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Reproducibility of performance and fatigue in trail running

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ABSTRACT

Objectives: This study aimed to test the reproducibility of running performance, neuromuscular fatigue markers and indirect muscle damage indicators in a field-based trail time-trial.
Design: Running performance and changes in classical physiological parameters were analysed in 11 experienced trail runners before and in the days following four bouts of outdoor trail running (15.6 km), 7 days apart.
Methods: Heart rate, running time and lactate concentration were monitored in each running bout. Maximal voluntary contraction torque, counter movement jump height, plasma creatine kinase activity and muscle soreness were assessed before and 1, 24 and 48 h post-race. Within-bout changes were elucidated using a two-way repeated measures ANOVA. Inter-repetition reproducibility was examined using an intraclass correlation coefficient (R) and the mean intra-subject coefficient of variation at each measurement time point.
Results: Running time was longer ($p < 0.05$) for the first bout compared with the other three bouts. Magnitude and time course of changes in counter movement jump height, creatine kinase activity and muscle soreness were similar among all four bouts (overall peak means: −17%, +35% and 54/100 mm respectively). The acute reduction in maximal voluntary contraction torque (peak mean: −17%) was attenuated exclusively in the fourth bout ($p < 0.05$). The two middle bouts showed good reproducibility (intraclass correlation coefficient and coefficient of variation) for running time, maximal voluntary contraction torque and counter movement jump height, but low to moderate for creatine kinase activity, muscle soreness, blood lactate and rate of perceived exertion.
Conclusions: A short outdoor trail run is a reliable model for investigations of fatigue and muscle damage, but certain methodological precautions should be respected.

1. Introduction

Trail races are off-road endurance runs covering distances from 15 to 75 km (>90 km for ultra trails) on unsurfaced mountain trails with extensive vertical displacement.[1] Distance and the climb distance^{-1} ratio (E/D, normal range: 40–65 m km^{-1}; 8–13%) are the main performance parameters.[1,2] Recent studies investigating trail races reported aspects of neuromuscular fatigue mainly assessed by maximal voluntary contraction (MVC) torque and changes in twitch and activation parameters.[1–3] For example, MVC torque of the knee extensors has been reported to decrease 23.5% after a 30 km trail run,[4] 32% after a 55 km trail run[1] and 35% after a 166 km mountain ultra-marathon.[2] The neuromuscular fatigue is often accompanied by increases in self-reported muscle soreness ratings and plasma bulk damage markers, such as creatine kinase (CK),[1,2,5] lasting for several days. This is associated with an exacerbated eccentric component invoked in the downhill phases. The physiological stress profile elicited through combined fatigue and muscle damage is specific to trail running.

Participant increases[6] invite the investigation of and development of strategies to minimise neuromuscular fatigue and structural damage to the muscle. However, evaluating trail-specific interventions is challenging, as trail race simulation in a laboratory is difficult due to terrain and grade variability. It may therefore be more effective to assess strategies and modalities that could affect performance and recovery in a field setting. Under this constraint, two factors might affect reproducibility of parameters examined in field trail runs.

Firstly, studies conducted in the field are associated with higher variability induced, for example, through environmental factors

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(temperature, wind, humidity and surface conditions). While the test-retest reproducibility of treadmill-based protocols has been frequently evaluated,[7,8] no previous study has investigated the reproducibility of variables associated with running performance, neuromuscular fatigue and muscle damage in a field-based trail run.

Secondly, it is well known that an initial bout of eccentric exercise induces a protective effect which decreases muscle damage and ameliorates recovery in subsequent bouts. This protective effect is referred to as "the repeated bout effect" and is generally observed from 2 to 6 weeks following the initial intervention in untrained muscles.[9,10] There have been several reports of diminished effect magnitude in trained muscle[11,12] yet, to the best of our knowledge, no previous study has investigated the repeated bout effect in a trail running model, especially performed by trained runners.

Classical fatigue-induction models are not suited to examining trail running as they do not take into account the rather severe gradients and variable surface encountered on typical courses. Prior trail investigations employed either treadmill simulation,[13,14] which disregards the terrain component completely, or competition analysis,[1,2,4] which is unsuited to intervention type investigations and involves a complicated measurement set-up. Therefore this study employed a short (<20 km) short distance trail with a medium E/D[1,2] of 52.88. This model is straightforward to implement and has the additional advantage that it reflects a typical training distance for recreational trail runners and entails a short recuperation time.

The aim of this study was therefore to examine the feasibility of using an outdoor trail run to evaluate future intervention strategies. To this end, the reproducibility of neuromuscular fatigue and structural muscle damage markers over 4 bouts of a 15.6 km trail run was determined in experienced trail runners.

2. Methods

Eleven actively competitive male trail runners (age: 34.7 ± 9.8 years, body mass: 72.3 ± 6.8 kg, height: 178.4 ± 7.0 cm, maximal oxygen uptake: 60.1 ± 6.5 mL min^{-1} kg^{-1}) participated in this study. Inclusion criteria included a minimum of 2 years trail racing experience and a training volume of 40–100 km wk^{-1} (mean: 60 ± 20 km wk^{-1}) in the 3 months preceding initial testing. For 2 days before and after each trial, the runners were requested to refrain from exercise and to adhere to a standardised nutritional routine. Written informed consent was obtained and the study was approved by the Institutional Human Research Ethics Committee.

After an initial maximal oxygen uptake (VO2max) test on a treadmill, all participants performed four bouts of trail running on the same course with 7 days rest between bouts. In each bout, running time, heart rate, post-run ratings of perceived exertion and blood lactate concentration were recorded. Immediately before (pre) and 1 (post), 24 and 48 h after the run the following parameters were assessed: maximal voluntary isometric knee extension (MVC) torque, counter movement jump (CMJ) height, plasma creatine kinase (CK) activity and muscle soreness. These variables were examined over time in each bout and each time point was compared between bouts.

Two weeks before the first bout, all participants completed a maximal incremental running protocol on a treadmill (+4%, Gymrol S2500, HEF Tecmachine, Andrezieux-Boutheon, France) in the lab while heart rate (RS800, Polar, Kemple, Finland) and pulmonary gas exchange (Oxycon Alpha, Jaeger, The Netherlands) were recorded. All instruments were calibrated before each test as described by the manufacturers. The protocol consisted of a 6 min warm-up at 9 km h^{-1} followed by an increase of 1 km h^{-1} every 2 min until volitional exhaustion. Maximal heart rate (HRmax) and oxygen uptake (VO2max) were determined as the highest 30 s mean, fulfilling the classical criteria of a respiratory equivalent greater than 1.1, an HR greater than 90% of the age prediction and a plateau in VO2 despite an increase in mechanical intensity.[15]

The trail time-trial consisted of 3 laps of a 5.2 km course (total distance: 15.6 km) starting close to sea level. Each lap was composed of a climbing segment (2200 m, 13%, 275 m climb) followed by a downhill segment (3000 m, −9%, 275 m descent). The course was exclusively on mountain single tracks with repeated technical sections on rocky and root-covered paths. Each participant was weighed and equipped with a Polar RS800 heart rate monitor, 680 ml of fluid containing carbohydrates (74 g L^{-1}) and 2 energy gels (carbohydrates: 18 g gel^{-1}). All participants were asked to wear similar clothes for each bout and to aim for the best completion time possible. Starting times were staggered, allowing 20 min between participants. Immediately after the run, a blood sample was taken from the ear lobe for lactate analysis (Lactate Pro, Arkray, Amstelveen, The Netherlands), participants were weighed, and RPE was verbally queried while standing using standard terminology and a 6–20 point Borg Scale.[16]

MVC testing took place in the laboratory about 10 min drive from the time-trial course before and 1, 24 and 48 h after the run. Following the motorised transfer, participants were securely strapped into an isokinetic dynamometer (Biodex System 3, Shirley, New York, USA) with the knee joint angle of the right leg at 90° (full leg extension = 0°). The axis of the knee joint was carefully aligned with the rotational axis of the dynamometer and all settings were kept constant throughout the experiment. Before each MVC, participants warmed up on the isokinetic dynamometer by repeating 10 one-second isometric contractions at 50% MVC (one second rest between contractions). After 3 min rest, in which participants were asked to indicate perceived muscle pain of the knee extensors on a 10 cm visual analogue scale visibly anchoring zero for 'no pain' and 10 for 'maximal pain', testing commenced. Participants were instructed to "extend the knee as hard and fast as possible" for the three 5-second MVC measures (55 s rest between attempts) while standardised verbal encouragement was given. The highest MVC value achieved in the three attempts was used.

Ten minutes after MVC testing, participants were positioned on an Ergo Jump system (Boscosystem, S. Rufina, Italy) and instructed to place their hands on their hips and to jump as high as possible and land with extended legs. Jumping position was standardised as described previously,[17] and the participants practised extensively under supervision before the measurements. Three jumps with 30 s rest between attempts were then recorded. The maximum jump height achieved was used for further analysis.

Blood samples were drawn from the antecubital vein using a standard vacutainer system and centrifuged for 10 min to obtain plasma. Plasma samples were aliquoted and stored in a freezer (−80 °C) until analysed for CK activity by a Roche Hitachi 911 chemistry analyser (Roche Diagnostics Corporation, Indianapolis, IN, USA).

A two-way repeated measures ANOVA (time (4) × bout (4)) was conducted on the absolute values of MVC torque, CMJ height, plasma CK activity, muscle soreness and lap times. A Newman–Keuls post hoc test was used for multiple comparisons to identify differences between individual time points. Reproducibility of parameters across bouts was examined with an intraclass correlation coefficient (ICC, R) and the mean intra-individual coefficient of variation (CV) was calculated for each time point.[18] Reproducibility was judged by the R values of ICC[19]: 0–0.25: little, 0.26–0.49: low, 0.50–0.69: moderate, 0.70–0.89: high, and 0.9–1.0: very high. The significance level was set at $p < 0.05$ and all data are presented as means ± standard deviation (SD).

Table 1
Mean ± SD values for total running time, mean heart rate [%HRmax], rate of perceived exertion (RPE [6–20 pt]) and blood lactate [mmol L^{-1}] measured immediately after the run for the first (1), second (2), third (3) and fourth (4) bouts of trail running. Reproducibility determined by an intraclass correlation coefficient (ICC, R) and coefficient of variation (CV in %) for all four bouts (1–4), the last three bouts (2–4), and the middle two bouts (2–3) are shown on the right.

Parameter	Bout				Reproducibility					
	1	2	3	4	1–4		2–4		2–3	
					ICC	CV	ICC	CV	ICC	CV
Running time (s)	5842 ± 521[a]	5511 ± 440	5623 ± 378	5628 ± 438	0.78	3.5	0.85	2.5	0.82	2.3
Heart rate (%)	91.8 ± 4.6	89.2 ± 5.7	90.1 ± 4.8	90.1 ± 3.5	0.54	3.2	0.49	3.0	0.55	3.4
RPE (6–20 pt)	17.9 ± 2.1	16.6 ± 1.9	17.6 ± 1.7	17.9 ± 2.0	0.33	8.4	0.52	7.1	0.56	5.9
Lactate (mmol L^{-1})	3.9 ± 1.7[a]	6.4 ± 1.1	5.3 ± 2.0	5.4 ± 1.6	0.38	27.6	0.41	22.8	0.66	16.1

[a] Indicates a significant difference from other bouts ($p < 0.05$).

3. Results

All bouts were performed in sunny conditions at similar temperatures (20–24 °C), low wind speeds (0–5 km h^{-1}), dry conditions and good visibility. There were no significant differences in the amount of fluid ingested during the run (444 ± 53 mL), weight loss from pre (72.3 ± 7.6 kg) to post (71.2 ± 6.5 kg) run, and the number of energy gels ingested (1.5 ± 0.2) among the four bouts.

Completion time was significantly elevated in the first bout compared to other bouts ($p < 0.05$, Table 1). Blood lactate was reduced following the first bout, but no significant differences were found for RPE or mean HR. The reproducibility was high for completion time, especially when the first bout was excluded, but low for mean HR, RPE and blood lactate.

The pre values for MVC torque and CMJ height showed no significant differences between bouts (Fig. 1). A significant interaction effect was found for MVC torque; in contrast to bouts 1–3, acute torque reduction was no longer significantly different from baseline in bout 4 (Fig. 1a). The reproducibility of post-exercise MVC torque was high (ICC 0.82–0.93; CV 5.3–8.7%), especially when only bouts 2–3 were considered (Table 2). No significant interaction effect was found for CMJ height, but CMJ height decreased significantly by post 24 h in all bouts and in no case returned to baseline by 48 h post-run. The reproducibility of CMJ height was moderate to high (ICC 0.55–0.82; CV 3.6–7.9%), and increased with exclusion of bouts 1 and 4 (Table 2).

Table 2
Reproducibility of knee extensor maximal voluntary isometric contraction torque (MVC), counter movement jump height (CMJ), plasma creatine kinase concentrations (CK) and visual analogue scale for muscle soreness determined by an intraclass correlation coefficient (ICC, *R*) and coefficient of variation (CV in %) for the four bouts (1–4), the last three bouts (2–4), and middle two bouts (2–3).

Parameter	Time	Reproducibility					
		1–4		2–4		2–3	
		ICC	CV [%]	ICC	CV [%]	ICC	CV [%]
MVC (N m)	Pre	0.62	10.7	0.83	6.6	0.95	4.6
	Post	0.82	8.5	0.81	8.6	0.93	5.3
	24 h post	0.84	8.7	0.83	8.1	0.84	7.5
	48 h post	0.88	7.3	0.91	6.6	0.89	7.3
CMJ (cm)	Pre	0.60	8.7	0.69	6.7	0.59	7.0
	Post	0.78	7.9	0.79	7.1	0.74	7.2
	24 h post	0.77	6.1	0.82	4.5	0.82	3.6
	48 h post	0.75	6.2	0.68	6.2	0.55	7.0
CK (IU L^{-1})	Pre	0.46	19.3	0.41	20.0	0.46	15.6
	Post	0.59	16.2	0.51	17.1	0.44	15.8
	24 h post	0.28	34.0	0.20	34.4	0.12	32.9
	48 h post	0.37	26.6	0.29	28.6	0.13	24.3
Muscle Soreness (mm)	Pre	0.89	17.10	0.88	16.1	0.89	11.00
	Post	0.16	48.8	0.29	50.3	0.67	51.5
	24 h post	0.25	47.0	0.22	52.6	0.31	49.0
	48 h post	0.51	55.0	0.55	60.1	0.61	51.4

Baseline values were similar among bouts for plasma CK activity and self-reported muscle soreness (Fig. 1). Both plasma CK activity and muscle soreness were significantly increased for all post-run time points in all bouts compared to baseline. No significant differences were evident for changes in plasma CK activity (Fig. 1c) and muscle soreness (Fig. 1d) among the bouts. As shown in Table 2, plasma CK activity showed low to moderate reproducibility post-run (ICC 0.12–0.59; CV 15.6–34.4%). Muscle soreness reproducibility was low to moderate (ICC 0.16–0.89; CV 11–60.1%), independent of exclusions.

4. Discussion

To the best of our knowledge, this was the first investigation of reproducibility of performance, neuromuscular fatigue and indirect muscle damage indexes over four outdoor trail runs performed by experienced runners. The primary results are an increased running time in the first bout accompanied by lower blood lactate concentrations, which we attribute to the lack of prior experience on the course. Furthermore, the indexes of neuromuscular fatigue and muscle damage were similar throughout bouts 1–3 and reduced in the last, maybe due to a repeated bout effect. These results indicate that the amount of bouts should be taken into account when using a short outdoor trail run as a fatigue or muscle damage model in order to evaluate intervention strategies to ameliorate performance or recuperation.

To characterise the effectiveness of the intervention, the time courses of parameters were examined. We observed a decrease in MVC torque post run (peak: −17%), which returned to baseline by 24 h in all bouts, CMJ decreases persisting until 48 h (peak: −17%) and increases in plasma CK activity (peak at 24 h: +35%) and muscle soreness (peak bout 1 at post: 54/100 mm; peak bouts 2–4 at post 24: 47/100 mm) (Fig. 1). These alterations are similar to those reported in previous studies examining fatigue and muscle damage in a trained cohort following long distance trail runs (30, 55 and 166 km), which report MVC reductions of 20–40%.[1,2,4] No studies examining fatigue after short distance field based trail runs exist to our knowledge.

In this study, ICC and CV values showed that reproducibility was high for running time, MVC torque and CMJ height – especially for the two middle bouts. Considerable variability existed for changes in blood lactate, plasma CK activity, RPE, and muscle soreness, making these parameters unsuitable as main outcome variables.

The reproducibility of completion time in the present study (Table 1) appears to be comparable to that of 'indoor' settings, especially when excluding bout 1. For example, Nicholson and Sleivert[20] reported a CV of 3.7% for completion time of two 10 km time trials 7 days apart on an indoor track. A review indicates that time trials (1500–5000 m) run on an indoor track have average CV values of ~2.5% for completion time.[21]

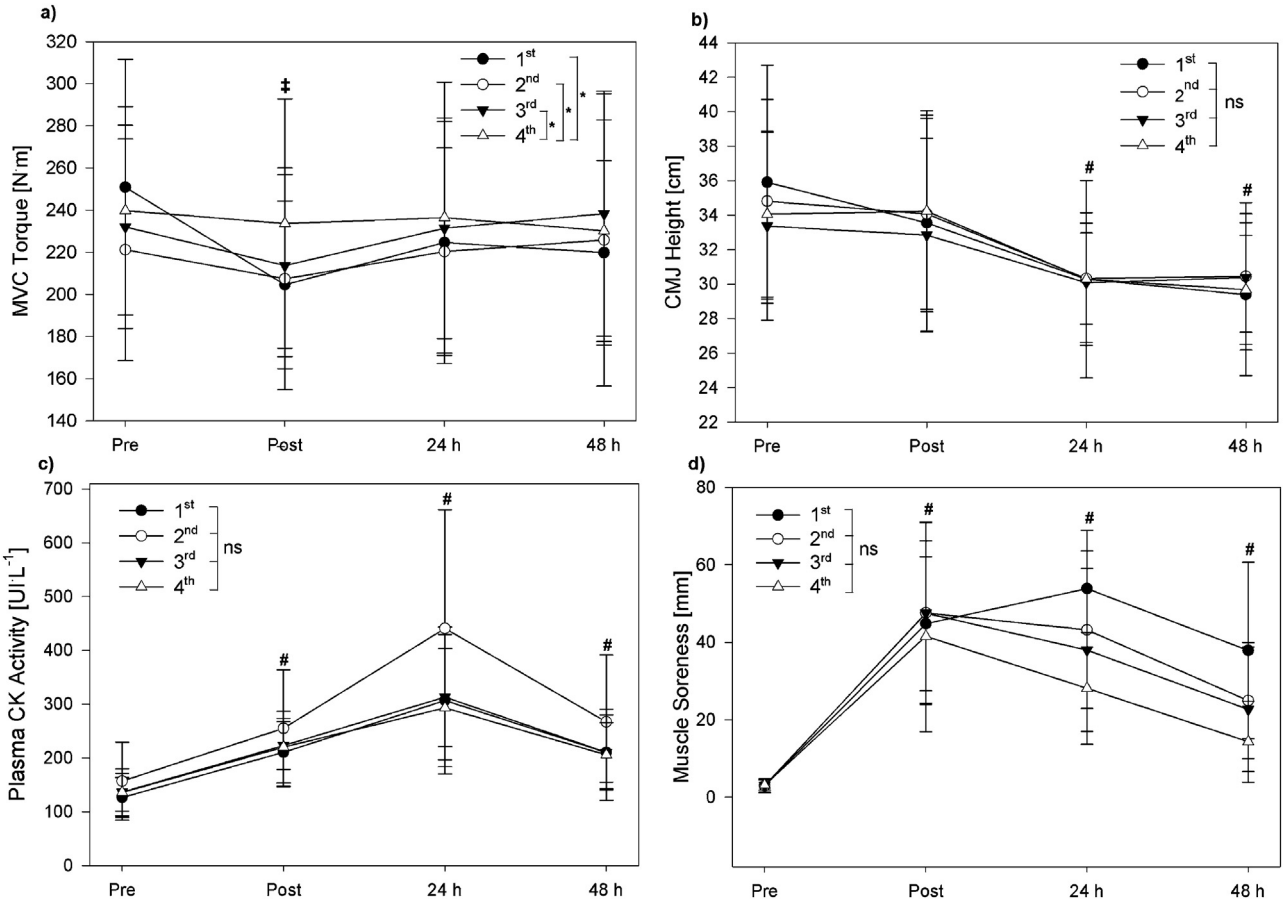

Fig. 1. Changes in maximal voluntary isometric contraction torque of the knee extensors (a), counter movement jump height (b), plasma CK activity (c) and muscle soreness (d) before (pre) and 1 h (post), 24 h and 48 h after the first (1st), second (2nd), third (3rd) and fourth (4th) trail running bouts. *Significant ($p < 0.05$) difference between bouts based on two-way ANOVA. #Significant ($p < 0.05$) difference from the baseline (pre) values for all bouts. ‡Significant ($p < 0.05$) difference from the baseline (pre) values for 1st 2nd and 3rd bouts. ns: No significant differences between bouts.

Despite similar running times among the last three bouts, RPE and post-run lactate concentration were largely variable (Table 1). This is not uncommon, Saunders et al.,[22] for instance, reporting a CV of 10–52% in lactate concentration in two repetitions of three 4-min bouts of treadmill running 7 days apart. RPE reliability has been reported to decrease rapidly with increasing exercise intensity and duration.[23] The relatively low reproducibility in RPE and lactate may be further accentuated in a trail race scenario due to the continuous variation of pace and terrain-induced changes in dissociation strategies and subsequent reduction in sensitivity to physiological cues.

MVC values were well reproducible for all time points in the examined scenario (Table 2), especially when excluding the very first test and the post-exercise test in the fourth bout. This concurs with results reported by Maffiuletti et al.,[24] who observed an ICC of 0.97 and CV of 5.5% for peak knee extensor MVC torque in 2 sessions 7 days apart. Changes in CMJ height following the trail run showed similar reproducibility for the two middle bouts and for the last three bouts as was reported previously.[17,25] It appears that the reproducibility of muscle function changes (MVC torque and CMJ) in outdoor trail running is comparable to that of laboratory based studies.[24,25]

Plasma CK activity and muscle soreness showed only moderate reproducibility in the presented study. A large variability in the CK responses to exercise has previously been reported,[11,26,27] and this is also reflected in the present study. The qualitative time profile of muscle soreness was similar in all four bouts. The reproducibility remains low in all time points, even after exclusion of bouts 1 and 4.

Reproducibility increased considerably in this study when only bouts 2 and 3 were considered. The dissimilarity of the first MVC test and running time from the others is probably related to task learning and highlights the importance of a familiarisation session in an ecological context. The second methodological result of this reproducibility study is the attenuation of acute post-exercise MVC reduction by ~6% in the fourth bout compared to bouts 2 and 3. As proposed in the introduction, this may be caused by a repeated bout effect conferred through the earlier exercise bouts. Similar attenuation has been reported by Thompson et al.,[28] in week 4 of their study on eccentric damage in the elbow flexors. Additionally, it has already been reported that eccentric-induced changes in indirect markers of muscle damage are smaller for resistance-trained individuals[11,12] and that the bulk of the protective effect is conferred within the first repetitions of a bout.[10] Therefore it was expected that a protective effect against muscle damage had already been invoked in our trained trail running population and would not be observed in the experiment. Nonetheless, MVC attenuation was observed, which leads us to believe that the amount of bouts should be limited to a maximum of three in an experimental design, even in well-trained subjects.

There are a number of limitations to the model presented, as for instance, it depends on the environmental conditions and is therefore primarily suited to climatically stable environments. Additionally the terrain and elevation will not be constant

between testing sites, making inter-protocol comparisons less trustworthy.

5. Conclusion

The reported results indicate that if only one group is used in a cross-over design to investigate an intervention effect on trail running, it seems necessary to instigate a familiarisation bout before conducting two testing bouts. In order to evaluate fatigue and muscle damage indexes reliably, the design should optimally take into account the repeated bout effect, even if the muscle damage invoked is minimal. From the outcome measures observed in this study, MVC and CMJ decline show the highest reproducibility and are therefore best suited as main outcome measures. In contrast, the magnitude of variability for RPE, lactate, CK and muscle soreness makes these markers insensitive to small changes and more appropriate as auxiliary variables. It appears that the reproducibility of the changes in variables in the present study is not largely different from that shown in laboratory-based studies,[22,24,25] indicating that an outdoor trail model is equally suited to a lab when evaluating trail running interventions. Therefore, the trail running model used in the present study can be used to investigate the effect of an intervention or a strategy on performance or fatigue; however, methodological precautions should be taken to ensure optimal reproducibility.

Practical implications

- For athletes: The first time a trail course is run, performance is likely to be reduced and fatigue accentuated.
- For researchers: Outdoor trail runs are a viable investigation model that may be used to assess trail-specific interventions when conducting prior familiarisation and limiting the accumulated eccentric stimulus.
- Due to the reduction in reliability after the third bout, this model is mainly applicable for simple within-group designs regarding a single intervention versus a control condition.

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