A PROCEDURE FOR QUANTITATIVE KINEMATIC ANALYSIS IN RUNNING ON TREADMILL

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The purpose of this paper is to describe and test a method and a special developed software package capable of doing a complete 3-D kinematic analysis in treadmill running, including the assessment of kinematic asymmetries by a simultaneous right and left analysis. A pilot study using 8 recreational runners demonstrated that accurate and repeatable quantitative data can be collected and analyzed with the procedure. Comparison of specific kinematic data with literature studies revealed same significant difference in total joint range of motion. Some measurements and samples plots are also presented and discussed. The method and the user friendly software presented here seems to be an useful tool for scientists, trainers and athletes to assess and evaluate biomechanical data during running.

KEY WORDS: optoelettronic system, bilateral asymmetries

INTRODUCTION: Treadmill running exercises are widely used in biomechanic research and exercise testing because they can provide standardized procedures that are simple and inexpensive in a controlled environment. Concurrently, a concomitant increase in the use of treadmills as a training and rehabilitation tool has been observed over the past decades. For kinematic data collection in particular, treadmills offer a means of attaining a continuous run in a fixed experimental area. This allows the acquisition of a larger number of running cycles per trial which increases the reliability of the kinematic variables. So far, despite the large number of motion analysis studies on running (Milliron & Cavanagh, 1990; Williams, at al., 1991; Hamill, et al., 1991), the analysis of body segments kinematics has generally been confined in the sagittal plane by using data obtained with a 2-D analysis. No kinematic data are generally available for frontal and horizontal plane. When asymmetries were evaluated, this was done by detecting data from one leg at time and subsequently comparing the scores obtained from the two sides in different trials. The purpose of this paper is to describe and validate a method and a special developed software package capable of doing a complete automatic 3-D kinematic analysis in treadmill running, including pelvis and trunk posture and the assessment of kinematic asymmetries by a simultaneous right and left analysis.

METHODS: The data reported here belongs to eight recreational runners (age: 28.7 ± 4 yr.; height: 174 ± 4 cm; body mass: 62 ± 3 kg), usually covering about 70 km/week. The first step in the present methodology is the capture of the motion of the athlete while running on a motorized treadmill. The standard protocol consists of a 15 min warm-up period in which the athletes were allowed to warm-up and became familiar with the experimental setting. Then the subject is asked to run at four different speeds (2.78, 3.33, 3.89, 4.44m/s). Data for at least 30 running cycles and three trials per condition were acquired. In our laboratory the capture motion operations are carried out by the ELITE system motion analyzer (BTS srl, Italy), yet it is also possible to use the software package with data coming from other optoelectronic recognition systems, both active and passive. The ELITE system, by means of four 100 Hz TV cameras paired off on the two sides of the runner, allows automatic 3-D reconstruction of a number of anatomical landmarks marked through the application of small passive reflective markers. Our standard protocol forecast the use of 21 markers (on the femoral condiles, malleola, fifth metatarsal heads, sacrum, posterior iliac superior spines to mark the pelvis and the lower limbs; on the acromions, elbows, and wrists to mark the arms, and on the spinous process of C7, T10, L5 to reconstruct the trunk) providing the kinematic data necessary to implement the fourteen segment rigid link model we used to represent the runners body for the analysis: pelvis, back, torso, neck-head, and right left arms, forearms, thighs, legs and feet. Finally, the 3-D co-ordinates and the appropriate body segment

parameters, stored in data files, are used as input for the computer program RUN which was written in Matlab (5.0 version for Windows). The software package also includes a relational data base written in C for the management of the quantitative and statistical comparison among the computed kinematic and asymmetries indexes.
The program is capable of producing a large amount of data, all of which is not reasonable to report here. In particular it provides a unique array of graphic display to allow the user to instantly diagnose and treat asymmetry problems. When we start to run the program we can see the main menu on the screen. It has five menu options. 1) Enter data: after an automatic identification of the main running cycle events (stance and flight phases), this routine normalizes the time over the running cycle. 2) Pre-elaboration: calculates internal joint rotation centers using markers co-ordinates and the measured anthropometric parameters. 3) Trajectories: plots and compares left right internal joint centers. 4) Angles: calculates relative and absolute joint angles and shows average angle patterns as a function of running cycle. Automatically identifies meaningful asymmetries. For each joint, left-angle versus right-angle plots are also used to evaluate asymmetries. 5) Post elaboration: stores the data in the data base. In our study we estimated the running phases by using an algorithm based only on kinematic. To detect the foot-strikes the algorithm scans the modulus of the knee acceleration-time curve looking for the minimum, while the toe off instant was detected analyzing the mid metatarsal head kinematics in the vertical plane. In a preliminary test session the accuracy of the above procedure was validated by placing the treadmill on a force platform and simultaneously recording GRF and kinematic. The comparison of the data measured by GRF and estimated by kinematics evidenced that our procedure overestimates the contact time of about 19 ms (9% of the support phase). This is mainly due by an anticipation of the foot-strike identification (about 14ms).
Basic statistics (mean values, standard deviations and ranges) were computed for all the kinetic parameters presented here. The variability of the kinetic parameters was then analyzed their coefficient of variation (CV), computed as the percentage ratio between standard deviation and mean.

RESULTS: In table 1, the average group values and the CV values of the stride time (ST) and contact time (CT) over the different speeds are reported. As expected, at the higher speeds both the ST and CT decrease. The variability of CT is higher than that of ST. The data showed a trend of decreasing and increasing variability respectively for CT and ST as the running speed goes up.
In table 2 some average group values for thigh, knee, and ankle angles at different speed are presented. Figure 1 is an example of the lower limb joint rotation plots in the sagittal plane for a subject of this study (running speed 3.89 m/s). The plot compares left and right patterns. Sticks superimposed to the curves display ± 1 time the local SD. The average has been computed on 30 running cycles. In table 3 the corresponding parameters describing the joint angles, and the left and right differences are also available in numerical form.

Table 1 Average Group Values and CV of Stride Time and Contact Time at Different Speeds

	Stride Time (ST)		Contact Time (CT)	
Speed (m/s)	Average	CV	Average	CV
2.78	733 (16)	1.5 (0.4)	241 (7)	4.1 (1)
3.33	695 (12)	1.3 (0.4)	234 (10)	4.6 (3)
3.89	666 (15)	1.2 (0.7)	220 (8)	4.7 (2)
4.44	642 (14)	1.1 (0.6)	213 (6)	5.2 (3)

DISCUSSION: Because of the limited number of subjects the results presented here should be interpreted as an illustration of the method and not as a statistically significant analysis. In addition, caution should be taken in drawing conclusions for overground running conditions. While a number of studies have compared kinematic data between overground and

Table 2 Average Group Values for Thigh, Knee, and Ankle Angles at Different Speed

Speeds (m/s)	2.78	3.33	3.89	4.44
THIGH				
Max. flexion angle	31.4 (5)	29.8 (4)	33.3 (6)	33.9 (6)
Max. extension angle	15.5 (2)	18.1 (1)	21.6 (3)	24.7 (2)
Total ROM	46.9 (4)	47.7 (5)	54.9 (5)	70.3 (6)
KNEE				
Footstrike angle	23.1 (3)	23.8 (2)	24.9 (3)	24.8 (2)
Max. support extension angle	19.4 (4)	16.8 (3)	17.8 (3)	18.0 (4)
Max. swing flexion angle	79.4 (8)	82.2 (8)	86.5 (7)	89.0 (9)
Total ROM	60.2 (10)	65.4 (11)	68.7 (13)	71.1 (12)
ANKLE				
Footstrike angle	13.3 (5)	15.6 (5)	17.0 (6)	19.0 (6)
Max. support dorsiflexion angle	30.0 (6)	27.6 (6)	30.2 (6)	34.1 (8)
Max. swing plantarflexion angle	-17.1 (4)	-18.8 (5)	-21.3 (4)	-20.5 (6)
Total ROM	47.1 (6)	46.4 (7)	51.5 (7)	54.6 (7)

Table 3 Parameters Describing the Joint Angles, and the Left And Right Differences (N=30 Running Cycles) Corresponding to the Plots of Figure 1

	Left	Right	Asymmetry (%)
HIP			
Footstrike angle	15.1	18.3	-17*
Max. swing flexion angle	22.4	25.0	-10
Max. support extension angle	-12.6	-12.4	2
Total ROM	35.1	37.4	-7
KNEE			
Footstrike angle	17.2	15.3	8
Max. support flexion angle	42.3	39.5	7*
Max. support extension angle	17.2	15.3	8
Max. swing flexion angle	83.1	82.4	1
Total ROM	63.7	64.4	-1
ANKLE			
Footstrike angle	18.2	11.7	36*
Max. support dorsiflexion angle	32.8	26.3	20*
Max. swing plantarflexion angle	-12.5	-18.6	-33*
Total ROM	45.4	44.9	1

All angles in degree. *Significant asymmetries, $p < 0.05$

laboratory treadmill running, results are often contradictory and the exact similarities and differences in running mechanics between these modes are still unclear. One of the main limitations of our protocol, like any other based only on kinematic data, is the accurate detection of the footstrike and toe off instants for the automatic identification of the main running phases (see the section method for the error estimate). Our stride parameters are consistent with those reported in literature at similar speeds (Cavanagh & Cram, 1990) even if our stride times are slightly lower. Differently, the variability of our data was significantly lower (mean CV: 1.3 vs. 5.9 for ST; 4.6 vs. 6.3 for CT) indicating that the method together with the system produced very repeatable values. Once corrected the sign angular

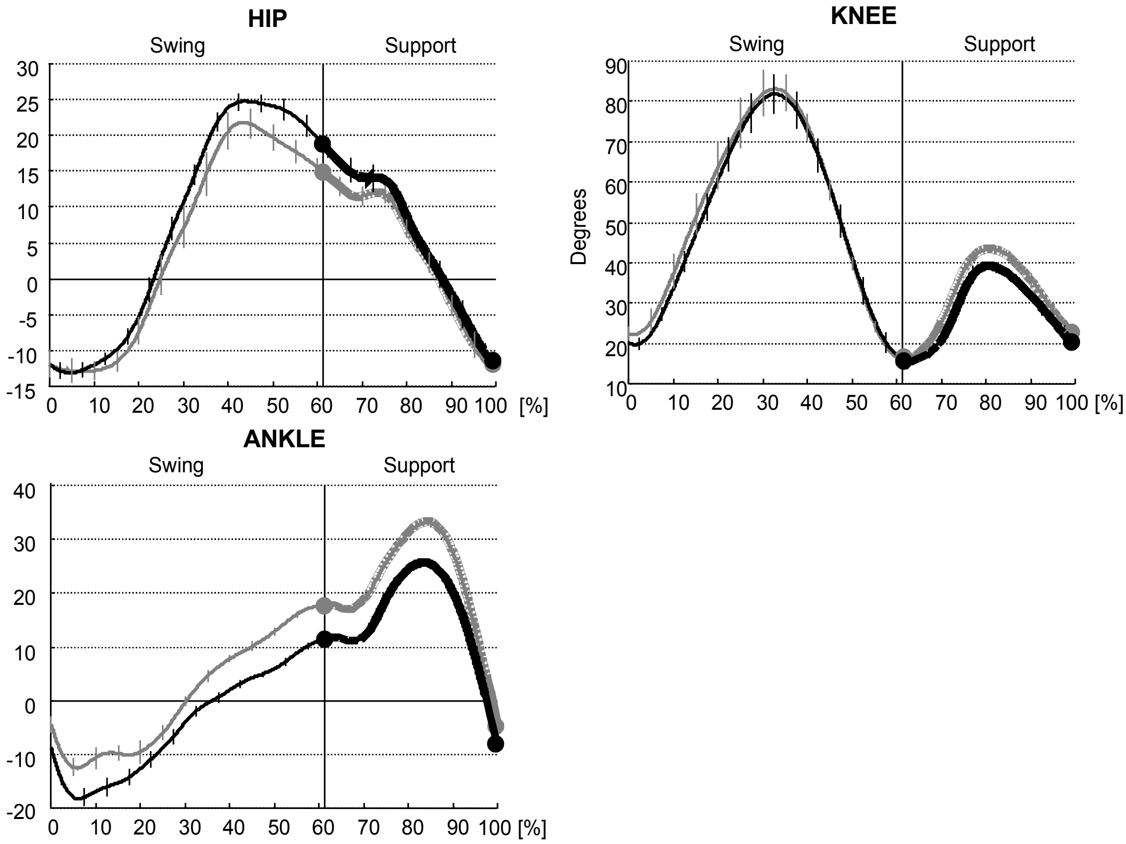

Figure 1 - Lower limb joint rotation plots in the sagittal plane for a subject of this study. (running speed 3.89 m/s).

conventions, the flexion-extension movements at the three lower limb joints observed in this study showed generally similar patterns to those reported by Hamill et al. (1991) for recreational female runners. Our sagittal ROM values for the knee, hip, and ankle joint were lower than those presented by previous researchers. Many factors, including subject group differences, data collection equipment, accuracy level of the measurements, data reduction and analysis procedures may explain the observed differences. The disagreement in joint excursions may be even due by differences in hip and ankle joint anatomical modeling and thus in thigh/pelvis and foot/shank angle computation.

CONCLUSIONS: The method and the user friendly software presented here seems to be an useful tool for scientists, trainers and athletes to assess and evaluate biomechanical data during running. The proposed model gives a good representation of the runner during its action. In particular the possibility to collect simultaneously data from both sides of the body appears to be very informative about asymmetries characterizing runners.

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