RELIABILITY OF THE LONG-RANGE CORRELATIONS OBTAINED FROM DETRENDED FLUCTUATION ANALYSIS OF RUNNING STRIDE INTERVALS

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Monitoring stride interval long-range correlations has been suggested as a method for coaches and clinicians to track changes in fatigue and injury risk. This study investigated the between-day reliability of stride interval long-range correlations during treadmill running. Stride interval long-range correlations were assessed on two occasions 1-week apart using detrended fluctuation analysis during 6 minutes of running at 11, 13 and 15 km·h^{-1}. Stride interval long-range correlations demonstrated good absolute reliability (95% limits of agreement: 0.11-0.14 arbitrary units) and relative reliability (intraclass correlation coefficient: 0.74-0.87) at each running speed. The absolute reliability values reported in this study can be used by athletes, coaches and clinicians to determine real changes in stride interval long-range correlations.

KEYWORDS: movement variability, repeatability, measurement error, treadmill.

INTRODUCTION: Distance running is a popular form of physical activity that is associated with a high incidence of injury (Videbaek, Bueno, Nielson, & Rasmussen, 2015). Determining risk factors for running injuries is a key step in addressing the high incidence of injury experienced by runners (Finch, 2006). Knowledge of injury risk factors allows for identification of runners at high-risk of injury and subsequent implementation of interventions designed to reduce likelihood of injury. Notably, the time interval between successive foot-ground contacts during running displays long-range correlations that breakdown in the presence of recent injury, acute fatigue (Meardon, Hamill, & Derrick, 2011), and the chronic fatigue that is associated with intense training (Fuller et al., 2017). As a result, monitoring stride interval long-range correlations could provide a means for monitoring injury risk and accumulation of fatigue in distance runners. Recent improvements in the quality and cost of wearable technologies (Willy, 2018) allow runners, coaches and clinicians to easily measure running stride intervals in order to detect the breakdown of long-range correlations. The within- and between-day reliability of stride interval long-range correlations measured during walking is excellent and good, respectively (Pierrynowski et al., 2005). However, to the authors' knowledge the reliability of stride interval long-range correlations measured during running is unknown. Good reliability during running assessment is important to ensure that meaningful changes in long-range correlation strength can be confidently accepted as real changes that are not attributable to measurement error. Incorrectly interpreting measurement error as real breakdowns in long-range correlations will lead to incorrect inferences about injury risk and mis-management of runners. Therefore, the purpose of the present study was to investigate the between-day reliability of stride interval long-range correlations measured during running.

METHODS: This reliability study used a between-day repeated measures design. Stride interval long-range correlations were assessed for ten male distance runners (age: 27 ± 6 years; body mass: 71.5 ± 8.4 kg; height: 1.79 ± 0.05 m) on 2 separate occasions at 3 different running speeds. Assessments were completed 1-week apart at the same time of day. A familiarisation session was completed by all participants 1-week before their first stride interval long-range correlation assessment. The participants used their own running shoes for all running and shoes were standardised between assessments. Participants refrained from training on the day of testing. All participants trained a minimum of 15 km per week and had no current or recent (3-month) injuries. Ethical approval was obtained from the University of South Australia Human Research Ethics Committee.

Running stride variability was assessed during 6-minute running trials performed on a motorised treadmill (Model 645, Quinton Instrument Co., WA, USA) at 11, 13 and 15 km·h^{-1}, after a 5-minute running warm-up at 8 km·h^{-1}. Running trials were performed in a fixed order with a 4-minute rest between trials. Force-sensitive resistors were placed underneath each shoe insole at the heel and forefoot to identify foot contacts based on uniaxial force data collected wirelessly at 2000 Hz using a Delsys Trigno system (Delsys Inc, Massachusetts, USA). Foot contacts were defined as the peak signal in MATLAB (R2016b, MathWorks, Natick, MA). Stride intervals were calculated as the time between consecutive right foot contacts and the length of each stride interval time series was approximately 500 strides. The distributional variability of each stride interval time series was determined using the stride interval coefficient of variation (CV).

Detrended fluctuation analysis (DFA) was used to determine the degree of long-range correlations in each stride interval time series. First, the initial 30-seconds of each time series was removed to account for participants adapting to the start of each run. Outliers were then removed if they were outside the inter-quartile range (IQR) by a magnitude of 1.5x IQR (Fuller et al., 2016). The median number of outliers removed by this process was 3 strides per time series. A separate DFA was then performed on the first 400 strides at each running speed using PhysioNet software (Goldberger et al., 2000). The PhysioNet software integrated the time series and then sectioned the integrated times series y(k) into non-overlapping bins with a length of n strides. A least squares line was then fit to the data in each bin of n strides to represent the local trend $y_n(k)$. The integrated time series was then detrended by subtracting the local trend in each bin. The root-mean-square fluctuation [F(n)] of this integrated and detrended time series was then calculated by:

$$F(n) = \sqrt{\frac{1}{N}\sum_{k=1}^{N}[y(k) - y_n(k)]^2}$$

This calculation was repeated across all bin sizes from 4 to 100 strides. The coefficient (α) relating log[F(n)] to log[n] indicated the degree of long-range correlations. Perfect long-range correlations were represented by α=1.00 and stride fluctuations that occurred in an entirely unpredictable sequence were represented by α=0.50 (Jordan, Challis, & Newell, 2006).

Statistical analysis was performed using a Microsoft Excel 2016 spreadsheet for analysis of reliability in sports science studies (Hopkins, 2015). Between-day differences in stride interval α and CV were investigated using paired-sample t-tests. The statistical significance level was set at 0.05. Absolute reliability was determined using limits of agreement. Relative reliability was determined using the intraclass correlation coefficient (ICC). ICCs were considered poor (ICC <0.50), moderate (ICC 0.50-0.74), good (ICC 0.75-0.89), and excellent (ICC ≥0.90) (Portney & Watkins, 2008).

RESULTS: There were no statistically significant differences between days for stride interval α or CV at any running speed (P > 0.14) (Table 1). Limits of agreement indicated that the absolute reliability of stride interval α was similar across speeds, with 95% of repeat measurements expected to be within 0.11, 0.13 and 0.14 arbitrary units for running assessments at 11, 13 and 15 km·h^{-1}, respectively (Table 1). Limits of agreement indicated that the absolute reliability of stride interval CV was better when assessed at 11 and 13 km·h^{-1} running speeds compared to 15 km·h^{-1} (Table 1); repeat measurements at 11 and 13 km·h^{-1} were expected to be within 33-34% compared to 63% at 15 km·h^{-1}. Relative reliability of stride interval α was moderate when running at 11 km·h^{-1} and good when running at 13 and 15 km·h^{-1} (Table 1). Relative reliability of stride interval CV was good when running at 11 and 13 km·h^{-1} and moderate when running at 15 km·h^{-1} (Table 1).

Table 1: Between-day reliability for stride interval α and CV.

Speed	Session 1	Session 2	Difference	LOA	ICC
11 km·h^{-1}					
α (AU)	0.75 ± 0.09	0.79 ± 0.11	0.04 ± 0.08	±0.11	0.74
CV (%)	1.23 ± 0.31	1.35 ± 0.45	0.12 ± 0.24	±0.33	0.86
13 km·h^{-1}					
α (AU)	0.75 ± 0.14	0.73 ± 0.14	-0.02 ± 0.10	±0.13	0.79
CV (%)	1.22 ± 0.45	1.29 ± 0.47	0.07 ± 0.24	±0.34	0.89
15 km·h^{-1}					
α (AU)	0.76 ± 0.17	0.71 ± 0.15	-0.05 ± 0.10	±0.14	0.87
CV (%)	1.26 ± 0.58	1.21 ± 0.44	-0.05 ± 0.45	±0.63	0.71

α = long-range correlation coefficient; AU = arbitrary units; CV, coefficient of variation; LOA, limits of agreement; ICC, intraclass correlation coefficient.

DISCUSSION: This study investigated the between-day reliability of stride interval long-range correlations and distributional variability during treadmill running at 11, 13 and 15 km·h^{-1}. Stride interval long-range correlations demonstrated good absolute and relative reliability at each running speed. In contrast, the relative and absolute reliability of stride interval distributional variability measurements was better at 11 and 13 km·h^{-1} compared to 15 km·h^{-1}.

To the authors' knowledge, this study is the first to investigate the reliability of stride interval long-range correlation measurements during running. The good between-day reliability for running conditions in the present study (ICC 0.74-0.87) is consistent with the previously reported good between-day reliability for stride long-range correlation measurements during walking (ICC 0.77) (Pierrynowski et al., 2005).

Stride interval long-range correlation assessment has previously been shown to detect differences between recently injured and healthy runners and fatigued and non-fatigued running conditions that conventional gait analysis assessments (i.e. mean stride interval) are not able to detect (Meardon et al., 2011). As a result, stride interval long-range correlations could be a useful running gait analysis measure for monitoring fatigue and injury risk in runners. Indeed, runners who experienced greater reductions in performance after a 2-week period of intense training designed to cause substantial fatigue also demonstrated greater reductions in stride interval long-range correlations (Fuller et al., 2017). The absolute reliability values in the present study can be used by athletes, coaches and clinicians to determine when changes in stride interval long-range correlations can be considered real changes. Establishing these values is important to ensure that normal between-day variations in stride interval long-range correlations are not incorrectly interpreted as real changes and used as a basis for inferring fatigue and injury risk status.

The limits of agreement in the present study suggest that changes less than 0.11, 0.13 and 0.14 arbitrary units should not be considered real changes for 11, 13 and 15 km·h^{-1} running speeds, respectively. These values indicate that reliability is marginally better at the slower running speed compared to faster speeds. Notably, slower running speeds (i.e. 10.5 km·h^{-1}) have also previously been shown to be more sensitive to the effects of the fatigue associated with intense training (Fuller et al., 2017). Taken together, these results suggest that slower running speeds are likely to maximise the signal-to-nose ratio for stride interval long-range correlation measurement. Therefore, slower running speeds should be used by athletes, coaches and clinicians when monitoring stride interval long-range correlations.

A limitation of the present study is the lack of within-day reliability assessment. However, between-day reliability was considered more meaningful for athletes, coaches and clinicians who are often interested in monitoring between-day changes in fatigue and injury risk markers.

CONCLUSION: Stride interval long-range correlations demonstrated good absolute and relative reliability for treadmill running at 11, 13 and 15 km·h^{-1}. Monitoring stride interval long-range correlations has been suggested as a method for coaches and clinicians to track changes in fatigue and injury risk. If generalizable to overground running, the absolute reliability values reported in this study can be used by athletes, coaches and clinicians to determine real changes in stride interval long-range correlations. This will reduce the likelihood of measurement error being incorrectly interpreted as a meaningful change and avoid subsequent inappropriate alterations to athlete training and management.

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