EFFECTS OF FATIGUE ON KINEMATICS AND SHOCK ATTENUATION DURING DOWNHILL TRAIL RUNNING

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This study assessed the effects of a competitive trail run on running kinematics and shock attenuation in well-trained trail runners. Nine male runners performed a simulated short trail running race. Prior and 5-min after the race, participants completed a 290-m downhill run at pre-determined preferred speed. Inertial measurement units were used to assess selected kinematic parameters. The contact time showed a moderate increase in the fatigued condition (pre: 0.215 (0.024) s vs. post: 0.226 (0.219) s; $p<0.01$; $d=0.51$), whereas flight time was largely decreased (pre: 0.129 (0.027) s vs. post: 0.104 (0.026) s; $p<0.01$; $d=0.94$). There was a moderate decrease in the post-race for peak sacrum acceleration (pre: 56.9 (15.8) m/s^2 vs. post: 49.1 (11.9) m/s^2; $p=0.038$; $d=0.56$), while peak tibial acceleration and shock attenuation showed no change ($p>0.05$). These findings confirm that running-induced fatigue impacts running kinematics, although shock attenuation was unaltered with the present fatiguing protocol.

KEYWORDS: IMU, overuse injury, running mechanics

INTRODUCTION: Trail running is an increasingly popular endurance discipline taking place over distances of tens to hundreds of kilometers, on unpaved surfaces and with significant elevation changes.

Similar to what is known to happen during normal level running, acute fatigue induced by trail running over various distances is associated with changes in a range of descriptors of running mechanics (Degache et al., 2013; Vernillo et al., 2015). However, despite reduced tolerance for impact is known to a consequence of fatiguing level treadmill running (Mercer et al., 2003; Clansey et al., 2012), no study has so far investigated if and to what extent impact shock attenuation is altered after fatiguing trail running.

Therefore, the aim of this study was to assess the effects of a competitive trail run on shock attenuation in well-trained runners. Other selected running kinematics indices were also assessed for purposes of comparison with previous studies. The athletes were analyzed while running downhill, because such running modality is present in most trail running races.

METHODS: Nine male trail runners (mean (SD) age: 31.5 (1.4) years; height: 175.9 (5.6) cm, body mass: 67.1 (6.5) kg; trail running training mileage/week 31.7 (11.5) km) were involved in the study.

The athletes were required to perform, with maximum effort, a short (17.8 km, total elevation change of 2000 m) simulated trail running race. Prior to the race (after a 15-min standardized warm-up), and 5-min after the end of the race, all participants completed a 290-m downhill run (average slope: 22.5 %) on a trail at an individually pre-determined preferred running speed, that was maintained by means of an acoustic signal with reference cones. The mean (SD) speed for the downhill running trial was 16.0 (1.8) km/h.

Four inertial measurement units (IMUs) (EXLs3, EXEL srl, Bologna, Italy, 200 Hz) were used to measure acceleration and obtain kinematic data. IMUs were attached by means of bi-adhesive tapeat the level of sacrum, on the anteromedial aspect of the proximal tibia (dominant side), and on the external surface of the dominant side shoe at the heel and the fifth metatarsal applying additional tape.

Examined parameters included contact time, flight time, step rate, peak sacrum acceleration, peak tibial acceleration, and shock attenuation. Peak sacrum and tibial accelerations were determined as the maximum acceleration values after initial foot contact of the IMUs along the

longitudinal axes of the tibia and the sacrum, respectively. Shock attenuation was calculated as the percentage difference between peak sacrum and tibial accelerations.
The mean values in the pre- vs. post-race conditions were examined with paired Student's t tests, with statistical significance set at $p<0.05$. Cohen's d was used as the effect size.

RESULTS: Data from a total of 671 running steps were used for analysis.
The contact time showed a significant moderate increase in the fatigued condition (average change: 5.1 %), whereas flight time was largely decreased (average change: 19.4 %) (Table 1). A small significant increase was observed for step rate (average change: 2.9 %). There was a moderate decrease in the fatigued condition for peak sacrum acceleration (average change: 13.7 %), while peak tibial acceleration and shock attenuation were not significantly changed (Table 1).

Table 1: Mean (SD) values of examined parameters in the pre- and post-race conditions

Parameter	Pre-race Mean (SD)	Post-race Mean (SD)	p-value	Cohen's d
Contact time (s)	0.215 (0.024)	0.226 (0.219)	<0.001	0.51
Flight time (s)	0.129 (0.027)	0.104 (0.026)	<0.001	0.94
Step rate (steps/s)	2.968 (0.228)	3.053 (0.215)	0.003	0.38
Peak tibial acceleration (m/s^2)	105.6 (23.2)	100.7 (22.1)	0.242	
Peak sacrum acceleration (m/s^2)	56.9 (15.8)	49.1 (11.9)	0.038	0.56
Shock attenuation (%)	52.0 (22.7)	51.4 (20.9)	0.241	

DISCUSSION: The present study aimed to assess the effects of fatigue induced by a simulated short trail running race on running kinematics and impact tolerance during downhill running. Overall, the results show changes of spatio-temporal parameters, with decreased flight time, and increased ground contact time and step rate. These changes, and in particular the longer contact times, can be attributed to altered neuromuscular activation patterns. Also, peak sacrum acceleration was moderately decreased. Conversely, there was no change in peak tibial acceleration and shock attenuation.
These findings are partially consistent with the study of Degache et al. (2013), who assessed running kinematics changes induced by a 5-hrs (37.5 (5.5) km) trail running bout in competitive trail runners. Those authors showed decreased contact time and increased step frequency after the trail running bout, with higher changes at the fastest speed (14 km/h) among those examined. Contrary to the present study, however, they observed no changes in flight time. Nevertheless, the comparison with the present findings should be made with caution, due to the differences in the running surface and slope (level treadmill vs. downhill trail). Vernillo et al. (2015) assessed the kinematics of level, uphill and downhill treadmill running before and after an ultra-trail (65-km) run. Concerning downhill running (speed: 10 km/h; slope: 5%), they showed increased stride frequency and decreased swing time, although the contact time was unchanged. The present findings therefore confirm previous observations of a general link between trail running-induced fatigue and altered spatio-temporal parameters during downhill running, but the varying effects on contact and flight times suggest that changes may be related to factors such as the running speed, the mechanical characteristics and the slope of the running surface.
Analysing the tolerance to impacts is of particular interest in trail running considering the possible implications in the prevention of impact-related overuse injuries. Indeed, unlevel trail running races are particularly challenging for runners in particular due to the high mechanical stress imposed by running downhill (Giandolini et al., 2016). The values of peak tibial and sacrum accelerations observed here, which were used to calculate shock attenuation in the time domain, are of comparable magnitude to those presented in a previous study where downhill trail running was assessed using a speed and a slope similar on average to the present study (Giandolini et al., 2016). To our knowledge, this is the first study in which peak

tibial and sacrum accelerations, and shock attenuation, were assessed in relationship to fatigue induced by a trail running race. Contrary to what shown for level treadmill running following a maximal graded test (Mercer et al., 2003) or a run at lactate threshold (Clansey et al., 2012), our findings shows no effect of a simulated short trail race on impact shock attenuation. This was observed despite a moderate decrease of peak sacrum acceleration, that is, one of the two components used to calculate shock attenuation, along with peak tibial acceleration, that, instead, resulted unchanged after the trail race. Some reasons may be suggested for the above finding. First, a 17.8-km trail running race could be not enough to induce fatigue levels leading to altered shock attenuation, and further investigations are needed to assess the effects of longer races. Furthermore, since the foot strike pattern affects shock attenuation in downhill trail running (Giandolini et al., 2016), a possible different outcome could be observed if the strike patterns of the runners were examined. This type of analysis also represents a perspective for future studies.

CONCLUSION: This study confirms, in trail running, previous results that running-induced fatigue impacts the kinematics of running, although shock attenuation was unaltered with the present fatiguing protocol. The findings contribute to the understanding of the tolerance to impacts in fatigued runners, which has implications for overuse injury prevention. Finally, the study highlights how IMUs may provide useful information to coaches and practitioners when assessing running kinematics in outside laboratory settings.

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