TREADMILL RUNNING: HOW LONG BEFORE BIOMECHANICS REACH A STEADY STATE?

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The purpose of this study was to investigate short-term biomechanical changes during treadmill running and whether footwear influenced this adaptation. Forty-five adults with experience in treadmill running over the last year performed an 8.5-min trial at a self-selected speed with three different midsole hardness. Kinetics, kinematics, soft-tissue vibrations and electromyographic activity were recorded at minutes 0, 2, 4, 6 and 8. The fastest adjustments were an increase of active peak and foot inversion. Step frequency and lower limb stiffness decreased then plateaued at minute 6. Duty factor, contact and flight times didn't reach a plateau. No time effect was found for passive peak, loading rate, leg muscle activity and soft-tissue vibrations. We recommend a minimum habituation period of 8-minutes to ensure that a maximum of biomechanical parameters reach a steady state.

KEYWORDS: Biomechanical adaptations; Familiarization; Running Footwear; Treadmill.

INTRODUCTION: Numerous studies investigated the effect of shoe characteristics on biomechanics (Sun et al., 2020). A typical design is to have participants running with the tested shoes for 3 to 10 minutes without familiarization to the footwear and/or the treadmill. Familiarization may be defined as a short adaptation process whereby differences in repeated measurements of a specific parameter stabilise to an acceptable level within a running session (Matsas et al., 2000). Therefore, assessing biomechanics within this familiarization period may not reflect authentic movement patterns whereas reported biomechanical differences may partly be due to insufficient consideration of the influence of familiarization time (Van Hooren et al., 2020). Throughout a treadmill running bout, changes in kinetics occurred rapidly during the first 30 seconds (White et al., 2002) and sagittal joint kinematics increased during the first 6 minutes (Lavcanska et al., 2005; Schieb, 1986). Stride length increased during the first 8-9 minutes (Simoni et al., 2020) and lower limb stiffness decreased during the first 4 minutes (Divert et al., 2005). In overground running, a reduction of muscles activities over the first 7 minutes occurred (Mohr et al., 2021). Other studies, quantifying the time needed to adapt to a new shoe condition, depicted foot strike pattern alterations during the first 7 minutes in minimalist footwear and an increase of tibial acceleration during the first 5 minutes (Delattre et al., 2013; TenBroek et al., 2013). To the best of our knowledge, whether soft-tissue vibrations changes with a few minutes of running is not known. Among other reasons, material limitations may have restricted previous studies from coupling electromyographic, kinematics, kinetics and vibration measurements. The aims of this study were thus to (i) investigate whether there were short-term changes in lower limb kinematics, kinetics, electromyography and soft-tissue vibrations during treadmill running, and (ii) determine whether midsole hardness would affect these changes. We hypothesized that (i) changes across variables would occur during the first few minutes of running and then would plateaued and (ii) the time-course of these changes would differ amongst the considered variables but not between shoes.

METHODS: Forty-five adults with experience in treadmill running were recruited (35.9 ± 13.2 years old, body mass: 64.6 ± 9.2 kg, height: 171.8 ± 8.1 cm). They warmed up for 10 minutes with their personal running shoes to be familiarized with the motorized treadmill (ADAL 3DC, HEF Techmachine, Andrézieux-Bouthéon, France). During the last 5 minutes, the speed dial was hidden and preferred running speed was determined (Moore et al., 2019). Then, three different shoe conditions built from the shoe model Arc'teryx Norvan LD™ differing only in their midsole hardness were tested in a randomized order (Asker 40C, Asker 55C, Asker 65C). Participants ran in each footwear condition for 8.5 minutes at their preferred running speed. Kinetics, kinematics, electromyography and vibration data were collected at the beginning of the running trial once the speed stabilized (T0), at minute 2 (T2), 4 (T4), 6 (T6) and 8 (T8). A minimum 5-min rest period was given to the participants between footwear conditions. Runners were equipped with two wireless EMG electrodes on the *gastrocnemius medialis* (GM) and *tibialis anterior* (TA) (Trigno Avanti Sensor, Delsys, Natick, MA). A tri-axial lightweight accelerometer (3273A4 Series, Dytran Instrument, Marilla St, Chatsworth, CA) was strapped on the GM muscle belly. Twenty-one reflective markers were attached on the right lower limb and markers trajectories were collected using a 10-camera motion capture system (Qualysis AB, Göteborg, Sweden). Ground reaction forces were measured with platforms included in the treadmill. Ten consecutive steps per shoe condition and time point were analysed. The vertical ground reaction force signal was low-pass filtered and subsamples were extracted using the vertical force. Contact time, flight time, duty factor (ratio of the ground contact time to the stride time) (Patoz et al., 2019), step frequency, vertical stiffness, passive peak, active peak and loading rate were calculated. At foot strike, ankle plantarflexion/dorsiflexion, foot inversion, knee flexion and hip flexion and foot/ground angles were extracted using Visual 3D software (C-Motion, Rockville, MD). Amplitude of soft-tissue vibrations, damping and settling time were determined (Khassetarash et al., 2019; Trama et al., 2019). Finally, the root-mean-square (RMS) of EMG signals was calculated for pre-activation (150 ms before foot strike), braking and propulsive phases. Normality of the data was checked by using the Shapiro-Whilk test. As no time x footwear interactions were found, all variables were averaged across all shoe conditions at T0, T2, T4, T6 and T8. One-way (time) repeated-measures ANOVA was carried out on the variables averaged across all shoe conditions at each time ($\dot{\alpha}$=0.05). When a significant time effect was found, Tukey post-hoc test was performed.

RESULTS: There was a significant 2.5% (+0.5 body weight) increase in active peak ($p = 0.001$) before plateaued at T4. Foot inversion at foot strike significantly increased by 8.9% (i.e. 1°) between T0 and T4 and started to stabilize at T4 ($p = 0.002$). Step frequency and vertical stiffness decreased until T6 by 1.6% (4 steps per minute) and 6.1% (-2.1 kN/m), respectively ($p < 0.001$). From T0 to T8, contact time increased by 11 ms while flight time decreased by 5 ms ($p < 0.05$). Duty factor increased by 3.1% ($p < 0.001$). Contact, flight times and duty factor were still significantly different between T6 and T8.

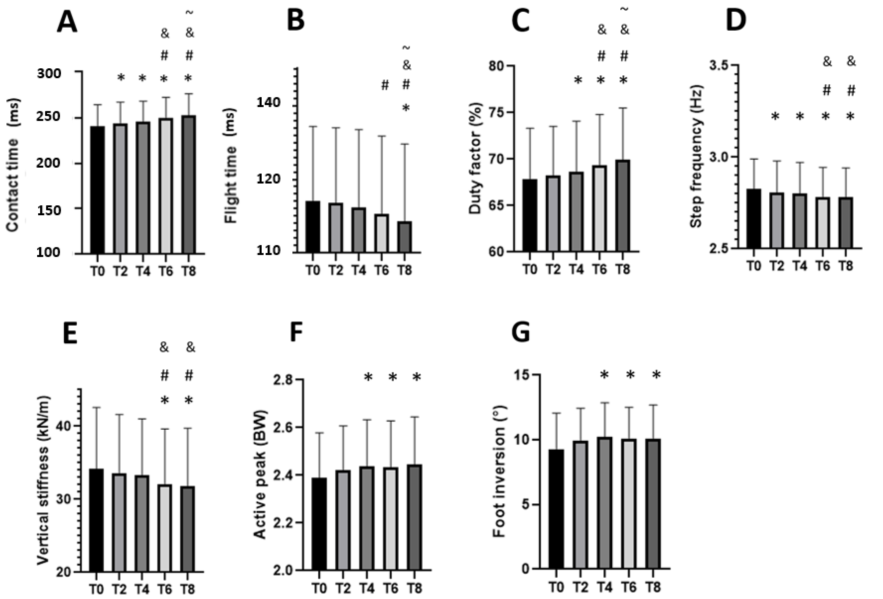

Figure 1: Temporal evolution of (A) contact time, (B) flight time, (C) duty factor, (D) step frequency, (E) vertical stiffness, (F) active peak and (G) foot inversion.
*Note: * denote significant time effect compared to T0, # compared to T2, & compared to T4, ~ compared to T6 (p < 0.05).*

DISCUSSION: Our results showed that (i) there was no change over time for soft-tissue vibrations, muscle activity, sagittal kinematics at initial contact, passive peak and loading rate; (ii) a steady state was reached at T4 for active peak and foot inversion angle, while vertical stiffness and step frequency stabilized at T6; (iii) contact and flight times and duty factor had still not stabilized at T8; (iv) these changes were independent of shoe midsole hardness.
A significant increase of contact time and a significant decrease of step frequency before reaching a steady state were previously depicted with more trained and faster runners, suggesting a fast familiarization to new running conditions (Simoni et al., 2020; TenBroek et al., 2013). In unexperienced treadmill runners, a longer stabilization time for step frequency (10 minutes) was required (Simoni et al., 2020). These spatiotemporal adjustments could be explained by apprehension of treadmill running at initial exposure, which resulted in a safer running style with initially higher step frequency and stiffness (Divert et al., 2005; Hong et al., 2012). Many different combinations of muscle forces can produce the same kinematic pattern (Herzog, 2016) and neuromuscular system is able to ensure a stabilized kinematic in the sagittal plan (Frost et al., 2002). The absence of sagittal plane kinematic adjustments across our shoe conditions was in line with (Hardin et al., 2004) who demonstrated an increase of hip extension at contact after the 15th minute because of fatigue. The only time effect we found in kinematics was an increase of foot inversion, with stabilization at T4. One could assume a holistic kinematics steady state is reached after four minutes in conventional running shoes. Unlike our results, a decrease in muscle activity was previously observed during the first 6 minutes of a 10-min over ground run (Mohr et al., 2021). However, it remained unclear whether their results could be generalized to protocols where participants run at self-selected speeds and/or on treadmill. In accordance with the previous literature (Hardin et al., 2004; Mohr et al., 2021; TenBroek et al., 2013), no significant footwear × time interactions were found, suggesting that the adaptation speed remained the same whatever the midsole hardness. However, the present results may not apply to minimalist shoes which may induced larger changes in running kinematics and tibial acceleration (Delattre et al., 2013) and thus, a longer stabilization process.

CONCLUSION:
The present findings provide methodological guidelines for studying biomechanics in treadmill running with conventional midsole hardness. Future experiments should include a minimum habituation period of 8 minutes to ensure that a maximum of biomechanical parameters reach a steady state. In regard to the present results, we recommend (i) to consider a minimum habituation period of 2 minutes when measuring soft-tissue vibrations, muscle activity and/or sagittal joint kinematics, (ii) to consider a minimum habituation period of 4 minutes when measuring ground reaction forces (then ensuring a steady state for passive and active peaks, and loading rate) and (iii), to consider a minimum habituation period of 6 minutes when measuring step frequency and/or vertical stiffness. Future experiments are needed to quantify the habituation period required for contact and flight times that seems to be greater than 8 minutes.

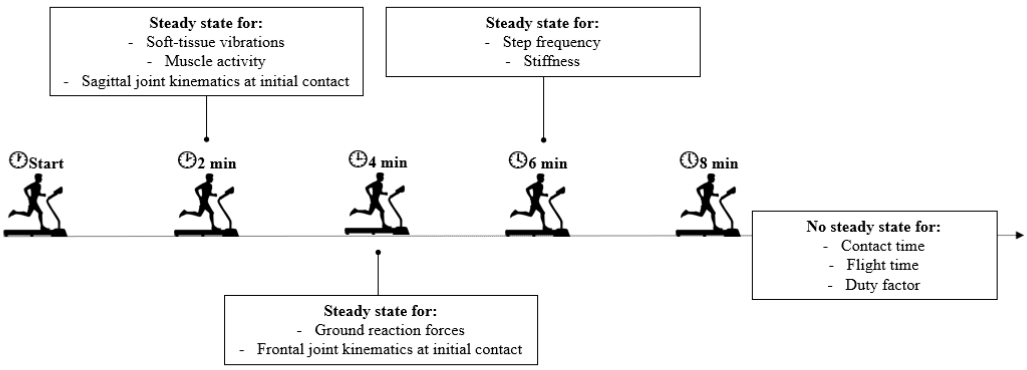

Figure 2: Overview of parameter stabilisation

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