EFFECTS OF AN EXTENSIVE RUNNING BOUT IN NOVICE FEMALE RUNNERS

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The purpose of this study was to characterize the spatiotemporal, force, and subjective effects that occur during an extensive run in novice female runners. Foot sole pressure, rate of fatigue, and speed were recorded during a 45-min flat ecological run. No significant effects were found in spatiotemporal, force-time, or rate of fatigue responses outside of the initiation phase of the running bout. When participants were grouped according to their pacing strategy, those with a decreasing speed over time exhibited significant decreases in rate of force development as time progressed. Participants tended to decrease mechanical loading variables, and increase their rate of fatigue throughout the run. Future studies should investigate a larger number of subjects to determine if these tendencies are characteristic of novice female runners.

KEYWORDS: pressure insoles, mechanical loading, stride variability, rate of fatigue

INTRODUCTION: Recreational running is one of the most globally-accessible sportive activities. With developments in wearable sensor technology and applications that provide feedback to the user, it is important to understand the profile of a user before providing activity-based recommendations. As a result, the running metrics that can be provided by wearable sensors should be investigated within user-types before any quality-based interpretation of the activity is made. Pressure insoles are a validated measurement tool (Seiberl et al., 2018) that can thus be used to define such user-types in ecological running conditions. The relationship of pressure measured at various locations under the foot sole can help identify the foot strike pattern and angle (Moore et al., 2020), as well as mechanical load descriptors such as loading rate, impulse, and peak force of the system during a gait cycle (Seiberl et al., 2018). Beyond these, spatiotemporal parameters can be calculated from the detection of initial contact and toe off events (defined classically via force or loading rate thresholds).

The continuous detection of spatiotemporal parameters can be beneficial for understanding the variability of movement during cyclical activities like running, which may be related to preferred movement patterns (Jordan et al., 2006). For example, Jordan et al. (2006) found that female participants had more stride variability during their preferred speed than when they ran faster or slower. Alternatively, Meardon et al. (2011) found that recreational runners without a history of running-related injury had reduced variability during a run than those with injury history. Therefore, further sample-specific investigation into stride variability and its implications are warranted.

Finally, it is also important to investigate the psychological experience of runners. The rate of fatigue (ROF) scale developed by Micklewright et al. (2017) can provide this insight in a non-obtrusive manner because it only requires the runner to report a number on an 11-point scale. Further, the ROF can be applied during daily life or physical activity (Micklewright et al., 2017), and is therefore a versatile subjective measurement tool that can indicate the sensation of fatigue without restricting participants to exertion-based physical or motor fatigue experiences. Thus, the purpose of the current study was to investigate the effects of an extensive ecological running bout on the spatiotemporal and force-time variables measureable from wearable pressure sensors to better understand and characterize novice female runners. The ROF was included to describe the psychological load of the run and to contextualize potential changes in pressure-derived metrics.

METHODS: Sixteen recreationally active female participants (1.66 ± 0.05 m, 57.9 ± 4.62 kg, 25.4 ± 2.5 yr) completed a single 45-min bout of running outdoors at a self-selected speed. All participants were capable of running 45 min continuously but self-identified as either beginner or novice recreational runners. Informed consent approved by the institutional review board was signed prior to testing. Participants rated their ROF four times (min 2 = M2, min 15 = M15, min 28 = M28, and min 41 = M41) during the running bout using a headset with an integrated microphone that recorded participants' numerical responses on an 11-point scale (0 = "not fatigued at all", 10 = "total fatigue and exhaustion, nothing left"; Micklewright et al., 2017). Running distance (km) and speed ($m \cdot s^{-1}$) were tracked using a Suunto Ambit 3 watch (sample frequency = 1 Hz). Speed was calculated as a mean of each 2-min period prior to the questionnaires, and characterized as increasing, decreasing, consistent or variable for each participant via visual inspection. Participants wore pressure insoles (Loadsol™; Novel GmbH; Munich, DE; sample frequency = 100 Hz) with two-sensor regions (fore and aft) within their personal running shoes. The insoles were used to calculate spatiotemporal gait parameters and indicators of mechanical loading.

To calculate the subsequent gait events and variables, the left insole signals were used. Initial contact and toe off were determined using a loading rate threshold of $\pm 1500 N \cdot s^{-1}$ (Seiberl et al., 2018). Using these events, average stride frequency (SF; $strides \cdot min^{-1}$) and ground contact time (GCT; s), were calculated for the 2-min period before each of the questionnaire time points. Average foot strike angle (FSA; degree) for each participant was estimated from the insoles using a previously developed machine learning model (Moore et al., 2020, 2021), and maximum force (F_{MAX}; $N \cdot kg^{-1}$), maximum rate of force development (RFD; $N \cdot s^{-1} \cdot kg^{-1}$) and impulse (IMP; $N \cdot s \cdot kg^{-1}$) were calculated during the same 2-min periods as the spatiotemporal variables. In order to assess stride variability, stride time (ST; s) was calculated for a period of 5-min leading up to the questionnaire time points. Because only two minutes were available before the first ROF questionnaire, the average participant-wise coefficient of variation (CV; %) and long range correlations (assessed via detrended fluctuation analysis; DFA; alpha) of the ST were calculated for only three periods (Jordan et al., 2006). All gait variables were processed using a custom code in MATLAB (R2020a; The MathWorks, Inc., Natick, MA, USA).

To assess group-level changes in the speed, gait variables, and ROF, repeated measures ANOVAs were performed for each variable considered across the three or four time points considered. If Mauchley's Test of Sphericity was violated, a Greenhouse-Geisser correction factor was applied. When significant effects were detected ($\alpha = 0.05$), post-hoc pairwise comparisons were performed with a Bonferroni correction to account for the multiple comparisons. Partial eta squared (η_p^2) was calculated as an estimate of effect size. Statistical comparisons were performed in SPSS Statistics (v.27; SPSS Inc., Chicago, IL, USA).

RESULTS & DISCUSSION: Significant effects were found when assessing speed ($p < 0.001$; $\eta_p^2 = 0.38$), GCT ($p < 0.001$; $\eta_p^2 = 0.40$), FSA ($p < 0.001$; $\eta_p^2 = 0.46$), and ROF ($p < 0.001$; $\eta_p^2 = 0.47$), but not SF ($p > 0.05$) across the four time points during running. Post-hoc pairwise comparisons revealed that significant differences only occurred between M2 and some of the later conditions (Figure 1). Although a significant main effect was detected, no significant differences were found in the pairwise comparisons of ROF with the Bonferroni correction factor. However, an increasing trend in ROF measures across time can be seen in Figure 1.

The force-time variables exhibited similar results, in that significant differences were only found between M2 and the later time points. Although no significant differences were found between the later periods of interest, the mean differences (MD) with M2 trended larger with time. Specifically, F_{MAX} in the RF sensor and total RFD (fore + aft sensor) during M2 was greater than M15 (MD: $F_{MAX} = 1.5 N \cdot kg^{-1}$, RFD = $0.8 N \cdot s^{-1} \cdot kg^{-1}$, $p < 0.001$), M28 (MD: $F_{MAX} = 1.9 N \cdot kg^{-1}$, RFD = $1.0 N \cdot s^{-1} \cdot kg^{-1}$, $p < 0.001$), and M41 (MD: $F_{MAX} = 2.2 N \cdot kg^{-1}$, RFD = $1.1 N \cdot s^{-1} \cdot kg^{-1}$, $p < 0.001$). Further, the IMP of the aft sensor region (over the whole GCT) was greater in M2 than M15 (MD: $5.4 N \cdot s \cdot kg^{-1}$, $p = 0.02$), while the IMP of the fore insole region was significantly less than M2 as time progressed (MD M15: $-9.5 N \cdot s \cdot kg^{-1}$, $p = 0.005$, M28: $-11.8 N \cdot s \cdot kg^{-1}$, $p = 0.001$, M41: $-14.2 N \cdot s \cdot kg^{-1}$, $p = 0.001$).No main effects were detected for the F_{MAX} in the fore section of the insole ($p = 0.16$).

Stride variability (CV and DFA alpha) did not differ between the three time points assessed (M15: CV = 1.83 ± 0.19 %, alpha = 0.74 ± 0.11; M28: CV = 1.84 ± 0.43 %, alpha = 0.71 ± 0.14, M41: CV = 1.91 ± 0.29 %, alpha = 0.74 ± 0.11; $p > 0.05$). These results are in line with those of the spatiotemporal and pressure variables, considering that the M2 was not included in these comparisons. The significant differences in the spatiotemporal and pressure variables between M2 and the later time points suggests that the participants in the current study needed some time to reach a stable, sustainable run state (supported by consistency in the variability).

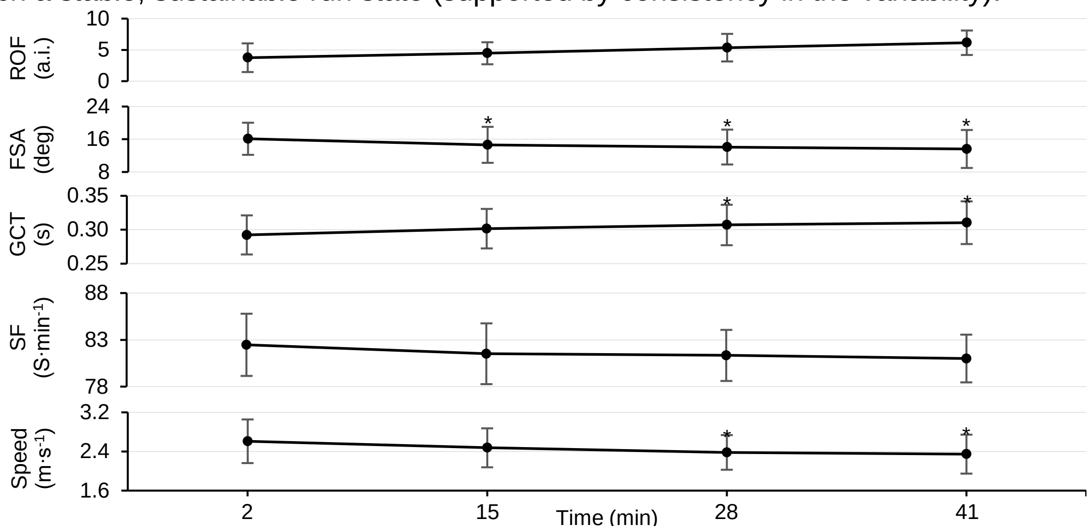

Figure 1. The average and standard deviation for speed, stride frequency (SF), grount contact time (GCT), foot strike angle (FSA), and ROF (rate of fatigue) measured at four time points during a 45 minute run is displayed. *significantly different from the first condition (minute 2); a.i. = arbitrary unit

Considering that no significant differences were found between M15, M28 and M41 in any of the measured variables, it can be concluded that force and spatiotemporal characteristics do not change on a group level after the initiation phase of the run for the current sample. To further characterize the current sample, the trend of the individual's speed was used to classify participants; four maintained their speed, seven decreased their speed, and five had increased or variable speeds throughout the duration of run. When considering only the subgroup of participants that decreased their speed throughout the run (n = 7), significant reductions in RFD were found in the M41 condition compared to both M15 (MD: 0.7 $N \cdot s^{-1} \cdot kg^{-1}$, $p = 0.010$) and M28 (MD: 0.5, $p = 0.028$). Significant main effects were also detected for GCT, FSA, F_{MAX}, and ROF in this subgroup, however the post-hoc comparisons revealed no significant pairwise differences due to the multiple-comparison Bonferroni correction factor. The reduction in RFD, with a tendency to reduce F_{MAX} (in the aft sensor region) and FSA, and increase GCT (Figure 2) suggests that there could be group-specific mechanical adaptations to an extensive run in novice runners.

No significant differences were found for the metrics that describe stride variability, however the alpha values calculated were consistent with those that Meardon and colleagues (2011) observed in a previously injured population during a sustained approximately 5.7 km run (alpha; beginning = 0.92, middle = 0.68, end = 0.79). The previous work investigated recreational runners with a training volume of approximately 30 km per week, and hypothesized that the injured population had higher stride variability (i.e. DFA alpha closer to 0.50) due to impairments that emerge from musculoskeletal injury. Following this assumption, the participants in the current study could run with higher ST variability than the non-injured population reported by Meardon et al. (2011) because they were not regular runners with movement patterns associated with a preferred or consistent movement attractor. Thus, future studies should systematically investigate the influence of training level, run duration, and injury status on the long-range correlations of ST.

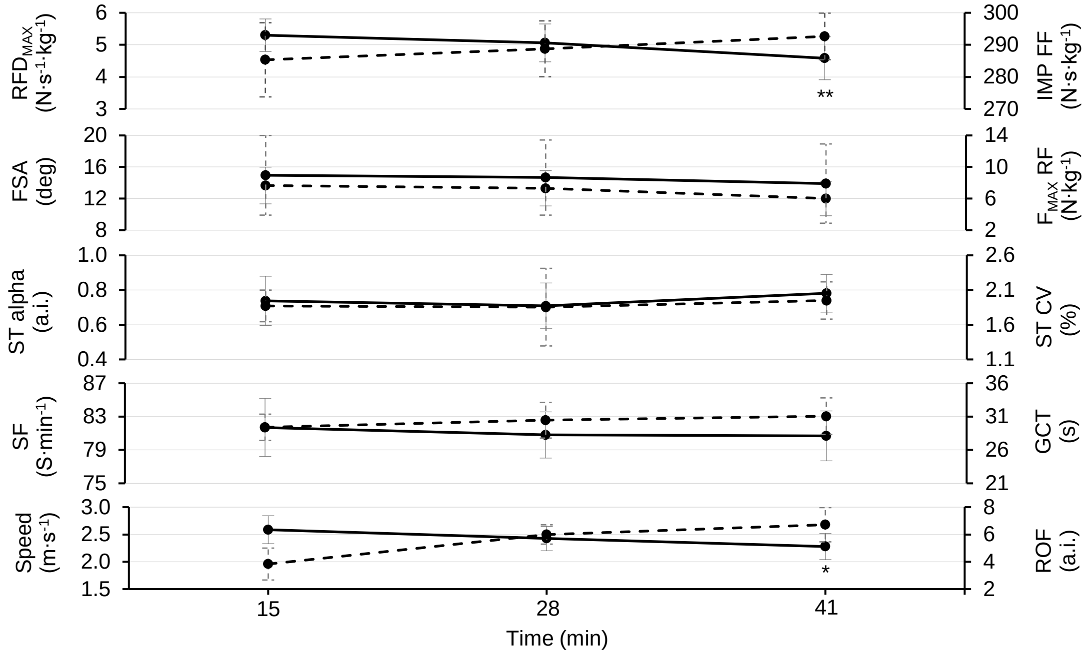

Figure 2. The stride variables (mean ±SD) of a reduced sample (n = 7) measured at three time points during a 45 minute run are presented. Presented variables include speed, rate of fatigue (ROF), stride frequency (SF), grount contact time (GCT), long range correlation of stride time (ST alpha), CV% of stride time (ST CV), foot strike angle (FSA), and maximum force measured from the aft insole region (F_{MAX} RF), maximum rate of force development (RFD_{MAX}), and the impulse measured from the fore sensor region (IMP FF). Primary Y-axis = solid lines, secondary Y-axis = dashed lines; *significantly different from the first condition (minute 15); ** signifcantly different from the first and second conditions; a.i. = arbitrary unit

CONCLUSION: Spatiotemporal variables and indicators of mechanical load did not statistically change over the course of an extensive run for a sample of female novice runners. However, over half of the participants decreased speed and increased ROF throughout the run. These changes were in conjunction with decreases in RFD and tendencies toward reduced mechanical loading, which may indicate a subconscious injury-prevention strategy.

REFERENCES

Jordan, K., Challis, J. H., & Newell, K. M. (2006). Long range correlations in the stride interval of running. *Gait & Posture*, *24*(1), 120–125. https://doi.org/10.1016/j.gaitpost.2005.08.003

Meardon, S. A., Hamill, J., & Derrick, T. R. (2011). Running injury and stride time variability over a prolonged run. *Gait & Posture*, *33*(1), 36–40. https://doi.org/10.1016/j.gaitpost.2010.09.020

Micklewright, D., St Clair Gibson, A., Gladwell, V., & Al Salman, A. (2017). Development and validity of the rating-of-fatigue scale. *Sports Medicine*, *47*(11), 2375–2393. https://doi.org/10.1007/s40279-017-0711-5

Moore, S.R., Kranzinger, C., Fritz, J., Stöggl, T., Kröll, J., & Schwameder, H. (2020). Foot strike angle prediction and pattern classification using LoadsolTM wearable sensors: A comparison of machine learning techniques. *Sensors*, *20*, 6737. https://doi.org/10.3390/s20236737

Moore, S.R., Kranzinger, C., Strutzenberger, G., Taudes, M., Martinez, A., Schwameder, H., & Kröll, J. (2021). Laboratory versus ecological running: A comparison of foot strike angle and pattern estimation. *ISBS Proceedings Archive*, *39*(1), 125.

Seiberl, W., Jensen, E., Merker, J., Leitel, M., & Schwirtz, A. (2018). Accuracy and precision of loadsol® insole force-sensors for the quantification of ground reaction force-based biomechanical running parameters. *European Journal of Sport Science*, *18*(8), 1100–1109. https://doi.org/10.1080/17461391.2018.1477993

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