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The location of the tibial accelerometer does influence impact acceleration parameters during running

Abstract

The analysis of tibial accelerations during running has become a topic of great interest for the running research community due to its potential relationship with running related overuse injuries. However, studies attaching the tibial accelerometer on the proximal section are as numerous as those attaching the accelerometer on the distal section. For this reason, this study aimed to investigate whether accelerometer location influences acceleration parameters commonly reported in running literature. To fulfil this purpose, thirty athletes ran at three different speeds (2.22 m/s, 2.78 m/s and 3.33 m/s) with three accelerometers attached on different locations: the forehead, the proximal section of the tibia, and the distal section of the tibia. Time-domain (peak acceleration, shock attenuation) and frequency-domain parameters (peak frequency, peak power, signal magnitude in both the low and high frequency range) were calculated for each of the tibial locations. A transfer function of the head signal relative to the tibial signal was also used to calculate shock attenuation in the frequency domain. The distal accelerometer registered greater tibial acceleration peak and shock attenuation compared to the proximal accelerometer. With respect to the frequency-domain analysis, the distal accelerometer provided greater values of all the low frequency parameters, whereas no difference was observed for the high frequency parameters. These findings suggest that the location of the tibial accelerometer does influence the acceleration signal parameters and thus researchers should carefully consider the location they choose to place the accelerometer so that equivalent comparisons across studies can be made.

Keywords: Tibial acceleration, Shock attenuation, Frequency analysis, Deceleration, Accelerometry.

Highlights (85 characters)

- Impact accelerations have been associated with running related overuse injuries.
- Controversy exists as to where exactly the tibial accelerometer should be placed.
- The distal accelerometer showed greater values of the time-domain variables.
- The distal accelerometer showed greater values of the low-frequency range variables.
- The location of the tibial accelerometer does influence the acceleration results.

Introduction

Rapid deceleration of the foot and leg at ground contact during running results in a shock wave that is transmitted throughout the body from the foot to the head. This shock wave, measured as impact accelerations via skin-mounted accelerometers (Kavanagh & Menz, 2008), has become of great interest to the running research community due to its potential relationship with overuse injuries (Milner, Ferber, Pollard, Hamill, & Davis, 2006; Wee & Voloshin, 2013).

Impact accelerations have been used to investigate a number of factors including the effects of fatigue (Verbitsky, Mizrahi, Voloshin, Treiger, & Isakov, 1998), foot strike (Gruber, Boyer, Derrick, & Hamill, 2014) and running surface (García-Pérez, Pérez-Soriano, Llana-Belloch, Lucas-Cuevas, & Sánchez-Zuriaga, 2014), or the shock attenuation properties of shoes (Chambon, Delattre, Guéguen, Berton, & Rao, 2014; Fong Yan, Sinclair, Hiller, Wegener, & Smith, 2013) and compressive garments (Lucas-Cuevas et al., 2015).

Most of the studies analysing impact accelerations during running have used two accelerometers, one accelerometer placed on the tibia, as it is a region with little amount of soft tissue between the skin and the bone, and a second accelerometer placed on the forehead to measure the effectiveness of the body at attenuating the acceleration resulting from the ground contact. However, the exact location of the tibia where the accelerometer should be placed remains unclear. Studies placing the accelerometer on the proximal section of the tibia (Duquette & Andrews, 2010; García-Pérez et al., 2014; Verbitsky et al., 1998) are as numerous as those placing the accelerometer on the distal section (Gruber et al., 2014; Milner et al., 2006; O'Leary, Vorpahl, & Heiderscheit, 2008).

However, we hypothesise that the exact location of the accelerometer on the tibia may play a major role in the resultant accelerations and could be affecting the comparison of results between studies. Therefore, the aim of this study was to investigate whether the location on the tibia where the accelerometer is placed influences the impact accelerations during running.

Methods

Participants

30 male runners (27.3±6.4 years; 175.3±6.6 cm; 69.9±9.2 kg) agreed to participate. Inclusion criteria included no history of lower extremity injuries within the last year. The study was approved by the University ethics committee.

Study Design

Three triaxial accelerometers (AcelSystem, Spain) were firmly taped to: a) the forehead; b) the distal end of the right tibia (Distal); and c) the antero-medial aspect of the right tibia (Proximal). Participants performed the test on a treadmill (TechnogymSpA, Gambettola, Italy) while wearing the same type of neutral running shoe (Adidas Galaxy, Germany). Participants warmed up for 10 min at 2.22 m/s and subsequently performed three runs of two minutes at 2.22 m/s, 2.78 m/s and 3.33 m/s in a random order. Accelerations were collected at 300 Hz for 15 seconds at the end of each run.

Data was analysed using Matlab (MathWorks, MA, USA). For the time-domain analysis, acceleration signals were filtered (Butterworth, second-order, low-pass, cut-off frequency= 50 Hz) and the tibial positive peak acceleration and the magnitude shock attenuation were calculated as reported elsewhere (Lucas-Cuevas et al., 2015).

For the frequency-domain analysis, the non-filtered stance phases extracted from the time-based signal were analysed. After removing the mean and linear trends, the signals were padded with zeroes to equal 2048 data points and power spectrums were calculated for the head and the tibia (Shorten & Winslow, 1992). Analyses of the low (3-8.5 Hz) and high (8.5-20 Hz) frequency ranges were performed to investigate the behaviour of the two local acceleration peaks occurring during running (Gruber et al., 2014; Shorten & Winslow, 1992). In order to measure the impact attenuation, a transfer function was calculated from the power spectrum of the head and tibia (Shorten & Winslow, 1992). In summary, the following frequency-domain variables were calculated in both the low and high frequency ranges: Tibial Signal Magnitude

(TSM_{low} and TSM_{high}), Tibial Peak Power (TPP_{low} and TPP_{high}), Tibial Peak Frequency [frequency of TPP_{low} (TPF_{low}) and TPP_{high} (TPF_{high})] and shock attenuation (ATT_{low} and ATT_{high}).

Statistical analysis

Data were analysed with SPSS software (SPSS, Chicago, IL). The Kolmogorov-Smirnov test was used to test normal samples. Acceleration parameters were analysed using a 2-way repeated measures ANOVA with Bonferroni post hoc tests where appropriate and a significance level set at $\alpha = 0.05$.

Results

Placing the accelerometer on the Distal location resulted in greater tibial acceleration peak and magnitude shock attenuation compared to the Proximal location for most of the running speeds (Figure 1).

Moreover, placing the accelerometer on the Distal location led to greater TSM_{low}, TPP_{low}, TPF_{low}, and ATT_{low} compared to the Proximal location. Interestingly, the location of the accelerometer did not influence the parameters of the high frequency range (TSM_{high}, TPP_{high},TPF_{high}, ATT_{high}) (Table 1).

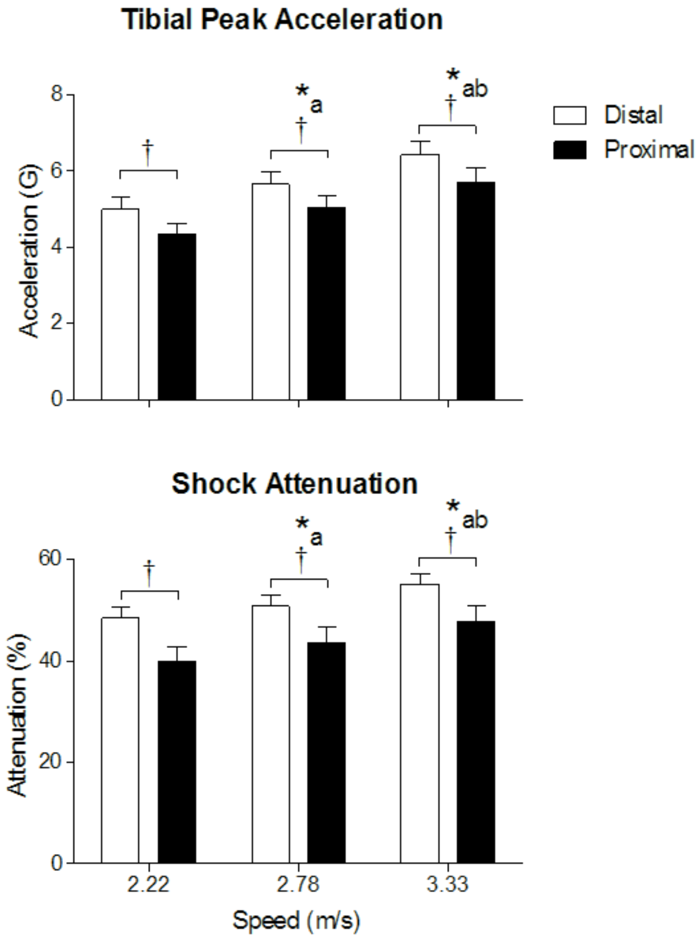

Figure 1. Mean (SE) tibial peak acceleration and shock attenuation of the distal and proximal accelerometers during running at 2.22, 2.78 and 3.33 m/s. † Significant difference between locations ($p < 0.05$). Significant difference between 2.22 vs 2.78 m/s (^{*a}), 2.22 vs 3.33 m/s (^{*b}) and 2.78 vs 3.33 m/s (^{*c}) ($p < 0.05$).

Table 1. Frequency-domain parameters of the distal (Distal) and proximal (Prox) tibial acceleration signals during running at 2.22, 2.78 and 3.33 m/s. Variables include: tibial signal magnitude within the low and high frequency ranges ($TSM_{low,high}$); peak power within the low and high frequency ranges ($TPP_{low,high}$); frequency of peak power within the low and high frequency ranges ($TPF_{low,high}$); shock attenuation in the low and high frequency ranges ($ATT_{low,high}$).

† Significantly different compared to the matching Distal signal. * Significant difference between 2.22 vs 2.78 (a), 2.22 vs 3.33 (b) and 2.78 vs 3.33 (c) m/s. Non significant: n.s.

	2.22 m/s		2.78 m/s		3.33 m/s		Speed
	Distal	Prox	Distal	Prox	Distal	Prox	
TSM_{low} (G^2/Hz)	0.154 (0.008)	0.120† (0.008)	0.238 (0.012)	0.175† (0.009)	0.339 (0.016)	0.260† (0.012)	*abc
TSM_{high} (G^2/Hz)	0.144 (0.010)	0.150 (0.010)	0.240 (0.016)	0.247 (0.017)	0.360 (0.020)	0.378 (0.028)	*abc
TPP_{low} (G^2/Hz)	0.058 (0.004)	0.044† (0.004)	0.076 (0.005)	0.061† (0.004)	0.099 (0.006)	0.089† (0.006)	*abc
TPP_{high} (G^2/Hz)	0.029 (0.002)	0.031 (0.002)	0.051 (0.004)	0.054 (0.004)	0.074 (0.005)	0.081 (0.006)	*abc
TPF_{low} (Hz)	6.12 (0.18)	5.34† (0.23)	5.93 (0.21)	5.38† (0.16)	6.06 (0.30)	5.40† (0.15)	n.s.
TPF_{high} (Hz)	14.09 (0.26)	14.04 (0.22)	14.04 (0.36)	14.40 (0.33)	13.87 (0.34)	14.29 (0.38)	n.s.
ATT_{low} (dB)	-26.51 (2.44)	-19.39† (2.61)	-31.35 (2.39)	-21.84† (2.80)	-33.74 (2.62)	-23.89† (3.11)	n.s.
ATT_{high} (dB)	-96.42 (3.78)	-100.05 (3.65)	-116.02 (4.85)	-117.20 (4.96)	-128.47 (4.55)	-129.92 (5.10)	*abc

Discussion

Impact accelerations are considered to be a direct measurement of the foot-ground collision. However, as attaching the accelerometer directly to the bone is not practical, a lightweight accelerometer attached to the tibia has been proposed to be a valid method to measure shock impacts. But, the place where the accelerometer is attached must be decided with great care. Whereas some authors indicated that accelerometers should be attached on proximal anatomical areas of the lower leg (Voloshin, 2000), other authors suggested that more distal locations would be better to reduce the angular motion and gravity interaction observed in the time domain analysis (Lafortune & Hennig, 1991).

Lafortune & Henning (1991) observed that a) gravity can lead to an overestimation of 1 G, and b) the angular motion of the shank at touch down can provoke an underestimation of -5 G of the axial peak acceleration. Therefore, the combined effect during running could result in an underestimation of -4 G. In this study, the distal accelerometer registered greater accelerations compared to the proximal accelerometer, which may be explained by the angular motion of the shank.

Shock attenuation was also greater in the distal accelerometer as a result of the higher peak accelerations measured at this location. This is consistent with previous studies observing greater shock attenuation following increases in impact acceleration, a mechanism to protect the head from excessive accelerations (Derrick, Hamill, & Caldwell, 1998; Gruber et al., 2014; Lucas-Cuevas et al., 2015).

Previous studies suggested tibial accelerations should be analysed in the frequency rather than in the time domain (Shorten & Winslow, 1992), but no study to date has investigated the influence of accelerometer placement on frequency parameters. Though, previous studies have observed that humans have a reduced capability to attenuate low frequency parameters (associated with movement pattern) (Derrick et al., 1998; Gruber et al., 2014).

In the present study, the low frequency components as well as the shock attenuation of the low frequencies were greater in the distal accelerometer. These results indicate that the distal accelerometer oscillates at a greater dominant frequency compared to the proximal accelerometer as a consequence of the greater speed experienced by the distal accelerometer within the running cycle. The lower peak power of the low frequency range indicates that the proximal accelerometer experienced lower movement than the distal accelerometer, thereby underestimating the actual magnitude as Lafortune & Henning (1991) demonstrated in the time domain. Surprisingly, no differences in the high frequency components were observed between accelerometers, thereby suggesting that both locations could be appropriate to study the shock attenuation of high frequencies.

Conclusion

The study of the frequency domain of the acceleration signal allows researchers to analyse the contents of the impacts generated during running and indicates how severe the high frequency components are as a result of extrinsic and intrinsic factors such as fatigue, running pattern or sport surfaces. Our results suggest that the location of the tibial accelerometer influences the magnitude of the variables both in the time and frequency domain. Although the high frequency parameters are unaffected, the time-domain and the low frequencies values are underestimated when placing the accelerometer on the proximal aspect of the tibia.

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