SIMPLIFIED 3-D MODEL FOR THE CALCULATION OF BODY SEGMENT KINEMATIC ASYMMETRIES IN CYCLING

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INTRODUCTION

Logically thinking, cycling appears to be a symmetrical activity, with each leg making an equal contribution. However, the structural base for the human movement, the musculoskeletal system, as well as its control, the neuronal system, are not perfectly symmetric. Marked differences may exist between the two body sides of normal healthy subjects, as well as athletes, in anthropometric dimension, in muscular weight and size and thus in the ability to produce force and power output. As evidenced by Vagenas & Hoshizaki (1986,1988) the systematic combination of structural and neuromuscular factors may be the source of bilateral differences frequently observed during the performance of symmetric physical activities.

The analysis of lower limb kinematics in cycling has generally been confined in the sagittal plane by using data obtained with a 2-D analysis. 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. Moreover, in previous models the external landmarks position is intended to compute directly the joint centers of rotation. This assumption in conjunction with the use of 2-D technique may results in large errors in linear and angular kinematics due to external/internal rotation of the limbs and to projection errors depending on the alignment of the segments with the film plane.

Given the potential relationship between asymmetries and performance and musculo-skeletal problems, the present work investigates the phenomenon of kinematic asymmetries by a simultaneous right and left analysis, providing a three-dimensional model for the calculation of body segment kinematics, by measuring the 3-D coordinates of a reduced number of external markers.

METHODS

Subjects of this study were 8 professional road cyclists, (age: 25.1 ± 4.0 yr.; body mass: 68.6 ± 6.4 kg), usually covering more than 25.000 km/year. The subjects used their own bicycle mounted on rollers fitted with an air-operated variable-load device. Data were recorded at three levels of external load (low, medium and high) with the cyclists pedalled at 90-95 RPM. Every acquisition lasted twelve seconds. The ELITE system motion analyzer (Ferrigno & Pedotti, 1985) was used with 4 TV cameras paired on the two sides of the cyclist to allow a double side 3-D analysis, with a sampling frequency of 100 Hz. Size of the passive retroreflective markers was 10 mm in diameter. The 3-D body coordinates (iliac crest, great trochanter, femoral condile, malleolus, fifth metatarsal head) and some anthropometric measures of the subject were the input of a mathematical model, providing the spatial kinematics of seven rigid segments belonging to the lower limbs (feet, shanks, thighs and pelvis), designed to match feasibility with accuracy. Due to the inevitable simplifications introduced, the use of the model is constrained to movement in which large rotation of body segments around their longitudinal axes are negligible like running, cycling and vertical jumping exercises.

To achieve reliable asymmetry assessments, in a preliminary test session the variability of the data was investigated considering the following sources of data variability: 1) The noise introduced by HW and SW components of the measurements system; 2) The errors associated with marker positioning. Such errors were considered as depending on two main elements: the experience of the operator to identify the needed anatomical repere points and the precision in placing a marker on known-visible target; 3) Modelling errors due to the assumptions and simplifications incorporated in the model (skin artifacts during the motion, estimation of body segment parameters)

RESULTS

The protocol reliability tests showed that the marker positioning is the most critical point while the noise of detection and reconstruction of 3-D data accounts for less than the 10% of the final data variability in the worst case. As expected the act of remarking increases the data variability along the vertical axis

Taking into account the results of the reliability tests, angular thresholds have been fixed for some angular variables to identify meaningful asymmetries of the subjects (Table 1).

	ROM	MAX	MIN
HIP	4°	5°	5°
KNEE	3°	4°	4°
ANKLE	2°	3°	3°

Table 1. Angular thresholds. Values are in degrees. ROM refers to the range of motion and MAX and MIN refers to the maximum and minimum angular joint flexion.

Tables 2, 3 and 4 show the mean and the standard deviation of some of the variables used for the analysis. They have been computed by grouping right and left patterns of the whole group.

For the knee and the hip joint our range of motion values were very similar to what was found by Cavanagh and Sanderson who reported respectively 74° and 43° in elite pursuit cyclists. Considering the ankle joint, our values were considerably lower than what presented by Cavanagh (50°). In comparing angular values among different subjects should be considered that variables such as seat height and angulation and handlebar position highly affect joint angles and range of motion of the lower limbs.

As it can be seen, when the load changes there is an evident trend of some variables. For example, the range of motion decreases at the hip joint, when the load increases, conversely it increases at the knee and at the ankle joint.

LOAD	Hip	Knee	Ankle
Low	41.8(2.5)	72.2(1.6)	17.3(7.9)
Medium	39.5(3.2)	73.1(2.3)	22.4(7.0)
high	38.2(3.5)	79.0(3.0)	26.6(7.4)

Table 2. Joint range of motion (degrees)

LOAD	Hip	Knee	Ankle
Low	94.1(5.8)	75.2(5.0)	114.3(9)
Medium	98.9(6.0)	73.6(4.1)	106(7.9)
high	98.1(4.0)	74.0(3.5)	96.3(7.1)

Table 3. Maximum joint flexion (degrees)

LOAD	Hip	Knee	Ankle
Low	135.1(5.0)	144.2(4.1)	130.3(3.1)
Medium	139.6(4.1)	148.2(3.6)	128.2(2.8)
high	141.4(4.3)	149.6(3.2)	126.1(4.2)

Table 4. Minimum joint flexion (degrees)

The individual examination revealed as the majority of athletes were characterized by significant left-right differences in the selected lower leg angles and in some linear kinematic parameters. These asymmetries appear to be subject, joint and pedalling modality dependent. In table 5, the significant asymmetries in the joint range of motion (ROM), maximum (MAX) and minimum (MIN) joint flexion are outlined. The data refers to the medium level of external load.

	HIP			KNEE			ANKLE		
	MAX	MIN	ROM	MAX	MIN	ROM	MAX	MIN	ROM
S1								-6.7°	4.8°
S2							3.4°	3.1°	
S3				-4.2°	-3.7°		5.1°	3.9°	
S4					-4.1°			3.2°	3.5°
S5	7.8°	8.0°					-5.9°	-4.3°	
S6	7.2°	10.1°		-5.0°					
S7		-6.2°					-5.1°	-5.2°	
S8					6.6°			-6.1°	-8.4°

Table 5. Significant differences of range of motion between right and left patterns. The positive sign means the dominance of the right on the left. Values are in degrees. Only the values above the threshold values outlined in Table 1 are reported.

The ankle is the joint more frequently characterized by angular asymmetries. They involve all the three angular variables selected. Hip and knee asymmetries are shown in a reduced number of subjects, and refer to maximum and minimum flexion only.

Anatomical asymmetries of the athletes may be the cause of the observed corresponding asymmetrical trends in the kinematic of the lower limb via automated compensatory mechanisms. As pointed out by Vanden-Abeele (1980) this could be the result of an interaction between the functional asymmetries of the axial neuromotor mechanisms on those of the lower limbs.

CONCLUSION

The method presented here seems to be an useful tool to assess and to evaluate biomechanical data during cycling. The proposed kinematic model gives indeed a good representation of the cyclist during his action. In particular the possibility to collect simultaneously data from both sides of the body appears to be very informative about asymmetries characterizing cyclists. Future investigations should be directed to select the more meaningful variables for asymmetries evaluation and to relate them to lower limb dominance, structural and strength asymmetries and eventually to the injury history of the subjects.

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