RELIABILITY OF KINEMATIC MEASUREMENTS DURING TREADMILL RUNNING

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This study aimed at determining the within- and between-day reliability of kinematic data during treadmill running. Seventeen young adult male recreational runners were evaluated in a treadmill running test. Nine reflective markers were placed on the right leg and kinematic data were collected twice on the first day (within-day reliability) and once on the second day (between-day).The peak values of the knee flexion, dorsiflexion, plantiflexion and eversion during stance and knee flexion during swing were evaluated. Higher reliability was observed in within-day (ICC > 0.94, lower CV, typical error and limits of agreement) compared to between-day. The eversion presented the lowest ICC (0.79) in between-day and heteroscedastic error in the within-day measurements. The results indicated that evaluated kinematic data were reliable during running in treadmill.

KEY WORDS: treadmill running, reliability, kinematic

INTRODUCTION: The increased awareness of aerobic exercise to maintain a healthy lifestyle has made running a popular physical activity. Despite its numerous healthy benefits, an elevated injury rate is associated. To understand how injuries occur, kinematic analysis is an important biomechanical tool, providing an objective assessment widely used in clinical gait analysis and sport research services. In order to obtain a widespread acceptance, the repeatability of the complex measurements is a fundamental requirement for locomotion analysis. When analyzing running gait, the deviations between normal and abnormal patterns are likely to be subtle (Schache, Blanch, Rath, Wrigley, Starr & Bennell, 2002). Therefore, understanding the day-to-day variability of the kinematic measurements is important, especially when assessing training effects or treatment responses over time. However, relatively few investigations have reported reliability of kinematic running assessment (Ferber, McClay Davis, Williams & Laughton, 2002), mostly conducted on a treadmill (Schache et al., 2002). Some running studies are performed on a treadmill for acquiring large datasets that better represent the movement pattern. While differences in the running pattern have been reported (Schache, Blanch, Dorn, Brown, Rosemond & Pandy, 2011), little is known about the treadmill running reliability. Consequently, the purpose of this study was to evaluate the within- and between-day reliability of kinematic data during running treadmill.

METHODS: Seventeen male recreational runners (age = 19.5 ± 1.1 years and body mass = 70 ± 9 kg) participated in the study. Only subjects that regularly practiced running activity at least once a week, for eight months in a row and run more than 3000 m in 12 min were included in the study. No subject had a history of musculoskeletal or neurological disease. All subjects signed an informed consent approved by ethics committee.

To measure the motions of the knee and the ankle in the sagittal plane (Figure 1b) and ankle-foot complex in the coronal plane (Figure 1a), nine spherical reflective markers were placed on the subjects' right leg (Leung, Mak & Evans, 1998). The same operator performed all marker placements to reduce inter-test variability. All subjects were required to complete a test familiarization, consisting of 15 min running on the treadmill at the same test condition. Data were collected on the second visit during two repeated running trials 1 min apart and on the third visit for one trial, respecting at least two days interval in between. The reliability was tested on kinematic data within and between-day. Each kinematic trial was collected for 1 min by three cameras (Qualisys Pro-reflex system, Sweden), sampled at 200 Hz. The subjects ran at 12 km/h on barefoot to avoid differences based on differing shoe properties.

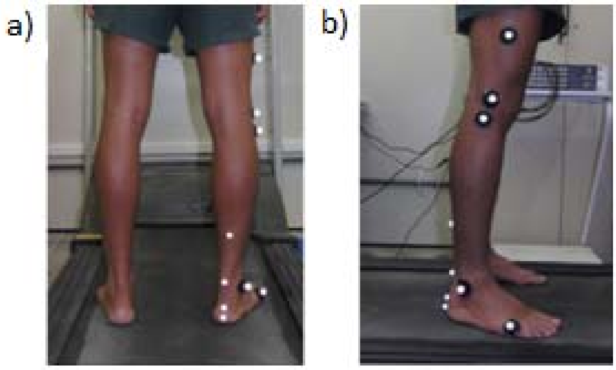

Figure 1: Location of the reflective markers in coronal plane (a) and sagittal plane (b).

Raw data were filtered using a 2nd order bidirectional Butterworth low-pass filter, cutoff frequency of 10 Hz. The variables of interest were the peak values of: knee flexion (KFS), dorsiflexion (DF), plantiflexion (PF) and eversion (EV) during stance phase and knee flexion during the swing (KFB). All angles were referenced to the standing position, with the exception of EV, where a zero reference was defined when the vertical axes of the calcaneus and tibia were parallel (McClay & Manal, 1998). The averaged peak angles were extracted from 1 min of each trial.
Intraclass correlation coefficients (ICC), one-way repeated-measures ANOVA, coefficient of variation (CV) and typical error were used to determine the within-day and between-day reliabilities, as well as Bland-Altman plot to analyze the agreement between sessions (Bland & Altman, 1986). The Pearson correlation coefficient between the mean repeated measures and absolute difference between sessions were calculated to verify the presence of heteroscedastic error. The level of significance was set at $\alpha = 0.05$. The ICC was computed in the SPSS 20.0 (IBM, SPSS Statistics, USA) and the others analysis were calculated by a routine developed at Matlab 7.4 (The Mathworks, USA).

RESULTS: Most of the studied variables exhibited high repeatability for both within and between tests (Table 1). ANOVA did not identify any significant difference among repeated measurements ($p > 0.05$). Within-day sessions presented higher ICC and lower CV and typical error compared to between-days for all measurements (Table 1). On the between-days comparisons ICC ranged from 0.79 to 0.96 with the lowest value in EV.

Table 1: Within and between days ICC, CV, typical error and Bland-Altman analysis.

Variables		ICC		CV (%)	Typical error angle (°)	Bland-Altman		
		R	p			Limits of agreement	Pearson Correlation R	Pearson Correlation p
KFS	Within	0.99	< 0.000	2.1	0.50	-1.38 – 1.41	0.01	0.96
	Between	0.85	< 0.000	13.2	3.40	-10.85 – 8.03	0.35	0.17
KFB	Within	0.96	< 0.000	4.7	3.48	-10.85 – 8.86	0.21	0.42
	Between	0.80	0.002	11.5	7.09	-18.26 – 21.09	0.27	0.30
DF	Within	0.99	< 0.000	1.8	0.38	-1.02 – 1.12	-0.16	0.54
	Between	0.98	< 0.000	6.3	0.99	-3.24 – 2.26	-0.02	0.93
PF	Within	0.96	< 0.000	6.0	1.49	-4.88 – 3.36	-0.10	0.70
	Between	0.83	0.001	16.4	3.33	-7.34 – 11.01	-0.35	0.17
EV	Within	0.99	< 0.000	5.5	0.17	-0.59 – 0.38	0.59	0.01
	Between	0.79	0.001	35.2	2.79	-8.18 – 7.28	-0.11	0.68

The Bland-Altman plot evidenced few differences outside 95% limits of agreement (Figure 2). In the within-day measurements only one subject was outside this limit (Figure 2b) and in the between-day measurements the random error component increased for two peak angles with one subject outside this limit (Figure 2h and 1j). All studied variables presented no heteroscedastic errors in both within and between-day evaluations (Table 1), except for the EV in the within-day comparison ($r = 0.59$, $p = 0.0134$), presenting an increase of the measurement error in higher angles (Figure 2e).

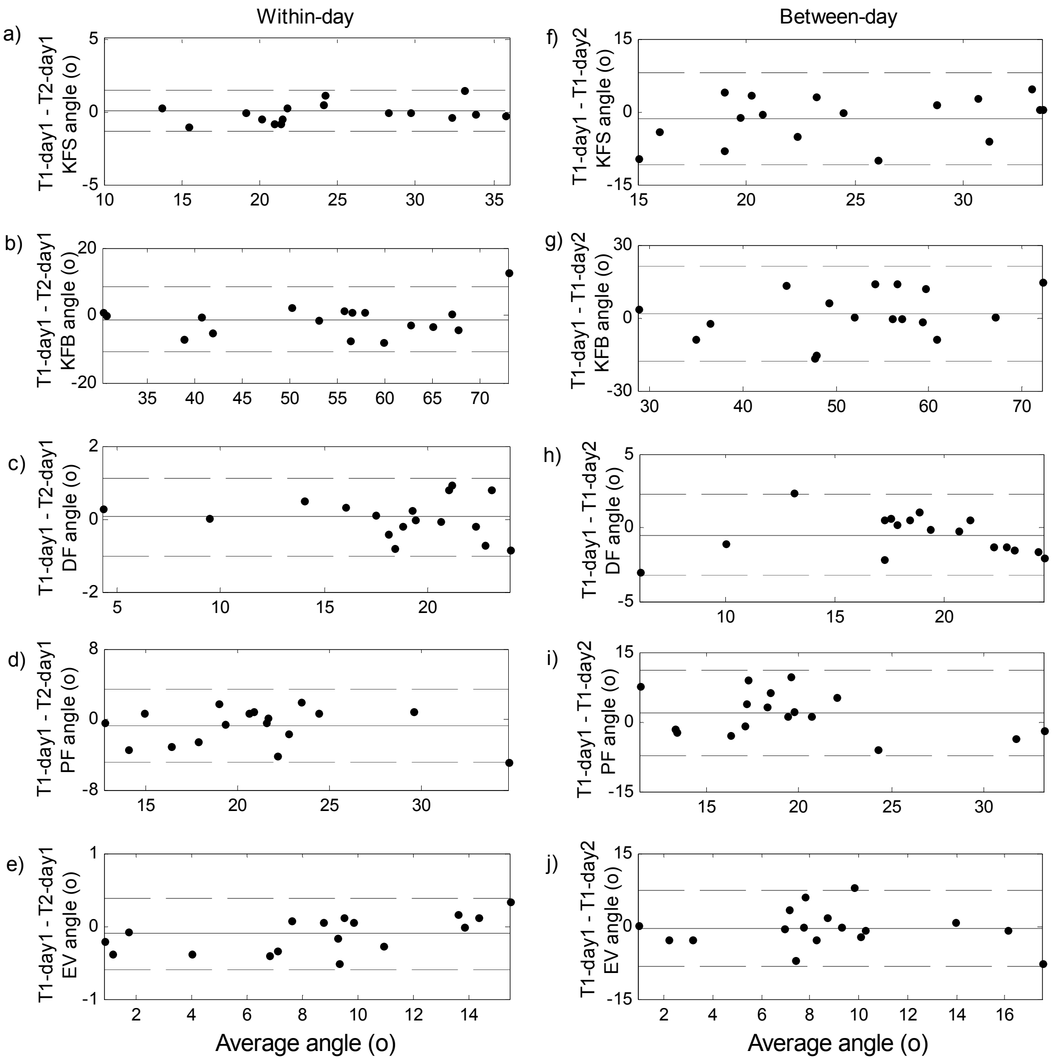

Figure 2: Bland-Altman plots with mean differences (solid lines) and 2 standard deviation (dashed lines) of the angles: knee flexion during stand (KFS) (a and f) and swing (KFB) (b and g), dorsiflexion (DF) (d and h), plantiflexion (PF) (d and i) and eversion (EV) (e and j). Within-day (T1_day1 and T2_day1) and Between-day(T1_day2) conditions.

DISCUSSION: The results show reliability for all discrete kinematic evaluated variables in both within and between-day tests. In within-day sessions all variables exhibited higher repeatability across trials ICC > 0.9 (Atkinson & Nevill, 1998), lower CV and typical error. Similar results was found by Ferber et al. (2002), attributing the within-day variability to measurement error, skin marker movement and inherent physiological variability during human locomotion. Although between-day kinematic ICC presented good repeatability (Atkinson & Nevill, 1998), the values were lower than within-day comparison (Table 1), agreeing with previous investigations (Ferber et al., 2002; Noehren, Manal & Davis, 2010). One commonly recognized problem in the day-to-day variability is due to changes in placement of markers over the skin (Ferber et al., 2002; Noehren et al., 2010) and movement variability. Therefore, Ferber et al. (2000) stated that care in marker placement must be taken to minimize between-day variability. Noehren et al. (2010) evidenced an increase in EV reliability during running with a marker placement device, compared to manual placement.

The lowest ICC was found for EV with higher CV (Table 1). This variable was the only measurement of frontal plane analyzed in the present study. Some authors state that frontal and transversal planes present worse between-day reliability (Ferber et al., 2002; Noehren et al., 2010). However, the ICC value of the EV found was higher than previous investigations: R = 0.63 (Ferber et al., 2002) and R = 0.71 (Noehren et al., 2010). The CV and typical error can be interpreted as the variation expected to occur from trial to trial if the participant performed multiple trials (Hopkins, 2000). Therefore, the present study suggests that the occurrence of up to 35% changes or absolute 2.79^o of eversion can be attributed to the typical error, instead of a significant change. The EV during running presents the smaller range of motion among studied variables, which may be extremely vulnerable to static offsets introduced by marker reapplication (Schache et al., 2002).

The Bland-Altman analysis evidenced an increase of the limits of concordance in between-days sessions in all analyzed variables (Figure 2; Table 1), however the mean difference between comparisons were still close to zero (Bland & Altman, 1986). According to Bland & Altman (1986) such analysis is informative, since it investigates any possible relationship between the measurements; however, it was not observed in previous running reliability investigations. The EV in within-day test presented an increase of the error measurement in higher angles, indicating a heteroscedastic error even with higher ICC (Table1). The reproducibility of kinematic data needs to be investigated on locomotion studies, particularly when comparisons are made between sessions in clinical or sports researches (Schache et al., 2002). This is a preliminary study and future studies should investigate the reliability in the hip and knee in the frontal and transverse plane and in different running speeds.

CONCLUSION: The kinematic data measured during treadmill running were reliable for both within and between-day assessments, presented higher ICC and lower CV, typical error and limits of agreement in the within-day measurements. Between-day reliability was higher in sagittal knee and ankle movements compared to eversion in the frontal plane, which presented lower ICC in between-day and heteroscedastic error in within-day measurement.

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