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ANALYSIS OF FORCES AND ANGLES OF THE LOWER MEMBER'S ARTICULATION DURING THE HUMAN GAIT

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Abstract. Biomechanics is the science that aims to study biological systems as well as understanding the behavior of the body during the performance of daily activities. The human march is the focus of countless works involving the understanding of its variables and the preservation of the systems that make up the human body. Human gait studies are carried out by means of kinematic data collections, whose objective is the study of motion, and kinetic data, in order to analyze the forces involved. This work focuses on the study of kinetic and kinematic variables. Volunteers, with no history of pathology related to human gait, were submitted to a controlled speed walk, and by means of two parallel positioned force platforms and a Qualisys image capture system, the reaction force of the Impact of the lower limbs on the ground and movement of the lower limbs during gait. The angles of the joints were found from a routine in Matlab through an equation involving routines to determine the Hip joint center and Cardan Angles. Strength data on the lower limbs were also analyzed in Matlab, distinguishing the force components at the foot pressure center in the three directions. The understanding of these variables may help in the diagnosis and treatment of human gait pathologies.

Keywords: Biomechanics; Forces; Angles of the joints; Lower limbs; Human Gait

1. INTRODUCTION

With the Development of Biomechanics, Science that aims at the study of the human body, results that represent the movement of the human body are being analyzed in order to contribute to the prevention and treatment of pathologies related to human walking. (MCARDLE et al., 1998).

A walking cycle is the time interval, or a sequence of movements, required for a member to touch twice in the ground. For each foot, it is possible to easily identify two phases of the Human March: a stance phase and a swing phase. The stance face is defined as a percentage of the cycle in which the foot is in contact with the ground, period between the touch of the ancle in ground and the detachment of the fingers. The swing phase corresponds to the period in which there is elevaction of the foot of work and the soecond touch of the foot in the ground. (ROSE (1998), RIBEIRO (2016)).

The human body can be defined as an articulated system in complete static or dynamic equilibrium, where the internal forces produce joint movements in the segments of the body. Through simplifications of the locomotor system, it is possible to represent a model that allows the simulation of transfer of internal forces in the joints, as well as the angular movement of the same. (RIBEIRO, 2015). The kinematic and kinetic data can be collected through ergonomic treadmills and platforms of force, respectively. With the data collected, it is possible to determine curves representing the angular motion in three directions for each lower limb joint and the ground reaction force for each phase of the human gait. (AMADIO, 2000)

When it comes to the analysis of the human body, reference should be made to the points and directions defined by the International Society of Biomechanics. (WU, 2002) The bony protuberances of the lower limbs are used as a

reference for kinematic analysis, and the direction Fz (Vertical), Fx (mid-lateral) and Fy (antero-posterior) are used capture forces in kinetic analysis. (RIBEIRO, 2016)

The angles of the joints can be determined from the Cardan Angles method, which by means of a rotation matrix between the analyzed segments estimates the angle at the joint that connects them. (PHADKE 2011)

2. REFERENTIAL THEORY

2.1 Anatomical points

According WU (2002) and RIBEIRO(2016), for biomechanics conventions, the reference anatomical landmarks, represented in the Figure 1:

Figure 1: Representation Osseous protuberances recommended by the International Society of Biomechanics

At where:
- ASIS: Anterior Superior Iliac Spine right/left
- PSIS: Posterior Superior Iliac Spine right/left
- FE: Lateral epicondyle.
- LC :The most lateral point on the border of the lateral tibia condyle
- MC: The most medial point on the border of the medial tibia condyle
- TT: Prominence of the tibia tuberosity.
- MM: Distal Apex of the medial malleolus.
- LM: Distal Apex of the lateral malleolus.
- IM: The inter-malleolar point located midway between MM and LM

2. 2 Hip joint center

The center of rotation of the hip, which allows the movement of the femur relative to the hip, can be determined by predictive and functional methods. In addition to the mechanical functionalities, the hip joint center is of great importance for a Kinematic study of the human gait, since it is commonly used as a reference system for determining coordinates of the limbs under analysis and angles of the lower joints, mainly hip and thigh. CAMOMILLA (2006) and RIBEIRO (2015), when comparing the method of estimation of the center of the hip joint, good results were found the for the method called Bell, this method used in the work.

BELL (1990) presents an estimation method, represented by equation 1, through anthropometric data previously collected. Since the joint angles represent the momentary motion, an instantaneous HJC position can be estimated from the data of the reflective markers captured by the Qualisys system during the walking of a volunteer under a speed control speed. (VIMIEIRO, 2008).

$$X = -0.19\,PW;$$
$$Y = -0,30\,PW;$$
$$Z = 0,36\,PW;$$

(1)

Where PW is the momentary distance between the reflective markers positioned in the ASIS bony protuberances.

2.3   Angles Cardan

According to BAKER (2011) and (VIMIEIRO 2008), the angles of the joints can be represented through the Cardan Angles that through a rotation matrix "R" transforms the coordinate system "B" into "A", and vice versa.

[B]=[R]*[A];

(2)

Considering the sequence of rotation extension(γ) in the z-axis, adduction (α) in x, and internal rotation (β) in y, we can represent "R" by equation 3.

R= Ry(β).Rx(α).Rz(γ)

(3)

The rotation matrix according to this sequence can be represented by equation 4.

$$R = \begin{bmatrix} \cos\beta\cos\gamma - sen\beta sen\alpha sen\gamma & \cos\beta sen\gamma + sen\beta sen\alpha\cos\gamma & -sen\beta\cos\alpha \\ -\cos\alpha sen\gamma & \cos\alpha\cos\gamma & sen\alpha \\ sen\beta\cos\gamma + \cos\beta sen\alpha sen\gamma & sen\beta sen\gamma - \cos\beta sen\alpha\cos\gamma & \cos\beta\cos\alpha \end{bmatrix}$$

(4)

3. METHODOLOGY

When it comes to human gait, two strands are analyzed, kinematics, motion analysis, and kinetics, forces involved in limbs. The study in question is based on data collected from 7 volunteers, from 21 to 30 years old, with no history of pathology associated with human gait, submitted to walking, with a velocity maintained at 4,5 km/h, on a treadmill instrumented with two force platforms and 6 arranged cameras in order to capture the entire movement of the lower limbs.

The study of soil reaction forces during walking was based on data collected by force platforms, represented by Figure 2, positioned under the treadmill, in parallel, allowing the walking cycle of each foot to be analyzed separately. The analysis of forces has as main objective, the study of the stance phase, since during the swing phase of the analyzed foot, there is no contact with the ground and the weight is fully supported by the other foot.
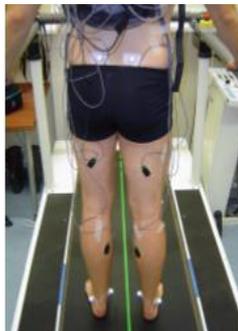

Figure 2: Demonstration of the capture of the force through the force platform.

The relative movement of the lower limbs may be represented by the angles of the joints connecting them. It is of great importance the analysis of the members during the whole cycle, observing points the rotations in the three directions. The kinematic data, which represent the movements of the lower limbs during the walk, were collected through the Qualisys® system, composed of 6 cameras that emit ultraviolet rays, reflected in the reflective markers located in the bony protuberances, represented in Figure 3, and returned to the camera representing the Movement of that marker in time.
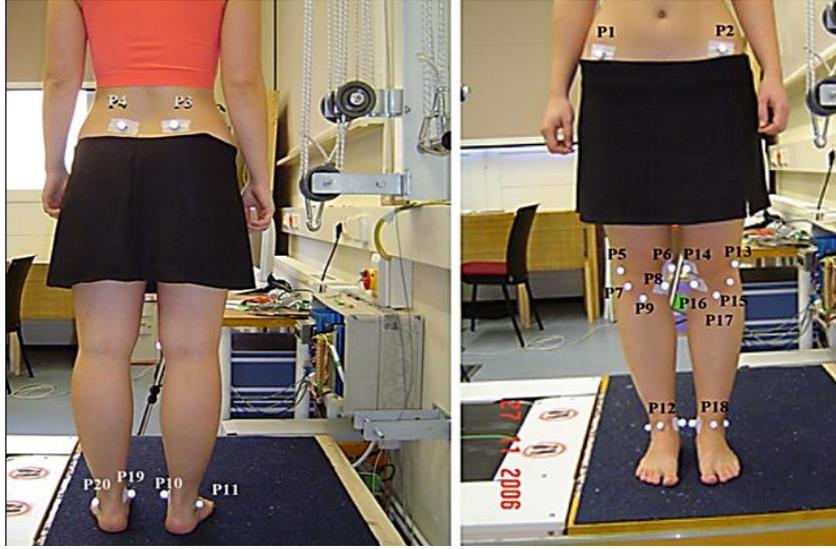
Figure 3: Reflexives markers fixed in volunteers.

The data are exported directly to the Matlab, where they are treated and interpolated in order to reproduce the movement of bone protuberances over time. The bony protrusions are used as reference systems for determining a coordinate system of the limbs under analysis, hip, thigh, leg and foot. For the thigh, is still used, an estimated point from a routine based on the Bell method (1991), represented in Equation 1 to determine the center of hip rotation.

With all the coordinate systems mounted on the lower limbs under study, it is possible to determine, by means of the Cardan Angles Method comparing the matrix indicated in equation 4, with any 3x3 rotation matrix, the angles representing the movement in each one of the directions, rotation extension (γ) in the z-axis, represented by equation 5, adduction (α) in x, represented by equation 6, and internal rotation (β), represented by equation 7.

$$\gamma = \tan^{-1}\left(\frac{-R_{21}}{R_{22}}\right)$$

(5)

$$\alpha = sen^{-1}(R_{23})$$

(6)

$$\beta = \tan^{-1}\left(\frac{R_{13}}{R_{33}}\right)$$

(7)

4. RESULTS AND DISCUSSION

Kinematic and kinetic data were collected, treated and analyzed using a routine developed in Matlab. The final curves were found, in both cases, through a mean percentage that best represents the analyzed group. First, the ground reaction force, and then the angles of the joints, will be analyzed.

The anthropometric data of the volunteers are shown in table 1.

Table 1: Anthropometric data of volunteers

Voluntary	Age	Weight (kg)	Height (m)	PW(mm)
1	30	79,4	1,77	265,81
2	21	77,4	1,68	281,43
3	29	93,3	1,79	256,18
4	31	77,5	1,72	253,98
5	22	61,7	1,57	239,98
6	25	55,3	1,65	234,43
7	24	66,8	1,71	204,17

4.1 Ground reaction forces

A reaction force to capture, separately, for each of the feet in order to observe the cycle of each foot in the last. Positive results in the z direction, vertical force, indicate that they are in the supporting phase and in contact with the soil, already null values indicate that they are in the balance phase. By analyzing the force in the antero-posterior direction and direction, positive values indicate acceleration and negative values indicate deceleration. The force in x, mid-lateral direction, representation of supination movement, positive and prognostic values, negative values.

The values of the ground reaction force of the volunteers do not represent individually. To analyze the group, the percentage strength was used in relation to the body weight, and it was possible to visualize for the group, a percentage magnitude in each stage of the tread.

The graph representing, as a percentage, a mean soil reaction force for the analyzed group is shown in Figure 4.
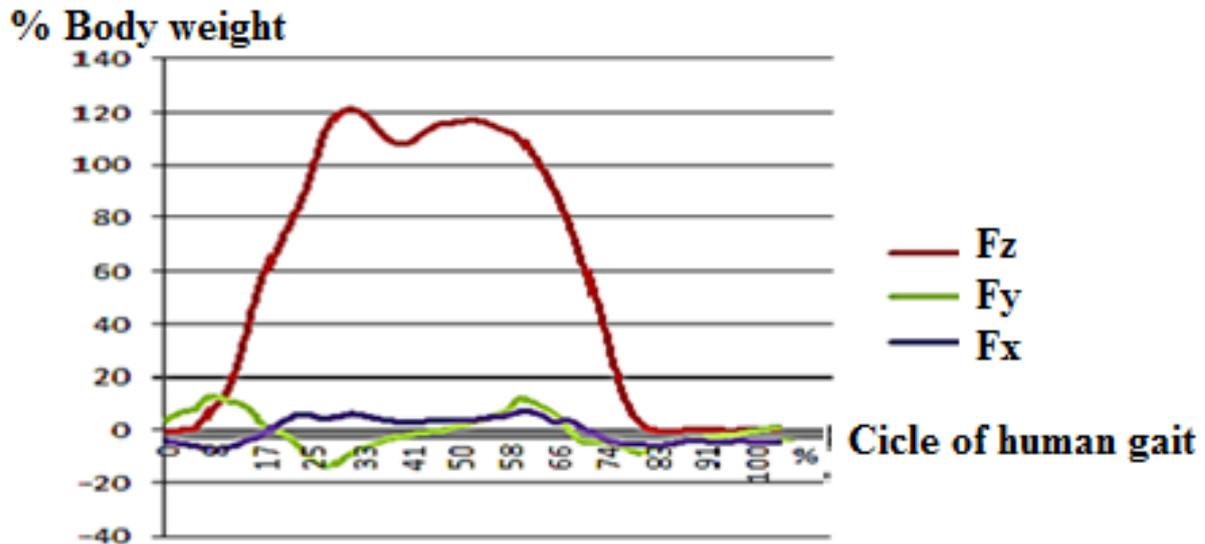

Figure 4: Representation of the soil reaction force for the group in the three directions.

The forces in the three directions were analyzed separately for the group, and the mean percentage value of the 7 bearers was used for the study.

The Fz reaction force represents, in addition to the weight of the feet, the force associated with the impact and thrust of the foot on the ground. It is noted that the foot starts in the stance phase and has increased magnitude as it approaches the ground, having a first peak represented the touch of the foot in the ground, followed by a tendency to stabilizetion and transfer of force to the foot in analysis, starting to one increasing until the second peak, characterizing the impulse for the swing phase, and finally, decreasing until total suspension of the foot. It is also noted that the peaks show a greater magnitude than the weight of the analyzed individual, this happens due to the increase of speed and acceleration of the foot in contact with the ground. The mean value, at a speed of 4.5 km/h for foot impact on the ground, corresponds to 120% of body weight. In the impulse, it corresponds to 118%.

By analyzing the force Fy, at the touch of the ground foot, we perceive a maximum deceleration, close to the maximum peak of the force Fz. After this point, there is an acceleration representing the beginning of the swing phase, which shows maximum, next to the second peak of the force Fz. Therefore, an acceleration is observed for the start of the swing phase, and a deceleration for the stance phase.

By analyzing the Fx force, it is noticed that there is a tendency to supnation at the moment of touch of the foot in the soil, presenting positive values throughout the period.

4.2. Angles of joint.

The first step in determining the joint angles was to determine the hip joint center during the walk. The average values found are shown in table 2. With the hip joint center point and the position of the other markers, it was possible to create of the systems and coordinates and the determination, by the Cardan method, of the angles corresponding to the movements of the members connected by the joints.

Table 2: Position of the volunteers' hip joint center

Voluntary	x (mm)	y(mm)	z (mm)
M1	95,692	-50,504	-79,743
M2	101,316	-53,473	-84,430
M3	92,228	-48,676	-76,856
M4	91.435	-48,257	-76,195
F1	86.394	-45,597	-71,995
F2	84.418	-44,554	-70,348
F3	73,079	-38,570	-60,899

In addition to the study of soil reaction forces, the mean values of the seven volunteers were used to characterize the curve that best represents the angles of the articulations during walking.

For the hip, the movement in the three directions can be represented by Figure 5. In the Figure 5-A) the peak correspondes to the touch of the foot in the ground where there is maximum extension of the thigh in relation to the hip, and the negative vale characterized maximum flexion, for swing phase. The variation of flexion/extension is of approximately 9.6° to 32.1°, presenting a total aplitude of 41.7°. For the adduction / abduction movement a total amplitude of 14° was observed, varying from -4.8° To 9.2°. The internal/external rotation movement has a variation of 22.51°, ranging from 14 ° to 8.5°.
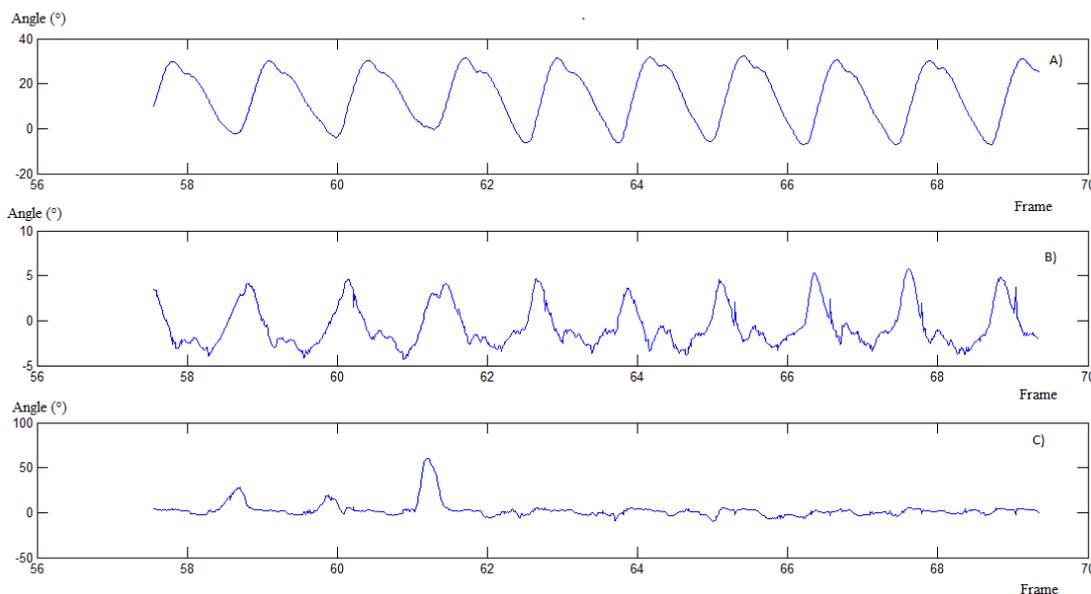

Figure 5: Representation of hip angles. A) Flexion / Extension. B) Adduction / Abduction. C) Internal / external rotation

Analyzing the angles for the knee, there is no movement in the x, adduction/abduction direction. The flexion / extension movement and internal/external rotation are shown in Figure 6.

For the flexion / extension movement, there is a variation of approximately 64°, with a minimum of -66° and a maximum of -2.3°. As for the internal / external rotation movement, values of -7.4° to 26.6° were observed, with a total amplitude variation of 34°. Comparing the values found for the hip and knee, we present a greater total amplitude, for both movements, for the knee joint, which guarantees a greater mobility to this joint. The knee flexion/extension movement presents a curve similar to the ground reaction force curve, with two very characteristic peaks, one with maximum extension at the touch of the heel in the ground and one with extension close to the maximum at the end of the support phase and beginning of the balance sheet phase.

The magnitude of the angles for the ankle is very low, about 5° in the three directions, and due to the contact of the foot in the ground, causes noises due to the movement of the superficial markers on the foot impact on the ground, therefore it will not be presented.
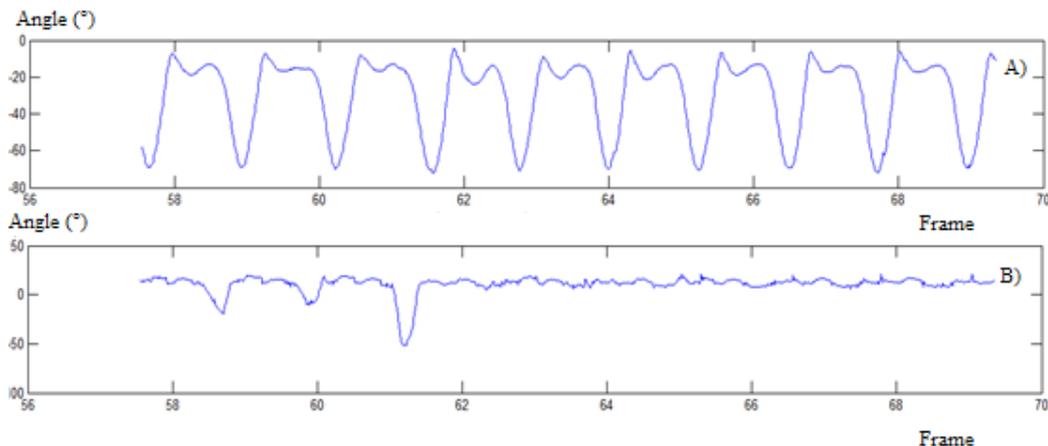
Figure 6: Representation of knee angles. A) Flexion / Extension. B) Internal / external rotation

5. CONCLUSION

The angles of the joints of the lower limbs during the human gait were calculated from the Cardan function, and through the graphs it was possible to visualize the behavior of the joints during the walk. Likewise, the soil reaction forces were analyzed and the percentage curve of the volunteers that came closest to the group mean was used, it was possible to visualize and observe the magnitude of the forces to which the feet are subjected. The results found for the angles of the lower limb joints and ground reaction forces, besides helping to understand the behavior of the segments during the human gait, can be used to simulate prototypes of prostheses developed to perform this type of movement.

6. ACKNOWLEDGEMENTS

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