CONSISTENCY AND VALIDITY OF ACUTE FOOT-STRIKE PATTERN ALTERATIONS DURING LABORATORY-BASED RUNNING

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Due to the limited learning time allotted in most foot strike pattern modification studies, the reliability of pattern alterations may be jeopardized. The purpose of the current study was to investigate the reliability and validity of requested acute alteration of foot strike patterns performed by participants in a laboratory environment. Participants employed a high degree of consistency within foot strike pattern conditions and across the steps within a condition (average within subjects 95% confidence interval = 0.5° - 4°). On a group level, participants accurately performed all foot strike conditions with the exception of the midfoot strike pattern. Thus, even with the alteration of foot strike pattern, a generally reliable and valid foot strike angle performance is evidenced.

KEYWORDS: foot strike angle, rearfoot, midfoot, forefoot, reliability

INTRODUCTION: Habitually shod and barefoot runners have been shown to employ different foot strike patterns while running (Lieberman et al., 2010). Associated with these foot strike patterns were significant differences in kinematically derived variables such as the mean rate of loading or the magnitude of the effective mass (Lieberman et al., 2010). The investigation of foot strike pattern alteration has thus been a popular topic in scientific research. However, several phases of learning may be necessary for the adoption of new motor skills (Luft & Buitrago, 2005). Thus, the consistency of foot strike pattern alterations within a group of participants may not be comparable to the habituated participants Lieberman and colleagues (2010) investigated.

In some cases, the effects and modification of a runner's foot strike pattern are investigated by facilitating a several-session to several-week training program with the goal of altering the degree of ankle dorsiflexion at landing (Cheung & Davis, 2011). In other methodology, a single session is used to investigate the influence of a foot strike pattern modification (Boyer & Derrick, 2015; Giandolini et al., 2013). In the latter studies, a trial performed outside of the requested foot strike pattern was repeated (Boyer & Derrick, 2015) or controlled a-priori using the ground reaction force profile (Giandolini et al., 2013). Cheung and Davis (2011) also reported that participants could not adhere with 100% accuracy to the altered foot strike pattern, even after eight weeks of specific training. This provides insight that the alteration of foot strike pattern may have limited reliability.

The validity of the performance of altered foot strike patterns may also be affected by the neural plasticity and habituation of participants investigated. Nishida and colleagues (2017) concluded that different neural control mechanisms (timing, duration, and magnitude of muscular activity) were associated with rearfoot and forefoot strike patterns. From a motor learning perspective, new movement patterns appear to advance through stages (Luft & Buitrago, 2005). More complex movements require sufficient sensory feedback, as well as the "overwriting" of previously learned movement patterns (Luft & Buitrago, 2005). For this reason, the performance of requested foot strike patterns may not be performed to an accurate and reliable extent without a sufficient training phase. Thus, it is unknown whether the performance of consciously altered foot strike patterns is accurate due to the lack of knowledge regarding the internal consistency and accuracy of participant performance. The purposes of the current study were to investigate the (i) intra-subject and (ii) intra-condition reliability of laboratory-based running with imposed foot strike pattern modifications. Additionally, the validity of the foot strike condition performance (iii) was investigated.

METHODS: Six over ground running conditions were performed in a laboratory setting by 30 injury-free recreational male runners. Participants appeared for one testing occasion where they ran loops with their natural running pattern (NA; no constraints), followed by extreme forefoot (EF), forefoot (FF), midfoot (MF), rear foot (HS), and extreme rear foot (EH) conditions in a randomized counterbalanced order. Participants were not given any condition-based feedback. For each loop, participants ran a straight distance (5 m) over a force platform (AMTI; Watertown, MA, USA; BP6001200) located in the centre of the straight phase. Participants then quickly changed direction before running the same straight phase. Ground reaction forces were collected (100 Hz) to detect the instant of ground contact, which was determined via the threshold-based recommendations of Seiberl and colleagues (2018). For each participant, 20 non-consecutive left foot-fall instants were recorded per foot strike condition.

Three-dimensional (3D) motion capture was recorded with a 13-camera Qualysis motion capture system (2019.3, Göteborg, Sweden) with a sampling rate of 100 Hz. Six retroreflective markers were secured to the shod left foot segment at the locations of the medial and lateral malleoli, the head of the 2nd metatarsal, the medial side of the 1st metatarsal, the lateral side of the 5th metatarsal, and the heel (at the same height as the 2nd metatarsal marker). Raw kinematic data were filtered using a 15 Hz low-pass filter and Visual 3D x 64 Professional (V3D; v6.03.06; Germantown, MD, USA) was used to calculate the foot segment angle in relation to the laboratory coordinates with shoe-elicited angulation being negated (C-Motion, Inc., 2017). The angle observed at the ground contact instant was the primary outcome variable (foot strike angle) for reliability assessment.

The purposes of the current study were investigated by assessing (i) intra-subject reliability, (ii) the intra-condition reliability (i.e. the steps within a condition) and (iii) the validity of the foot strike patterns performed. For the subsequent reliability analysis (i, ii) the twenty recorded steps within a condition were separated into two groups (steps 1-10 = $S_{1\text{-}10}$, and steps 11-20 = $S_{11\text{-}20}$) that were analysed separately. (i) For each participant, 12 (one per foot strike condition, per step group) 95% confidence intervals (CI) of the mean were calculated. This individualised calculation served as an indication of intra-subject reliability. The 95% CIs of each participant were then pooled into a sample descriptive mean for each condition and step group, henceforth referred to as the “within subjects confidence interval” ($WSCI_{95}$). (ii) Paired-samples t-tests ($\alpha = 0.05$) were run to subsequently assess whether there were differences between the $WSCI_{95}$ of $S_{1\text{-}10}$ and $S_{11\text{-}20}$ within a condition. (iii) Finally, the mean foot strike angle and 95% CI were calculated for all samples within a condition (30 participants x 20 steps = mean of 600 steps per condition). The resulting 95% CI ranges were compared to the foot strike pattern definitions by Altman & Davis (2012); FF < -1.6°, MF = -1.6 - 8.0°, HS > 8.0°. This served as an anecdotal assessment of validity. To determine if participants differentiated between conditions, a repeated measures ANOVA was performed to determine if there were any differences across the mean foot strike angles for each condition. Where applicable, a Greenhouse-Geisser correction factor was used, significance was assessed at $\alpha = 0.05$, and partial eta squared (η_p^2) was calculated as a determinant of effect size. All statistics were performed using SPSS Statistics v.26.

RESULTS: (i) The $WSCI_{95}$ for each condition and step group is presented in Figure 1. (ii) Significant $WSCI_{95}$ mean differences were found between $S_{1\text{-}10}$ and $S_{11\text{-}20}$ of the EF ($p = 0.044$; $t = 2.12$; $df = 27$) and NA ($p = 0.005$; $t = 3.08$; $df = 28$) conditions. The $WSCI_{95}$ of the FF, MF, HS, and EH were not significantly different from one another ($p > 0.05$), though the $WSCI_{95}$ of the EH condition were nearly statistically different ($p = 0.058$; $t = 1.98$; $df = 28$). (iii) The mean foot strike angle and 95% CI range for each condition are presented in Figure 2 with respect to literature-based ranges (Altman & Davis, 2012). All mean foot strike angles were significantly different from one another: $F(3.71, 1674.59) = 4445.34$ ($\eta_p^2 = 0.908$).

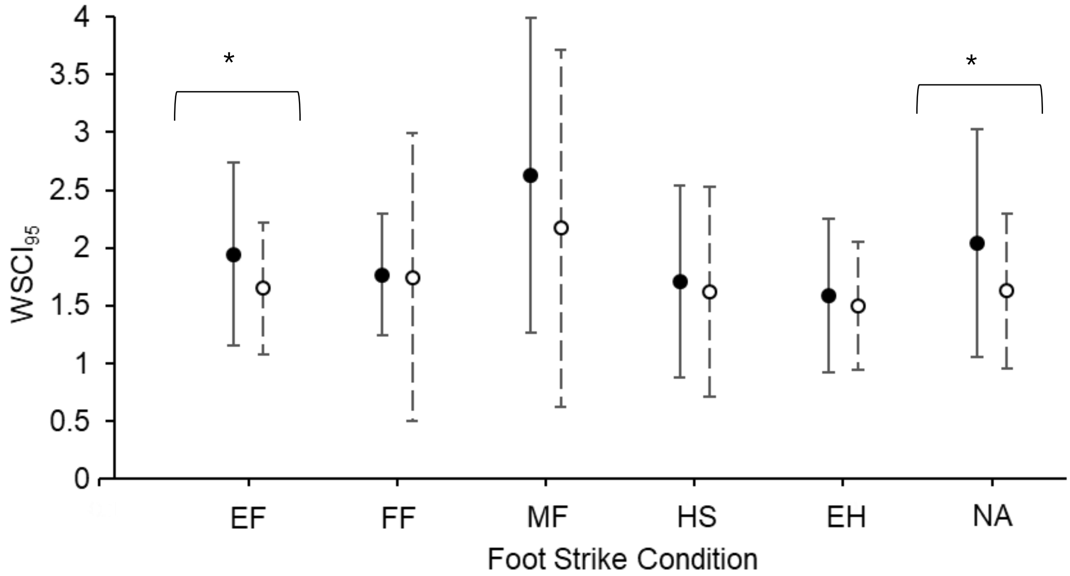

Figure 1. The 95% pooled within subjects confidence interval ($WSCI_{95}$) and standard deviation (error bars) are presented for steps 1-10 (S_{1-10}; solid circles) and 11-20 (S_{11-20}; open circles) separately for six foot strike conditions: EF = extreme forefoot, FF = forefoot, MF = midfoot, HS = heel strike, EH = extreme heel strike, and NA = natural. *= Significant mean differences were observed between S_{1-10} and S_{11-20}

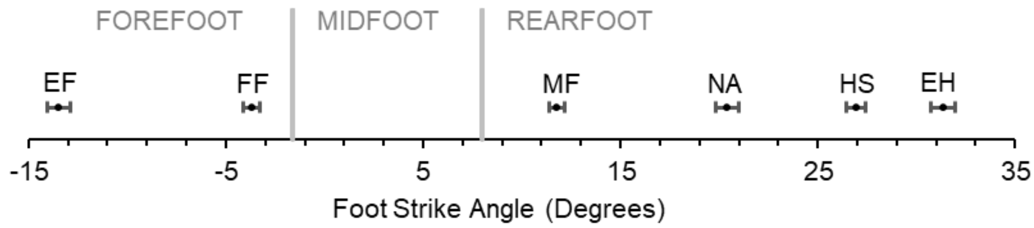

Figure 2. The foot strike angle mean and 95% CI (error bars) are presented for six running foot strike conditions (EF = extreme forefoot, FF = forefoot, MF = midfoot, HS = heel strike, EH = extreme heel strike, NA = natural). The two vertical bars represent the literature based cut-offs for the forefoot, midfoot, and rearfoot strike patterns (Altman & Davis, 2012).

DISCUSSION: The purposes of the current study were to investigate the intra-subject and intra-condition reliability of laboratory-based running with imposed foot strike pattern modifications. In addition, the performance of the condition was verified by comparing the measured foot strike angle to literature-based references. The standard deviation of the $WSCI_{95}$ suggests that the majority of samples (95%) will have a mean that falls within approximately 0.5 - 4° of the currently reported mean, regardless of the foot strike pattern employed. Further, a trend for a reduced $WSCI_{95}$ degree range in S_{11-20} can be seen across all foot strike conditions. In two of these conditions, NA and EF, this reduction was significantly different; mean difference (S_{1-10} - S_{11-20}) = 0.41 and 0.29°, respectively. Because this difference occurred across the NA foot strike condition, it may indicate a familiarization with the laboratory testing environment. However, with only a minute reduction in mean $WSCI_{95}$ in these two conditions, and a comparable $WSCI_{95}$ across the rest, the collection of additional steps beyond 10 is not warranted for the reliability of the mean foot strike angle within the conditions performed. It is important to note that the participant's footstrike pattern may adapt over the course of longer measurements (Luft & Buitrago, 2005). However, the current study supports that when testing on an acute level, the within subject and condition measurement of foot strike angle are generally stable.

Importantly, the midfoot strike pattern had the largest $WSCI_{95}$ mean (2-2.5°) and standard deviation range (approximately 4°) in both S_{1-10} and S_{11-20}. This may reflect the limited constraints of the 8° range that defines the condition (Altman & Davis, 2012), but can also be supported by the current study's evidence that on average, participants were not able to

employ a MF strike consistent with literature based ranges (Figure 2). Importantly, Lieberman and colleagues (2010) found that an entire sample of habitually shod athletes naturally employed a rearfoot strike pattern, which was comparable to the findings in the current study (NA = 20.4°, Figure 2). Thus, the near 9° reduction of foot strike angle that participants accomplished in the MF condition from their natural foot strike pattern may have been perceived as a midfoot ground contact. The inability of participants to differentiate a proper MF strike from an incorrect one may explain the high standard deviations seen in the $WSCI_{95}$ means. Cheung and Davis (2011) found that even after eight weeks of landing pattern modification training (toward a non-rearfoot strike), 10% of foot strikes recorded were still classified as rearfoot strikes. This may reflect the findings of Nishida and colleagues (2017) that differing neural synergies are learned with different foot strike patterns. Further, the learning of a MF strike pattern may be more difficult than the FF or HS conditions due to the less extreme sensory feedback, which is an important aspect of motor skill learning (Luft & Buitrago, 2005). Thus, the employment of a MF strike pattern may require a greater learning than the other strike conditions to ensure reliable performance of the condition.
Finally, participants were able to differentiate between the conditions as evidenced by the significant differences found across foot strike conditions. With the exception of the MF condition, all other means were consistent with the range expected from the foot strike pattern requested (Figure 2; Altman & Davis, 2012). Although an additional level of inconsistency in the performance of these primary conditions may have occurred due to the non-ecological testing conditions of the laboratory environment, generally acceptable CI ranges and mean comparisons indicate the measurements in the current study were replicable and consistent across participants, steps, and foot strike conditions employed.

CONCLUSION: Participants employed a high degree of consistency within foot strike pattern conditions. Researchers can use the reported range as a future comparative reference for the consistency of both altered and natural foot strike patterns. Further, researchers should be cognisant of the tendency of higher observed variability in the midfoot strike condition. Because little, if any, effects of familiarisation were observed, ten steps (compared to 20) are sufficient for future acute analyses. Finally, participants can perform valid rear and forefoot strike conditions outside of their natural footstrike pattern, but researchers should verify the performance of midfoot strike conditions instead of inferring condition adherence.

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