THE INFLUENCE OF HIGH-INTENSITY RUN DURATION ON TIBIAL ACCELERATION AND SHOCK ATTENUTION

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The aim of this study was to investigate the effects of high-intensity fatiguing running on tibial acceleration and shock attenuation. Fourteen highly-trained male runners volunteered and completed an incremental treadmill-based lactate threshold test. On a subsequent test day, tibial acceleration and head acceleration values were recorded in all runners during two 20-minute treadmill running bouts at each subject's lactate threshold (3.5mM) speed. Results indicated no significant change in tibial acceleration during the running bouts, however head acceleration did significantly increase (38%) over time. This resulted in an overall decrease in shock attenuation due to the fatiguing running. The results indicate that these highly-trained runners may show improved movement strategies that allow them to maintain tibial acceleration rates even in a fatigued state.

KEY WORDS: accelerometer, fatigue, impact, running, shock attenuation

INTRODUCTION: The loading response during running has been linked to the occurrence of chronic overuse injuries due to the high forces experienced during each footfall (Munro *et al.,* 1987; Hreljac, 2004). The ability to deal with such high forces when the neuromuscular system is in a fatigued state is also of interest as this is a frequent occurrence, particularly in highly-trained runners. Foot collisions with the ground create shock waves which in turn are transmitted and dissipated through the body's passive structures (e.g. bone) and active movements such as knee flexion during impact. The process of the body in attenuating these shock waves is to absorb the impact energy resulting in a reduced shock rating at the head (Hamill *et al.,* 1995). It has been reported that during fatiguing running tibial acceleration values typically increase (Mizrahi *et al.,* 2000; Verbitsky *et al.,* 1998). However, research examining the effect of sustained high-intensity running on shock attenuation has shown more conflicting findings. Derrick *et al.* (2002) reported a signficant increase in shock attenuation from 74% at the beginning to 77.5% at the end of a 15-minute high intensity fatiguing run. In contrast, Mercer *et al.* (2003) reported that the body's effectiveness of attenuating shock was reduced by 12% after a run to exhaustion (~ 10 minutes). Therefore, the research is still unclear on how effectively the body attenuates impact shock during high intensity running in a fatigued state. Greater understanding of the mechanisms of shock attenuation during fatigued running may provide important insight into the development of overuse injuries in highly-trained runners (Verbitsky *et al.,* 1998). The aim of this study was to investigate tibial acceleration and shock attenuation during two bouts of high intensity fatiguing running.

METHODS: Fourteen male distance runners were recruited for the study (35 ± 11 years; 71.7 ± 9.5 kg; 1.77 ± 0.06 m; 14.65 ± 2.4 km/h lactate threshold (LT) speed at 3.5 Mm). All participants were free from musculoskeletal injury and signed an informed consent form as approved by the University ethics board. Participants performed a treadmill (HP Cosmed, UK) incremental onset of blood lactate accumulation test for identification of their LT speed at 3.5 Mm blood lactate concentration. This LT speed was then used during their subsequent treadmill fatigue running protocol. Participants returned to the lab on a separate occasion to complete this fatiguing protocol. The fatigue protocol began with a five minute self-selected warm-up on the treadmill (0.1% gradient), followed by two bouts of 20 minutes running at each participant's LT speed. Between the two 20-min running bouts participants were asked to conduct 8 acceptable over ground running trials along a 15-m runway at 4.5 $m.s^{-1}$, taking approximately 7-10 minutes (part of a related study). Rating of perceived exertion (RPE) on a scale of 1-20 was taken at the 3rd (start) and 20th (end) minute of each treadmill running bout as a physiologically valid tool for prescribing exercise intensity and fatigued state (Steed *et al.,* 1994). Two mounted bi-axial (10g; sensitivity range of ± 400mV/g; frequency response of 5-6 kHz) accelerometers (Noraxon, Arizona, U.S.A) were attached to the surface of each participant's distal antero-medial aspect of the tibia and anterior aspect of the forehead. Both head and leg accelerometers were securely fastened using water repellent adhesive bandage (Levotape, UK). In addition, the head accelerometer was secured tightly by an elasticated head band. Vertical (axial) acceleration data were recorded at 1500 Hz from both accelerometers for 20 s during the 1st (start) and 20th (end) minute of each 20-minute treadmill running bout. Data were recorded using Qualisys Track Manager (Savedalan, Sweden) and processed in Visual 3D (C-motion, Germantown, U.S.A,). Head and leg accelerations were interpolated from 1500 Hz to 1600 Hz and filtered using a Butterworth low-pass 4th order filter with a cut-off frequency of 70 Hz (cut-off frequency selected based on residual analysis, see Winter, 2005). Peak head and tibial accelerations were averaged for each 20-s recording. Shock attenuation was calculated using the method described by Mercer *et al.* (2010) and shown in Equation 1.

$$\text{Shock attenuation} = \left(1 - \left(\frac{\text{Peak head acceleration}}{\text{Peak tibial acceleration}}\right)\right) \times 100 \quad (1)$$

A repeated measures ANOVA (SPSS version 17.0.0, SPSS Inc., Chicago, IL) was used to assess the significance of run duration (four time levels) on peak tibial acceleration, peak head acceleration, shock attenuation and RPE values. When significant run duration effects were noted, pairwise comparisons were used to determine between which time intervals the significant changes occurred. An alpha level of $p<0.05$ was used throughout.

RESULTS: Peak acceleration, shock attenuation and RPE values at the start and end of each 20-min running bout are displayed in Table 1. There was no significant change in peak tibial acceleration during the running bouts, however, peak head acceleration and RPE showed significant increases over time (38% and 43% respectively, from the start of bout 1 to the end of bout 2). Shock attenuation showed significant decreases over time (3.5% from the start of bout 1 to the end of bout 2). The results of pairwise comparisons are also displayed in Table 1 and indicate that significant changes in peak head acceleration, shock attenuation and RPE occurred between the start and end of bout 1 and also the start of bout 1 and the end of bout 2. However, there were no significant changes in peak head acceleration or shock attenuation between the end of bout 1 and the end of bout 2, despite significant increases in RPE during this period.

Table 1
Mean (SD) for each variable recorded at the start and end of each running bout

	Bout 1 (20 min)		Bout 2 (20 min)		p-value
	Start	End	Start	End	
Peak tibial acceleration (g)	8.9 (2.2)	9.4 (2.4)	8.8 (2.4)	9.1 (2.7)	0.292
Peak head acceleration (g)	0.71$^{a\,b}$ (0.36)	0.90^{a} (0.32)	0.80^{d} (0.34)	0.98$^{b\,d}$ (0.48)	0.001
Shock attenuation (%)	91.5$^{a\,b}$ (4.9)	89.5^{a} (5.0)	89.8 (5.8)	88.3^{b} (6.8)	0.001
RPE	12.2$^{a\,b}$ (1.1)	14.7$^{a\,c}$ (1.3)	13.1^{d} (1.2)	17.5$^{b\,c\,d}$ (1.4)	<0.001

p-value indicates significance of time factor on each variable. Superscripts indicate significant difference ($p<0.05$) between ^{a} Start Bout 1 and End Bout 1; ^{b} Start Bout 1 and End Bout 2; ^{c} End Bout 1 and End Bout 2; ^{d} Start Bout 2 and End Bout 2.

DISCUSSION: The results of this study showed peak tibial acceleration values did not significantly increase during two 20-minute bouts of high intensity running despite evidence of fatigue (increased RPE values at constant absolute workloads). This is in contrast with previous research (Mizrahi *et al.,* 2000; Verbitsky *et al.,* 1998; Voloshin *et al.,* 1998) which reported a significant increase in tibial acceleration during 30 minutes of LT running when subjects were in a fatigued state. A possible explanation for the difference in findings observed could relate to differences in the training status of the subjects recruited. In the current study, all participants were highly trained endurance athletes whereas the previous studies (Mizrahi *et al.,* 2000; Verbitsky *et al.,* 1998; Voloshin *et al.,* 1998) recruited non-athletic populations. This theory is supported by research by Mercer *et al.* (2003), who also used experienced runners and reported no significant change in peak leg accelerations after a high-intensity exhaustive run. The different responses to fatiguing running could, therefore, be a result of the adoption of more effective movement strategies by the highly-trained endurance runners in response to fatiguing running. This is an important finding, given the reported links between high tibial acceleration and increased injury risk. Further research is required to identify what specific movement strategies may be adopted by these highly-trained runners to maintain such constant tibial accelerations during the loading response stage.

Peak head acceleration was shown to significantly increase by 0.27 g or 38% from the start of the first 20-minute bout to the end of second 20-minute bout. Similar magnitude non-significant increases have been reported in previous studies (Mercer *et al.,* 2003; Derrick *et al.,* 2002). This combination of increased head acceleration with no change in the acceleration at the distal tibia in the current study, results in a significant decrease in shock attenuation values (91.5% to 88.3%). This finding is in agreement with work by Mercer *et al.* (2003) who reported a 6% reduction in shock attenuation with no significant change in tibial acceleration. Once more, the results are in contrast to previous findings by Derrick *et al.* (2002), Voloshin *et al.* (1998) and Verbitsky *et al.* (1998) due to their reports of large increases in tibial acceleration. Again, this can possibly be explained by differences in the subjects' training status. It is not yet clear what the effects of these increased head acceleration values and concomitant decreased shock attenuation values are for highly-trained runners. It is hypothesised that the increased head accelerations could be linked to greater shock values through other body regions, thus implying a greater chronic loading despite control over tibial acceleration values. However, the magnitude of such additional loading through other body structures in these highly-trained runners would appear to be low, due the maintenance of peak tibial acceleration values at non-fatigued levels.

CONCLUSION: The present findings showed that peak tibial accelerations were not affected by fatiguing running over two 20-minute bouts, while overall shock attenuation reduced slightly. Results suggest that highly-trained endurance athletes may adopt more effective movement strategies in a fatigued state in order to prevent increases in tibial acceleration. However, further research is required to elaborate on the existence and components of such movement strategies. These results should provide a greater insight into the prevention of overuse injuries in both highly-trained and recreational runners.

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