed in recent years and, today, some devices provide power data during running (e.g. Stryd™or Runscribe™).

To fill the aforementioned gaps in the literature, an incremental running protocol to exhaustion was performed by trained endurance runners and power output recorded with the Stryd™ power meter was averaged at each stage to determine the P–V relationship using a multiple-point method (10, 12, 14, and 17 km·h^{-1}) as well as three two-point methods based on proximal (10 and 12 km·h^{-1}), intermediate (10 and 14 km·h^{-1}) and distal (10 and 17 km·h^{-1}) velocities. This study aimed to determine if the power-velocity (P–V) relationship in endurance runners fits a linear model when running at submaximal velocities, as well as to examine the feasibility of the "two-point method" for estimating power values at different running velocities.

2. Methods

2.1. Participants

Eighteen recreationally trained male endurance runners (age range: 19–46 years; age: 34 ± 7 years; height: 1.76 ± 0.05 m; body mass: 70.5 ± 6.2 kg) voluntarily participated in this study. All participants met the inclusion criteria: (1) older than 18 years old, (2) able to run 10 km in less than 40 min, (3) training on a treadmill at least once per week, (4) not suffering from any injury (points 3 and 4 related to the last 6 months before the data collection). After receiving detailed information on the objectives and procedures of the study, each subject signed an informed consent form in order to participate, which complied with the ethical standards of the World Medical Association's Declaration of Helsinki (2013). It was made clear that the participants were free to leave the study if they saw fit. The study was approved by the Institutional Review Board.

2.2. Procedures

Subjects were individually tested on one day. The testing session started with the collection of anthropometric data. Then, participants performed an incremental running test on a motorized treadmill (HP cosmos Pulsar 4 P, HP cosmos Sports & Medical, Gmbh, Germany). The initial speed was set at 8 km.h^{-1}, and speed increased by 1 km.h^{-1} every 3 min until exhaustion [22]. The slope was maintained at 1% in order to reproduce the effects of air resistance and try to obtain results as similar as possible to field conditions [23]. The treadmill protocol was preceded by a standardized 10-min accommodation program (5 min walking at 5 km.h^{-1}, and 5 min running at 10 km.h^{-1}). Participants were experienced in running on a treadmill but anyway, previous studies on human locomotion have shown that accommodation to a new condition occurs in ∼6-8 min [24,25].

2.3. Materials and testing

For descriptive purposes, body height (cm) and body mass (kg) were determined using a precision stadiometer and weighing scale (SECA 222 and 634, respectively, SECA Corp., Hamburg, Germany). All measurements were taken with the participants wearing underwear. Body mass index (BMI) was calculated from the subjects' body mass and height (kg. m^{-2}).

Power output (in W) was estimated with the Stryd™ power meter (Stryd Power meter, Stryd Inc. Boulder CO, USA). Stryd™ is a relatively new carbon fibre-reinforced foot pod (attached to the shoe) that weights 9.1 g. Based on a 6-axis inertial motion sensor (3-axis gyroscope, 3-axis accelerometer), this device provides twelve metrics to quantify performance: pace, distance, elevation, running power, form power, cadence, ground contact time, vertical oscillation, leg stiffness. To the best of the authors´ knowledge, just one study has examined its validity and reliability (in this case, to measure spatiotemporal gait characteristics [26]), with no data to demonstrate validity and reliability of this device to measure power and related variables. For this study, only two out of twelve metrics (running velocity and power output) were used. Those variables were obtained from Stryd´s website (https://www.stryd.com/powercenter/analysis) into the. fit file. Then, data were analyzed using the publically available software (Golden Cheetah, version 3.4) and exported as. csl file. Those files were imported from Excel® (2016, Microsoft, Inc., Redmond WA) and laps were done every 3 min. Twenty seconds were removed from each stage (10 s at the beginning and 10 s at the end) in order to avoid data close to changes in running velocity. Mean and standard deviation (SD) were calculated for those variables at each stage. Therefore, power output was obtained at each stage from 8 km·h^{-1} to exhaustion (range: 16-20 km·h^{-1}). Four methods were considered in the present study to estimate power output at different running velocities: (1) multiple-point method (10, 12, 14, and 17 km·h^{-1}), (2) two-point method proximal (10 and 12 km·h^{-1}), (3) two-point method intermediate (10 and 14 km·h^{-1}), and (4) two-point method distal (10 and 17 km·h^{-1}) (Fig. 1). Velocities lower than 10 km·h^{-1} were excluded from the models because resulted uncomfortable for trained endurance runners, while velocities higher than 17 km·h^{-1} were excluded from the models because some runners did not reach those levels during the protocol.

2.4. Statistical analysis

Descriptive data are presented as means and standard deviation, while the Pearson's correlation coefficient (r) are presented through their median values and ranges. Normal distribution for all variables (Shapiro–Wilk test) and the homogeneity of variances (Levene's test) were confirmed ($p >$ 0.05). The r coefficient was used to evaluate the strength of the individual P–V relationships. A 1-way repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc tests was applied at each velocity condition to compare the measured values of power against the values of power obtained from the 4 estimation methods (i.e., multiple-point method, two-point method proximal, two-point method intermediate, and two-point method distal). To further explore the validity of the 4 estimation methods, the r coefficient and the Cohen's d effect size (ES) were calculated between the measured power and the values of power obtained from the 4 estimation methods. The scale used to interpret the magnitude of the ES was specific to training research: negligible (< 0.2), small (0.2–0.5), moderate (0.5–0.8), and large (≥0.8) [27]. Finally, Bland-Altman plots were constructed to examine the presence of systematic and proportional bias between the measured and estimated values of power. Heteroscedasticity of error was defined as an $r^2 >$ 0.1 [28]. Significance was accepted at $p \leq$ 0.05. All statistical analyses were performed using the software package SPSS (IBM SPSS version 22.0, Chicago, IL, USA).

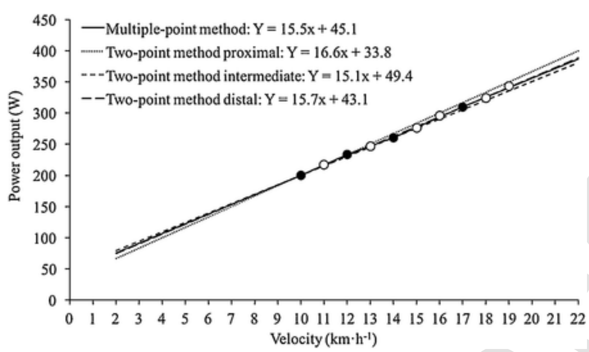

Fig. 1. Power-velocity relationship obtained for a representative participant. The individual points represent the power values recorded against 10 different velocities. The black points denote the velocities that were used for the 4 estimation methods (multiple-point method: 10, 12, 14, and 17 km·h^{-1}, two-point method proximal: 10 and 12 km·h^{-1}, two-point method intermediate: 10 and 14 km·h^{-1}, and two-point method distal: 10 and 17 km·h^{-1}). Note that the regression lines of the two-point method distal are not easily appreciated due to their high overlap with the multiple-point method.

3. Results

The strength of the P–V relationship was very high (r = 0.999 [0.994, 1.000]). The ANOVAs revealed significant differences between the measured and the estimated values of power at all the velocities analysed (Table 1). However, most of the ES comparing the measured and estimated values of power were trivial (ES < 0.2) with the only exception of the two-point method proximal that overestimated power outputs at high velocities (see Fig. 2; lower panel). The magnitude of the correlations between the measured power and the power values estimated from the 4 methods was very high for the individual velocities (Fig. 2) as well as when the data of all velocities were pooled (Fig. 3).

Bland–Altman plots revealed heteroscedasticity of error for the two-point method proximal (r^2 = 0.139) and for the two-point method intermediate (r^2 = 0.128) with increasing differences in favour of the estimated power at higher running velocities, while heteroscedasticity of error was not observed for the multiple-point method (r^2 = 0.091) and two-point method distal (r^2 = 0.092) (Fig. 4).

4. Discussion

This study explored the possibility of predicting power outputs at different running velocities from the recording of power values under only two velocity conditions ("two-point method"). The use of the two-point method to estimate power output at different running velocities is justified by the strong linearity observed in the current study for the P–V relationship. Despite that the three two-point methods examined in this study were able to provide valid estimations of power output, the two-point method based on distant veloci-

Table 1
Comparison of the measured values of power against the values of power obtained from the 4 estimation methods.

Velocity (km·h^{-1})	ANOVA (Snedecor's F)	Measured power (W)	Multiple-point method (W)	Two-point method proximal (W)	Two-point method intermediate (W)	Two-point method distal (W)
11 (n = 18)	10.3*	217.1 ± 18.8	216.1 ± 19.1	216.1 ± 19.0	215.7 ± 19.1*	215.4 ± 19.1*
13 (n = 18)	7.9*	252.2 ± 22.3	250.4 ± 22.0*	251.9 ± 22.0	250.7 ± 22.2*	249.7 ± 22.1*
15 (n = 18)	5.5*	285.2 ± 25.6	284.6 ± 25.1	287.6 ± 25.1	285.7 ± 25.4	284.0 ± 25.2
16 (n = 18)	6.0*	301.8 ± 27.0	301.7 ± 26.7	305.5 ± 26.7	303.2 ± 27.1	301.1 ± 26.7
18 (n = 17)	5.7*	334.4 ± 30.5	334.9 ± 30.5	340.2 ± 30.5	337.0 ± 31.0	334.4 ± 30.6
19 (n = 11)	5.0*	339.1 ± 31.4	340.5 ± 29.8	347.7 ± 30.6	344.2 ± 31.2	339.7 ± 29.7
20 (n = 6)	3.6*	343.3 ± 26.8	346.7 ± 29.0	349.4 ± 27.1	347.3 ± 27.8	346.7 ± 29.3

Mean ± standard deviation.
* denotes a significant F value and significant differences respect to the measured power ($p <$ 0.05).

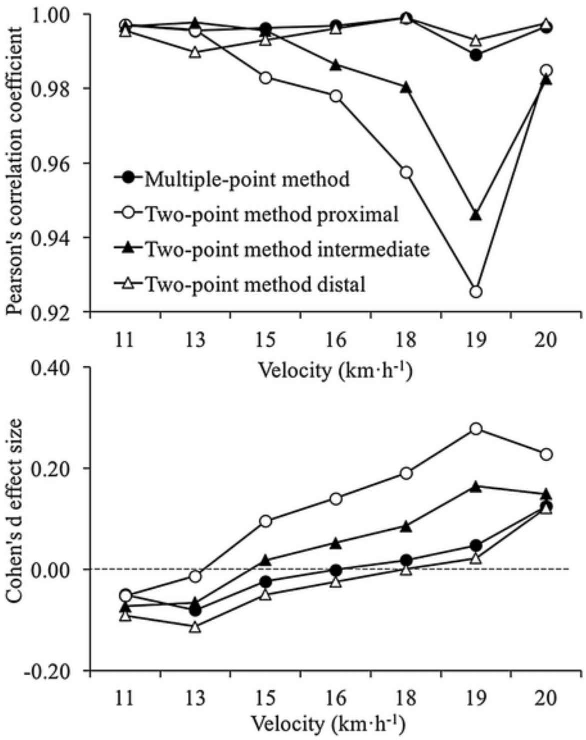

Fig. 2. Pearson's correlation coefficients (upper panel) and Cohen's *d* effect size (lower panel) between the measured and the estimated values of power from the multiple-point method (filled circle), two-point method proximal (empty circle), two-point method intermediate (filled triangle) and two-point method distal (empty triangle) at different running velocities. Effect size = (estimated power mean – measured power mean) / SDboth.

ties (i.e., 10 and 17 $km{\cdot}h^{-1}$) provided the most accurate estimations, especially at high running velocities. It is important to note that the two-point method distal was able to provide power output with the same accuracy than the multiple-point method.

As we earlier mentioned, the validity and reliability of the two-point method has been tested during a wide variety of resistance training exercises [9,15,16]. Zivkovic et al. [15] tested twelve participants during functional movement tasks against multiple loads, and an almost perfect level of agreement between the routinely used "multiple-point method" and a simple "two-point method" was reported. Some previous studies also used the two-point method during cycling [18,19,29]. In a recent work, García-Ramos et al. [29] aimed to determine the two optimal resistive forces for testing the F–V relationship in cycling. The experiment involved twenty-six men, who were tested on maximal sprints performed on a leg cycle ergometer against 5 flywheel resistive forces (R1–R5), and the authors concluded that the two-point method in cycling should be based on 2 distant resistive forces (R1-R4). This finding, consistent with the current study, was reinforced by an intervention study from the same research group [19]. In this case, the authors reported that specific changes on the F–V parameters during a cycling-based training program can be accurately monitored by applying just two distinctive resistances during routine testing. Despite methodological differences, these previous studies are in line with the current findings, showing that the two-point method (with distant loads) accurately predicts the F–V and P–V relationships in protocols and exercises where variables are linearly, or close to, related.

Despite the benefits attributed to the two-point method, in terms of time and effort [13,14], limited evidence has examined the possibility to apply this method to running. Some previous studies have applied the multiple-load method to determine the F–V relationship during maximal runs (i.e. sprints) [11,12]. Cross et al. [11] determined the F–V relationship from the velocity recorded against a range of sled-resisted sprints [11], whereas Samozino et al. [12] used

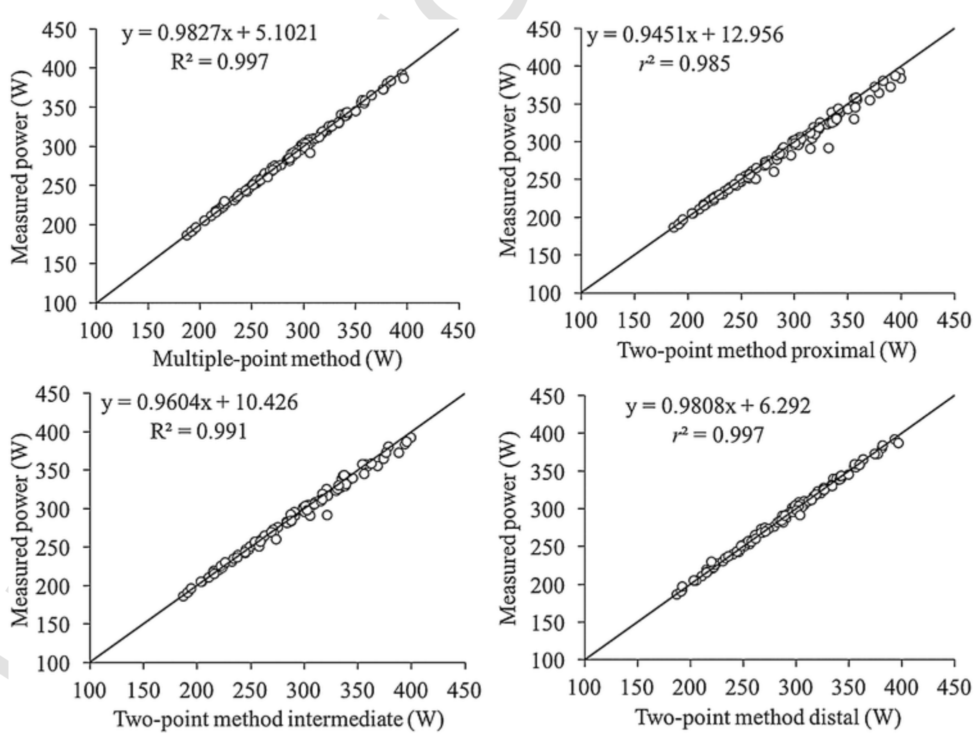

Fig. 3. Relationship between the measured and the estimated values of power from the multiple-point method (upper-left panel), two-point method proximal (upper-right panel), two-point method intermediate (lower-left panel) and two-point method distal (lower-right panel). The regression equation and the Pearson's coefficient of determination (r^2) are depicted.

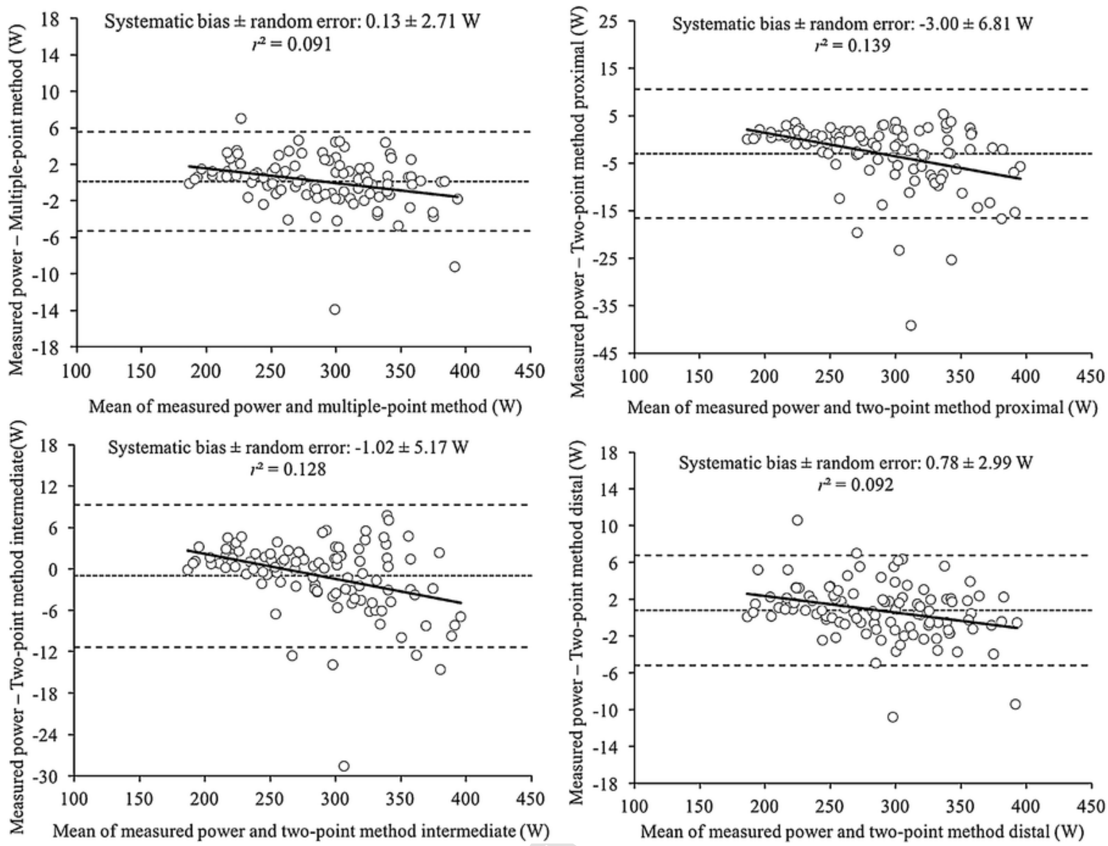

Fig. 4. Bland–Altman plots showing differences between the measured power and the values of power estimated from the multiple-point method (upper-left panel), two-point method proximal (upper-right panel), two-point method intermediate (lower-left panel) and two-point method distal (lower-right panel). Each plot depicts the averaged difference and 95% limits of agreement (dashed lines), along with the regression line (solid line) (n = 106). r^2, Pearson's coefficient of determination.

the anthropometric and spatiotemporal data recorded during an unloaded sprint [12]. Despite it seems well established that multi-joint functional tasks typically reveal strong and approximately linear F–V relationship patterns [5], a mistake would be committed if results from the aforementioned studies were compared to those reported by the current work. With maximum values of force against a tested load (i.e. maximal sprint), the higher the force the lower the velocity, obtaining a linear F–V relationship and a parabolic P–V relationship. However, in the current study performed at submaximal intensity, the resistance (i.e. runners´ body mass in this case) is constant and, therefore, the P–V relationship is linear.

To the best of the authors´ knowledge, no previous studies have tested the feasibility of using the two-point method to determine the F–V or P–V relationship during running at submaximal intensities (commonly used for endurance runners in training and competition). Dobrijevic et al. [20] tested 28 physically active subjects on their maximum pulling force exerted horizontally while walking or running on a treadmill set to different velocities (5–12 km.h^{-1}), and concluded that the F–V relationship could be strong, linear, and reliable at velocities tested, and the "two-velocity method" could provide reliable and ecologically valid indices of force, velocity, and power. Before comparing their findings with the current study some points need to be considered. First, based on the aforementioned rationale, the application of their maximum pulling F while walking or running ensures a linear F–V relationship and a parabolic P–V relationship what differs from our study, obtaining a linear P–V relationship. Second, the methodological differences according to the population involved (physically active vs. trained endurance runners) and the velocities tested (~5-12 km·h^{-1} vs. ~8-21 km·h^{-1}) makes the comparison difficult. Despite those differences, the results reported provide support to the feasibility of using the two-point method to estimate the power output during running at a wide range of velocities. The current study is focused on endurance runners and suggests that the assessment of power output, easy-to-obtain data with new devices such as Stryd™ power meter, under only two distant velocities (i.e., 8 and 17 km·h^{-1}) provided the most accurate estimations - with the same accuracy than the multiple-point method. From a practical standpoint, this information might be crucial for coaches. Confirmed the linear P–V relationship during submaximal runs, any interval workout (including distant velocities) might be enough to update the P–V profile during running and, therefore, give coaches information about adaptations to the training program (monitoring) and work capacity almost on a daily basis (periodization and training design).

Finally, some limitations must be addressed. The validity and reliability of the power output data from the Stryd™ system is still unknown. However, a recently published book [30] indicated that the external mechanical power (W/kg) reported by this system is highly correlated (R^2 = 0.96) with metabolic cost (VO_2 in ml/kg/min). It is a relatively new device and more research is clearly needed to determine its potential. Other point to consider, though not necessarily a limitation, is related to the protocol itself. This is an incremental test to exhaustion, which means that high levels of fatigue are ensured at the end of the protocol. Since the duration that exercise can be maintained decreases as the power requirements increase, and vice versa [31], the fatigue induced might influence on the power output if compared with data from just two-point methods (i.e., 10 and 17 km·h^{-1} as proposed in the current study). Notwithstanding these limitations, the current work highlights the linear P–V relationship during running in a wide range of submaximal intensities (typically performed in training and competition contexts), as well as confirms the effectiveness of the two-point method based on distant velocities (i.e., 10 and 17 km·h^{-1}) for accurately estimating P–V profile.

In conclusion, the results obtained in the current study show that the two-point method based on distant velocities (i.e., 10 and 17 km·h^{-1}) is able to provide power output with the same accuracy than the multiple-point method. The data reported also indicate a strong linearity for the P–V relationship. Therefore, since the two-point method is quicker and less prone to fatigue, we recommend the assessment of power output under only two distant velocities to obtain an accurate estimation of power under a wide range of submaximal running velocities.

Authors' contributions

FGP: analysis and interpretation of data and drafting the article; PALR: conception and study design, acquisition data, revising the manuscript critically; LERS: conception and study design, acquisition data, revising the manuscript critically; AGR: conception and study design, acquisition data, revising the manuscript critically. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Conflict of interests

The authors declare that they have no conflict of interests.

Declarations of interest

None.

Acknowledgements

The authors would like to thank to all the participants.

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