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Physiological and Biomechanical Responses Induced by a Continuous Test and an Intermittent Test in Middle-Distance Runners

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Purpose: This study aimed to examine middle-distance runners' acute physiological and biomechanical responses to 2 maximal aerobic speed tests: an intermittent test (5×1 min_{test}) and a continuous test (University of Montreal Track Test [UM-TT]). ***Methods:*** Twenty trained male middle-distance runners completed the UM-TT and 5×1 min_{test} on separate days. The rating of perceived exertion, peak heart rate, and maximal aerobic speed of both tests ($V_{\text{UM-TT}}$ and $V_{5\ \times 1\text{m}}$) were analyzed. Heart-rate variability (time and frequency domain) and spatiotemporal parameters were measured preexercise and postexercise at 5, 30, and 60 minutes. ***Results:*** No differences were found between $V_{\text{UM-TT}}$ and $V_{5\times 1\text{m}}$ (18.4 [1.0] vs 18.5 [0.9] $\text{km}\cdot\text{h}^{-1}$, $r = .88$, $P = .14$). Peak heart rate was similar between tests (UM-TT: 188.6 [4] $\text{beats}\cdot\text{min}^{-1}$ vs 5×1 min_{test}: 189 [2] $\text{beats}\cdot\text{min}^{-1}$, $r = .63$, $P = .23$). Rating of perceived exertion was higher in UM-TT (UM-TT: 8.1 [0.5] vs 5×1 min_{test}: 7.6 [0.7], $r = .47$, $P = .009$). For both tests, heart-rate-variability parameters indicated higher sympathetic/lower parasympathetic activity compared with baseline at all time points ($P < .001$), without differences between tests. Stride frequency and duty factor increased postexercise ($P < .05$), with no changes in contact time and stride time ($P > .05$), without differences between the 2 tests. ***Conclusions:*** Both tests significantly changed heart-rate variability and biomechanical parameters, with no differences between the tests. As 5×1 min_{test} was perceived as less demanding, it may be a less taxing alternative for assessing maximal aerobic speed in middle-distance runners.

Keywords: continuous test, heart-rate variability, biomechanics, perceived exertion

The assessment of runners' performance through different exercise testing protocols has emerged as a central concern for coaches and athletes.[1] However, the fatigue induced by physical exertion during these tests must be taken into account because it is important to understand the physiological and biomechanical responses triggered by various types of exercise. By considering fatigue, we can better gauge the limits and recovery needs associated with various types of exercise tests.[2] Moreover, a more nuanced understanding of fatigue induced by exercise testing is essential to preventing overexertion during testing.

Several field tests have been proposed for evaluating maximal aerobic speed (MAS), which is one of the most common variables tested in field-based running tests.[3] The University of Montreal Track Test (UM-TT) is one of the most commonly used tests to obtain MAS.[4] This is a continuous incremental field test considered highly reliable.[4] In contrast, intermittent tests with their unique protocol offer a different perspective on aerobic capacity assessment, with protocols that differ from continuous tests in structure and pacing.[5] A new short intermittent field test (5×1 min_{test}) has recently been developed to assess MAS.[6] This test requires few materials and is easier to perform and faster to implement (about 2.5 times faster) than UM-TT.[6] The 5×1 min_{test} is highly reproducible and has a strong correlation with the MAS values determined using UM-TT.[6] However, the different nature of these 2 tests may elicit different physiological and biomechanical responses, and hence fatigue.

Running-induced acute fatigue could be typically measured by physiological and biomechanical parameters.[7] The physiological fatigue can be measured using heart-rate variability (HRV) from electrocardiogram recordings obtained from wearable sensors.[7] HRV, which provides information on both sympathetic and parasympathetic activity, is a useful measure for evaluating cardiovascular autonomic regulation.[8] Thus, monitoring the response of HRV measures during postexercise recovery may provide insights into cardiovascular autonomic function.[9] Studies have indicated that HRV is a sensitive indicator of autonomic recovery after high-intensity exercise, capable of distinguishing between different recovery phases by monitoring changes in sympathetic and parasympathetic activity.[10] Biomechanical fatigue refers to changes in spatiotemporal parameters while running, such as stride time and frequency and contact time which can affect running performance and increase injury risk.[11] On the other hand, biomechanical characteristics in running are influenced by various kinematic and kinetic factors, which play a considerable role in improving running economy.[12] By comparing the results of the 2 different tests (UM-TT vs 5×1 min_{test}), it is possible to better understand which test induces the greater physiological and biomechanical strain in runners and hence provide practical evidence to help coaches and runners to choose the best test to evaluate MAS.

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Although the physiological responses of UM-TT have been studied previously,[9] the physiological and biomechanical responses induced by 5×1 min_{test} have not been studied or compared before. Hence, the aim of the present study was to investigate the physiological (HRV parameters) and biomechanical (spatiotemporal parameters) acute responses induced by intermittent test (5×1 min_{test}) and a standard continuous test (UM-TT) designed to determine MAS in middle-distance runners.

Materials and Methods

Participants

According to the sample size calculation, 15 to 17 runners were required to produce a statistical power of ≥0.8 (with a significance level of $\alpha < .05$) based on previous research that examined the biochemical and physiological responses to an endurance exercise.[13,14] The inclusion criteria were: (1) age between 18 and 35 years, (2) regular middle-distance running training during the last 2 years, and (3) free from injuries that can have an impact on performance in the last 6 months. Participants were asked to avoid strenuous exercise for a minimum of 48 hours, caffeine 12 hours, and heavy meals for 4 hours prior to each testing. The experimental procedures were approved by the local institutional research ethics committee in accordance with the Declaration of Helsinki. All subjects were informed about the research protocols and provided informed consent.

Study Design

This study employed a cross-sectional design, wherein the same athletes underwent 2 distinct sessions, allowing for evaluation between the 2 MAS tests (UM-TT and 5×1 min_{test}) in a random order. All participants had prior experience with field exercise evaluation and were assessed on 2 different days on a synthetic running track at least 48 hours apart. A submaximal run of 5 minutes at 10 $km{\cdot}h^{-1}$, followed by a recovery period (sitting position) of 5 minutes,[15] was carried out before (baseline) and during recovery, after each test (5, 30, and 60 min) to assess physiological and biomechanical parameters using a Movesense sensor attached to the chest using a belt with electrodes. Movesense sensor (Suunto) is a lightweight and waterproof device used for performance testing. Bluetooth was used to transmit data to an iOS Movesense application (Movesense showcase App, Suunto). The validity of the Movensense sensor has previously been described.[16,17] At the end of each exercise bout, participants indicated their rating of perceived exertion (RPE, 0–10 Borg's scale).[18] All experimental tests were carried out in a controlled setting (same time of day with temperature of 25 °C–27 °C and ~60% humidity).

Physiological and Biomechanical Measurements

The physiological (HRV: time and frequency domain) and biomechanical (spatiotemporal parameters) variables were assessed before and after both UM-TT and 5×1 min_{test}. During the 10-minute period (5 min submaximal continuous running test interspersed by passive 5 min recovery periods), parasympathetic function was assessed by analyzing the last 2 minutes (from the 480th to the 600th seconds) of HR recovery[9] via electrocardiogram recordings (Movesense; sampling rate: 512 Hz). Time-domain parameters included mean RR interval (in milliseconds), root mean square of the successive differences (RMSSD; in milliseconds), and standard deviation of the NN intervals (SDNN; in milliseconds). Frequency-domain parameters included low (LF: 0.04–0.15 Hz) and high frequency (HF: 0.15–0.4 Hz), and LF:HF ratio was determined. Kubios software (v.3.5.0, HRV analysis, University of Eastern Finland)[19] was used to calculate the time and frequency-domain characteristics of the RR intervals. The spatiotemporal parameters were extracted from the raw accelerometer and gyroscope signals at an acquisition frequency of 208 Hz by analyzing the last 2 minutes (from the 180th to the 300th seconds) of 5-minute submaximal continuous running test. The spatiotemporal parameters were calculated using an online platform (https://andreazignoli.shinyapps.io/view_data/; version 0.9.1). The Shiny web app utilized for data processing has been developed and validated in a recent study.[20] The spatiotemporal parameters included stride frequency (in hertz), duty factor (in percentage), and contact (in seconds) and stride times (in seconds). The definition and calculation of these parameters has been reported previously.[21]

Incremental Exercise Test

Incremental exercise test was adapted from UM-TT. The test has been proven to be extremely reliable ($r = .97$) for determining MAS between sessions.[4] Initial speed at the first stage was set at 8 $km{\cdot}h^{-1}$ and increased by 0.5 $km{\cdot}h^{-1}$ every minute until exhaustion. Subjects adjusted their running speed (between cones placed every 20 m along the track) by a prerecorded beep. The velocity (in kilometers per hour) at the last completed stage was determined as $V_{UM\text{-}TT}$.

Intermittent Test

The 5×1 min_{test} is a track running test that requires very little equipment (whistle and stopwatch), easy to use, and can be used in training sessions. The reliability of 5×1 min_{test} has already been confirmed and considered as highly reliable ($r = .87$) for assessing MAS across testing sessions.[6] The test consists of 5×1 minute runs (the greatest possible distance) interspersed with 30-second passive recovery periods (the stopping point of the first minute will later be the starting point of the second minute, and so on). The reference velocity (determined as $V_{5\times1m}$) is calculated using the following equation[6]:

$$V_{5\times1\,m}(\mathrm{km}\cdot\mathrm{h}^{-1}) = \frac{D}{91},$$

where D denotes the runner's total distance traveled (in meters).

Statistical Analysis

Values are expressed as mean (SD). A Shapiro–Wilk test was used to assess data normality. A 2-factor repeated-measures analysis of variance was performed to examine any differences in HRV and spatiotemporal parameters between the 2 tests (UM-TT and 5×1 min_{test}) and over time (baseline and postexercise recovery at 5, 30, and 60 min). A Bonferroni post hoc test was used when significant main effects were found to investigate differences between time periods (baseline and postexercise recovery at 5, 30, and 60 min). A Cohen's d effect size was calculated to assess the magnitude of changes between the studied variables. The effect size values were interpreted as proposed by Hopkins et al[22]: <0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; and >1.2, large. Student t test for paired sample, Pearson coefficient correlation (r), and limits of agreement analysis (Bland–Altman plot) were used to compare $V_{UM\text{-}TT}$ versus $V_{5\times1m}$, HR_{peak}, and RPE measures between UM-TT and 5×1 min_{test}. Statistical significance was set at $P<.05$. All the statistical analyses were carried out using SPSS software (version 23).

Results

Participant Characteristics

Twenty trained male middle-distance runners participated in this study (21.9 [3.9] y, 1.76 [5.0] m, 68.8 [6.6] kg). The participants were drawn from various local running clubs. The participants had more than 5 years of experience, with 6.9 (1.6) hours weekly training.

Associations Between UM-TT and 5×1 min_{test}

Figure 1 illustrates the Bland–Altman plot of $V_{UM\text{-}TT}$ and $V_{5\times1m}$. No differences were found between the 2 tests (UM-TT: 18.4 [1.0] vs 5×1 min_{test}:18.5 [0.9] km·h^{-1}, $r=.88$, $P=.14$). HR_{peak} was not different between both tests (UM-TT: 188.6 [4] beats·min^{-1} vs 5×1 min_{test}: 189 [2] beats·min^{-1}, $r=.63$, $P=.23$). RPE was higher during UM-TT compared with 5×1 min_{test} (UM-TT: 8.1 [0.5] vs 5×1 min_{test}: 7.6 [0.7], $r=.47$, $P=.009$). The average duration of the UM-TT was 18.2 (1.0) minutes, whereas the 5×1 min_{test} was shorter ($P<.01$), with an average duration of 7 (0) min.

Cardiac Autonomic Activity and Biomechanical Responses

The analysis of variance results indicated a significant main effect of time across both tests, indicating changes in HRV ($P<.001$) and spatiotemporal parameters ($P<.05$; except for contact time and stride time) across the recovery period. However, there was no significant main effect of test ($P>.05$), nor was there a significant time × test interaction ($P>.05$). Mean HRV responses of both tests are presented in Table 1. Concerning the HRV time-domain

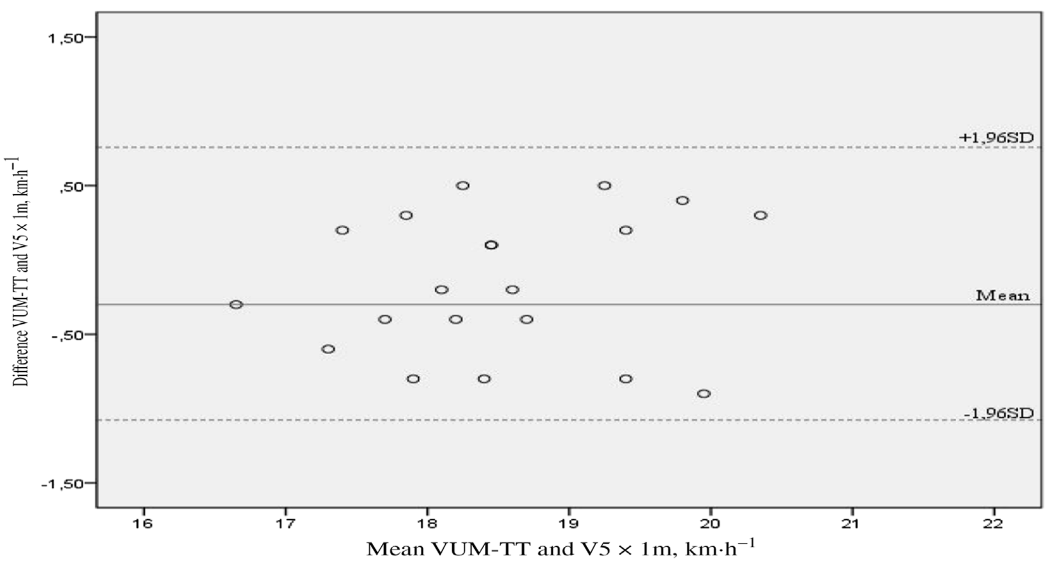

Figure 1 — Bland–Altman plot of maximal aerobic speed measured for UM-TT and 5×1 min_{test}. UM-TT indicates University of Montreal Track Test; 5×1 min_{test}, intermittent test.

Table 1 Heart-Rate-Variability Parameters at Baseline and During Recovery Postexercise

	Test	Baseline	5 min	30 min	60 min	*P*	ES
HR_{peak}, beats·min^{-1}	5×1 min_{test}	73.2 (9.5)	91.0 (11.5)*	87.3 (9.8)*	84.2 (8.5)*	<.001	0.74: moderate
	UM-TT	73.7 (6.8)	89.9 (8.4)*	87.9 (6.8)*	84.3 (6.1)*		
Mean RR interval, ms	5×1 min_{test}	832.7 (107)	669.1 (87)*	695.2 (80)*	712 (77)*	<.001	0.76: moderate
	UM-TT	820.4 (82)	673.6 (66)*	686.4 (53)*	717 (54)*		
RMSSD, ms	5×1 min_{test}	50.1 (22.3)	17.9 (19.1)*	17.1 (8.9)*	27.9 (18.4)*	<.001	0.46: small
	UM-TT	50.6 (32.1)	13.0 (5.2)*	15.7 (6.3)*	27.4 (20.7)*		
SDNN, ms	5×1 min_{test}	51.7 (21.5)	18.3 (8.0)*	23.1 (8.1)*	36.2 (21.4)*	<.001	0.52: small
	UM-TT	50.8 (25.2)	18.2 (7.8)*	22.3 (10.9)*	26.6 (10.9)*		
LF:HF	5×1 min_{test}	2.9 (1.7)	9.7 (9.3)*	6.8 (5.6)*	5.3 (2.7)*	<.001	0.30: small
	UM-TT	2.6 (2.4)	7.6 (5.7)*	6.8 (4.0)*	3.6 (2.4)*		

Abbreviations: ES = effect size; HR_{peak} = peak heart rate; LF:HF = ratio of low-frequency power to high-frequency power; mean RR interval = mean interval between consecutive R spikes; RMSSD = root mean square of successive differences; SDNN = SD of normal R-R intervals.
*Significant difference from baseline ($P<.05$).

parameters, mean RR interval, RMSSD, and SDNN ($P < .001$) decreased compared with baseline at 5, 30, and 60 minute following UM-TT and 5×1 min_{test}. HRpeak values increased ($P < .001$) after both tests (at 5, 30, and 60 min postexercise). For frequency-domain parameters of HRV, resting LF:HF ($P < .001$) was increased after both tests (at 5, 30, and 60 min postexercise). With regard to spatiotemporal parameters, stride frequency and duty factor both increased relative to baseline ($P < .05$) for both tests (stride frequency at 5 and 30 min; duty factor at 30 min postexercise). By contrast, contact time and stride time were not different from baseline ($P > .05$; Figure 2). All changes found were similar for both tests at all time points.

Discussion

The present study aimed to evaluate the acute physiological and biomechanical responses induced by an intermittent test and a standard continuous test in middle-distance runners. The main findings revealed that both tests significantly changed HRV measures, with significant changes in both time- and frequency-domain measures (decrease in mean RR interval, RMSSD, and SDNN; increase in HR_{peak}; and LF:HF ratio) at all time points during postexercise recovery. Importantly, no significant differences were found between the UM-TT and 5×1 min_{test} for any HRV parameters, indicating both tests produced similar autonomic recovery patterns. Additionally, the intermittent and continuous tests significantly increased stride frequency, and duty factor, while contact and stride time remained stable. Furthermore, no significant differences were observed between the tests regarding MAS and HRpeak, although the continuous test elicited a higher RPE.

While both UM-TT and 5×1 min_{test} are effective for evaluating MAS, the choice between them should consider the context of the assessment. For example, the observed higher RPE during UM-TT compared with the 5×1 min_{test} suggests that the continuous test imposes a greater subjective load on athletes, which might influence a preference and performance in different testing scenarios.[23] That is, the UM-TT is more mentally demanding due to the required sustained effort without the relief provided by intermittent rest periods.[24] In contrast, the 5×1 min_{test} might be perceived as less taxing given the presence of relief moments thereby resulting in a lower RPE. Moreover, the lack of significant differences in HR_{peak} between the 2 tests suggests that both tests can be used for evaluating HR_{peak} performance. This finding is in accordance with another study that found similar values between the UM-TT (192.3 [8.0] beats·min^{-1}) and the Yo-Yo intermittent recovery test (191.4 [7.8] beats·min^{-1}).[25] Previous studies that compared a continuous and an intermittent tests to estimate MAS showed that, although MAS obtained during both tests were significantly correlated, there was a difference of 9% to 15% between both types of tests,[26,27] which is in contrast with our findings. These incongruences between our findings and those of previous studies may be explained by the use of different continuous and intermittent tests. Notwithstanding such differences, coaches might favor the 5×1 min_{test} for MAS assessment, given its lower perceived exertion and quicker administration.

The significant changes in HRV parameters observed in our study align with the existing literature that highlights the sensitivity of HRV to different exercise modalities and intensities.[28] Studies have shown that both continuous and intermittent exercise can lead to marked decreases in time-domain (eg, RMSSD and SDNN) and increased frequency-domain (eg, the LF:HF ratio) HRV parameters postexercise, indicating enhanced sympathetic and reduced parasympathetic activity during recovery.[29] In our study, significant reductions in time-domain HRV parameters were evident at 5-, 30-, and 60-minute postexercise, reflecting acute autonomic stress and recovery patterns, which is in accordance to the findings from previous research.[30] The RMSSD measure typically decreases following intense exercise due to the withdrawal of parasympathetic tone and the dominance of sympathetic activity[31] then gradually returns to baseline during the recovery period.[32]

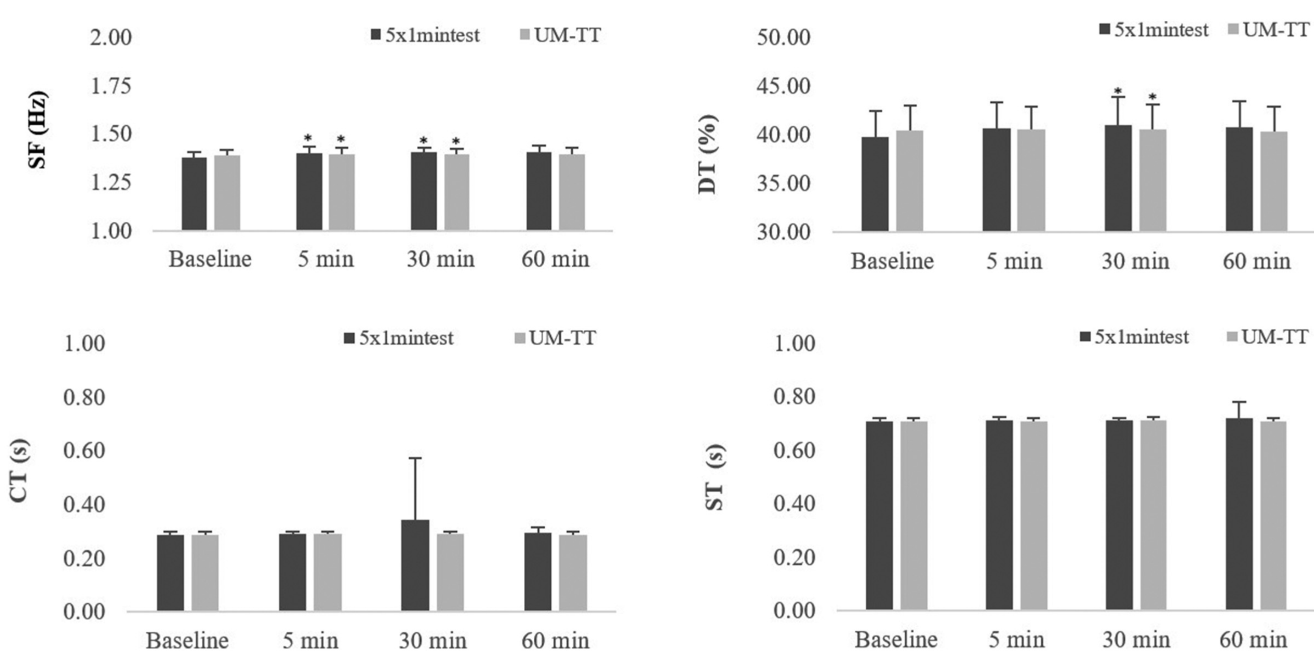

Figure 2 — Measures of spatiotemporal parameters before and after the 5×1 the min_{test} and UM-TT. 5×1 min_{test} indicates intermittent test; UM-TT, University of Montreal Track Test; SF, stride frequency; DT, duty factor; CT, contact time; ST, stride time. *Significant difference from baseline ($P < .05$).

Similarly, the SDNN decreases with exercise-induced stress. This aligns with studies showing that high-intensity exercise lead to reduced SDNN, indicating a lower HRV due to heightened sympathetic activation and reduced parasympathetic influence.[8,33] The LF:HF ratio increases postexercise. The observed increase in the LF:HF ratio in our study is consistent with previous findings where postexercise recovery is characterized by elevated the LF:HF ratio, reflecting increased sympathetic modulation and reduced parasympathetic influence.[10] The significant changes in physiological parameters suggest that both the continuous UM-TT and 5×1 min_{test} induce substantial autonomic stress.

The biomechanical responses observed in our study particularly the increases in stride frequency and duty factor align with previous research indicating that running-induced fatigue impacts gait parameters.[34] It was shown that fatigue can lead to an increase in stride frequency and altered duty factor, reflecting compromised neuromuscular control and efficiency.[35] Our findings, consistent across both the UM-TT and 5×1 min_{test}, showed significant increases in stride frequency at 5- and 30-minute postexercise, which corroborates the fact that fatigue influences these aspects of running biomechanics in both continuous and intermittent regimes.[11] Interestingly, the stability of contact and stride times may suggest a compensatory running mechanism.[36] While fatigue impairs certain biomechanical aspects, runners might adjust other parameters to maintain overall performance. The unchanged contact time and stride time could imply that runners are adapting their stride length or ground contact patterns to offset the increased stride frequency and duty factor.[37] This strategy may help sustain running efficiency and prevent a further decline in performance.[38] Our findings suggest that these stable parameters could be key markers in running biomechanics under fatigue, providing a monitoring base for running economy.

Limitations

While this study provides interesting insights, several limitations should be acknowledged. The sample size was limited to trained, healthy male middle-distance runners, which restricts generalizability to other populations. Other important metabolic, neuromuscular, and kinetic aspects were not explored such as blood lactate, maximal voluntary contraction force, ground reaction forces, and peak swing velocity of the foot. These parameters are essential to understanding the full spectrum of fatigue induced by both types of tests. Additionally, the study focused on short-term recovery periods up to 60 minute, without assessing long-term adaptations. Future studies should extend the assessment period to include long-term recovery and adaptation, examining the effects of both continuous and intermittent exercise over longer periods.

Practical Applications

This study shows that middle-distance runners' physiological and biomechanical reactions to MAS testing can be evaluated using the UM-TT and 5×1 min_{test}. As both tests are effective for MAS assessment and there are no significant differences between them for both HRV parameters and biomechanical responses, coaches can use both tests, acknowledging the fact that 5×1 min_{test} may be the less taxing alternative. Even though these results are limited to MAS testing, more investigation is required to determine whether these reactions apply to other training loads or competitive settings.

Conclusions

This study analyzed the acute physiological and biomechanical responses of trained middle-distance runners to an intermittent test (5×1 min_{test}) and a continuous test (UM-TT). Both tests elicited similar physiological and biomechanical responses in the runners. Although maximal aerobic speed and peak heart rate were not different between tests, the UM-TT elicited higher perceived exertion. heart-rate-variability parameters significantly changed from baseline to 60 minutes postexercise, indicating increased sympathetic and decreased parasympathetic activity postexercise. Stride frequency and duty factor significantly increased, while contact time and stride time remained stable across both tests. These findings indicate that the 5×1 min_{test} is a valid alternative to the more commonly used UM-TT for assessing maximal aerobic speed, while offering the advantage of being shorter in duration and less demanding.

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