SYMMETRY AND REPRODUCIBILITY OF KINEMATIC PARAMETERS DURING VARIOUS RUNNING TECHNIQUES

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The purpose of this study was to examine the reproducibility and the symmetry of a wide number of kinematic parameters while running with various running techniques. Each of twelve tested persons ran on a treadmill in combinations of three velocities (2.5, 3.0 and 3.5m/s) and three stride frequencies (preferred, +/-10% from preferred). Three cycles were recorded for each running task using a video camera (250 Hz) at each side of the body. Intraclass correlation coefficients (ICC generally > 0.80) for both legs were high. Only the angular velocity parameters demonstrated low reproducibility (ICC < 0.75). Significant ($P < 0.05$) differences often appeared between the cycles of the 1st and 3rd or 1st and 5th minutes, but seldom between those of the 3rd & 5th minutes. The absolute symmetry Index (ASI) for the linear and angular displacement parameters and the contact time during all running techniques were low (< 8%), while those for the angular velocity and flight time were clearly higher (> 10%).

KEY WORDS: biomechanics, repeatability, symmetry index, stride length, treadmill.

INTRODUCTION: A large assortment of kinematic parameters have been examined, for analysing human running. While the degree of reproducibility of several of these parameters during normal human running has been demonstrated by several authors (e. g. Diss 2001), it still remains open the question of to which extent these findings are also valid for a variety of running techniques. Running with systematic variation in stride frequency (Farley and Gonzales 1996) or running velocity (Arampatzis et al. 2000) may provide additional information about the muscular function. Typically, studies reached conclusions which described the average performance of groups in experimental conditions without taking into account that the reproducibility of the additional parameters may vary with running task. This is also of great interest with regard to the sparseness of data acquisition. Several studies analysed the symmetry between homologous body segments, with respect to forces and movements developed during normal human running (e. g. Vagenas and Hoshizaki 1992) whereby the degree of symmetry is likely to be controversial. This may reflect the differences in the definition of running symmetry, the applied methodology as well as to the parameter itself. However, the relevance of systematic variation in stride frequency or running velocity for kinematic symmetry assessment, has not yet been proven. Therefore, the aims of this study were to examine the reproducibility and the symmetry of a wide number of parameters obtained from kinematic analysis when running at different velocities and deliberate change of stride frequencies.

METHODS: Twelve female long distance runners (height: 167 +/-7cm, mass: 58.58 +/-6.01kg) participated in this study. The athletes ran on a treadmill at three velocities (2.5, 3.0 and 3.5m/s) and three stride frequencies (preferred, +/-10% from preferred). The rhythm was set by a metronome. The athletes were filmed from their left and right side using two genlocked high-speed (250 Hz) video cameras placed orthogonal to the main plane of motion. A whole running cycle – from heel strike to ipsilateral heel strike - was analysed. The left and right running cycles always correspond to consecutive footfalls. Three step cycles per velocity and frequency were systematically recorded for 5min. for each side, left and right: cycle 1 (0.5 – 1.5 min.), cycle 2 (2.5 – 3.5 min.) and cycle 3 (4 – 5 min.). The two-dimensional coordinates of the digitised markers were smoothed using a fourth-order lowpass Butterworth filter with a cut-off frequency of 15 Hz. For the right leg the instants of touch-down and take-off were determined by using customised pressure measuring insoles (Paromed 1000 Hz). For the left leg, this same events were calculated from the video sequences (250 Hz). 32 kinematic parameters per side left an right were calculated and analysed. Reproducibility test: For each velocity, frequency and side left and right the analysed cycles were divided into 3 groups: cycle 1, cycle 2 and cycle 3. The differences among groups were checked using a non parametrical test for several dependent samples. At those parameters where differences were found, a non parametrical test for two dependent samples was applied in order to localise the differences between the groups ($P<0.05$). Intraclass correlation coefficients (ICC) were calculated to examine the relationship of the groups.

Symmetry test: The following equation was used to analyse symmetry:

$$ASI = \frac{|X_r - X_l|}{\frac{1}{2}(X_r + X_l)} \times 100\%$$

where X_r given parameter from the right leg and X_l is the corresponding parameter from the left leg. The presence of differences between means of the right and left leg was checked using a non parametrical test for two dependent samples ($P<0.05$).

RESULTS: *Reproducibility.* Table 1 shows the ICC for several kinematic parameters from the right body side. *Symmetry.* Table 2 shows the mean ASI and SD of several parameters.

Table 1. ICC for kinematic parameters during 3.5 m/s with three different stride frequencies for the right leg .

Stride frequency	**-10%**		**preferred**		**+10%**	
Velocity in m/s	2.5	3.5	2.5	3.5	2.5	3.5
foot angle at touch down	0.93	0.97	0.96	0.94	0.97	0.94
knee angle at touch down	0.85	0.74	0.76	0.75	0.75	0.81
knee angle at take off	0.80	0.90	0.72	0.85	0.80	0.85
hip angle at touch down	0.88	0.90	0.93	0.89	0.77	0.89
max hip angle velocity at flight phase	-0.02	0.68	0.73	0.54	0.55	0.61
vertical position of the hip at touch down	0.80	0.91	0.74	0.87	0.90	0.94
vertical position of the hip at take off	0.82	0.93	0.79	0.89	0.97	0.96
max vertical velocity of the hip at flight phase	0.77	0.72	0.64	0.44	0.73	0.73
contact time	0.90	0.94	0.76	0.93	0.87	0.97

Table 2. The symmetry index for kinematic parameters during 3.0 m/s with three different stride frequencies (cycle 3).

Stride frequency	**-10%**	**preferred**	**+10%**
Velocity	3.0 m/s	3.0 m/s	3.0 m/s
foot angle touch down	5.67 (5.22)	5.75 (4.61)	5.70 (3.80)
min foot angle velocity at foot contact	19.55 (19.61)	20.72 (21.60)	25.59 (22.44)
knee angle at touch down	3.25 (2.53)	3.04 (2.84)	3.24 (2.82)
min knee angle velocity at foot contact	10.90 (6.05)	9.93 (6.61)	13.15 (7.19)
vertical position of the hip at touch down	4.72 (4.35)	4.44 (3.65)	3.60 (3.44)
min vertical velocity of the hip at foot contact	19.20 (11.07)	15.83 (12.06)	14.61 (11.09)
time flight phase	20.95 (12.77)	16.74 (13.36)	20.46 (18.03)
contact time	5.82 (5.47)	6.01 (4.18)	4.96 (5.20)

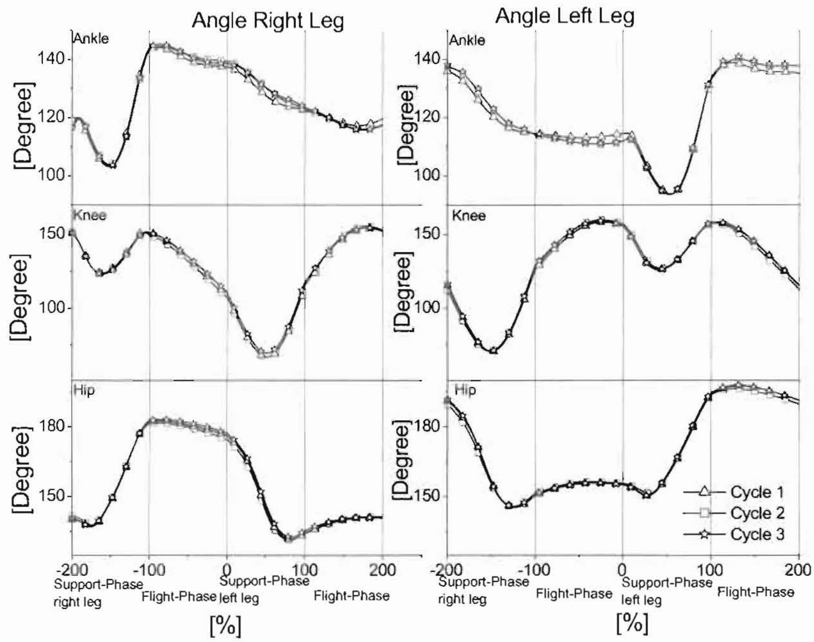

Figure 1. Angle of the ankle, knee and hip angle at 3.0m/s for the three measured cycles (1, 2, 3) of the right and the left leg.

DISCUSSION: *Reproducibility.* The present findings clearly demonstrate that nearly all the applied kinematic parameters for all running techniques are reproducible, for both legs. In general, only the linear and angular velocity parameters showed low ICC (most of data < 0.70). The analysis of their coefficient of variation reveals a high variability, which often exceeds 30%. A possible explanation for this could be that the velocity parameters are derived from the measurement position whereby each position may contain error. The current findings clearly demonstrate that kinematic parameter reproducibility gained from normal human running is also valid for a variety of running techniques. Bearing in mind the sparseness of the data acquired, these findings for the applied criteria indicate that a single sample database would permit that the kinematic results were calculated more accurately. Significant differences for both legs ($P < 0.05$) generally occurred between step cycles 1 & 2 and 1 & 3 but seldom between the step cycles 2 & 3. It is argued that they result primarily from tested persons accommodating themselves to the treadmill. The measuring of step cycle 2 started after 2 to 3 min. whereby the athletes may need this time to adapt to the treadmill. It must be noticed that there are some differences in the reproducibility of several parameters between the left and right hand side of the body side. In general, the ICC of the parameters contact time, vertical position of the hip at touch-down and take-off of the right body side, are higher than those for the left side whereby significant differences between the step cycles ($P < 0.05$) were regularly found for the parameters foot touch-down and contact time only for the right leg. This may be attributable to the methods used for assessing the left and right events. The pressure measuring insoles (1000 Hz) with a temporal resolution of 1ms made easier the identification of the events of the right leg and more accurate than for the left leg (video camera 250 Hz) which in turn affected the

calculated angles. This might demonstrate that the choice of parameters together with the equipment used should be expected to achieve an acceptable level of reproducibility.
Symmetry. It was determined for all running techniques that the left-right symmetry differences at the linear and angular displacement parameters and the contact time were small (ASI most of data < 8%), whilst the angular and linear velocity parameters and the flight times were high (ASI > 10%). The low symmetry of the velocity parameters may be partly attributable to their generally low reproducibility. Further analysis of the results of the present study reveals that the linear displacement parameters at the hip were not significantly different ($P < 0.05$), suggesting that each leg, irrespective of the running technique, experienced essentially the same kinematic pattern. In contrast, all other kinematic and temporal parameters analysed, were generally significantly different ($P < 0.05$). Specifically, the angular displacement and the temporal (e.g. contact time) parameters often showed differences between homologous body segments. Vagenas and Hoshizaki (1992), who analysed kinematic parameters of the rearfoot motion, also found significant asymmetries during normal human running. However, the present findings reveal that the percentile differences, indicated by ASI, were generally smaller than 8% for the angular displacement parameters and the contact times. Thus, the findings of statistical significant differences between left and right sides may be not of greater relevance. Since the angular velocity parameters and the flight times ASI were clearly above 10%, and most of the data was significantly different, it is suggested that the experienced kinematic patterns, irrespective of running velocity or stride frequency, are not the same.

CONCLUSIONS: a) The reproducibility of the kinematic-data is generally high and allowing a 2 to 3 min. period for adaptation to the treadmill before kinematic assessment could result into a higher reproducibility, b) the left-right symmetry was lower for the angular velocity parameters and higher for linear and angular displacement parameters, c) the reproducibility and symmetry of the kinematic data does not depend primarily on the running velocity or deliberate change in running technique, but rather on the parameter itself, d) considering the sparseness of the data acquired, the present findings indicate that a single sample database would allow the kinematic results, for criteria used, to be calculated accurately.

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