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Gait variability and symmetry remain consistent during high-intensity 10,000 m treadmill running

Brian Hanley *, Catherine B. Tucker

Carnegie School of Sport, Headingley Campus, Leeds Beckett University, United Kingdom

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ABSTRACT

The aim of this study was to analyze changes in gait variability and symmetry in distance runners. Fourteen competitive athletes ran on an instrumented treadmill for 10,000 m at speeds equivalent to 103% of their season's best time. Spatiotemporal and ground reaction force data were recorded at 1500, 3000, 5000, 7500 and 9500 m. Gait variability and inter-leg symmetry were measured using median absolute deviation (MAD) and the symmetry angle, respectively. There were no overall changes during the running bout for absolute values, symmetry angles or variability, and there were only moderate changes in variability between successive testing distances for three variables. Even with these few changes, variability was low (<4%) at all distances for all variables measured and, on average, the athletes were symmetrical for five of the seven gait variables measured. There were greater mean asymmetry values for flight time (1.1–1.4%) and for impact force (2.0–2.9%), which might have occurred because of muscle latency as the lower limb responded passively to impact during initial contact. Although most athletes were asymmetrical (>1.2%) for at least one variable, no one was asymmetrical for more than four of the seven variables measured. Being asymmetrical in a few variables is therefore not abnormal and not indicative of asymmetrical gait and given many practitioners analyze symmetry (and variability) on an individual, case-study basis, caution should be taken when assessing the need for corrective interventions.

1. Introduction

Movement variability is a normal and functional feature of human movement prevalent in sports performance. Too much or too little variability within movement can be detrimental in performing motor tasks (Davids et al., 2003; Srinivasan et al., 2015). It has been identified that expert performers exhibit reduced variability in outcome-related variables compared with lesser-skilled performers (Fleisig et al., 2009), and that the principal variables that determine running speed (i.e., step length and frequency) have reduced variability in expert runners (Nakayama et al., 2010), which is another example of reduced outcome variability. Beyond sports performance, there is evidence of increased variability in pathological gait compared with healthy gait (e.g., outcome measures such as step length and frequency), such as in Parkinson's disease (Moon et al., 2016), and high gait variability has been associated with increased fall risk in the elderly (Toebes et al., 2012). Conversely, it has been suggested that increased movement variability between strides in running (e.g., variability of coordination between segments) is beneficial as it allows for an even distribution of stresses across the tissues and the ability to adapt to any changes that arise in the environment (Hamill et al., 1999). There might therefore be a window of optimal variability that exists depending on the motor task (Meardon et al., 2011) within which an individual will vary movement to achieve the desired outcome, and which alters depending on internal and external factors.

One factor that might affect movement variability is how fatigued the individual is at any given time during the task. In general, variability is expected to increase with prolonged activity or muscle fatigue (Meardon et al., 2011; Missenard et al., 2008). This might be because movement variability allows flexibility in adjusting to perturbations in the environment and thus helps to preserve performance, as was found to occur with muscle fatigue in occupational tasks such as hammering (Srinivasan and Mathiassen, 2012). However, the relationship between movement variability and movement outcome, and its change in response to increased fatigue, has not been fully investigated in sports performance. Previous studies have examined changes in movement variability before, after or at a specific time during the fatiguing protocol

* Corresponding author at: Fairfax Hall, Headingley Campus, Leeds Beckett University, LS6 3QS, United Kingdom.

E-mail address: b.hanley@leedsbeckett.ac.uk (B. Hanley).

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(e.g., Nakayama et al., 2010), yet few have measured whether it changes at multiple points during a fatiguing protocol within a well-trained cohort of sportspeople. Understanding the consistency of variability is thus important in understanding whether it changes as fatigue increases and, for researchers, in terms of making an informed choice as to when to sample for an athlete's typical variability during exercise.

Whereas movement variability can measure, for example, the similarity of movements within a limb, between-limb similarities are typically measured using symmetry scores. Although having a dominant limb is normal, it can be disadvantageous to have asymmetrical lower limbs in activities such as running, as one limb can be required to increase work to compensate for the weaker side (Levine et al., 2012). Asymmetry occurs when there is any deviation from symmetry, i.e., the exact replication of one limb's movement by the other (Exell et al., 2012). Measurements of asymmetry have been used in running research to highlight not only an increase in injury risk (Schache et al., 2009), but also by physicians to quantify functional deficits resulting from lower limb injury (Girard et al., 2017). However, being asymmetrical for any given spatiotemporal variable (e.g., step length) does not signify that the individual has an inter-limb imbalance that negatively affects gait, as the same outcome is achievable in different ways (Levine et al., 2012); it is therefore important to also consider the causative factors, such as external forces (Sadeghi et al., 2000). It would be rare for both lower limbs to replicate each other's movements exactly, as variability within a limb means that it does not even replicate its own movements precisely. Even in healthy individuals, it has been suggested that the underlying musculoskeletal structure can be asymmetrical, e.g., the Achilles tendon (Bohm et al., 2015). Criteria for meaningful differences between limbs depend on the measure used; for example, previous research on racewalking found that a symmetry angle of 1.2% or more, established using difference testing and effect sizes on multiple (>40) right and left steps, was indicative of an individual being asymmetrical for that variable (Tucker and Hanley, 2017), and could be a practically useful reference for other gait studies. The symmetry angle (Zifchock et al., 2008) is a dimensionless measure of asymmetry that does not suffer from artificial inflation, unlike the symmetry index that requires a reference value (Exell et al., 2012), and is therefore a robust measure of asymmetry that can be used across spatiotemporal and kinetic variables.

Like variability, it is possible that symmetry values alter during an exercise bout, for example when the athlete is fatigued, or as they become accustomed to its intensity. Recent research by Radzak et al. (2017) found differences in symmetry angle between rested and fatigued-state running for several gait variables, although other variables were asymmetrical both before and after the fatiguing protocol. Similar research (Brown et al., 2014; Girard et al., 2017) found that dominant and non-dominant legs fatigued at similar rates, and thus inter-leg asymmetries are not likely due to lower limb dominance (Brown et al., 2014). The measurement of variability or symmetry at a single instant might not represent an athlete's typical state, given that intensive endurance activity usually results in local muscular fatigue (Mizrahi et al., 2000). Furthermore, it is important to assess asymmetry on an individual basis as athletes employ different mechanisms for contralateral limbs to achieve similar outcomes (Exell et al., 2017). Previous research has predominantly analyzed variability and symmetry changes before and after fatiguing exercise (e.g., Gates and Dingwell, 2011), but it will be useful to identify any changes that occur at different times during the exercise bout. The measurement of gait variables at multiple distances will allow for an appreciation of how frequently an athlete experiences variability or asymmetry, and provide an indication of the validity of a single measurement in assessing these factors. The aim of this study was to analyze changes in variability and symmetry during 10,000 m treadmill running. Based on previous research on changes in variability and symmetry with fatigue, it was hypothesized that both would increase during a high-intensity continuous running protocol.

2. Methods

2.1. Participants

The study was approved by the Faculty Research Ethics Committee, and 14 competitive male distance runners (31 ± 7 yrs, 1.79 ± 0.07 m, 66.4 ± 5.6 kg) gave written informed consent. Their season's best time for 10 km (in road racing) ranged from 31:00 to 35:20. All participants were over the age of 18 and free from injury.

2.2. Protocol

After a 10-min warm-up and familiarization period (Matsas et al., 2000), each participant ran for 10,000 m on an instrumented Gaitway treadmill (h/p/Cosmos, Traunstein, Germany) (LaRoche et al., 2012) at a speed equivalent to 103% of their season's best 10 km road race speed (Hanley, 2015). Each athlete ran at a constant pace for the duration of the test, with a mean belt speed of 17.56 km·h^{-1} (± 0.59). The treadmill's inclination was set at 0% during data collection (Paquette et al., 2017). Participants were all habitual treadmill users and wore their normal training clothing and footwear for indoor training sessions. The treadmill incorporated two in-dwelling piezoelectric force plates (Kistler, Winterthur, Switzerland) that recorded vertical ground reaction forces (GRF) (1000 Hz) and temporal data. The force plates also recorded the position of the center of pressure from which step length was measured. Data were collected for 30 s at 1500, 3000, 5000, 7500 and 9500 m, which allowed for the collection of 45 (± 3) steps per foot during each sampling period. The Rate of Perceived Exertion (RPE) Scale (Borg, 1975) was used to measure perception of fatigue on a scale of 6–20 (e.g., a score of 11 represented a 'fairly light' rating, and 15 represented a 'hard' rating).

2.3. Data processing

The GRF data were exported and smoothed using a recursive second-order, low-pass Butterworth filter (zero phase-lag). The optimal cut-off frequency was calculated during a pilot test using residual analysis (Winter, 2005). The results showed an optimal cut-off frequency ranging from 48 to 52 Hz, so it was decided to use 50 Hz as the cut-off frequency for all trials. The mean and standard deviation (SD) of the noise occurring during the final 50 ms before ground contact (visual inspection) were calculated, and initial contact was considered to begin when the vertical force magnitude was greater than the mean plus 3SD of the noise. The mean and 3SD of the noise during the first 50 ms after toe-off were used in a similar way to identify the end of contact and the beginning of flight. The vertical GRF data variables analyzed were impact peak force, maximum force and impulse. The impact peak was defined as the highest recorded force during the first 70 ms of contact, and the maximum force was identified as the next peak in the vertical GRF trace during midstance (and whose magnitude was always greater than the impact peak force) (Fig. 1) (Hanley, 2015; Watkins, 2010). Impulse was also calculated in the vertical direction only as the time integral of the force curve using the trapezoidal rule (Caderby et al., 2013). All kinetic variables were normalized for each athlete's body weight (BW). Step length was defined as the distance from each foot strike to the next foot strike of the opposite foot. Contact time was defined as the time duration

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