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RELIABILITY AND APPLICABILITY OF AN INCREMENTAL TRACK TEST WITH A PACER BICYCLE: A NEW AND ALTERNATIVE TO TREADMILL PROTOCOLS

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ABSTRACT

Assessing running endurance performance often relies on treadmill-based incremental tests, which may not always be practical or accessible. Therefore, it is crucial to develop reliable and cost-effective alternatives suitable for real-world training environments. This study compared the reliability and performance outcomes of incremental tests conducted on a treadmill versus those performed on a track while being guided by a bicycle, involving eleven amateur runners (6 men, aged 44.27 ±3.90 years, BMI 25.26 ±2.54 kg/m²). Each participant completed two tests under both conditions. Key variables analyzed included Peak Velocity (Vpeak), Time to Exhaustion (TE), Peak Heart Rate (HRpeak), and Rating of Perceived Exertion (PE). The results indicated that the track test yielded a significantly higher TE, particularly among women, suggesting a potential advantage for endurance evaluation. Both testing conditions exhibited strong reliability (α = 0.816; Ω = 0.937), with high consistency observed for Vpeak (r = 0.94) and HRpeak (r = 0.91-0.94). Collectively, these findings suggest that the bicycle-guided track-based incremental test serves as a practical and cost-effective alternative to treadmill protocols for assessing endurance performance. Given its high reliability and feasibility, this method offers a viable solution for evaluating endurance capacity, especially when treadmill testing is impractical. Future research should aim to refine its applicability across various training contexts.

Key words: Running. Exercise test. Physical Education. Training.

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RESUMO

Confiabilidade e aplicabilidade de um teste incremental em pista com uma bicicleta guiam: uma nova alternativa aos protocolos de esteira

A avaliação do desempenho em resistência na corrida frequentemente depende de testes incrementais realizados em esteira, os quais podem não ser sempre práticos ou acessíveis. Portanto, é fundamental desenvolver alternativas confiáveis e de baixo custo, adequadas a ambientes de treinamento do mundo real. Este estudo comparou a confiabilidade e os resultados de desempenho de testes incrementais realizados em esteira com aqueles executados em pista, guiados por uma bicicleta, envolvendo onze corredores amadores (6 homens, idade média de 44,27 ±3,90 anos, IMC 25,26 ±2,54 kg/m²). Cada participante realizou dois testes em ambas as condições. As variáveis principais analisadas foram: Velocidade de Pico (Vpeak), Tempo até a Exaustão (TE), Frequência Cardíaca Máxima (FCmáx) e Escala de Esforço Percebido (EP). Os resultados indicaram que o teste em pista resultou em um TE significativamente maior, especialmente entre as mulheres, sugerindo uma possível vantagem na avaliação da resistência. Ambas as condições de teste apresentaram forte confiabilidade (α = 0,816; Ω = 0,937), com alta consistência observada para Vpeak (r = 0,94) e FCmáx (r = 0,91-0,94). Coletivamente, esses achados sugerem que o teste incremental em pista guiado por bicicleta é uma alternativa prática e econômica aos protocolos em esteira para a avaliação do desempenho em resistência. Dada sua alta confiabilidade e viabilidade, esse método oferece uma solução viável especialmente quando o teste em esteira não é possível. Pesquisas futuras devem buscar aprimorar sua aplicabilidade em diferentes contextos de treinamento.

Palavras-chave: Corrida. Teste de Esforço. Educação Física. Treinamento.

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INTRODUCTION

Endurance performance assessment is a fundamental aspect of sports science, guiding training and competition strategies (Coyle, 1999, Benhammou et al., 2024).

Traditionally, treadmill-based incremental tests are the gold standard for evaluating key physiological parameters such as oxygen consumption (VO_2) and lactate thresholds, which are essential for monitoring endurance capacity and predicting performance (Brandon, 1995; Nikolaidis et al., 2023).

However, treadmill protocols may not always reflect real-world running conditions and can pose logistical and financial constraints, limiting their accessibility for athletes and coaches (Thuany et al., 2021).

The incremental test plays a crucial role in assessing aerobic capacity and planning sports training, as it allows for the determination of key parameters essential for performance prediction and training individualization. Among these parameters, peak velocity (Vpeak) and critical velocity (CV) stand out as fundamental metrics for endurance sports training prescription, as they reflect the ability to sustain effort at different intensities and durations (Tanaka et al., 1984).

Accurate identification of these variables enables more individualized training adjustments, optimizing physiological adaptations and athletic performance.

Moreover, studies indicate that variability in incremental test protocols can significantly impact these indicators, highlighting the importance of standardizing procedures to ensure greater reproducibility and applicability of results (Bentley et al., 2007; Denadai et al., 2004; Patoz et al., 2021).

A relevant issue is that the literature shows significant variability in incremental test protocols, which may influence both maximal and submaximal physiological variables and the purposes for which they are used.

The primary factors altering these protocols include sample characteristics, warm-up procedures, stage duration, velocity increments, surface incline, type of surface used, and progression format (Vucetic et al., 2015; Manoel et al., 2021; Cruz et al., 2017).

These variations can significantly impact the results obtained, including peak velocity and time to exhaustion (Bentley et al., 2007).

Additionally, incremental tests are usually conducted on treadmills and in laboratory settings. One of the main drawbacks of laboratory assessments is the challenge of replicating real-world conditions that athletes experience daily. However, there is a gap regarding incremental running protocols conducted on treadmills in gym environments and track-based tests guided by bicycles, with most track protocols typically being guided by auditory signals (Carminatti et al., 2013; Souza et al., 2014; Leger, Boucher, 1980; Manoel et al., 2021).

Furthermore, few studies on incremental tests have investigated test-retest reliability particularly in runners (Benhammou et al., 2024).

Therefore, this study aims to evaluate the reliability of two types of incremental tests, as well as to examine the relationships between treadmill-based testing and track-based testing guided by a bicycle. Investigating these differences and their implications is essential for better understanding how these protocols can be optimized to improve the accuracy and applicability of results in different training and competition contexts. We believe that a detailed analysis of these aspects will contribute to the development of more robust and standardized guidelines for assessing runners' performance metrics.

MATERIALS AND METHODS

Sample

The study sample consisted of 11 amateur adult runners of both sexes, including five women and six men, all engaged in regular training aimed at a 21 km competition. Participants followed two different training load distribution strategies, either polarized or pyramidal, both with similar exercise volumes, averaging approximately 35 km per week.

They were instructed to maintain their daily routines unchanged, including their training regimens. Additionally, preliminary 3000 m and 1000 m tests were conducted two weeks before data collection to characterize the sample, during the participants' usual training hours.

Ethical considerations

The conduct of experiments involving human beings must comply with the specific

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resolutions of the Brazilian National Health Council (Resolutions No. 196/96 and No. 466/12). This study was approved by the Human Research Ethics Committee of the Federal University of Viçosa (Universidade Federal de Viçosa - UFV), under the Certificate of Presentation for Ethical Consideration (CAAE) number 70753023.3.0000.5153 and Opinion number 6.253.380. All participants were informed about the study's procedures and objectives and signed an Informed Consent Form prior to data collection.

Anthropometric assessment

Before the beginning of the tests, participants underwent an anthropometric evaluation, which included body mass measurement using a digital scale (Multilaser® HC022 Digi Health) and height assessment using a portable stadiometer (Avanutri®).

Study design

The crossover study design consisted of four incremental tests, with two performed on a track and two on a treadmill, with a minimum interval of two days and a maximum of one and a half weeks between them. The total data collection period lasted four weeks, and the tests were scheduled according to the participants' availability, preferably during their usual training hours.

The tests were designated as Track 1, Treadmill 1, Track 2, and Treadmill 2. Participants were randomly assigned into two groups using the website randomizer.org, following the sequence outlined below. The methodological design is presented in Figure 1.

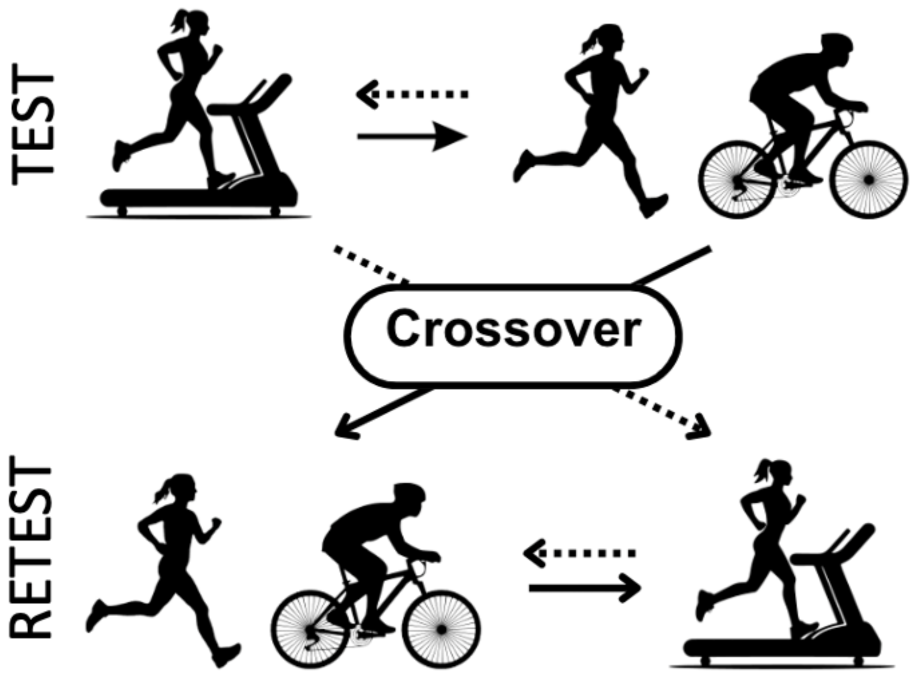

Figure 1 - Schematic representation of the crossover study design.

Incremental test protocol

Participants were instructed to follow their usual training routines and avoid physical exercise in the 24 hours preceding each test. All tests were performed using a chest heart rate monitor (Garmin® HRM Dual) connected to a sports watch (Garmin® Forerunner 735), with heart rate data collected via the Garmin Connect software.

The Rating of Perceived Exertion (RPE) was assessed using the Borg scale, ranging from 6 to 20. Verbal encouragement was standardized, with specific verbal cues given at each minute of the tests. Researchers ensured that the tone of voice remained consistent across all test sessions.

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The test protocol was structured and adapted from Leger, Boucher (1980) and consisted of three phases: warm-up, main test, and cool-down. Initially, the warm-up included 1200 meters of light running, followed by a brief pause to prepare participants for the main test.

The test started at a speed of 7 km/h for 3 minutes, with increments of 1 km/h per minute, continuing until voluntary exhaustion. The cool-down phase also consisted of 1200 meters of light running to facilitate recovery.

Peak velocity was determined based on the highest speed maintained for at least 20 seconds after a speed increment during the incremental test (Leger, Boucher, 1980).

Track-based incremental test protocol

The track-based test was conducted on a 400-meter outdoor track. Data collection took place in the presence of other athletes, who were instructed not to interact with the participants. Cones were used to delimit lanes 1 and 2 exclusively for research purposes, positioned every 20 meters.

During the warm-up and cool-down, participants were instructed to maintain a light Rating of Perceived Exertion (RPE), not exceeding 13.

The lead researcher, riding a bicycle in lane 1, paced the test in front of the participant using a digital magnetic speedometer (Sunding™), calibrated according to the manufacturer's recommendations. Another researcher, riding a bicycle in the adjacent lane, recorded RPE and time to exhaustion in real time.

Time to exhaustion was determined when the distance between the participant and the lead researcher on the bicycle exceeded 20 meters, marked by cones.

Treadmill-based incremental test protocol

The treadmill-based test was conducted on a treadmill (Speedo® TR8 PRO+) set at a 1% incline (Jones, Doust, 1996). Data collection took place in a gym environment, without external verbal stimuli except from the researchers.

On the treadmill, warm-up and cool-down speeds were controlled between 8 and 9 km/h. The research team was responsible for treadmill settings, except for stopping the test, which was done either upon voluntary exhaustion or upon request by the participant.

The variables RPE, time to exhaustion, and peak velocity were recorded by the research team during data collection. Time to exhaustion was determined when the participant voluntarily stopped the exercise or requested the test to be halted.

Data analysis

Data analysis was performed using the Statistica 10.4 software. Descriptive analyses of the sample were conducted, followed by t-tests to compare differences between men, women, and the total sample.

A Generalized Linear Model (GLM) was applied to analyze time to exhaustion (T.E.), peak velocity (Vpeak), peak heart rate (HRpeak), and peak perceived exertion (PEpeak), using Duncan's post-hoc test. Additionally, correlations were conducted for the tests (Track 1 and Treadmill 1) and retests (Track 2 and Treadmill 2) to assess reliability, using Cronbach's α and McDonald's Ω.

Data are presented as mean ± standard deviation, and statistical significance was set at $p>0.05$.

RESULTS

Descriptive sample data

The study sample consisted of runners with a mean age of 44.27 ± 3.90 years. The participants had a mean body mass of 70.25 ± 11.68 kg and an average height of 166.34 ± 8.38 cm, resulting in a mean body mass index (BMI) of 25.26 ± 2.54 kg/m^2.

Additionally, time-trial running tests of 3000 m and 1000 m were performed. The mean completion time for the 3000 m test was 15.52 ± 1.76 minutes (min), while the mean time for the 1000 m test was 4.53 ± 0.53 min. Statistical analysis indicated significant performance time differences between men and women for both tests ($p<0.05$), as analyzed using the independent samples t test (Table 1).

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Table 1 - Descriptive sample data.

	Woman (n=5)	Men (n=6)	Total sample (n=11)
Age (years)	44,20 ± 3,83	44,33 ± 4,32	44,27 ± 3,90
Body mass (Kg)	65,68 ± 9,33	74,07 ± 12,83	70,25 ± 11,68
Height (cm)	162,36 ± 7,87	169,65 ± 7,86	166,34 ± 8,38
BMI (Kg/m^2)	24,83 ± 1,91	25,61 ± 3,11	25,26 ± 2,54
3000m (min)	16,87 ± 1,57	14,39 ± 0,93*	15,52 ± 1,76
1000m (min)	4,95 ± 0,33	4,17 ± 0,39*	4,53 ± 0,53

These data are detailed in Table 1, which provides a comparative view of the test results, broken down by gender and highlighting the significant differences observed.

Incremental tests

Significant variations were observed in T.E., Vpeak, and HRpeak, while PEpeak remained consistent across groups.

Regarding time to exhaustion, data revealed that women exhibited significantly longer times on the track compared to the treadmill in both the first and second tests (p=0.02). A similar pattern was observed among men, who also showed higher values for Track 1 compared to Treadmill 1 (p=0.02). For the total sample, a higher value was noted between the track 1 and Treadmill 1 (p=0.01). Furthermore, differences between men and women were statistically significant across all evaluated tests.

In terms of peak velocity, men consistently achieved higher values than women in all tests, with no other statistical differences between test conditions. Regarding peak heart rate, Track 2 showed higher values than Treadmill 1 in the total sample, indicating variations in cardiac response to different test conditions (p=0.04).

Finally, the analysis of peak rating of PEpeak did not reveal statistical differences, suggesting that the perception of effort was similar across all groups and test conditions. These results are detailed in Table 2, which compares differences between sexes and test conditions for each analyzed variable.

Table 2 - Comparison between sex and test conditions.

	Condition	Woman (n=5)	Men (n=6)	Total sample (n=11)
T.E.	Treadmill 1 (min)	9,39 ± 1,06	11,52 ± 1,20†	10,55 ± 1,55
	Track 1 (min)	10,16 ± 1,18*	12,32 ± 1,26*†	11,34 ± 1,62*
	Treadmill 2 (min)	9,48 ± 1,12	11,65 ± 0,86†	10,66 ± 1,47
	Track 2 (min)	9,88 ± 1,28#	12,07 ± 0,97†	11,07 ± 1,56*
V_{Peak}	Treadmill 1 (km/h)	14,40 ± 1,14	15,50 ± 1,38†	15,00 ± 1,34
	Track 1 (km/h)	14,40 ± 0,89	16,50 ± 1,22†	15,54 ± 1,50
	Treadmill 2 (km/h)	13,40 ± 1,14	15,83 ± 0,75†	14,72 ± 1,55
	Track 2 (km/h)	14,00 ± 1,41	16,16 ± 0,75†	15,18 ± 1,53
HR_{Peak}	Treadmill 1 (bpm)	175,40 ± 7,53	179,00 ± 10,71	177,36 ± 9,14
	Track 1 (bpm)	174,00 ± 8,15	180,66 ± 11,60	177,63 ± 10,29
	Treadmill 2 (bpm)	173,20 ± 8,52	176,83 ± 9,64	175,18 ± 8,89
	Track 2 (bpm)	170,00 ± 7,21	178,66 ± 8,80	174,72 ± 8,94‡
PE_{peak}	Treadmill 1 (escore)	18,40 ± 1,14	18,33 ± 1,86	18,36 ± 1,50
	Track 1 (escore)	17,60 ± 1,34	18,50 ± 1,87	18,09 ± 1,64
	Treadmill 2 (escore)	18,00 ± 1,00	18,66 ± 1,50	18,36 ± 1,28
	Track 2 (escore)	18,20 ± 1,64	18,83 ± 1,32	18,54 ± 1,43

GLM TEST – T.E. = Time to Exhaustion; Vpeak = Peak Velocity; HRpeak = Peak Heart Rate; PE peak = Peak Rating of Perceived Exertion. * Different from treadmill in test 1; # Different from treadmill in test 2; † Different from women in the same test; ‡ Different from track in test 1.

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Test and retest

Correlation analysis was used to evaluate consistency between results obtained in different test conditions (Track 1 and Treadmill 1) and retest (Track 2 and Treadmill 2). A very strong positive linear relationship ($r > 0.9$) was observed for time to exhaustion, peak velocity, and peak heart rate, indicating high consistency between measurements taken at different times and conditions (Asuero et al., 2006).

A strong positive linear relationship was identified for time to exhaustion, with correlation coefficients of 0.92 in the test and 0.95 in the retest, indicating high stability in endurance measures. Peak velocity and peak heart rate also showed strong correlations, with coefficients of 0.94 for peak velocity and 0.95 and 0.91 for peak heart rate in the test and retest, respectively, suggesting a consistent response among participants, regardless of test environment.

On the other hand, peak rating of perceived exertion showed a moderate correlation, with coefficients of 0.63 in the test and 0.55 in the retest. Although these values indicate a moderate correlation, they reflect greater individual variation in effort perception compared to other physiological variables.

The results of the correlation analyses between tests and retests are visually represented in Figure 2.

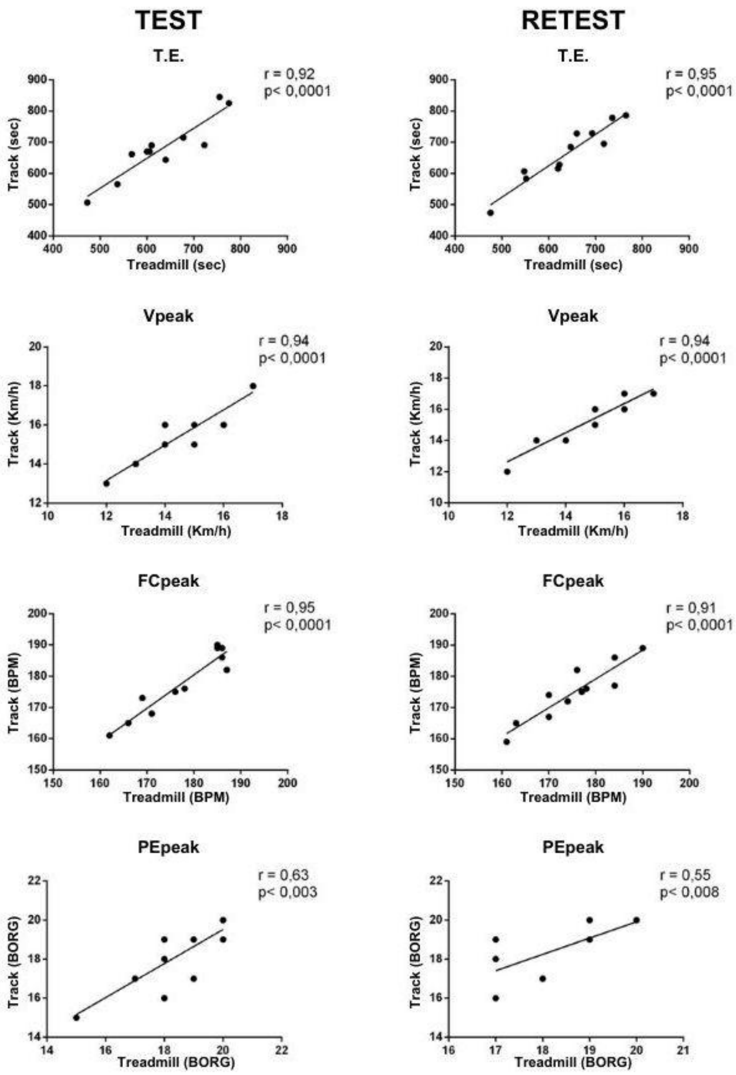

Figure 2 - Correlation between track and treadmill tests and retests.

Pearson's correlation: Classification of results, Very Strong: r ≥ 0.9; Strong: 0.7 ≤ r < 0.9; Moderate: 0.5 ≤ r < 0.7; Weak: 0.3 ≤ r < 0.5; Very Weak: 0.0 ≤ r < 0.3; No Correlation: r = 0. T.E. = Time to Exhaustion; Vpeak = Peak Velocity; HRpeak = Peak Heart Rate; PEpeak = Peak Rating of Perceived Exertion.

Test reliability

To assess the reliability of the measurement instruments used in the study, statistical tests were conducted, including Cronbach's α and McDonald's Ω. As can be seen in table 3, the overall sample showed a Cronbach's α of 0.816, indicating very good reliability, while values for men and women were 0.790 and 0.807, respectively, demonstrating good reliability. McDonald's Ω yielded even more robust results, with a value of 0.937 for the total sample, 0.899 for men, and 0.947 for women, reflecting excellent reliability.

Analysis of combined variables revealed that, except for women's peak heart rate and all variables evaluated specifically for men, all other McDonald's Ω assessments fell into the "excellent" category in terms of correlation interpretation. On the other hand, Cronbach's α evaluations, although mostly excellent, identified reliability as "very good" for women's peak heart rate and "good" for all variables in men.

Table 3 - Data reliability based on Cronbach's α and McDonald's Ω.

	Woman (n=5)		Men (n=6)		Total sample (n=11)	
	Cronbach's α	Mcdonald's Ω	Cronbach's α	Mcdonald's Ω	Cronbach's α	Mcdonald's Ω
All Variables	0.807	0.947	0.790	0.899	0.816	0.937
T.E.	0.962	0.967	0.937	0.948	0.978	0.979
V_{peak}	0.960	0.968	0.925	0.948	0.910	0.919
HR_{peak}	0.873	0.884	0.929	0.942	0.909	0.913
PE_{peak}	0.989	0.990	0.969	0.973	0.973	0.974

T.E. = Time to Exhaustion; Vpeak = Peak Velocity; HRpeak = Peak Velocity; PEpeak = Peak Rating of Perceived Exertion. Reliability assessment based on Cronbach's α and McDonald's Ω: Excellent: α, Ω ≥ 0.9; Very Good: 0.8 ≤ α, Ω < 0.9; Good: 0.7 ≤ α, Ω < 0.8; Acceptable: 0.6 ≤ α, Ω < 0.7; Poor: 0.5 ≤ α, Ω < 0.6; Unacceptable: α, Ω < 0.5 (Bonniga, Saraswathi, 2020).

DISCUSSION

The present study aimed to evaluate the reliability of two incremental running tests - one conducted on a treadmill and the other on a track guided by a pacing bicycle. The results reveal an agreement between the tests performed on the treadmill and on the track, indicating that both methods are compatible and alternative approaches for assessing amateur runners' performance. This central finding supports the applicability of track-based tests, particularly when treadmill use is impractical or unavailable.

Although the results indicate agreement between treadmill and track tests, the Generalized Linear Model (GLM) applied to the data revealed some significant differences that deserve attention. In the first treadmill test, participants showed a shorter time to exhaustion compared to the first and last track tests, this aligns with previous findings that indicate treadmill running requires an initial adaptation period, even for experienced runners (Lavcanska et al., 2005). However, the findings of the present study indicate that this does not appear to impact peak velocity.

Contrary to previous findings indicating higher peak velocities in treadmill-based incremental tests compared to field-based protocols utilizing auditory pacing (Manoel et al., 2022), the present study observed comparable values between both conditions. This similarity may be attributed to the implementation of a bicycle pacer, which likely provided more consistent speed regulation throughout the test.

Furthermore, while systematic reviews suggest that treadmill and overground running exhibit physiological discrepancies, particularly at submaximal intensities (Miller et al., 2019), the present study did not identify significant differences in variables like heart rate, rating of perceived exertion (RPE), and performance between the two test modalities.

From a mechanical perspective, treadmill running is known to reduce knee flexion moments and propulsive forces compared to overground running, likely due to belt-assisted forward propulsion (Riley et al., 2008; Van Caekenberghe et al., 2013; Van Hooren et al., 2020).

Additionally, intra-stride variations in belt speed and differences in surface stiffness can alter lower limb loading patterns (Savelberg et al., 1998; Ferris et al., 1998).

While these biomechanical discrepancies may not have directly impacted peak velocity in this study, they should be considered when applying treadmill-based results to real-world running performance, particularly for training prescription and competition strategies.

A key strength of this study was the use of a pacing bicycle as an alternative to traditional auditory cues in track-based incremental testing.

The use of the bicycle to dictate the speed at which the runners should run at each stage is something that stands out at this time, as it makes it easier for the runners to maintain their pace. Unlike sound-based protocols, which can be affected by environmental factors such as wind, noise, and reaction time variability, the bicycle pacer ensured more consistent speed regulation.

This may explain why, unlike previous studies where treadmill-based tests resulted in higher peak velocities than field tests with auditory pacing (Manoel et al., 2022), the present study found comparable values between both conditions. The ability to intuitively adjust running pace in an outdoor setting may also enhance adaptation to race conditions, improving both physiological and psychological responses (Miller et al., 2019; Hasebe et al., 2023).

Furthermore, correlation and reliability analyses confirmed strong consistency between the treadmill and track-based protocols, reinforcing the viability of the bicycle-guided test as a reliable and practical alternative (Bonniga, Saraswathi, 2020).

Given its simplicity and applicability, this method may be particularly useful when treadmill testing is impractical, offering an accessible, cost-effective solution for endurance performance assessment (Leger, Boucher, 1980).

Although the tests showed strong reliability, the design of the protocol may still influence the results and should be considered. The one-minute stage protocol used in this study provides a practical and time-efficient alternative for incremental assessments; however, previous research suggests that longer stage durations (e.g., three-minute increments) may yield stronger correlations with race performance (Manoel et al., 2022; Machado et al., 2013; Kuipers et al., 2003).

Given the widespread use of peak velocity (Vpeak) as a key performance metric, future studies should examine bicycle-paced incremental tests in comparison to longer-stage treadmill and track protocols.

The compatibility of treadmill and track tests has direct implications for training programs and future research. The present study suggests that coaches and researchers can select either treadmill or track tests based on logistics, specific objectives, and resource availability, without compromising the quality of peak velocity assessments for 1-minute stage protocols.

Furthermore, these findings encourage future studies to compare track-based tests with auditory versus bicycle-guided pacing and explore how different track test protocols impact specific performance variables, such as running economy and rating of perceived exertion.

CONCLUSION

This study confirms that incremental running tests on the track are a simple, cost-effective, and efficient alternative for treadmill-based and bicycle-guided track evaluations, with both conditions showing strong agreement.

The ability to use the track for performance testing not only expands research and training options but also serves as a viable alternative when treadmill testing is not possible.

Moreover, this approach can better simulate competition-like conditions, making the incremental test more representative of real-world race scenarios.

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