KINEMATIC ASYMMETRY DURING A 30-MINUTE HIGH INTENSITY RUN

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Asymmetry in movement is topical but poorly understood in terms of knowing how it relates to musculoskeletal health, and how it typically varies during an activity in otherwise healthy individuals. The aim of this study was to investigate how asymmetry of running kinematics changed over the course of a 30 minute, high intensity run in a group of healthy young adult males. Using 3D motion analysis, average, variability and asymmetry data related to ground contact time, stride time, duty factor, and relative phasing of heel strike to the opposing stride cycle were acquired. No effect of time on average or variability of calculated variables was observed and between-limb differences were small, but responses were highly individualised and metric-dependent. Caution is hence advised in use and interpretation of group analyses when asymmetry is a metric of interest.

KEYWORDS: coordination, fatigue, gait, running, variability

INTRODUCTION: Running is one of the most popular recreational sports, involving people from all around the globe completing distances from 1-2 km, right up to ultramarathon distances or further. Most people complete activities of a distance that is long enough to induce at least some element of fatigue by the end, and it is known that as an individual tires, lower limb mechanics change (Derrick et al., 2002; Radzak et al., 2017). Between-limb differences in function, structure, and mechanics have traditionally been viewed negatively based on the work of Knapik et al. (1991) who reported asymmetry greater than 15% in isokinetic knee flexor strength and hip extensor flexibility was associated with increased injury risk in female collegiate athletes. However, recent work suggests this value is conservative across a wide range of biomechanical measures (Exell et al., 2012; Furlong and Harrison, 2015; Furlong and Egginton, in press).

Asymmetry is anecdotally hypothesised to negatively influence injury risk by redistributing forces to other parts of the body. Fatigue potentially negatively influences this distribution even further. However, there is little robust, long-term scientific evidence to support this hypothesis. Although both limbs are equally used to run, one limb is typically preferred to be used to kick a ball or recover one's balance. It is possible that with development of fatigue, one limb responds differently than the other given its different prior training history and control. The aim of this study was to investigate if outcome-focused kinematics (ground contact time, stride time, duty factor), co-ordination (discrete relative phasing) and variability of these kinematics and coordination were affected by fatigue, and if preferred and non-preferred limbs responded the same way. Results may provide further insight into lower limb control during running, and the influence of training history on biomechanical responses.

METHODS:

Participants: Following university ethical approval and written informed consent, eleven healthy, recreationally active males (age: 23.8 ± 3.5 years, height: 1.77 ± 0.10 m, mass: 76.8 ± 13.5 kg) participated in this study. All were injury free for the preceding 3 months, did not have a history of lower limb surgery or a running injury that precluded them from running for more than one month, and preferred their right leg for kicking a football. Participants were advised to refrain from unaccustomed activity for 24 hours preceding data collection.

Cooper run: To establish a comparable relative speed for all individuals to complete testing, all subjects completed a 12 minute Cooper run at least one week prior to motion analysis data collection. All preliminary tests were completed on a Mondo-surface 400 m athletics track. Following a self-selected cardiovascular and dynamic stretching warm-up, subjects were instructed to run as far as possible in 12 minutes. All runs were completed individually to eliminate competition bias with emphasis on an even pacing strategy to achieve the furthest distance. Participants were informed of the elapsed time after each lap, and a 15 s countdown provided to signal the end of the run. If a partial lap was completed, total distance ran was calculated using the track markings to the nearest 10 m.

Motion analysis: An eighteen-camera three-dimensional motion analysis system (250 Hz, T20 and 40 series, Vicon Motion Systems Limited, Oxford, UK) was used to capture kinematic data as participants ran on a HP Cosmos Saturn treadmill (Traunstein, Germany) at a 1% incline and 85% of the calculated average Cooper run speed. Participants wore their own running shoes which were the same footwear used during the Cooper run. Reflective markers (14 mm, B&L Engineering, California, USA) defined the anatomical bony landmarks of both limbs; for the purposes of this analysis, markers attached to the medial 1st metatarsophalangeal head, lateral 5th metatarsophalangeal head, superior distal hallux, calcaneus and medial and lateral malleolus were used to track the foot segment. Motion analysis data was acquired in 30 second blocks at 0,10,20, 30 and 40 minutes of the trial period: this analysis concentrates on data up to 30 minutes. Upon completion of the 40 minutes, all participants reported a rating of perceived exertion of at least 17 (very hard).

Data analysis: All data was reconstructed and labelled using Nexus 1.8.5 (Oxford Metrics PLC, Oxford, UK), with incomplete marker trajectories up to 10 frames long reconstructed using the quintic spline gap filling procedure. Files were then imported into Visual 3D (v6.01.22, C-Motion, Germantown, MD, USA) for further processing. Data were filtered using a fourth order, zero-lag, low-pass filter at 12 Hz, established using residual analysis (Winter, 2005). Ground contact time (GCT) was calculated as the time difference between the instant of maximum calcaneal acceleration in the vertical direction (heel-strike) and maximum hallux jerk in the vertical direction (toe-off), which has been shown to be accurate to 1.1 ms in measuring GCT (Handsaker et al., 2016). Stride time (ST) was defined as the time between consecutive heel strikes using the same limb, with duty factor (DF) defined as GCT expressed as a percentage of ST. Relative phase was defined as the timing between consecutive preferred and non-preferred heel-strikes, expressed as a percentage of that non-preferred ST, and timing between consecutive non-preferred and preferred heel-strikes expressed as percentage of that preferred limb ST. Ten strides in each time block were analysed for each limb for each person.

Statistical analysis was completed in SPSS (IBM SPSS Statistics 24, IBM Corp., Armonk, NY., USA), with effect size (ES) calculated using Cohen's d correcting for dependence among means (Morris and DeShon, 2002). Greenhouse-Geisser corrections were applied where sphericity was violated. Outputs were interpreted using Hopkins (2006), i.e. <0.2 = trivial, <0.6 = small, <1.20 = medium, 1.20 and above = large. Medium or greater effects were considered of practical significance. Coefficient of variation (COV) was calculated as the standard deviation expressed as a percentage of the mean value. Absolute symmetry index (ASI) was calculated by expressing the absolute difference between the preferred and non-preferred limb as a percentage of the average of both limbs. Average ASI is hence a better representation of true between-limb difference than average symmetry index, where positive and negative between-limb differences cancel each other out.

RESULTS AND DISCUSSION: Average distance covered in the Cooper Run was 2.73 ± 0.34 km. This resulted in an average test speed of 11.6 ± 1.5 km/hour or approximately a 51 minute 10 km time. This is 52% of the age-graded time for the average age of participants in this study; the 10 km world record time for a 24 year old male is just under 27 minutes. Results are hence indicative of responses of typical recreational male runners.

No effect of time on calculated average variable was observed in either limb, which is somewhat unexpected given previously reported increases in GCT as fatigue develops (Hayes and Caplan, 2012). It is possible that despite the high-intensity nature of the protocol, by 30 minutes fatigue simply had not manifested. There was no statistical or practical effect on the variability of almost all calculated kinematics with trivial or small ES observed, with the exception of between-limb difference in ST COV at 0 mins where ES was moderate (0.615).

This may represent a typical between-limb difference in level of variability in a non-fatigued state. Interestingly, this effect disappears at the later time points, indicating the variability of the kinematics of the two limbs are more similar as they fatigue which is potentially associated with musculoskeletal dysfunction.

Group average ASI was low across all variables at all time points, typically less than 2% for GCT, SF, ST and DF (Table 1). GCT ASI is slightly lower than that of Radzak et al. (2017), who reported a statistically significant ASI of approximately 2.9%; the lack of statistical significance in this cohort may be due to the smaller sample size. Magnitude of all differences were small (ES <0.46). This is not unexpected due to the single-belt motorised treadmill-based protocol used, which requires both limbs to move at the same velocity. A slightly larger difference in asymmetry of phasing was observed of up to 2.4% but ES were also small. Asymmetries in this metric are also expected to be low but some difference due to altered coordination strategies used by the two limbs is not unexpected. The discrete time points chosen are only one measure of coordination; results do not mean similar joint kinematics or kinematic coordination strategies were utilised to achieve these symmetric outcomes. This phenomenon is well established in motor control theory given the degrees of freedom in the musculoskeletal system. Radzak et al. (2017) observed increased symmetry of lower limb kinetic measures (vertical stiffness, loading rate, and free moment), while asymmetry of knee internal rotation and knee stiffness increased, indicating a potential limitation in the use of asymmetry as an outcome metric in biomechanical analysis. These relationships hence requires further investigation.

Group level analyses hide there are large between-limb differences for some individuals, similar to the findings of Furlong and Egginton (in press). Figure 1 illustrates examples from measured duty factor and phasing, and also the range COV data in Table 1. Data show some individuals maintain reasonable symmetry at each time point for the selected variables, but others are markedly different (e.g. P3, P4 or P8). Some responses are mixed, dependent on the time point in question (e.g. P1). Importantly, results highlight a key issue in the use of asymmetry, particularly, formulae incorporating a directionality component. as an injury predictor or monitoring metric. Calculated asymmetry is highly dependent on the metric in question, which is supported by the large differences in directionality shown in Figure 1.

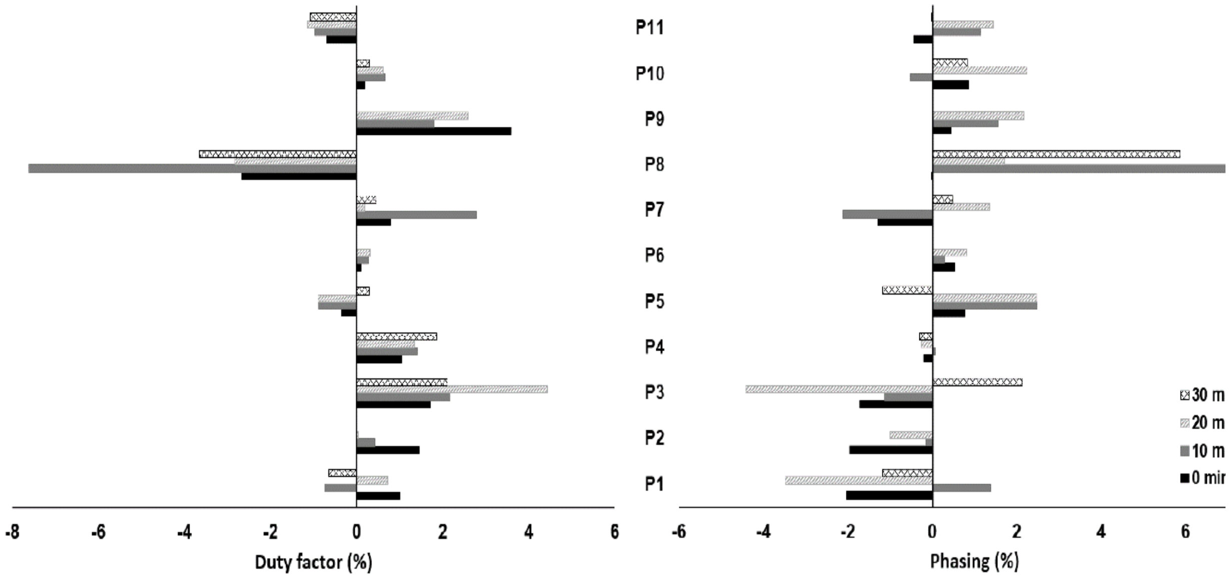

Figure 1. Between-limb differences in duty factor and phasing for each participant at 0, 10, 20 and 30 minutes of protocol. Differences presented are actual differences between preferred and non-preferred limbs (e.g. if P = 20%, NP = 10%, difference (presented) = 10%)

Table 1. Group average, absolute symmetry index (ASI), and coefficient of variation (COV) of ground contact time (GCT), stride time (ST), duty factor (DF) and relative phase (RP) for both limbs at 0, 10, 20, and 30 minutes of protocol; P indicates preferred limb and NP non-preferred limb.

		0 minutes		10 minutes		20 minutes		30 minutes	
		P	NP	P	NP	P	NP	P	NP
GCT	Mean ± SD (s)	0.257 ± 0.031	0.252 ± 0.025	0.258 ± 0.035	0.258 ± 0.028	0.261 ± 0.031	0.258 ± 0.027	0.256 ± 0.036	0.257 ± 0.030
	ASI (%, mean)	1.6		0.1		1.3		0.3	
	Mean COV (%)	2.8	2.7	4.4	2.6	4.8	3.4	2.9	2.4
	Range COV (%)	7.0	7.0	19.9	6.6	13.4	6.9	7.6	6.6
ST	Mean ± SD (s)	0.717 ± 0.041	0.717 ± 0.041	0.713 ± 0.040	0.713 ± 0.040	0.712 ± 0.038	0.712 ± 0.038	0.717 ± 0.036	0.717 ± 0.036
	ASI (%, mean)	0.0		0.0		0.0		0.1	
	Mean COV (%)	1.0	1.3	1.3	1.1	1.3	1.7	1.6	1.3
	Range COV (%)	1.3	3.5	2.5	1.9	1.6	3.7	3.6	2.6
DF	Mean ± SD (s)	35.8 ± 4.1	35.2 ± 3.4	36.2 ± 4.6	36.3 ± 3.8	36.7 ± 4.2	36.2 ± 3.5	35.8 ± 4.7	35.9 ± 4.0
	ASI (%, mean)	1.6		0.2		1.3		0.4	
	Mean COV (%)	2.7	2.3	4.1	2.5	4.6	3.0	2.6	2.4
	Range COV (%)	7.9	5.0	19.8	6.1	13.4	6.2	6.0	5.2
RP	Mean ± SD (%)	49.7 ± 0.6	50.2 ± 0.5	50.6 ± 1.6	49.4 ± 1.6	50.1 ± 1.2	49.9 ± 1.2	50.5 ± 1.4	49.6 ± 1.3
	ASI (%, mean)	0.9		2.4		0.6		1.9	
	Mean COV (%)	1.5	1.7	1.9	1.8	2.2	2.5	2.2	2.1
	Range COV (%)	3.1	4.5	3.6	3.3	3.8	5.9	6.3	5.4

CONCLUSIONS:

Group results show in a group of young, healthy male adults, outcome-based kinematic measures of both limbs respond similarly to a high-intensity treadmill-based running protocol. Average, variability, and asymmetry of selected kinematics (GCT, ST, DF) and co-ordination do not appear to be influenced by development of fatigue during a 30 minute high intensity run. However, asymmetry results are individual and metric-dependent, hence caution is advised in use of group analyses where this is the outcome metric of interest.

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