THE KNEE KINEMATICAL COORDINATION INVESTIGATION OF AN IMC CHILD DURING GAIT

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Abstract: Cerebral palsy patients (cerebral infirm motor or IMC in French) present kinematical and kinetic differences with normal subjects and between their own left/right sides. These kinematical differences can be in relation with segmental coordination differences. The aim of this study is to characterize such segmental organization between the shank and the thigh for a cerebral palsy child in order to compare this coordination between left/right sides with the method of relative phase. A population of healthy subject let to validate our method with Byrne et al.'s results [1]. A young cerebral palsy child constitutes our clinical population for this study. A motion capture system (Vicon250) was used in order to capture movements of shank and thigh in sagittal plane. All the subjects walk at their self-selected speed along a horizontal walkway (9m). The angular position and angular velocity (calculated from position) of the shank and the thigh are computed as Byrne et al. After validation of our healthy results with Byrne et al's ones, we can describe the patient's curves. For him, the same path is observed between left and right sides. However, right side globally leads the left side. An important part of the stance phase presents the same temporal organization between these two sides.

Introduction

Cerebral palsy come from difficulties observed during childbirth or before this phase (antenatal). Young patients with cerebral palsy are associated with damages in their central nervous system [2]. According to the touched part of the nervous system, several cases of cerebral palsy can be described: lesions on pyramidal system can be associated with several cases like spasticity, hypotony…; lesions on brainsterm motor nuclei are associated with athetoid; lesions on cerebellum are associated with ataxy. Several paresies can be observed according to the number of members reached: monoplegy, diplegy, triplegy… These nervous damages induce several abnormalities: primary (directly in relation to central nervous problems), secondary (growth disorders) and thirsty (compensations of the primary and secondary disorders). The two last abnormalities depend on the primary ones. Gage defines five primary abnormalities like loss of selective control, abnormal muscle tone and relative imbalance between agonist and antagonist muscles. Such primary abnormalities are then associated with several adaptations, which can be quantified by Gait Analysis since such patients present difficulty in coordination learning. This gait analysis can be classified on two important views. The first one corresponds to kinematical data that let to describe spatial movement. This analysis let to describe what happens during gait cycles. The second view corresponds to kinetic approach. This one is based on kinematical data, anthropometrical and inertial models in order to describe forces and powers of each articulation ([2],[3]). This study, which is focused on segmental coordination, is only based on kinematical data.

Kinematics data (positions and velocities) suggest the existence of a spatial and temporal movement organization in order to produce a a healthy people fluidic gait [4]. This gait is based on the use of a minimum of energy in order to produce the less fatigue as possible. For healthy populations, this particular organization has been studied with relative phases based on positions and velocities [1][4]. A such method application to quantify inter-segmental or inter-articular coordinations is in relation with Bernstein approach. In this approach, he tends to explain how the body exchanges the informations of disturbance with the neuromuscular system. Moreover these informations are associated with several behaviors and several variables which could interact with the system [5]. Then, the hypothesis of Bernstein rests on the simplification of the different inter-segmental organizations combinations in order to be treated by our limited number of neurons. In this prospect, the relative phase let to consider, for instance, the relation between two biomechanical quantities (position and velocity in this study) between two segments. Such approach has been used in order to depict modifications on behaviors when an adaptation is imposed [4]. Gait can be consider as cyclic and dissipative movment.

IMC develop different kinematical patterns with disequilibrium between right and left legs that consist, for instance, on a loss on angular amplitude for only a lower limbs' side, figure 1.

This should be particularly shown on knee angles. For instance, it is possible to discern some angular amplitude differences whether significant point of time seem similar.

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The aim of this study is to verify if these angular differences are dependent with coordination differences.

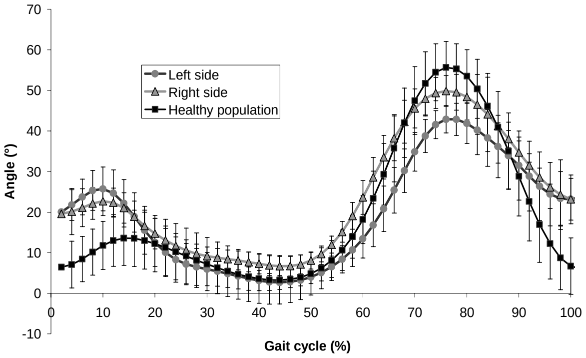

Figure 1: Knee flexions of IMC child and healthy population during gait cycle.

Materials and methods

In this study, the dissymmetric kinematical pattern of one IMC adolescent (10years; 34.5kg; 1m36) is studied. Then, these data are validated by a comparison with a reference pattern obtain after the study of fourteen healthy adolescents (13.57years±0.75; 36.28kg±6.6; 1m46±0.1). To collect all the data and for all the subjects, parental permissions and consents were obtained. The healthy population is compared and validated with Byrne et al. data [1]. All the subjects walk at their self-selected speed along a horizontal walkway (9m). Kinematics data were collected with a motion capture system (Vicon) with five cameras as describe in figure 2.

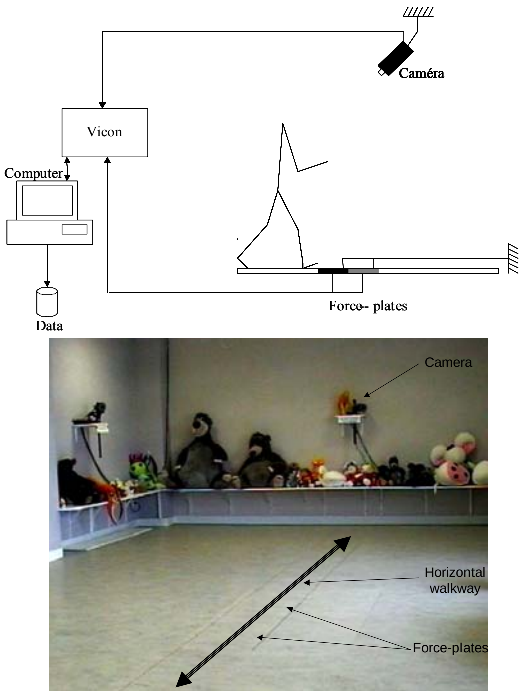

Figure 2: Gait analysis.

Gait cycles (strides) were defined between two heel strikes for the same side. Strides are determined with two AMTI force-plates (1000Hz). Kinematical model is based on markers positioned on the lateral malleolus, the lateral epicondyl and greater trochanter. For the video capture, the frequency was 50Hz. Only the coordination between shank and thigh were considered in this paper. The considered angles are obtained from the studied segmental axis with respect to the antero-posterior direction in sagittal plane. During three strides, velocities were computed from position measurement in the sagittal plane before using a Butterworth low-pass filter (6Hz). In order to obtain relative phases [2], phase planes were constructed with angular position (xx') and velocity (yy') for thigh and shank in sagittal plane in reference to horizontal (figure 3).

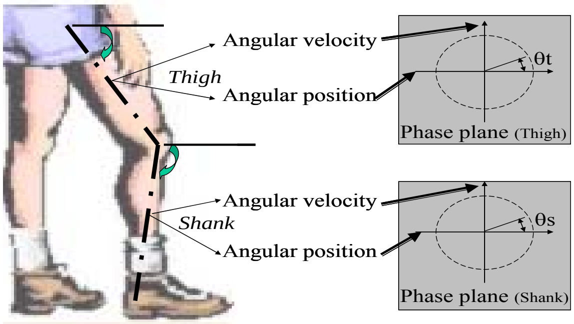

Figure 3: Method use to calculate relative phase.

This phase plane let to verify the continuity of data during a complete gait cycle. As explained figure 3, phase angles (°) (θ_s for the shank and θ_t for the thigh) were computed from the phase plane of each segment. Relative phase (°) corresponds to the difference between two angular phases. Then, in this study, the relative phase between the shank and the thigh was defined as:

$$\Psi_{s-t} = \theta_s - \theta_t$$

This variable let to describe the temporal organization between the two segments studied here during a gait cycle. The sign of Ψ_{s-t} is in relation to the temporal organization between these two segments. A positive value of Ψ_{s-t} indicates that the shank leads the thigh. Oppositely, a negative value of Ψ_{s-t} indicates that the thigh leads the shank. In order to make the understanding of such data easy, piecewise descriptions are realized according to the fact that several parts of the pattern are defined between two points where a changing of sign is observed.

A Mann-Whitney U test was realized to compare gait velocities for patient and healthy subject. The p-level used to determine the statistical difference between these two velocities is 0.05.

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Results

The results are divided in healthy subjects' results and IMC patient's results. The healthy population results are compared with Byrne et al.'s one in order to validate the method used. Figure 4 presents our results.

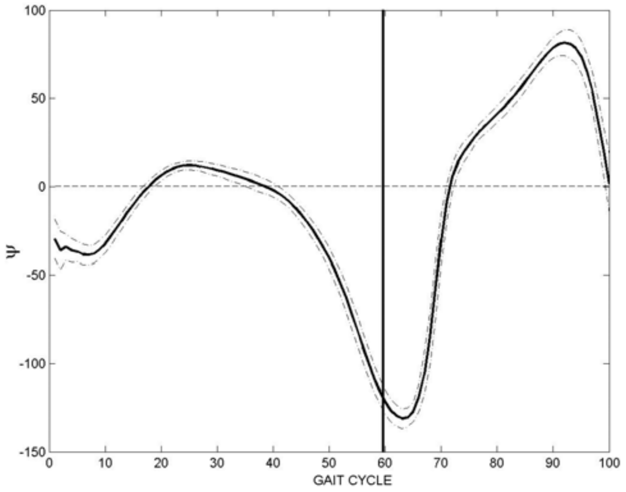

Figure 4: Relative phases (°) between shank and thigh for healthy population during gait cycle. The mean ± standard deviation is presented. Vertical line corresponds to foot off.

Byrne et al. computed their data only during stance phase. The comparison between their results and our results during this gait phase shows the same path. Then, we assume that the method employed with healthy subjects can be use with IMC subject.

About the IMC subject, coordination between thigh and shank is exposed on figure 5. During the braking phase, Ψ_{s-t} is negative, which indicates that thigh is ahead of the shank. During the middle of the stance phase, Ψ_{s-t} becomes positive, which indicates that the shank is ahead of the thigh during the stance phase. When Ψ_{s-t} becomes close to zero, both the two segments are nearly in-phase. During the propulsion phase, Ψ_{s-t} becomes more and more negative, which indicates that the thigh is leading the shank more and more. During the swing phase, Ψ_{s-t} start from negative values to positive values (71%), and then at the end of swing phase, from 71% to 100%, Ψ_{s-t} is positive that is to say that the shank is leading the tight.

The comparison between figures 4 and 5 reveals that the same path is globally observed between the healthy population and the IMC patient. Differences can be depicted during the braking phase (0-15% of gait cycle) and the middle stance (15-45% of gait cycle). These differences are due to earlier variation on relative phase evolution. Then, for IMC patient, the curves come from negative to positive values around 10% of the gait cycle. For the healthy population, this evolution appears around 17% of the gait cycle. The difference corresponds to an early Ψ_{s-t} change of sign and then, the IMC subject has his shank leading the thigh before the healthy subjects. Conversely, the thigh leads the shank earlier at the end of this gait phase.

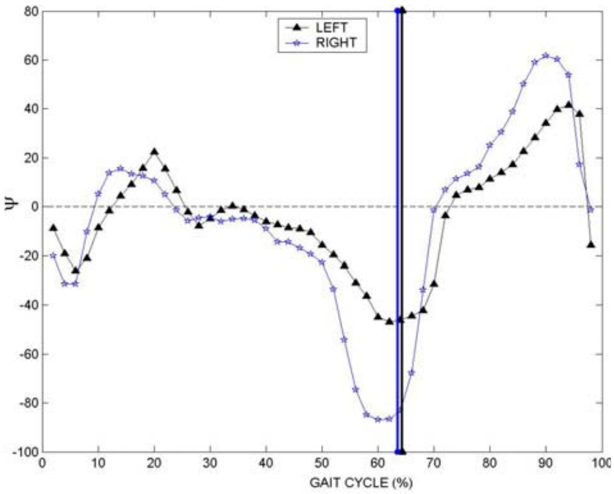

Figure 5: Relative phases (°) between shank and thigh for IMC child during gait cycle for right (gray) and left (black) sides. Vertical lines correspond to foot off by side.

The differences between right and left relative phases of the IMC child are analyzed from figure 5. The curves follow the same path and we notice that right side globally leads the left side. During braking phase (0-15%), relative phase is negative which indicate that thigh leads the shank. From 15% to ≈30% gait, relative phase is positive: shank leads the thigh. From 30% to 60%, relative phases from right and left sides are identical and negative then, thighs lead shanks. From 60% to ≈75%, the right side leads the left side. From ≈75% to 100%, relative phase is positive then the shanks lead the thighs.

For this subject, the mean gait velocity is 5.20km/h. The velocities between healthy population and cerebral palsy adolescent present no statistical difference (Z=1.48; p=0.13). The patient walks with the same velocity as the healthy population during this gait analysis.

Discussion

In this study, the healthy population allows to validate the data obtained [1]. This analysis shows that, for the cerebral palsy child studied, knee flexions between right and left sides (for the patient) and between patient and healthy population (figure 1) are different. Other differences are noticed (figures 4-5) on the shank-thigh relative phases which described inter-segmental coordination. For the patient, the results show that left side globally leads the right side. A dissymmetric behavior can be observed between 0 to 30% and 60 and 100% of the gait cycle. The first dissymmetric behavior seems to be directly in relation with knee flexion (figure 1). The left side presents a more important knee flexion angle than right side and the left curve of flexion decreases before the right curve around 10% of gait cycle, which is in relation with angular velocity of flexion. During the second knee flexion, the right side presents a knee flexion curve which increases before the curves of the healthy population and left side. The flexion velocity is globally more important for right side and healthy population. About the inters-segmental coordination, during a part of stance phase (≈30% to 60%) the cerebral palsy patient behaves symmetric since the two sides present similar relative phases. This part of relative phase curve is similar with healthy population one's. During the swing phase, cerebral palsy patient presents relative phase curves for which left side leads the right side. Moreover, the healthy population leads the cerebral palsy subject. This observation can be in relation with the less important angular position and velocity within the knee flexion for the patient than the healthy population. Then, the comparison between the knee angle and the relative phase between the shank and the thigh seems to show that relative phase curves let to precise temporal inter-segmental coordination. Indeed, the calculation used to obtain relative phase curves include segmental angular positions and segmental angular velocities.

For the healthy population, just the right side was studied here. This choice is in relation to other works, which develop symmetrical organization between the two sides [6]. These authors present several approaches which describe this phenomenon. Asymmetrical observation between left and right sides are associated with pathological gait [6]. However, the side studied for the healthy population has been chosen the same as in Byrne et al.'s article.

About the gait velocity, no statistical difference was observed between the two populations. The absence of difference between gait velocities can be in relation to the length of the walkway (9m). For each subject, the strides studied were localized around the middle of the walkway. This allows a comfortable gait velocity regarding to energy consumption ([7],[8]). Moreover, the absence of difference between these gait velocities let to compare directly relative phase curves between the two populations [9]. Then the differences observed between the relative phases curves are the result of specific behaviors due to cerebral palsy. Particularly, the most important modification between the two populations appears during the stance phase (during the braking phase). This result could be in relation to the control of movement during this stabilization phase. During this phase, the knee and the hip present a significant flexion in order to reduce the dynamic impact of the global weight on the foot. The result observed on relative phase curves can be in relation with the knee flexion during this braking phase. This braking phase is the result of different muscle contractions in order to protect the ankle against important torques (gait dynamic, weight) [10].

This analysis is based on kinematical data (angular positions and velocities). Like developed Davis [11], clinical gait analysis involves different people like physical therapist, clinical therapist, kinesiologist. Then, such kinematical data should be completed by an electromyographical approach. According to Sutherland, this global electromyographical analysis represents a mirror of muscular activity [3]. The coordination study can be in relation to spasticity with important co-contraction of antagonists muscles (Rectus femoris and hamstrings for instance). The relations between kinematical coordination and electromyographical activities can be explaining according two principles. The first one is directly dependant of the relation between torque produced by the antagonist couple and the velocity of movement [10]. The second principle [12] is in relation with the state plane identified during relative phase determination (figure 3). This plane is based on angular position and angular velocity. The yy' axe is contained between maximal and minimal angular velocities. For each of these two values, the segmental kinetic energy presents the more important values of the gait cycle. The segmental potential energy is maximum during the gait cycle on two points corresponding to the bound in the xx' direction. During the gait cycle, the quotient [kinetic energy/potential energy] varies. Then, the phase plane expresses the transfer between kinetic and potential energy. The difference between two quotients obtained with two segments let to precise the temporal organization (coordination) between these two segments.

However, differences between relative phase curves can be in relation to articular weakness [1]. These authors evaluated inter-segmental coordination of two populations which present different means of age. The differences observed on relative phase curves may be in relation with articular weakness of the elder population. Then, such study based on the inter-segmental coordination analysis with pathologic population could be coupled with a clinical analysis (articular magnitude evaluation with a goniometer), which let to quantify articular weakness of each subject.

Finally, the inter-segmental coordination studied in this work considers only the sagittal plane with relative phases. Gait deficiencies in the three dimensional space can be observed in cerebral palsy. Then a 3D analysis could improve these results. In this approach, dynamical systems analysis has been used to quantify an inter-segmental coordination with a biomechanical view. Such analysis could be completed with control theory and mathematical views to characterize the relationship between motor control and spatiotemporal inter-segmental configuration (figure 6).

The figure 6 (extracted from [13]) let to describe the movement organization. "Space" corresponds to movement amplitude and direction. These data corresponds in our study to kinematical analysis.

"Time" corresponds to inter-segmental or inter-articular coordination. Mechanical perturbations could induce several adaptations.

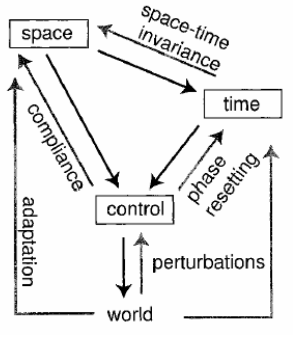

Figure 6: movement organization [13].

Conclusion

Clinical gait analysis (kinematical, kinetical and electromyographical analysis) is currently practiced for cerebral palsy patients, a clinical population who suffered of problem on coordination. This clinical gait analysis let to describe gait organization in space. After a phase of methodology validation with a healthy population, our approach associated such space organization with an analysis of inter-segmental coordination in order to precise how the movement is realized in time and space and the differences between left and right sides for cerebral palsy patient. Such gait analysis based on inter-segmental coordination could help the medical staff to evaluate the consequences of rehabilitation.

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