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Research article

Prediction of Half-Marathon Power Target using the 9/3-Minute Running Critical Power Test

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Abstract
Running power output allows for controlling variables that have been previously overlooked by relying solely on speed, such as surface, gradient and weight. The ability to measure this external load variable now enables the analysis of concepts that have predominantly been studied in cycling, such as the Critical Power (CP), in the context of running. This study aims to predict the CP target at which trained athletes run a half-marathon and determine whether races of this distance can serve as a valid alternative to update the CP record. A group of nine trained athletes performed the 9/3-minute Stryd CP test and participated in a half-marathon race in two separate testing sessions conducted in the field. The average power during a half-marathon race is a valid alternative method for determining the CP in trained athletes, as evidenced by the agreement (95% CI: -0.11 to 0.37 W/kg) and trivial systematic bias (0.13 W/kg) between methods. The linear regression model half-marathon power = 0.97 + 0.75·CP (W/kg) showed low standard error of estimate (0.29 W/kg) and significant large association between methods (r = 0.88; p = 0.002). Coaches and athletes should be aware that the CP target for a half-marathon race is 97.3% of the CP determined by the 9/3-minute Stryd CP test.

Key words: Running power; IMU; field; endurance performance; exercise testing.

Introduction

For the kinetic analysis of physical activity or sport, it is crucial to utilize measuring instruments that quantify the forces that cause movement, to calculate work, power, and energy (Marroyo and López, 2015). In cycling, the increasing availability of power measurement devices has prompted some authors (Allen and Coggan, 2012) to link power output with a Functional Threshold Power or Critical Power (CP). With the advent of running power measurements, these concepts have also been extended to the sport of running (Cartón-Llorente et al., 2021, Ruiz-Alias et al., 2022, Ruiz-Alias et al., 2023, Olaya-Cuartero et al., 2019, Olaya-Cuartero et al., 2023, Dearing and Paton, 2022).

Specifically, CP is defined as the maximum work rate at which fatigue-induced metabolites remain below critical levels (Hill, 1993). From a physiological perspective, Johnson et al. (Johnson et al., 2007) established that CP is a key component of the aerobic system, representing an exercise intensity that allows the maintenance of a steady state without an exponential increase in VO_2 and blood lactate concentration.

In the realm of running, the Stryd device stands out as the recommended tool for ecologically measuring running power (Olaya-Cuartero and Cejuela, 2020). Running power increases alongside velocity, being Stryd to be the most reliable and accurate wearable device for running power output (Jaén-Carrillo et al., 2020). Unlike internal measures like heart rate, running power remains unaffected by external factors such as temperature, dehydration, or caffeine (Stryd Team, 2023). Recent attention in the running community has been drawn to the running power meter, particularly the Stryd Summit Power Meter, due to its ability to accurately capture external work and maintain consistency across various running conditions (Ruiz-Alias et al., 2022, Imbach et al., 2020, Cerezuela-Espejo et al., 2021). Traditionally, predictive variables for half-marathon performance in male runners have relied on race time analysis (Gómez-Molina et al., 2017). However, the emerging paradigm in running introduces power-based protocols that account for previously overlooked factors influenced by surface, gradient, and body mass (Ruiz-Alias et al., 2022). Running power output data offers a more precise representation of running intensity, further enhancing the significance of the narrow CP threshold (Ruiz-Alias et al., 2022). Stryd provides valuable data, including a realistic estimate of CP (Dearing and Paton, 2022). The 9/3-minute Stryd CP test determines CP intensity based on ventilatory thresholds and maximum oxygen uptake (Ruiz-Alias et al., 2022). Critical Power determination has been explored not only in specific disciplines like cycling through the 3-Min All-Out test (Moya et al., 2018, Burnley et al., 2006) , but also in running using the 9/3-minute Stryd CP test (Ruiz-Alias et al., 2022, Olaya-Cuartero et al., 2023), and in the context of triathletes where CP interchanges between these disciplines (Olaya-Cuartero et al., 2023). Various tests and protocols, such as the 3-Min All-Out test, 9/3-minute Stryd CP test, 3/6-laps test, 30-minutes test, have been examined for determining the Functional Threshold Power or CP in running (Olaya-Cuartero et al., 2019). These studies provide a practical foundation as measuring running power offers the advantage of data collection in real-world training and competition settings compared to laboratory-based devices (Norris et al., 2014). However, further specific evidence is needed to delve into power-derived concepts, such as the estimated Power Target based on Critical Power (Ruiz-Alias et al., 2023) .

The purpose of the study was twofold. Firstly, it aimed to predict the CP target based on the 9/3-Minute Stryd Critical Power test at which trained athletes run a

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half-marathon. Secondly, it sought to determine whether races of this distance can be a valid alternative to update the CP record. It is hypothesized that the 9/3-Minute Stryd Critical Power test performed by trained athletes can accurately predict the half-marathon CP target and demonstrate the validity of recorded power output over this distance for updating the CP record.

Methods

Experimental design

An observational study was conducted, comprising two field sessions carried out over two weeks, aiming to determine the running CP and the percentage (%) of CP at which athletes completed the half-marathon. The first field session (first week) involved collecting anthropometric measurements from the participants prior to initiating the 9/3-Minute Stryd CP test (Ruiz-Alias et al., 2022), which was used to establish the CP value designated as 100%. In the second field session (second week), participants completed the same half-marathon race under identical weather conditions and at the same time of day, wearing the same footwear as in the 9/3-Minute Stryd CP test.

Participants

Nine trained athletes (age 38.1 ± 5.4 years, height 1.75 ± 0.06 m, body mass 71.8 ± 6.4 kg, ∑ 8 skinfolds 75.6 ± 31.1 mm, muscle mass 23.8 ± 11.6 kg, fat mass 8.13 ± 4.25 kg, fat mass 11.1 ± 4.7 %) voluntarily participated in this study. All participants were recruited from the same local club. The inclusion criteria were established to select trained athletes (McKay et al., 2021): which included: (1) > 150 min/week training volume; (2) active involvement in the sport of running; (3) participation at the regional level; (4) half-marathon time 1:25:36 ± 00:11:20 (hh:mm:ss). All injured or unhealthy subjects were excluded. Before participating, they read and signed an informed consent document that provided them with information about the characteristics of the study and the strictly scientific use of the obtained data. The study, which has been approved by the ethics committee of the University of Alicante (2023-02-04), adhered to the ethical guidelines stated in the Declaration of Helsinki of the World Medical Association.

Anthropometry

Anthropometry was used to estimate the body composition of the athletes. All measurements were conducted by the same anthropometrist, Level 1 of the International Society for the Advancement of Kinanthropometry. The physical characteristics of the participants, including age, body mass, and height, were measured following the protocol of Ross and Marfell-Jones (Ross and Marfell-Jones, 1991). The equipment used for the measurements consisted of a Holtain skinfold caliper (Holtain Ltd., Crymych, UK), a Holtain bone breadth caliper (Holtain Ltd., Crymych, UK), scales, a stadiometer, and anthropometric tape (SECA Ltd., Hamburg, Germany). The measurements were taken three times for each participant, including biepycondilar humerus, bi-styloid, and biepicondylar femur breadths, as well as relaxed arm, flexed and tensed arm, waist, hip, and calf girths. Skinfolds were taken at the triceps, subscapular, biceps, iliac crest, supraspinal, abdominal, thigh and calf sites. Muscle mass, fat mass, and bone mass were estimated using the Lee equation (Lee et al., 2010), Withers equation (Withers et al., 1987), and Döbeln equation, modified by Rocha (Rocha, 1975) , respectively. Somatotype was calculated using the Heath-Carter equations (Carter, 2002).

Stryd critical power test

On the first day of testing, the running CP was determined using the 9/3-minute Stryd CP test, following the protocol established in previous studies (Olaya-Cuartero et al., 2023, Ruiz-Alias et al., 2022). The test was conducted on a certified 400-m athletics track. The participants performed a warm-up consisting of 10 min of low to moderate intensity exercise, followed by 2 to 3 high-intensity 1-min short bouts with 2 min of active rest. Prior to the main test, the running power meter (Stryd Summit Power Meter) was attached to the laces of the right shoe. The main test consisted of two maximum efforts, one lasting 9 min and the other lasting 3 min, with 30-min active recovery break between the two efforts (Olaya-Cuartero et al., 2023, Ruiz-Alias et al., 2022). To mark the start and end of each maximal effort, a Fox 40 Classic whistle (Fox 40 International, Hamilton, Ontario) (Flamme and Williams, 2013) was blown by a researcher. During the test, the participants received immediate feedback on their wristwatches regarding the running pace (min/km) and the remaining time for each maximal efforts. The power output in absolute values (W) in the 9- and 3-min trials was recorded and later entered into the Stryd CP calculator (https://www.stryd.com/powercenter). The process of algorithmic calculation of the raw data remains undisclosed by the company as part of its know-how (Cartón-Llorente et al., 2021).

Half-marathon: race

On the second day of testing, all athletes participated in the “International Half-Marathon Villa de Santa Pola”, which took place on Sunday, January 22, 2023. This event is recognized as one of the top 4 half-marathons in Spain and is included in the international calendar, as highlighted by the homologation report of the Royal Spanish Athletics Federation. The race covered a distance of 21,097 m and featured a positive and negative altitude difference of 72 m. The course followed an urban and circular route, consisting in two laps. During the race, the weather conditions were favourable (temperature 9ºC, relative humidity 28%, wind speed: 3.5 m/s; absence of rain: 0.0 l/m^2). Prior to the race, the running power meter was calibrated following the manufacturer's instructions. The average power value for the entire half-marathon distance (21,097 m) was measured with the Stryd Power Meter and analyzed at the Stryd Power Center.

Statistical analysis

Descriptive statistics were presented as mean ± SD. Inferential statistics were reported using both the *p*-value and 95% confidence interval (95%CI). The normal distribution of data was confirmed using the Shapiro-Wilk test, and the homogeneity of variances was assessed using the Levene test. A paired samples t-test was used to compare the power output between the 9/3-minute Stryd CP and the half-marathon. The effect size (ES) was calculated the Hedges's *g* corrected ES (Cohen, 1988a), and interpreted as trivial, small, moderate, large, and very large for the thresholds of 0.2, 0.4, 0.8, 1.2, and 2.0, respectively (Cohen, 1988b). Bland-Altman plots were used to assess the agreement between the two methods (Bland and Altman, 1986). These plots analyzed the differences in power output pairs against their mean values and helped identify random errors, and proportional bias between the methods (Bartlett and Frost, 2008). In a Bland-Altman plot, a bivariate Pearson's product-moment correlation coefficient of the differences against the averages larger than 0.1 suggests that there is proportional bias present in the differences between the two methods being compared (Atkinson and Nevill, 1998). On the other hand, the relationship between paired observations was examined using the Bivariate Pearson's product-moment correlation coefficient *r* and linear regression analysis, using the following thresholds for *r*: 0.1, 0.3, 0.5, 0.7, and 0.9 were assessed as trivial, small, moderate, large, and very large association, respectively (Hopkins, 2002). The coefficient β_0 (intercept) and β_1 (slope) of the predictive linear regression equation $y = \beta_0 + \beta_1 x$ were estimated using Ordinary Least Squares regression. The standard error of estimate (SEE), calculated as the standard deviation of the residuals of the regression equation, was used to evaluate the goodness of fit of the linear regression model. All statistical analyses were computed with an available spreadsheet for reliability (Hopkins, 2017) and with SPSS v. 28 (IBM Corp, Armonk, NY, USA).

Results

Figure 1 shows the CP data determined by the 9/3-minute Stryd CP test and the half-marathon (HM) race relative power (W/kg). The athletes ran the half-marathon race at 97.3% of their CP, based on the CP value determined by the 9/3-minute Stryd CP test of each subject.

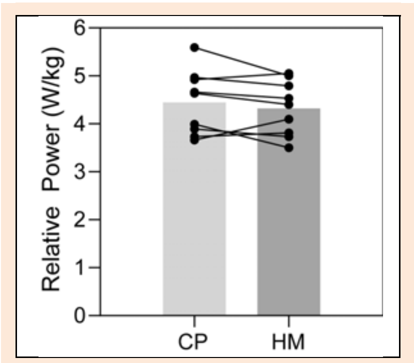

Figure 1. Difference between the CP and the average power of the HM race.

Based on the results presented in Table 1, the paired *t*-test comparing the differences in power output (0.13 W/kg) between the 9/3-minute Stryd CP test and the half-marathon races did not show statistical significance (p = 0.267), with trivial ES (0.19; 95%CI -0.11 to 0.51). Figure 2(a) illustrates the method agreement, showing a very large linear relationship between power output using the 9/3-minute Stryd CP and half-marathon. The calibration equation HM = 0.97 + 0.75·CP (W/kg) indicates a low intercept around 1 W/kg and slope close to unity. The ability of the model to fit the data is demonstrated by SEE around 0.3 W/kg.

Table 1. Agreement between power output using the 9/3-minute Stryd CP and the half-marathon.

Parameters	Mean	SD	95% CI
HM relative power (W/kg)	4.32	0.57	3.88 to 4.76
CP relative power (W/kg)	4.45	0.67	3.93 to 4.96
Paired difference (W/kg)	0.13	0.31	-0.11 to 0.37
Lower LoA (W/kg)	-0.49	–	-0.92 to -0.06
Upper LoA (W/kg)	0.75	–	0.31 to 1.17
Cal. eq. intercept β_0 (W/kg)	0.97	–	-0.64 to 2.59
Cal. eq. slope β_1	0.75	–	0.39 to 1.11
Pearson's correlation *r*	0.88	–	0.52 to 0.97
SEE	0.29	–	0.19 to 0.58

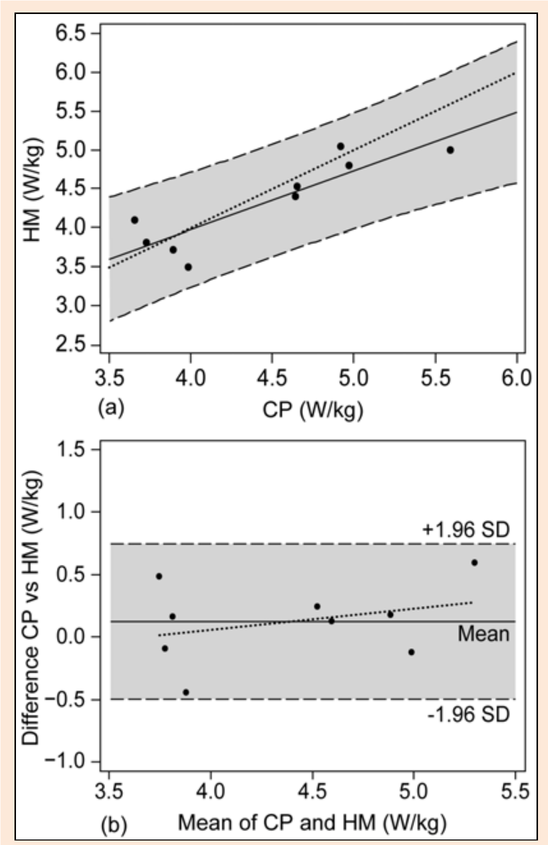

Figure 2. Agreement between the power output of the 9/3-minute Stryd CP and the half-marathon: (a) Linear regression analysis. Solid central line represents the fitted equation; upper and lower dashed lines show 95% confidence intervals; dotted line represents line of equality $y = x$; (b) Bland Altman plot. Solid central line represents the mean between methods (systematic bias); upper and lower dashed lines show systematic mean ± 1.96 SD (random error); dotted line depicts linear regression (proportional bias).

The Bland-Altman plots in Figure 2(b) display high agreement between the 9/3-minute Stryd CP and HM methods. The LoA, representing the reference interval for the difference between measures, are narrow: ± 0.62 W/kg and all power observations fall within these limits. The Linear regression equation of the differences $y = -0.61 + 0.17x$, and determination coefficient $r^2 = 0.1$ indicate homoscdasticity of errors.

Discussion

This study aimed to predict the CP target based on the 9/3-Minute Stryd Critical Power test for trained athletes running a half-marathon. Additionally, we aimed to explore whether half-marathon races could serve as a valid alternative for updating the CP record. The key findings of the present study indicate that there were no significant differences between the CP value determined by the 9/3-minute Stryd CP test and the CP target in a half-marathon race, which is typically run at ~ 100% of the CP.

For a proper discussion and interpretation of the results, it should be noted that, according to the scientific literature, the commonly used method for the determination of running CP is the 9/3-minute Stryd CP test (Olaya-Cuartero et al., 2023, Ruiz-Alias et al., 2022). The concept of running CP has been investigated using this same protocol in high-caliber athletes by Ruiz-Alias et al. (Ruiz-Alias et al., 2022) in relation to ventilatory thresholds and maximum oxygen uptake. In depth, different models to predict long-duration power output has been compared (Ruiz-Alias et al., 2023).

Additionally, this protocol has been employed in triathletes to analyze the interchangeability of CP between running and cycling disciplines (Olaya-Cuartero et al., 2023). Similarly, it has also been used with triathletes to determine CP for the running segment (Olaya-Cuartero, 2019, Olaya-Cuartero et al., 2019). Therefore, due to the limited scientific literature on running power, the CP obtained from the 9/3-minute Stryd CP test is considered as 100% (Ruiz-Alias et al., 2022). Using data from this test, the percentage of CP at which trained athletes run the half-marathon race can be calculated.

Firstly, examining the Bland-Altman plots (Bland and Altman, 1986), which illustrate the agreement (95% CI: -0.1145 to 0.3704) between the 9/3-minute Stryd CP test and the average power of the half-marathon, it is demonstrated that all data are within the 95% limits of agreement, as shown in Figure 2(b). Therefore, none of the trained athletes were considered outliers. This is an important consideration given the low sample size. To further analyze this, effect sizes (Cohen, 1988a) were calculated to compare the standardized means differences between the two methods and interpreted as trivial (ES = 0.19) (Cohen, 1988b). The agreement between the tests is also supported by the mean difference being close to zero (0.13 W/kg, indicating the absence of systematic differences as evidenced by the fact that this value falls within the 95% confidence interval.

Secondly, the agreement for the determination of CP is further supported by the regression analysis, revealing a significant large association ($r = 0.88$; $p = 0.002$) between both methods. Moreover, the homogeneity of the data can also be appreciated through the determination coefficient ($r^2 = 0.1$) which falls within the threshold of homoscedasticity of errors (Hopkins, 2002) . This indicates that the measurement range does not pose any issue, as the measure is neither overestimated nor underestimated. Additionally, the calibration equation with a slope of 0.75 and the intercept of 0.97 W/kg demonstrates the ability to predict the power value of the half-marathon based on the 9/3-minute Stryd CP test (Olaya-Cuartero et al., 2023, Ruiz-Alias et al., 2022). Likewise, from a practical point of view through the analysis of the power-duration curve aforementioned (Ruiz-Alias et al., 2023), the power corresponding to the time of the half-marathon (1:23:35 ± 00:11:20 hh:mm:ss) could also be used as valid to determine the running CP record. Indeed, with these power and speed data, it would be possible to calculate and estimate the energy expenditure data by continuous logarithmic regression (Ardigò and Capelli, 2012).

Thirdly, the SEE value indicates that an error of 0.3 W/kg is typically assumed when using power prediction in the half-marathon based on the 9/3-minute Stryd CP test considered as the gold standard. Furthermore, the confidence limits of the SEE support the assumption of a low standard error between 0.2 W/kg in the best-case scenario to 0.7 W/kg in the worst-case scenario (Hopkins, 2017).

Finally, these results are further supported by the non-significant differences and small ESs observed between the CP determined by the 9/3-minute Stryd CP test and the average power of the half-marathon race. These results are consistent with the agreement demonstrated by both methods, providing justification for the use of the 9/3-minute Stryd CP test to determine the intensity at which a half-marathon can be run. The non-significant differences observed are less than 3%, as the half-marathon race is typically run at 97.6% of the CP previously determined by the 9/3-minute Stryd CP test considered as the 100% (Ruiz-Alias et al., 2022). Thus, these results provide new external load data that can be practically measured in race compared to traditional internal load data such as the Respiratory Compensation Threshold at 87.6% ± 5.2% VO_{2max} in male half-marathon runners (Gómez-Molina et al., 2017).

The main limitation of the study is attributed by the small sample size. To mitigate this limitation, ES are presented alongside statistical *p*-values. Additionally, it is noteworthy that the second field test was performed during the same half-marathon race, under identical weather conditions, and with consistent characteristics, such as distance, elevation gain, and course for all participants of the study. This data holds significant value for coaches and athletes, as it provides insights into the percentage of CP that can be sustained during a half-marathon, while also enabling the adjustment of CP value throughout the course of such a race.

Future studies should explore the percentage of CP required to run races of varying distances, including 3 km, 5 km, 10 km, half-marathon, and marathon, across different levels of runners (recreationally active, trained, highly trained/national level, elite/international level and world-class athletes), and sexes (females). Examining these factors will contribute to a more comprehensive understanding of the relationship between CP and performance across different race distances and athlete populations.

The study's results confirmed the hypotheses. The 9/3-Minute Stryd Critical Power test accurately predicted the CP target during a half-marathon run by trained athletes, and the half-marathon distance proved a valid alternative for updating the CP record.

Conclusion

The present study highlights that the average power in a half-marathon race can serve as a valid alternative method to determine running CP in trained athletes, as evidenced by the agreement and nonsignificant differences observed when compared to the 9/3-minute Stryd CP test. This finding implies that coaches and athletes can use the 9/3-minute Stryd CP test to predict the CP target at which a half-marathon can be run, which is estimated to be approximately (97.3%).

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All experiments comply with the current laws of the country in which they were performed. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The data sets generated and analyzed during the current study are not publicly available but are available from the corresponding author, who was an organizer of the study.

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Key points

- The study demonstrates that the average power during a half-marathon race can be a valid alternative method for determining Critical Power (CP) in trained athletes.
- There is agreement and a negligible systematic bias between the 9/3-minute Stryd CP test and average power during the half-marathon race, indicating the validity of the alternative method.
- A linear regression model shows a significant association between the methods and a low standard error of estimate, supporting the accuracy of the CP determination using the alternative method.
- Coaches and athletes can utilize the 9/3-minute Stryd CP test to predict the target CP at which a half-marathon can be run, estimated to be approximately 97.3%.

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