ACUTE EFFECTS OF OUTDOOR SURFACES ON RUNNING GAIT SYMMETRY AND REGULARITY ASSESSED BY TRUNK ACCELEROMETRY

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The purpose of this study was to investigate if trunk accelerometry measures were influenced by outdoor surface while running. A sample of highly-trained (n=12) and recreational (n=17) ran on three independent surfaces, namely asphalt, synthetic track, and wood-chip. Dependent accelerometry measures were step frequency (S_{FREQ}), step symmetry (S_{SYM}), stride regularity (S_{REG}), axis contribution to total amplitude (RMS_{RATIO}) and sample entropy (S_{EN}). Surface effects on accelerometry measures were consistent for both running groups. Several significant differences existed between wood-chip and either asphalt or synthetic track. The results suggest that surface specific considerations should be made when quantifying trunk accelerometry measures related to running gait symmetry and regularity during running.

KEY WORDS: Accelerometer, outdoor surfaces, running

INTRODUCTION: Recent advances in miniaturization and the cost of wireless accelerometers have resulted in a widespread availability of devices that have been applied to running gait analysis. The trunk has become a suitable location for the accelerometer due to its ability to estimate whole-body accelerations in close proximity the centre of mass (CoM) (McGregor et al., 2009; Moe-Nilssen & Helbostad, 2004). In the natural world, runners encounter many surfaces that can compress under their feet (Ferris et al., 1998). Although a runner's CoM trajectory can remain stable over surfaces that differ in stiffness (Karamanidis et al., 2006), uneven outdoor ground typically found in running trails can generate multiple, irregular perturbations to which the runner must adapt to, even at the level of the CoM (Menz et al., 2003). Indeed, tri-axial accelerations of the CoM have shown to increase significantly at the trunk when walking on irregular surfaces (Menz et al., 2003; Moe-Nilssen, 1998).
Selection of proper training surfaces and terrain has been suggested as a preventative measure to reduce running-related injury (Clement & Taunton, 1981). For the application of online calculation and prospective monitoring of running gait measures in outdoor environments, it becomes important to consider how a runner may or may not adapt running pattern between training surfaces. Some accelerometry measures do not depend on step detection, peak detection or setting of optimal thresholds. Thus, in this study the step frequency (S_{FREQ}), step symmetry (S_{SYM}), stride regularity (S_{REG}), the root mean square ratio (RMS_{RATIO}) and sample entropy (S_{EN}) of trunk accelerations of running gait were analysed. To the knowledge of the authors the relationship of these measures with running surface has not been previously analysed and reported on. The aim of the present study was therefore to investigate if the aforementioned symmetry and regularity measures were influenced by outdoor surface during running in a sample of highly-trained and recreational runners.

METHODS: Two predetermined groups of runners aged 18 to 33 years of mixed gender were recruited for this study; highly-trained long-distance runners (mileage >50km /week, n = 12) and recreational runners (mileage < 30 km/week, n = 17). All runners were screened to have no history of lower extremity injury within the past three months. Written informed consent was received from all runners prior to participation in accordance with the Declaration of Helsinki. All runners performed a standardized warm-up. The experimental protocol involved running on three different outdoor surfaces (asphalt, synthetic track, and wood-chip trail) all of equal linear distance of 90 m. Photo electronic timing gates (RaceTime

2 system, Microgate, Bolzano, Italy) were positioned to measure average running speed from the 10 m to 70 m mark, thus excluding the first and last 10 m resembling the acceleration or deceleration phases respectively. Two trials were recorded for each runner at self-selected running speeds after a practice trial was provided to familiarize the runner to each surface. Five minute rest period were provided between each surface. All runners ran in their own pair of running shoes during the testing protocol.
A tri-axial accelerometer (X50-2 wireless accelerometer, range ± 50g, sampling at 1024 Hz, 13-bit resolution, 33g weight, Gulf Coast Data Concepts, MS, USA) was securely mounted over the L3 spinous process of the trunk to approximate the CoM (Moe-Nilssen & Helbostad, 2004). The accelerometer was placed directly on the skin using double sided tape and additional adhesive spray.
Tilt-corrected (Moe-Nilssen & Helbostad, 2004) CoM accelerometry measures of the lower back motion pattern during running were examined using S_{FREQ}, S_{SYM}, S_{REG}, RMS_{RATIO}, and S_{EN}. All accelerometry measures were calculated using customized MATLAB software version 8.3 (The Mathworks Inc., Natick, MA, USA). Eight seconds of tri-axial accelerometry signals (8192 samples, ~20 steps) from each running trial was used for analysis. The average of two trials was taken as the accelerometry measure for each individual.
S_{FREQ}, S_{SYM}, and S_{REG} were computed using the unbiased autocorrelation procedure previously described by Moe Nilssen et al., (2004). The first peak of autocorrelation (S_{SYM}) indicates a correlation between consecutive steps and is therefore considered the symmetry index. The first peak of the autocorrelation also indicates the lag in recorded samples for one step, and thus, with additional knowledge of the sampling frequency of the accelerometer, can be used to calculate S_{FREQ} (defined as steps per minute). The second autocorrelation peak (S_{REG}) represents a correlation between consecutive strides and can be considered as a regularity index. After normalization to the zero lag component, the maximum value for S_{SYM} and S_{REG} is one.
The RMS_{RATIO}, defined as the ratio of each acceleration axis RMS relative to the resultant vector RMS assesses the proportion of amplitude or variability that occurs in each respective axis (vertical, mediolateral, or anteroposterior) compared to the total acceleration amplitude or variability (McGregor et al., 2009).
S_{EN} was calculated using the non-linear mathematical algorithms previously described in detail by Richman and Moorman (Richman & Moorman, 2000) and quantifies the uncertainty or unpredictability of the accelerometry time series (Yentes et al., 2013), with a larger value indicating a less periodic and irregular pattern. Each accelerometry time series from the training surface trials contains 8192 data points. Input parameters for our SampEn calculation were firstly, a series length (m) of 2 data points, and secondly, a tolerance window (r) normalized to .2 times the standard deviation of individual time series (Yentes et al., 2013).
To evaluate the effect of running surface on the accelerometry measures we used 2 x 3 repeated measures ANOVA with training status (highly-trained vs. recreational runners) as the between-group factor and training surface (asphalt, synthetic track, and wood-chip trail) as the within-group factor. The alpha threshold was set at 0.05. Significant main effects for surface were subjected to post hoc Student's t-tests and Bonferroni corrected for multiple comparisons (specifically, surface effect is corrected for 3 comparisons). Correlations were performed to determine the relationship between accelerometry measures and running velocity (Bonferroni corrected p level < 0.01). All statistical analyses were performed using SPSS 20 (SPSS, IBM, USA).

RESULTS: Running velocity showed no significant main effect for surface ($F_{1,27} = 0.52$; $p = 0.6$) or interaction effect with training status ($F_{1,27} = 1.6$, $p = 0.2$). The mean (SD) running velocities (m/s) were 3.77 (0.60), 4.00 (0.75), and 3.73 (0.62) for asphalt, synthetic, and wood-chip surfaces respectively. However, a significant main effect for training status ($F_{1,27} = 7.9$; $p < 0.05$) was detected for running velocity, where highly-trained runners ran on average 0.56 m/s (~ 2 km/hr) faster than recreational runners.

No significant surface by training status interactions were observed for any dependent accelerometry measures (all $p > 0.05$). Comparisons between surfaces were thus made for highly-trained and recreational runners combined (n = 29). Significant main effects for surface were observed for S_{FREQ} ($F_{1,27} = 7.43$, $p = 0.003$), vertical RMS_{RATIO} ($F_{1,27} = 9.04$, $p = 0.001$), mediolateral S_{REG} ($F_{1,27} = 11.95$, $p < 0.001$), anteroposterior S_{REG} ($F_{1,27} = 2.86$, $p = 0.04$), and anteroposterior S_{EN} ($F_{1,27} = 5.66$, $p < 0.009$). Post hoc analysis revealed that the locus of the significant differences detected between surfaces all involved the wood-chip surface, and that no significant differences existed between asphalt and synthetic surfaces. (Table 1).

Table 1
Mean (SD) for accelerometry measures between surfaces (n = 29).

	Asphalt	Synthetic	Wood-chip
S_{FREQ} (steps/min)			
Vertical	169.84 (7.92)* #	168.72 (9.21) #	167.52 (8.38) #
S_{SYM} (unit less)			
Vertical	0.77 (0.10)	0.78 (0.10)	0.78 (0.09)
Mediolateral	0.51 0.14)	0.52 (0.13)	0.48 (0.12)
Anteroposterior	0.52 (0.13)	0.53 (0.14)	0.51 (0.13)
S_{REG} (unit less)			
Vertical	0.78 (0.11)	0.81 (0.09)	0.79 (0.09)
Mediolateral	0.63 (0.12)*	0.64 (0.09)*	0.57 (0.11)
Anteroposterior	0.59 (0.12)	0.61 (0.13)*	0.57 (0.13)
RMS_{RATIO} (unit less)			
Vertical	1.08 (0.10)*	1.06 (0.11)	1.05 (0.09)
Mediolateral	0.48 (0.10)	0.48 (0.10)	0.49 (0.10)
Anteroposterior	0.43 (0.12) #	0.44 (0.12) #	0.46 (0.10) #
S_{EN} (unit less)			
Vertical	0.121 (0.020)	0.121 (0.022)	0.122 (0.022)
Mediolateral	0.321 (0.071)	0.327 (0.065)	0.323 (0.075)
Anteroposterior	0.379 (0.101)* #	0.376 (0.121)*	0.346 (0.085)

* Significantly different from wood-chip (P < 0.05).
# Significantly associated with running velocity (P < 0.01).

S_{FREQ} was positively associated with running velocity on asphalt ($r = 0.48$, $p = 0.008$), synthetic ($r = 0.50$, $p = 0.006$) and wood-chip ($r = 0.55$, $p = 0.002$) (**Table I**). The anteroposterior RMS_{RATIO} was also positively associated with running velocity on the asphalt ($r = 0.47$) synthetic ($r = 0.59$) and wood-chip ($r = 0.45$) surfaces ($p = 0.01$ for all). The anteroposterior S_{EN} was negatively associated with running velocity but only for concrete ($r = -0.46$, $p = 0.01$), and not synthetic ($r = 0.32$, $p > 0.05$) or wood-chip ($r = 0.07$, $p > 0.05$). No other significant associations were identified between accelerometry measures and running velocity, with correlation coefficients ranging from -0.12 to 0.19 (asphalt), -0.22 to 0.36 (synthetic), and -0.26 to 0.25 (wood-chip) ($p > 0.05$ for all).

DISCUSSION: The purpose of the current paper was to investigate the influence of outdoor running surfaces on trunk accelerometry measures related to running gait symmetry and regularity during self-selected running in highly-trained and recreational runners. The main finding was that no significant differences existed between asphalt and synthetic surfaces for any accelerometry measures. In contrast, several significant differences in accelerometry measures existed between the wood-chip surface compared to either asphalt or synthetic surface. This finding may be supported by the hypothesis that variable surface terrains are likely to challenge the postural control system and stability of human locomotion (Menz et al., 2003).

Running requires a certain level of maintenance of balance and speed control, while minimizing the amount of energy usage (Warren et al., 1986). When runners were on the

wood-chip surface, they decreased their S_{FREQ}, in agreement with previous results during walking over an irregular surface compared to regular surface (Menz et al., 2003). In addition wood-chip running promoted decreased mediolateral S_{REG}, anteroposterior S_{REG}, vertical RMS_{RATIO}, and anteroposterior S_{EN}. In line with their definitions, this would imply less correlation between consecutive strides (Moe-Nilssen & Helbostad, 2004) (both mediolaterally and anteroposteriorly), a smaller contribution or proportion of the vertical accelerations (McGregor et al., 2009) to the resultant, and a more regular acceleration time-series (Yentes et al., 2013) anteroposteriorly while running over the wood-chip surface.
Runners often train on surfaces that suit their convenience. An “out of the lab” approach allows runners to have their running gait quantified at their own terms, but at the expense of controlled conditions i.e. laboratory which offers a consistent surface. Knowing which measures of running gait are robust to surface terrain offers more insight into identifying other factors that could occur while running such as technique breakdown due to fatigue or overuse injury development.

CONCLUSION: The usefulness of accelerometry measures of running gait on outdoor environments can be enhanced, provided that the influence of surface and running velocity on these measures are known. The results suggest that surface specific considerations should be made when quantifying trunk accelerometry measures related to running gait symmetry and regularity during running.

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