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Article

# Gait Stability and Structure During 30-Minute Treadmill Running: Implications for Protocol Duration and Shoe Familiarity

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## Featured Application

Many gait and footwear studies are underpowered in terms of step count because the stability and temporal structure of gait parameters during a typical run are not well understood. The data presented shows stability and persistent structure in propulsive phase variables, but higher variability and weaker persistence in loading phase kinetics. Based on these patterns a minimum of 11-17 minutes of data collection, including warm-up, is recommended to obtain practically stable values, regardless of footwear familiarity.

## Abstract

Many peer-reviewed studies report spatiotemporal or kinetic parameters of running gait without considering their stability, temporal structure, or relationship to typical run durations. This study investigated the stability and temporal structure of key spatiotemporal and kinetic parameters during a 30-minute easy-paced treadmill run ( $13 \text{ km}\cdot\text{h}^{-1}$ ) while participants wore familiar and unfamiliar every day running shoes. Step-level data were analysed across the full time series and in sequential 1-minute epochs to determine how long each parameter takes to reach practical stability and whether this differs between shoe conditions. Approximately, 2,450 steps were analysed per condition. Within-participant variability was low ( $\text{CV} < 2.5\%$ ) for all parameters and conditions except for peak impact force ( $\text{CV} = 6.9\text{--}7.0\%$ ) and average loading rate ( $\text{CV} = 8.4\text{--}8.7\%$ ). DFA- $\alpha$  indicated persistent temporal structure for stride duration, swing time, and active peak force, whereas loading-phase kinetics showed weak long-range dependence. No significant differences were observed between shoe conditions for variability or temporal structure, although ground contact time was slightly longer in the unfamiliar shoe. Practical windows of stability relative to each participant's 30-minute mean ranged from 11 to 17 minutes for spatiotemporal variables, 9-17 minutes for active peak force, and within the first minute for impact related parameters and impulse. These findings indicate that studies examining spatiotemporal and kinetic parameters during easy-paced treadmill running require 11-17 minutes of continuous data to obtain 1-minute epoch estimates that are practically stable relative to 30-minute averages, regardless of footwear familiarity.

**Keywords:** running; running shoes; gait; long-range correlations; protocol duration

## 1. Introduction

While *Homo erectus* is credited with perfecting bipedalism and running [1,2], footwear emerged much later (3627-3377 BCE) for protective purposes [3], and much later again (1920's) for performance purposes in the guise of the modern shoe [4]. One of the earliest studies examining midsole cushioning and its influence on running gait, with the aim of attenuating impact force [5], required participants to run repeatedly over a force plate until five successful right-foot strikes were obtained. Success was defined as achieving a speed  $\pm 5\%$  of the  $4.5 \text{ m}\cdot\text{s}^{-1}$  target, equivalent to a considerable

range 15.6-17.0 km·h<sup>-1</sup> or a running pace 3:32-3:51 min·km<sup>-1</sup> which could alter parameters considerable [6]. Although this methodology is traditional, concerns have been raised regarding its ecological validity due to limited exposure to the test condition [7]. Specifically, key methodological elements are often missing, including the mean ± variability of running speed, an appropriate duration of run time or number of steps [8,9], and the corresponding variability of spatiotemporal, kinematic or kinetic parameters [10,11].

A mini review of 56 relevant studies [7] found 91% of research analysed fewer than 10 steps, with only 9% analysing more than 10, with no clear justifications for either approach. A more recent, multi-database search (EbscoHost) for “running shoe” (English-language, peer-reviewed, full-text; January 27, 2024 - January 27, 2025) identified 161 articles from 16 databases. Of these, 52 pertained to running-shoe properties and their biomechanical or physiological effects, and 13 specifically examined ground reaction forces or parameters of gait. The most common protocol remained the repeated-force-plate approach, where participants ran over the same plate multiple times to acquire valid steps [12-21]. Only three studies used instrumented treadmills, with data collection windows ranging from 0.5 – 6.0 min [22-24]. Despite the availability of instrumented treadmills and pressure-sensing insoles capable of capturing thousands of consecutive steps, research practices have changed little.

Importantly, relatively short sampling windows that average many consecutive steps (e.g. 1-minute epochs), can give the impression of early stability because the averaging process smooths out step-to-step variability. This approach provides a practical and representative estimate of mean behaviour within a relatively short duration [25,26]. Understanding how using such a small epoch behaves relative to longer continuous running, and how many epochs are required to obtain stable mean estimates, would therefore be informative for running-protocol design. When individual continuous steps are analysed directly over prolonged periods typical of normal run duration, the gait signal is non-stationary, with fluctuations that accumulate over time [27]. Whereas, the use of discontinuous sampling can capture variability between different steps, it cannot reveal the temporal structure of these fluctuations or the presence of long-range correlations. The long-range structure of this continuous data can instead be examined using detrend fluctuation analysis (DFA), which has been used to explore running ability [28], injury proneness [29], and footwear effects [30]. As a result, far more consecutive steps may be required than typically used [7] before practical stability is reached. These underlying dynamics highlight the need for research designs that consider both mean behaviour and step-level structure when evaluating interventions such as footwear.

There is a lack of direction regarding the protocol duration or number of steps required to reliably assess kinetic and spatiotemporal parameters of running gait when comparing running shoes. Therefore, this study aims to investigate the stability and structure of key spatiotemporal and kinetic parameters over a 30-minute easy-paced treadmill run. Step-level were analysed across the full time series and in chronological 1-minute epochs to determine how long these parameters take to reach practical stability, defined as the time point at which a given 1-minute epoch no longer differs from the 30-minute average. A secondary aim is to evaluate whether differences occur between familiar and unfamiliar shoe conditions.

## 2. Materials and Methods

### 2.1. Material Properties

Sixteen recreational to nationally competitive endurance runners (mean ± SD; height (cm) 172.6 ± 6.4, body mass (kg) 64.2 ± 8.2, Body Mass Index 21.5 ± 1.4, and a typical weekly volume (km·wk<sup>-1</sup>) 68.2 ± 16.1) free of injury participated, after giving written consent in accordance with the University Human Ethics Committee approval. All participants were accustomed to running on a treadmill.

This sample size was based on a priori statistic (G\*power V 3.1.9.7, Heinrich-Heine University, Dusseldorf, Germany) for analysis of variance (ANOVA) repeated measures within factors, with an alpha value of 0.05, power 0.8, and various effect sizes (0.297-0.730) based on primary dependent variables including stride duration, ground contact time, peak impact force, and average loading rate. All effect size values were based on in-house preliminary analyses. Given the nature of the repeated measures design and the correlation among repeated observations it was deemed a sample size of 16

(8 male, 8 female) participants to be adequate for our analysis and exceeds the minimum required total sample size for most conditions.

## 2.2. Procedures and Measurements

The experimental protocol consisted of two trials with a footwear intervention where the participant wore their everyday running shoe that they complete most of their weekly volume in, and one they were unfamiliar with (Altra, Torin 7), whilst running for 30-minutes at a treadmill speed of  $13 \text{ km}\cdot\text{h}^{-1}$ . This speed has been shown to produce significant differences in vertical ground reaction forces [25,31,32]. Participants were required to deem this pace as recovery-to-easy i.e. relatively slow, in order to participate. This pace was selected to facilitate completion of the two 30-minute trials and because slower speeds are recommended for reliably assessing long-range correlations in gait dynamics [33]. Each trial was performed in one session on the same day, performed in a counter-balanced order of shoe conditions, and separated by 10-15 min to minimise sequence effect on the dependent variables of interest.

Upon arrival at the laboratory, participants were measured, weighed, and had their footwear size determined by a shoe specialist to ensure best fit of the unfamiliar shoe based on participant input and expertise. Trial order was selected, and the appropriate footwear was fitted with a flexible pressure insole to record kinetic data (LoadSol® Pro, Novel GmbH, Munich, Germany), whereupon each insole (left and right) was configured for the specific participant and followed the manufacturer's bipedal calibration process.

Participants were given no warm-up period on the treadmill (Life Fitness, Hamilton, New Zealand) to facilitate no interference with analysis. Each condition was performed for a period of 30 min, with data logged at 200Hz throughout where participants were blind to any dependent variables being measured.

LoadSol® time\*force data were uploaded into MATLAB (R2022b, (MathWorks, Inc., Natick, MA, United States) as previously used by this group [26,34]. Data were up-sampled to 1,000 Hz, and processed using force threshold values of 20-30 N to determine initial foot contact and toe-off [35]. From these outputs the following dependent variables were calculated using techniques previously described for running [36,37] and expressed per body weight (N) where appropriate (BW): a) Peak vertical impact force ( $\text{N}\cdot\text{BW}^{-1}$ ) identified as the first peak in heel strikes and found between initial contact and the active peak. If a first peak was not present for any step (mid-forefoot strike) it was defined as the force at 13% of the stance phase; b) Active peak vertical force ( $\text{N}\cdot\text{BW}^{-1}$ ) was the second peak for heel strike runners, or the highest force reading of each step for mid-forefoot strikers; c) To calculate the average rate of loading ( $\text{N}\cdot\text{BW}^{-1}\cdot\text{s}^{-1}$ ) the difference between forces at 20% and 80% of the peak impact force was divided by the corresponding time interval (s) between these two points; d) Impulse (N·s), the area under the force-time curve; e) Ground contact time (s) was the time the foot remained in contact with the floor; f) Swing time (s) was the time the foot has no contact with the ground; g) Stride duration was the time from one initial impact to the next initial impact for the same foot.

## 2.5. Statistical Analysis

Dependent variable data were computed for each step and summarised as mean  $\pm$  SD, along with the corresponding CV (%) per independent variable. Normality of all dependent variables were evaluated using the D'Agostino & Pearson normality test. Full series (30-minute) averages for each dependent variable and their corresponding CV% were compared between shoe familiarity conditions using paired t-tests when normality assumptions were met, or Wilcoxon signed-rank when they were violated.

DFA was employed to determine the scaling exponent alpha ( $\alpha$ ), characterising the long-range correlation structure of each dependent variable [38]. For each time series, the mean was subtracted, and the cumulative sum was computed to generate an integrated signal. This signal was divided into segments of varying window sizes. Within each window, a local linear trend was fitted and removed, and the root-mean-square fluctuation was calculated. Fluctuations were averaged across all windows of the same size, and this procedure was repeated across logarithmically spaced window sizes

ranging from short segments ( $\geq 5$  steps) to a fraction of the total series length ( $N/4$  to  $N/9$ ). The scaling exponent  $\alpha$  was obtained as the slope of the linear fit to the log-log relationship between fluctuation magnitude and window size. DFA results were only interpreted when the scaling behaviour was clearly linear.

Full-series data was segmented into 1-minute epochs. To assess each epoch provided an estimate equivalent to the participants full 30-minute mean, epoch values (expressed as a percentage of the full-series mean) were tested against 100% using a one-sample t-test or Wilcoxon signed-rank test when normality were violated. For parameters in which a substantial proportion of epochs failed normality, Wilcoxon tests were applied to all epochs to ensure consistent and robust inference.

All statistical analyses were performed using GraphPad Prism (V 8.4, (GraphPad Software, San Diego, CA, United States). Statistical significance was set at  $p < 0.05$ .

### 3. Results

This study analysed a mean $\pm$ SD 2459 $\pm$ 163 and 2449 $\pm$ 150 steps for familiar and unfamiliar shoes, respectively. There was no paired t-test difference between condition ( $t=0.689$ ,  $p=0.502$ ). The overall 30-minute means, corresponding CV%, normality outcomes, and the paired difference tests for each shoe condition are summarised in table 1. Statistical difference between shoes were present in ground contact time, active peak force and impulse while CV% values were similar across conditions.

**Table 1.** The overall mean  $\pm$  (SD), mean CV%, dataset normality test results for the complete 30-min trial, with paired difference test results between conditions for both dependent variables.

Dependent Variable	Familiar Shoe			Unfamiliar Shoe			Dependent Variable test (t- or W-; p-value)
	Mean $\pm$ SD	CV%	Normality (K2, p-value)	Mean $\pm$ SD	CV%	Normality (K2, p-value)	
Stride Duration (s)	0.733 $\pm$ 0.04 5	1.4 $\pm$ 0.6	1.133; 0.567	0.744 $\pm$ 0.00 4	1.4 $\pm$ 0.7	1.401; 0.496	1.263; 0.227
<b>Ground contact time (s)</b>	0.224 $\pm$ 0.01 8	1.9 $\pm$ 0.4	2.194; 0.334	0.227 $\pm$ 0.01 9	1.8 $\pm$ 0.3	3.652; 0.161	2.388; 0.032
Swing time (s)	0.509 $\pm$ 0.04 8	1.9 $\pm$ 0.7	0.246; 0.884	0.511 $\pm$ 0.04 3	1.9 $\pm$ 1.0	0.360; 0.835	0.367; 0.719
Peak Impact Force (N)	981 $\pm$ 188	6.9 $\pm$ 1.7	3.673; 0.162	1017 $\pm$ 215	7.0 $\pm$ 1.4	1.807; 0.405	1.884; 0.081
AVLR (N $\cdot$ s <sup>1</sup> )	37274 $\pm$ 914 0	8.4 $\pm$ 1.1	2.228; 0.328	37747 $\pm$ 910 6	8.7 $\pm$ 1.1	0.096; 0.953	0.473; 0.644
<b>Active Peak Force (N)</b>	1717 $\pm$ 270	2.2 $\pm$ 0.5	4.433; 0.109	1745 $\pm$ 336	2.2 $\pm$ 0.5	7.336; 0.026	59; 0.068
<b>Impulse (N<math>\cdot</math>s)</b>	238 $\pm$ 44	1.8 $\pm$ 0.4	10.39; 0.006	245 $\pm$ 57	1.9 $\pm$ 0.6	14.34; 0.008	59; 0.068

Where data is displayed as italics one or more trial did not pass the normal distribution test. That specific data is highlighted in bold and statistical difference testing uses Wilcoxon's Signed-Rank Test. Otherwise, all difference testing uses a paired t-test.

DFA- $\alpha$  values indicated persistent temporal structure for stride duration and swing time, with  $\alpha$  ranging from 0.81 to 0.85 across shoe conditions (Table 2). Ground contact time showed weaker persistence ( $\alpha=0.73$ -0.74). Loading-phase kinetic parameters, including peak impact force and average loading rate, demonstrated weak to minimal long-range dependence ( $\alpha=0.67$ -0.69). In contrast, propulsive-phase kinetics such as active peak force exhibited stronger persistence ( $\alpha=0.77$ -

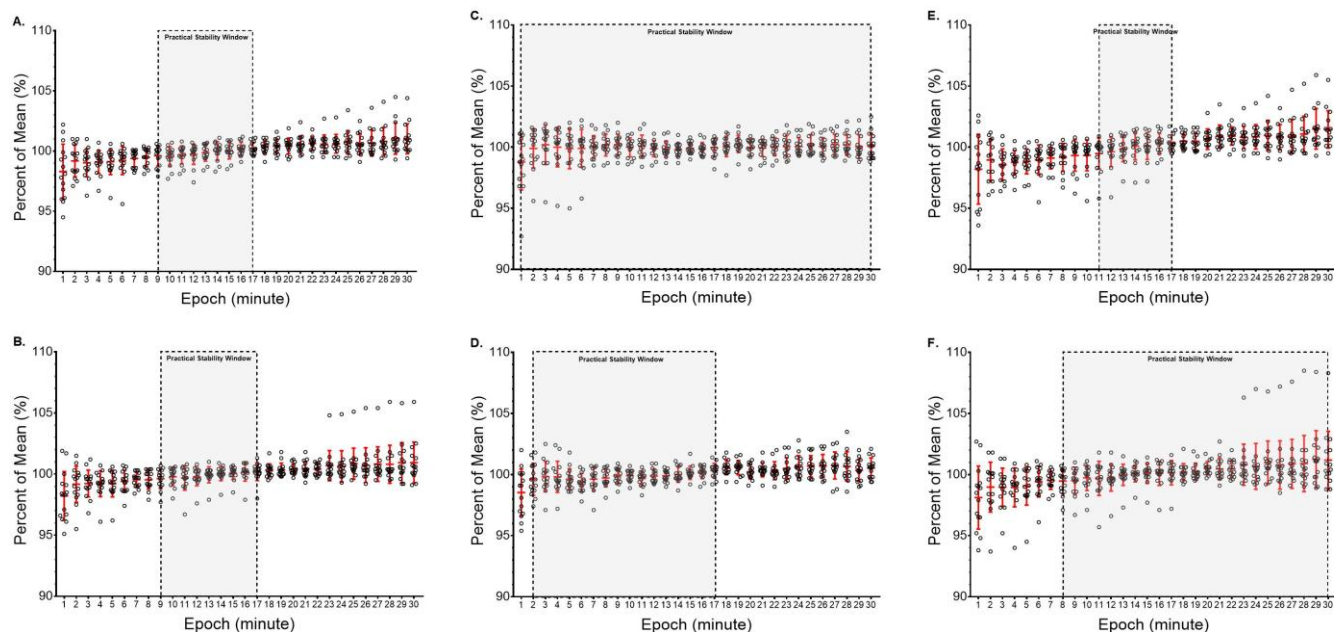
0.79). Impulse also showed a relatively persistent structure ( $\alpha=0.83$ ). No significant differences in DFA- $\alpha$  were observed between familiar and unfamiliar shoes for any parameter (Table 2).

**Table 2.** The DFA- $\alpha$  mean  $\pm$  (SD), CV%, dataset normality test with the corresponding correct paired difference test results between conditions.

Dependent Variable	Familiar Shoe			Unfamiliar Shoe			Dependent Variable test (t- or W-; p-value)
	Mean $\pm$ SD	CV%	Normality (K2, p-value)	Mean $\pm$ SD	CV%	Normality (K2, p-value)	
Stride Duration (s)	0.85 $\pm$ 0.09	10.3	0.269; 0.874	0.81 $\pm$ 0.08	9.67	0.688; 0.709	0.029; 0.977
<i>Ground contact time (s)</i>	<b>0.73<math>\pm</math>0.08</b>	<b>10.2</b>	<b>6.551; 0.038</b>	<b>0.74<math>\pm</math>0.05</b>	<b>6.51</b>	<b>11.560; 0.003</b>	<b>21; 0.541</b>
Swing time (s)	0.84 $\pm$ 0.08	9.9	0.075; 0.963	0.84 $\pm$ 0.08	8.97	0.810; 0.667	0.001; 0.999
Peak Impact Force (N)	0.67 $\pm$ 0.06	8.7	5.801; 0.055	0.69 $\pm$ 0.07	10.0	2.884; 0.237	1.565; 0.140
AVLR (N·s <sup>1</sup> )	0.68 $\pm$ 0.07	10.9	2.839; 0.242	0.69 $\pm$ 0.07	9.7	1.823; 0.402	0.595; 0.561
<i>Active Peak Force (N)</i>	<b>0.79<math>\pm</math>0.06</b>	<b>7.0</b>	<b>9.565; 0.008</b>	<b>0.77<math>\pm</math>0.06</b>	<b>7.3</b>	<b>9.320; 0.010</b>	<b>-23; 0.502</b>
Impulse (N·s)	0.83 $\pm$ 0.87	8.9	0.290; 0.865	0.83 $\pm$ 0.07	7.9	0.767; 0.682	0.146; 0.886

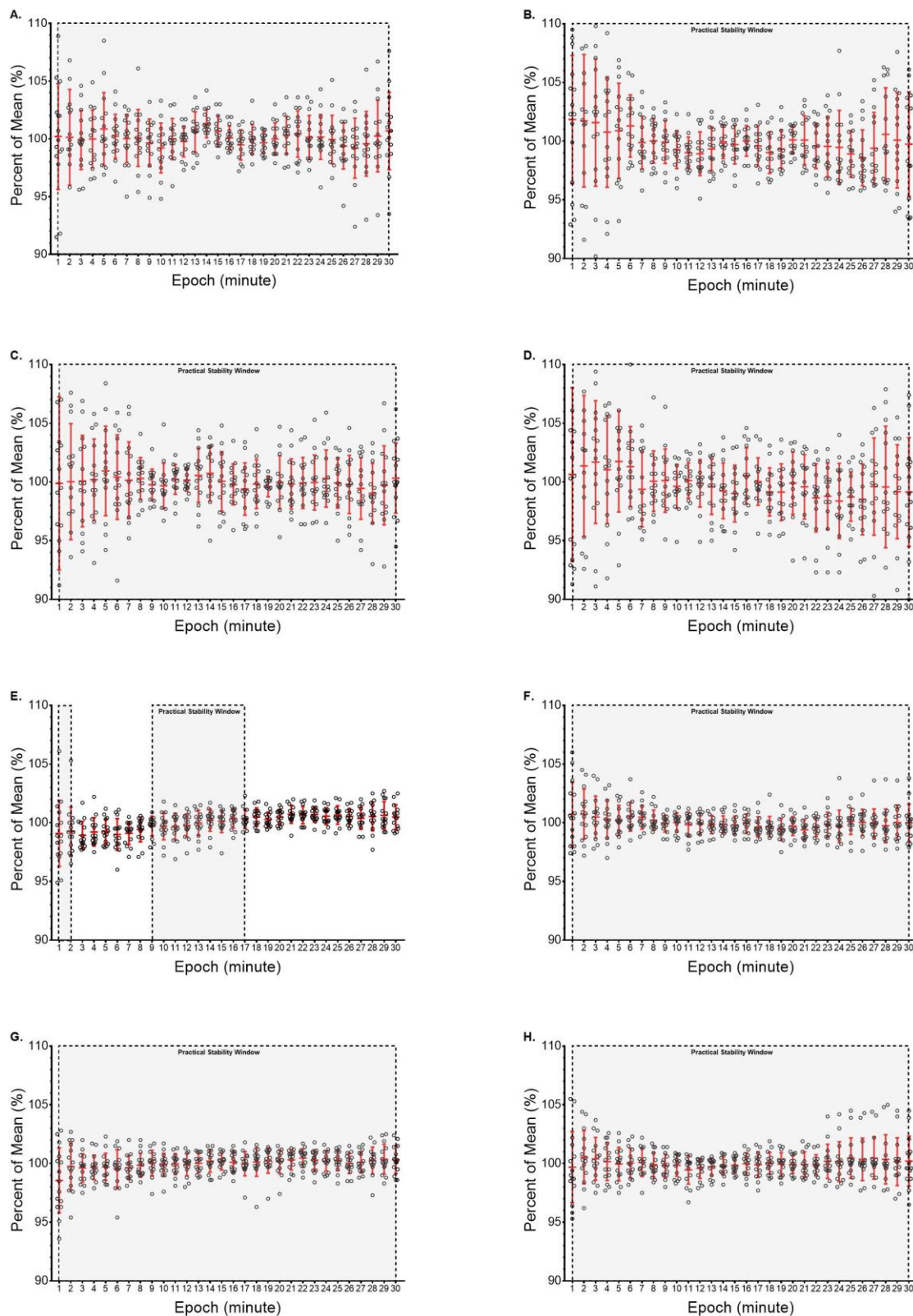
Where data is displayed as italics one or more trial did not pass the normal distribution test. That specific data is highlighted in bold and statistical difference testing uses Wilcoxon's Signed-Rank Test. Otherwise, all difference testing uses a paired t-test.

One-sample tests for the spatiotemporal parameters (Figure 3) compared each 1-minute epoch with the participant's 30-minute mean and identified practical stability windows in which epoch values did not differ from the full-series mean ( $P>0.05$ ). For stride duration, this stability window occurred between 9 and 17 minutes in both shoe conditions (Figure 3A-B). Ground contact time showed no significant difference across any epoch in the familiar shoe, whereas in the unfamiliar shoe the stability window extended from 2 to 17 minutes (Figure 3D). Swing time required epochs between 11 and 17 minutes to match the 30-minute mean in the familiar shoe (Figure 3E), and between 8 to 30 minutes for the unfamiliar shoe (Figure 3F).



**Figure 3.** Spatiotemporal 1-minute epochs expressed as a percentage of each participants 30-minute mean. The shaded practical stability window denotes the period in which epoch values did not differ significantly from the full-series mean (one-sample tests). Panels show: **A.** Familiar shoe stride duration, **B.** Unfamiliar shoe stride duration, **C.** Familiar shoe ground contact time, **D.** Unfamiliar shoe ground contact, **E.** Familiar shoe swing time, and **F.** Unfamiliar shoe swing time.

One-sample tests for the kinetic parameters (Figure 4) were consistent with the variability observed in Table 1, where moderate-high between-participant variability meant epoch choice was less critical for loading-phase kinetics. Peak impact force, average loading rate and impulse showed no significant difference across any epoch ( $p > 0.05$ ) in either shoe condition. In contrast, active peak force showed low variability (Table 1) and demonstrated a practical stability window between 9 and 17 minutes in the familiar shoe (Figure 4E), whereas no significant differences were observed across any epoch in the unfamiliar shoe (Figure 4F).



**Figure 4.** kinetic 1-minute epochs expressed as a percentage of each participants 30-minute mean. The shaded practical stability window denotes the period in which epoch values did not differ significantly from the full-series mean (one-sample tests). Panels show: **A.** Familiar shoe peak impact force, **B.** Unfamiliar shoe peak impact force, **C.** Familiar shoe average loading rate, **D.** Unfamiliar shoe average loading rate, **E.** Familiar shoe active peak force, **F.** Unfamiliar shoe active peak force, **G.** Familiar shoe impulse, and **H.** Unfamiliar shoe impulse.

#### 4. Discussion

This study investigated the stability and temporal structure of key spatiotemporal and kinetic parameters during a 30-minute easy-paced treadmill run, with the goal of determining how long each parameter required to reach practical stability and whether this differed between familiar and unfamiliar shoe conditions. The main findings showed no differences between shoe conditions at a low relative speed for variability, long-term correlations, or practical windows of stability for any parameter. Spatiotemporal and active peak force exhibited low within-participant variability (<2.5%), whereas peak impact force and average loading rate were comparatively higher (6.9-8.7%). Parameters with low variability demonstrated strong persistent temporal structure (DFA- $\alpha$  >0.7), while loading-phase parameters showed only weak persistence (DFA- $\alpha$  <0.7). To capture data representative of an individual's 30-minute run, a practical stability window of approximately 11 to 17 minutes was required, although this was parameter dependent. Specifically, loading-phase kinetics reached stability within the first minute of running.

Runners continuously adjust their gait to produce the most efficient movement for the conditions which are shaped by environmental, mechanical, and morphological constraints [9]. Consequently, it has been suggested that the variability rather than mean values provides more meaningful insight into system organization [39]. Using a treadmill helps minimize variability introduced by environmental factors when assessing running gait [10,40], but doing so requires a substantial number of steps to obtain reliable data. In this study, the overall mean $\pm$ SD number of steps (2454 $\pm$ 157) used for spatiotemporal and kinetic analyses was considerable and representative of run durations commonly performed by runners [41].

The low variability of spatiotemporal variables (Table 1) is not unexpected on a treadmill [33,42,43], where the surface is consistently flat and smooth, while the belt moves at a constant speed. Under these conditions there will still be small fluctuations to facilitate flexible motor control [29], including minor fore-aft shift in centre of mass position on the treadmill. This relative stability is reflected in the uniform ground reaction forces during the propulsive phase, evidenced by the within-participant mean CV of 2.2 $\pm$ 0.5% for active peak force reported here for both familiar and unfamiliar footwear, and consistent with previous comparisons of minimalist versus cushioned footwear [34] and different midsole densities in geometrically identical shoes [44]. This consistency likely contributes to the stable timing of early swing, although not necessarily the terminal component of swing, which influences the resultant impact. However, impact loading exhibited considerably higher variability, which did not differ between shoes (CV=6.9 $\pm$ 1.7% and 7.0 $\pm$ 1.4% for familiar and unfamiliar shoes), and this variability cannot be attributed to proportional changes in active peak force, as no such changes occurred. Instead, prior work suggests that peak impact force is sensitive to natural variations in limb acceleration, joint positioning [45], and/or strike pattern [26] at the moment of contact. As these were not measured in this study, it is difficult to determine the specific source of fluctuation. Nevertheless, the variability observed here, while slightly lower, is consistent with some of the original work performed on discontinuous steps [5] and with continuous step data collected over much smaller duration samples (2 minutes), where peak impact force and average loading rate variability (CV%) were 8.7 $\pm$ 2.4% and 11.8 $\pm$ 2.0%, respectively [44].

While the CV% provides information about the magnitude of the step-to-step variability, it is insensitive to subtle neuromuscular changes related to how the body moves to control the centre of mass trajectory [46]. As such, it does not tell us anything about how the fluctuations are temporally structured [47]. DFA- $\alpha$  addresses this by characterizing the variability over time [48]. While all parameters exhibited  $\alpha$ -values >0.5 in both shoe conditions, indicating positively correlated (non-random) fluctuations. Stride duration, swing time, and active peak force showed the strongest persistence with no differences between condition (Table 2), suggesting that the nervous system allows slow, coherent drifts in the centre of mass trajectory, rather than correcting them step-by-step. This tolerance likely reflects the lower balance related demands associated with these aspects of gait where peak active force is regulated primarily through feedback mechanism following initial contact of the current step [49]. The 1-minute epoch data (Figure 3-4) further illustrates this behaviour, revealing a gradual upwards drift across the 30-minute run, with data starting below and ending above the overall mean. In contrast, loading-related parameters (peak impact force and average loading rate) showed weaker persistence with no difference between condition (Table 2), with tighter

step-by-step regulation around the mean and a pattern in which high impacts were followed by lower impacts, reflected in the more scattered 1-minute epochs (Figure 4 A-D). This pattern likely relates to the runners' need to maintain dynamic balance [50] through a combined feedback-feedforward control mechanism, in which they both react to the collision and anticipate the next one [51,52], and where medial-lateral instabilities require corrective responses [53]. Interestingly, ground contact time appeared to reflect the combined influence of loading and propulsive phases of gait, with the  $\alpha$ -value falling between that of stride duration, swing phase, active peak force, and the loading parameters. As such, this variable likely integrates how the body manages both loading and propulsion, and its temporal structure represents the combined influence.

As the variability and temporal structure did not differ between shoe conditions, the one-sample analysis could be used to determine an optimal sampling window for each parameter to match the full 30-minute time series. Parameters with strong persistence and low variability, such as stride duration in both conditions, swing time (Figure 3), and active peak force in the familiar shoe condition (Figure 3E and 4E), required a sampling window duration centred around the middle of the run. This reflects the gradual and upwards drift observed across the time series, meaning early or late samples alone would not adequately represent the full dataset. In contrast, the loading phase kinetic variables showed weaker persistence, and the 1-minute epoch comparisons indicated that samples ranging from 1 to 30 minutes were similarly representative of the full time series. This suggests that impact related parameters stabilise almost immediately despite their higher step-to-step variability (Table 1). Impulse showed a similar sampling behaviour (Figure 4G-H), likely because it integrates the variable loading phase with the highly consistent propulsive phase. This integration smooths out the early stance fluctuations, resulting in a relatively stable and persistent overall signal.

While studies targeting specific parameters or phases of gait may choose sampling durations specific to their needs, the present findings indicate that, regardless of shoe familiarity or the parameter analysed, a minimum of 11 minutes of continuous running at the set speed (including warm-up) are required before collecting a 1-minute epoch that reflects a 30-minute run.

Although the primary aim of this study was to evaluate gait stability rather than compare mean gait performance between shoe conditions, the overall means are reported for transparency (Table 1). Only one parameter reached significance, where participants spent slightly longer during ground contact in the unfamiliar, standardised, with zero running kilometres compared to participants unrestricted age or type of familiar shoe. Other mean values (peak impact, active peak force, impulse) approached significance, but interpreting these differences is outside the scope of this discussion. Importantly, shoe familiarity did not influence variability, temporal structure, or stability windows which were the focus of this study.

## 5. Conclusions

This study showed that spatiotemporal and kinetic parameters during a 30-minute easy-paced treadmill run exhibit low variability and strong temporal persistence, except for loading-phase kinetics, which were more variable and demonstrated weaker persistence. These patterns did not differ between familiar and unfamiliar footwear, except in the case of a small increase in ground contact time in the unfamiliar shoe. Practical stability windows ranged from 11-17 minutes for spatiotemporal variables, 9-17 minutes for active peak force, and within the first minute for impact related parameters. Collectively, these findings indicate that studies investigating gait during easy-paced treadmill running require at least 11 minutes of continuous running at the set speed to obtain 1-minute epoch estimates that are relative to 30-minute averages, regardless of footwear familiarity.

**Author Contributions:** **P.W.Macdermid:** Conceptualization (lead); Project administration (equal); Methodology (lead); Software (lead); formal analysis (lead); Investigation (equal); Data curation (lead); Writing—Original draft (lead); Visualization (lead); Writing—review & editing (equal). **S.J.Walker:** Conceptualization (support); Methodology (support); Investigation (equal), Writing—review & editing (equal). **D. Cochrane:** Conceptualization (support); Project administration (equal); Methodology (support); Ethics (lead); Writing—review & editing (equal). **All:** authors have read and agreed to the published version of the manuscript.

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**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Massey University (OM1 24/44 approved 12 June 2025).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** All data supporting the conclusions of this article are provided within the manuscript.

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**Conflicts of Interest:** There are no conflicts of interest.

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