THE RELIABILITY AND VARIABILITY OF THREE-DIMENSIONAL TIBIAL ACCELERATION DURING RUNNING

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Axial and resultant peak tibial acceleration might be useful for screening/monitoring runners at risk of lower limb injury. This study quantified between-session reliability and variability of axial and resultant peak tibial acceleration during running. Fourteen runners completed four running speeds at two testing sessions seven days apart with tri-axial wireless accelerometers attached to the tibia. Average mean differences between sessions across all four speeds (for the right or left side) were 4.5-5.7% (ES 0.01-0.17; ICC 0.73-0.95; CV% 7.5-17.9) for axial and 0.9-5.1% (ES 0.01-0.12; ICC 0.84-0.97; CV% 5.9-13.9)) for resultant peak tibial acceleration. While both axial and resultant peak tibial acceleration are reliable and therefore appropriate for monitoring and assessment of an intervention, resultant peak tibial acceleration should be preferentially used.

KEY WORDS: screening, monitoring, resultant, between-day.

INTRODUCTION: To achieve an accurate and reliable assessment of running gait, facilities with highly equipped motion capture systems and force plates are required. These systems are complex, expensive, require considerable space, and are time consuming for data collection and analyses. The laboratory conditions, and therefore results, are often difficult to apply to real-world sporting environments. Improvements in sensor technology and data analysis techniques have enabled the development of real-time mobile devices capable of measuring meaningful running biomechanics information. Wearable sensors, such as accelerometers, are light-weight, low cost and user friendly, and therefore have the potential to make quantified gait assessment more readily available (Higginson, 2009). Wearable accelerometer sensors can also be used both in the laboratory and during field-based assessments (Sinclair, Hobbs, & Protheroe, 2013). A number of studies have examined the effectiveness of accelerometers compared to in-ground force plates, force instrumented treadmills, digital video and motion analysis systems, in determining running gait variables (Auvinet, Gloria, Renault, & Barrey, 2002; Dufek, Mercer, & Griffin, 2009; Laughton, Davis, & Hamill, 2003; Sinclair et al., 2013). While these studies have provided support for the use of accelerometers, the varied placements of devices, the small selection of running speeds, and the potential change in running kinematics from force plate targeting (Challis, 2001), has left questions. Specifically, if accelerometers are to be used to influence decisions made by coaches and clinicians, an appreciation of the running movement variability at different speeds is one element that is required. In addition, between-session reliability needs to be determined before the devices can be used longitudinally to evaluate the effects of interventions designed to reduce the risk of injury or improve performance. The purpose of this study was to determine the between-session reliability and variability of 3D tibial acceleration at four running speeds.

METHODS: Testing was conducted in a laboratory over two identical sessions, separated by one week. Procedures were approved by institutional human research ethics and participants provided written informed consent. Fourteen male runners, aged 33.6 ±11.6 years, who were injury free at the time of data collection, volunteered for this study. Runners had been regularly participating in running for 8.7 ±8.1 years, and ran on average 30.3 ±25.5 Km in 4.4 ±5.2 training sessions per week.

Equipment: Acceleration data were collected from tri-axial wireless accelerometers (IMeasureU Limited, Auckland), which were attached at the intersection of the middle and distal thirds of the antero-medial aspect of participants' right and left tibia. The y-axis of the device was aligned with the long axis of the tibia using the same technique employed by Sinclair et al., (2013). Data were logged to the onboard memory of the accelerometers at 1000 Hz for the duration on the running trials, and then downloaded after each session for processing. Runners wore standardised neutral running shoes (Asics Kudrow, Kobe, Japan).
Procedures: Height, weight and tibia length were measured according to standard ISAK protocols. Running trials were completed on an instrumented treadmill (Bertec, Columbus, OH). Following a 5-minute warm-up and familiarisation at a self-selected pace, runners ran for two minutes at 2.7, 3.0, 3.3 and 3.7 m/s.
Data processing: Processing was carried out using a custom Matlab script (Mathworks, MA, USA). At each speed, data were visualised to ensure stabilization in gait patterns after changes in treadmill speed, and a subsequent 50 s trial defined. A fourth order, dual pass 60 Hz Butterworth low-pass filter with a cut-off frequency of 16 Hz was applied and the resultant acceleration was calculated as $r = (x^2 + y^2 + z^2)^{0.5}$. Peak tibial accelerations (PTAs) were determined from axial and resultant acceleration data for statistical analysis.
Data analysis: Group mean and standard deviations were calculated for the peak axial and resultant PTAs across the four running speeds from sessions one and two. Using the Hopkins (2015) analysis of reliability, data were log transformed to reduce bias arising from non-uniformity of error. Reliability and variability outcomes were presented as percentage changes. Measurement variability outcomes included intraclass correlation coefficients (ICC) and the typical error of the measurement expressed as a coefficient of variation percentage (CV%). An ICC <0.70 is indicative of 'poor' agreement and high measurement variability, 0.7≤ ICC ≤0.80 represents a questionable outcome, and ICC >0.8 represents an excellent outcome (Atkinson & Nevill, 1998; Cormack, Newton, McGuigan, & Doyle, 2008; Hopkins, 2015). A CV of <10% is considered small variation. Between session reliability measures included percentage differences in the means (MDiff%) and Cohen's effect sizes (ES). Effect sizes were interpreted as trivial (0.0-0.1), small (0.11-0.3), moderate (0.31-0.5), large (0.51-0.7), very large (0.71-0.9), or extremely large (0.91-1.0) (Hopkins, Marshall, Batterham, & Hanin, 2009).
An interpretation of the average measurement variability and reliability was based on the methods of Bradshaw, Hume, Carlton and Aisbett (2010), where average measurement variability was interpreted as 'small' when the ICC was >0.70 and the CV was <10%, 'moderate' when ICC was <0.70 or CV was >10%, and 'large' when ICC <0.70 and CV >10%. Average reliability was interpreted as 'good' when the difference in the mean was less than 5% and the ES was trivial to small. Average reliability was interpreted as 'moderate' when the aforementioned criteria for 'good' were breached for either the MDiff% or the ES (MDiff >5% or ES = moderate to large). Average reliability was categorised as 'poor' when both the MDiff% and the ES criteria were breached (MDiff >5% and ES = moderate to large).

RESULTS AND DISCUSSION: An average of 61 ±1.5 steps were analysed for the 14 runners for each running speed during each testing session. Descriptive, reliability and variability statistics for axial PTA are presented in Table 1, and for resultant PTA in Table 2. The mean axial PTA values ranged from 5.5 g to 8.1 g, which are consistent with other research, where runners have run at comparable speeds (Abt et al., 2011; Giandolini, Horvais, Farges, Samozino, & Morin, 2013; Hamill, Derrick, & Holt, 1995). The average mean differences in axial PTA between sessions ranged from 0.0 to 0.3 (4.5 to 5.7%). An ES of less than 0.3 is indicative of a minimal change in a variable of interest from one session to the next. No measures of axial PTA exceeded an ES of 0.17.

Table 1: Axial peak tibial acceleration - between-session variability and reliability

	Left				Right			
Speed (m/s)	2.7	3.0	3.3	3.7	2.7	3.0	3.3	3.7
Session 1 Mean ±SD (g)	5.5 ±1.8	6.4 ±1.9	7.2 ±2.1	8.1 ±2.5	5.8 ±1.7	6.4 ±1.7	7.1 ±2.0	8.1 ±2.2
Session 2 Mean ±SD (g)	5.6 ±2.0	6.7 ±1.8	7.0 ±2.1	8.0 ±2.7	5.8 ±1.6	6.2 ±1.7	7.1 ±2.1	7.8 ±2.5
Mdiff (g)	0.1	0.3	-0.2	0.0	0.2	0.1	0.0	-0.3
CV% (90%CL)	16.3 (12.2-25.1)	11.9 (8.9-18.1)	9.8 (7.4-14.9)	12.3 (9.2-18.8)	17.9 (13.4-27.7)	7.5 (5.7-11.3)	10.6 (8.0-16.2)	9.2 (7.0-14.0)
ICC (90%CL)	0.83 (0.61-0.93)	0.88 (0.72-0.95)	0.92 (0.79-0.97)	0.91 (0.78-0.96)	0.73 (0.43-0.89)	0.95 (0.87-0.98)	0.91 (0.78-0.96)	0.93 (0.84-0.97)
Variability rating	Moderate	Moderate	Small	Moderate	Moderate	Small	Moderate	Small
Mdiff% (90%CL)	0.0 (-9.6-10.6)	5.7 (-2.0-13.9)	-2.2 (-8.1-4.2)	-1.1 (-8.5-6.9)	3.7 (-7.1-15.8)	-3.3 (-7.9-1.4)	-0.5 (-7.0-6.4)	-4.5 (-9.9-1.3)
Effect Size	0.05	0.17	0.07	0.01	0.12	0.11	0.11	0.11
Reliability rating	Good	Moderate	Good	Good	Good	Good	Good	Good
Use	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

While axial PTA (often measured using a uni-axial accelerometer) is the most common variable measured and reported, with the emergence of more accessible tri-axial sensors, the reporting of resultant PTA values is emerging. The advantage of using the resultant PTA compared to the axial PTA is that the resultant PTA is not influenced by the orientation of the device on the limb. As expected, the mean resultant PTAs were all higher in magnitude than axial PTAs, ranging from 7.6 to 12.1 g, due to the resultant value incorporating the additional two axes (x and z). While the absolute mean difference in PTA between sessions one and two were comparable between the axial and resultant measures (0.0 to 0.3 g), because of the smaller absolute axial PTA magnitudes, the MDiff% in PTA was higher for the axial direction. This, combined with marginally larger effect sizes at some running speeds, indicated that the reliability of the resultant measures was slightly better.

Table 2: Resultant peak tibial acceleration - between-session variability and reliability

	Left				Right			
Speed (m/s)	2.7	3.0	3.3	3.7	2.7	3.0	3.3	3.7
Session 1 Mean ±SD (g)	7.6 ±3.0	9.2 ±3.2	10.5 ±3.6	11.8 ±3.7	7.9 ±2.9	9.1 ±3.0	10.3 ±3.2	12.0 ±3.6
Session 2 Mean ±SD (g)	8.0 ±2.7	9.4 ±2.9	10.6 ±3.3	12.1 ±3.8	7.9 ±2.4	8.7 ±2.5	10.5 ±3.0	11.9 ±3.4
Mdiff (g)	0.3	0.2	0.1	0.3	0.0	-0.3	0.1	-0.1
CV% (90%CL)	12.7 (9.6-19.5)	6.9 (5.2-10.4)	6.3 (4.8-9.5)	8.7 (6.5-13.1)	10.1 (7.6-15.4)	5.9 (4.5-8.9)	13.9 (10.4-21.3)	6.6 (5.0-10.0)
ICC (90%CL)	0.90 (0.75-0.96)	0.97 (0.92-0.99)	0.97 (0.93-0.88)	0.95 (0.87-0.98)	0.93 (0.82-0.97)	0.97 (0.92-0.99)	0.84 (0.64-0.93)	0.96 (0.91-0.99)
Variability rating	Moderate	Small	Small	Small	Moderate	Small	Moderate	Small
Mdiff% (90%CL)	5.1 (-3.0-13.9)	2.4 (-2.1-7.1)	1.7 (-2.4-5.9)	2.0 (-3.5-7.8)	1.9 (-4.5-8.7)	-2.5 (-6.2-1.3)	1.5 (-7.0-10.7)	-0.9 (-5.1-3.4)
Effect Size	0.12	0.05	0.03	0.08	0.01	0.11	0.05	0.04
Reliability rating	Moderate	Good	Good	Good	Good	Good	Good	Good
Use	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

A CV of 10% or less is considered small in pure test-repeats (Bennell, Crossley, Wrigley, & Nitschke, 1999). For the axial direction, only three from eight of our CV% were greater than 10% (9.2 to 17.9%). The coefficients of variation combined with intra-class correlation coefficients between 0.73 and 0.95, indicate that axial PTA measures had moderate or small levels of variability at all running speeds. However, when compared with the equivalent resultant PTA variables, in all cases the CVs and ICCs were higher. While it is not possible to determine the cause of this increase in measurement variability in the axial direction, one possible reason is the need to align the y-axis of the accelerometer as closely as possible with the long axis of the tibia. While every effort was made to ensure this was achieved, it is a difficult task that does not need to be considered when using resultant PTAs.

CONCLUSION: Tibial acceleration is a useful measure in injury prevention studies in runners. It is therefore important to use a measure of acceleration that shows the least variability across sessions. In all cases the quantitative measures of measurement reliability and variability were of a magnitude indicating 'good' to 'moderate' reliability and 'small' to 'moderate' measurement variability. No bias in the differences in variability or reliability between left and right sides, or between the different running speeds were detected. The results were however superior for resultant over axial measreuments. We can be confident that measures of peak resultant tibial acceleration can be used with runners to assess and monitor their impacts throughout an intervention.

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