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ESCOLA SUPERIOR DE BIOTECNOLOGIA
PORTO

MOTOR CONTROL AND VARIABILITY OF GAIT IN ADULTS AND CHILDREN

by
Sofia da Conceição Novais Martins

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MOTOR CONTROL AND VARIABILITY OF GAIT IN ADULTS AND CHILDREN

Thesis presented to *Escola Superior de Biotecnologia* of the *Universidade Católica Portuguesa* to fulfill the requirements of Master of Science degree in Biomedical Engineering

by
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Resumo

A presente tese tem como objetivo avaliar experimentalmente a variabilidade cinemática das variáveis ângulos articulares e centro de massa dos adultos e crianças saudáveis.

A trajetória do centro de massa corporal é um parâmetro relevante no estudo da marcha humana, pois reflete o movimento de todo o corpo. Uma alteração na trajetória do centro de massa do corpo pode indicar uma manifestação clínica de uma patologia subjacente. Uma vez que reflete todo o movimento do corpo, o centro de massa pode fornecer parâmetros úteis para a avaliação global da marcha e, em combinação com outros dados cinemáticos e cinéticos, dar uma análise mais precisa, permitindo assim a aplicação prática.

A maturação da marcha é frequentemente modelada como um pêndulo invertido, e parece estabilizar na idade de 7-8 anos.

A variabilidade das variáveis da marcha em adultos e crianças podem ajudar a compreender a importância da cinemática do centro de massa no desenvolvimento de marcha durante a maturação.

Para a realização deste estudo foram selecionados dois grupos (adultos e crianças) num total de 20 indivíduos sendo estes fisicamente ativos, sem qualquer disfunção traumático-ortopédica e sem dificuldades na marcha independente. Os participantes caminharam ao longo do laboratório para a análise da marcha realizando 15 caminhadas, divididas em grupos de 5 suportando em vários pontos anatómicos marcadores refletores e ainda um sensor inercial possibilitando desta forma a obtenção dos ângulos articulares, a trajetória do centro de massa e aceleração do centro de massa para cada caminhada-teste.

Os resultados mostram que durante a marcha, as crianças apresentam maior variabilidade que os adultos devido ao facto que o controlo do sistema nervoso central está focado na progressão do centro de massa e não sobre a sua estabilização lateral, pois, através desde estudo pode-se concluir que nas crianças a variabilidade no eixo médio-lateral é maior do que nos adultos.

Palavras-chave: marcha, variabilidade, centro de massa.

Abstract

This thesis aims to experimentally evaluate the kinematic variability of joint angles and of center of mass in healthy adults and in children.

The trajectory of the body´s center of mass is a relevant parameter in the study of human motion, because it reflects the movement of the whole body. A change in the trajectory of the body's center of mass may indicate a clinical manifestation of an underlying pathology. Once it reflects the whole body movement, the center of mass can provide useful parameters for assessment of the global motion, and in combination with other kinematic and kinetic data provide a more detailed analysis, thus allowing the practical application.

The maturation of the march is often modelled as an inverted pendulum, and it seems to stabilize at the age of 7-8 years.

Observing the variability of gait variables in adults and children can help you understand the importance of the center of mass kinematics in the gait development during maturation.

For this study we selected two groups (adults and children) in a total of 20 physically active individuals without any traumatic-orthopedic dysfunction and no difficulties in independent walking. Participants took 15 walks along the laboratory for analysis of the gait, divided into groups of five, supporting at various points anatomical reflectors markers and also an inertial sensor, thus enabling the determination of the joint angles, the trajectory of the center of mass and acceleration of the center of mass for each walk-test.

The results show that during walking, children have greater variability than adults, due to the fact that control of the central nervous system is focused on the progression of the center of mass and not on its side stabilization. Through this study, we can conclude that the variability in children in the medial-lateral axis is greater than in adults.

Keywords: gait, variability, center of mass.

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List of abbreviations

acLAFE	Angle cycle left ankle flexion/extension
acLAIE	Angle cycle left ankle intra/extra rotation
acLHPAA	Angle cycle left hip abduction/adduction
acLHPFE	Angle cycle left hip flexion/extension
acLHPIE	Angle cycle left hip intra/extra rotation
acLKAA	Angle cycle left knee abduction/adduction
acLKFE	Angle cycle left knee flexion/extension
acLKIE	Angle cycle left knee intra/extra rotation
acLPROT	Absolute angles
acPOBLI	
acPTILT	
acRAFE	Angle cycle right ankle flexion/extension
acRAIE	Angle cycle right ankle intra/extra rotation
acRHPAA	Angle cycle right hip abduction/adduction
acRHPFE	Angle cycle right hip flexion/extension
acRHPIE	Angle cycle right hip intra/extra rotation
acRKAA	Angle cycle right knee abduction/adduction
acRKFE	Angle cycle right knee flexion/extension
acRKIE	Angle cycle right knee intra/extra rotation
acRPOBLI	Absolute angles
acRPROT	
acRPTILT	
C7	7th Cervical Vertebrae
CCD	Charge-coupled device
CMb	Center of mass of the body
COM	Center of Mass
DOF	Degrees of freedom
EMG	Electromyography
std%	The relative standard deviation

1. Introduction

1.1 Locomotor system

The anatomical position, by convention, is based on the posture of the human body and thus allows to describe the spatial positions of the organs, bones and the various components of the human body. In anatomical position, the human body should be upright (standing position), face forward and look oriented to the horizon, the extended upper limbs parallel to the trunk and palms facing forward, legs together, with the toes facing forward (Figure 1).

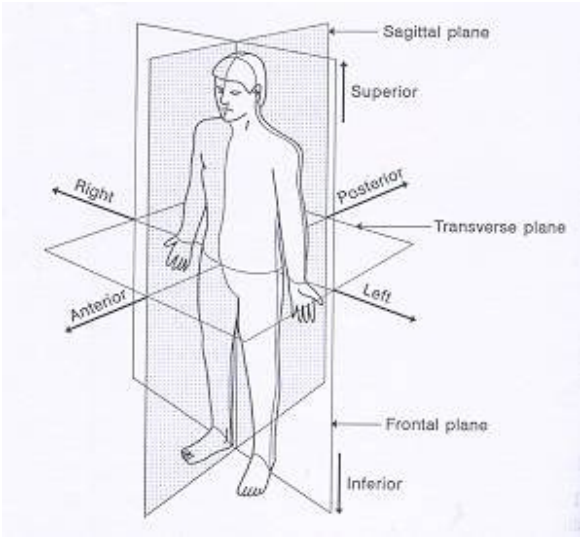


Figure 1.1 - The anatomical position, with three reference planes and six fundamental directions (Whittle, 2007).

The movement of the body members is described using reference planes:

1. Sagittal plane-divides the body into right and left portions.
2. Front plane-divides the body on top and bottom.
3. Transverse plane-divides the body into anterior and posterior portions.

In Figure 1.2 and Figure 1.3, it can be seen that there are three mutually perpendicular axes about which there may be a joint movement:

1. Flexion and extension - plantar flexion and dorsiflexion, respectively (these movements occur at the sagittal plane).
2. Abduction and adduction (these movements are found in the frontal plane).
3. Internal and external rotation - medial and lateral rotation, respectively (these movements occur at the transversal plane) (Whittle, 2007).

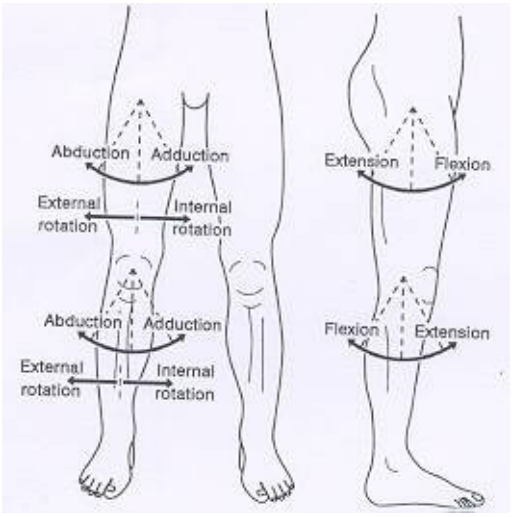


Figure 1.2 - Movements about the hip joint (above) and knee joint (below) (Whittle, 2007).

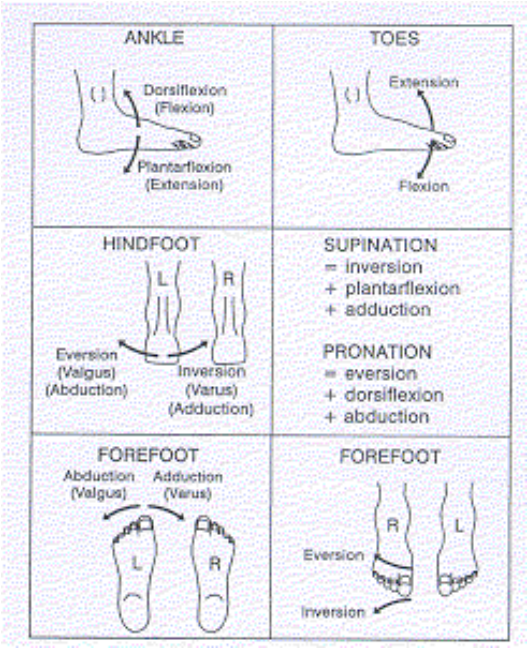


Figure 1.3 - Movements of the ankle, toes, hindfoot and forefoot (Whittle, 2007).

There are other terms which are used to describe the movements of body segments or joint segments are:

1. Varus and valgus - describe an angle of a joint towards or away from the midline, respectively (for example: knock knees - valgus, bowed legs - varus).

2. Pronation and supination - rotations around the longitudinal axis of the hand or foot (for example: pronation brings both hands thumbs together, supination of both feet bring soles together).

3. Inversion and eversion - plantar flexion, supination and adduction (for example: inversion – little toe medial and downwards, eversion - little toe laterally and upwards) (Whittle, 2007).

1.2 Gait cycle

The gait is one of the main human skills, being a common activity of daily living. It is a form of movement which involves the whole body (Estrázulas *et al*., 2005).

The gait cycle is the interval or time sequence between two successive events occurring from heel strike to heel strike of the same foot. The gait cycle is divided into two phases: the stance phase and the swing phase (Figure 1.4) (Whittle, 2007; DeLisa, 1998).

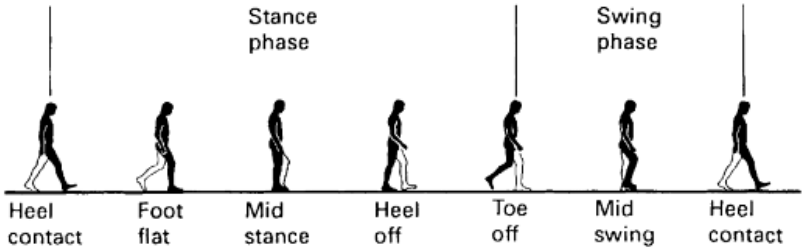


Figure 1.4 - Positions of the legs during a single gait cycle from right heel contact to right heel contact (Whittle, 2007).

The stance phase, which is also called as a support phase or contact phase lasts from the contact of the heel to the toe. The swing phase lasts from the toe off to the heel of the last contact (DeLisa, 1998).

1.2.1 Gait cycle timing

In Figure 1.5 we can see the times of contact of the heel and toe during a single gait cycle.

In each gait cycle, there are two periods of double support and two periods of simple support. Depending on the speed, the support phase persists about 60 percent of the cycle, the swing phase of about 40 percent, and each double support period of about 10 percent (Whittle, 2007).

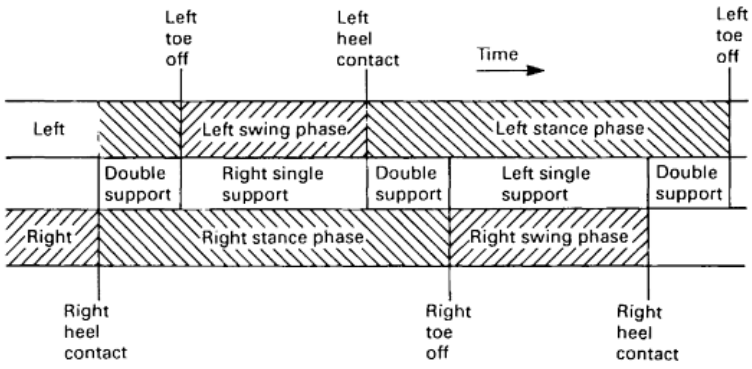


Figure 1.5 - Timing of single and double support during a single gait cycle from right heel contact to right heel contact (Whittle, 2007).

The analysis of a person's walking pattern identifies the different movements occurring in the joints. Thus, the gait phases have a functional purpose and a critical pattern of selective synergistic movement (Perry & Burnfield, 2010).

1.3 Walking and gait

Normal human walking can be defined as "a method of locomotion which involves the use of both legs, alternatively, to provide both support and propulsion". Thus the gait is the form or walking style instead of the process itself. Consequently, it makes more sense to speak of a difference in gait between two individuals than about the difference in walking (Whittle, 2007).

1.3.1 History

Throughout history there has been a progression in studies of human locomotion.

In 344 BC, the famous ancient Greek philosopher, Aristotle (384-322 BC) analyzed the quality of the movement of animals, in order to analyze the phenomenon geometrically. He drew an animated mechanical model according to the number, type of joints and its functions in the body of an animal and he was the first to describe the action of the muscles and joints movements during locomotion (Medved, 2001).

Aristoteles stated that if a subject walked along a wall with a reed dipped in ink attached to his head the line drawn by the reed would not be straight, but in zig-zag (Baker, 2007).

The first experience in gait analysis was performed by Giovanni Alfonso Borelli (1608-1679), a pupil of Galileo, who correctly deduced that there is medio-lateral movement of the head while walking. Borelli also studied the mechanics of muscles and was the first to conclude that the forces within the tendons and muscles are considerably larger than those loads imposed externally. He also determined the center of mass of the body by balancing the body around a prismatic pivot in three mutually orthogonal planes (Medved, 2001; Baker, 2007).

In the 1870s, Marey and Muybridge were two pioneers in the kinematic measurement. Marey made several photo exposures, on a single plate of a subject who was dressed in black, except for brightly illuminated stripes on the limbs. Muybridge, using cameras, has shown that when a horse is trotting, there are times when it has all its feet off the ground at the same time (Whittle, 2007).

An important application of science in the mechanics of human motion has been studied by Braune and Fischer during the nineteenth century. They comprised the human body as rigid in form of a series of dynamic links. They combined experiences with cadavers, in order to determine the inertial properties of the body segments, with photographic kinematic measures of soldiers. They were, therefore, the first to describe accurately an analytical reconstruction of 3D trajectories on body land markers, typical of central projections, with an accuracy of several millimeters (Whittle, 2007; Medved, 2001).

To better understand the gait, a force platform was developed that allows to get the kinetics of human movement. This instrument was first developed in the 1970s by Amar and Elftman and later appeared accurate three-dimensional instruments that enabled to measure the direction and the magnitude of the ground reaction force (Whittle, 2007).

During the gait cycle different muscles are activated. In the 1940s, Scherb studied the role of the muscles initially by palpation and later using electromyography (EMG) (Whittle, 2007; Baker, 2007).

The development of clinical gait analysis was driven by two surgeons, Jacquelin Perry and David Sutherland. As electromyography is an analog signal, it would be easier to capture and reproduce than the three-dimensional motion data. Thus, in the 1960s and 1970s, Perry and Sutherland played a leading role in gait analysis. Perry developed methodological approaches to observational gait analysis and instrumental methods for measuring simple temporal-spatial parameters. Sutherland continued to seek ways of obtaining three-dimensional information from cine film and reported on a method for making measurements of five joint angles using semi-automated digitization from three cameras.

The biomechanics of human gait involves the synchronization of bone, neurological and muscular system (Fish & Nielsen, 1993).

In short, gait analysis is complex and the evolutionary process is continuous over time, as there are modern technological advances, such as force platforms, electromyography, high-speed film and analytical laboratories of computerized gait.

1.4 Gait measurement techniques

To analyze the biomechanical gait it is necessary to have information on the movement (kinematics), human inertia parameters and internal and external forces (kinetics).

To analyze gait we resort to measurement techniques using:

- A motion measurement system (motion analysis)
- A force platform (measurement of forces on the ground by foot)

- An electromyography (EMG) data acquisition system.

(Begg & Palaniswami, 2006)

1.4.1 Kinematics (Motion)

Kinematics – movement analysis - describes how a body moves in space.

The basic parameters of kinematics and motion analysis are:

1. Time, t, in seconds (s)
2. Position, p, in meters (m)
3. Linear displacement, s, in meters (linear distance, s)
4. Linear speed, v, in m / s (linear velocity, v)
5. Linear acceleration, a, in m / s^2 (linear acceleration, a)
6. Angular displacement, θ, in degrees or radians (θ angle)
7. Angular velocity, ω, in ° / s or rad / s (angular velocity, ω)
8. Angular acceleration, α, in ° / s^2 or rad / s^2 (angular acceleration, α)

(Begg & Palaniswami, 2006)

The 3D motion analysis is the most commonly used procedure for accurately measuring the movement of a body in space. Thus, there are four main types of motion analysis equipment:

• Video digitizing systems (e.g., Peak, APAS)

• Video-based reflective/passive marker systems (e.g., VICON, Motion Analysis, Elite, Qualysis, Peak, APAS)

• Optoelectronic or active marker systems (e.g., Optotrak, CODA)

• Magnetic tracking systems (e.g., Ascension, Polhemus)

(Begg & Palaniswami, 2006)

1.4.2 Passive marker systems

In order to capture movement, subjects involved in the analysis use reflective markers (passive markers). Video cameras capture the reflections from the markers that contain infrared flash illuminators in each camera lens by sending out pulses of infrared light that are reflected back into the lens from the markers.

Thus, image processing systems are able to isolate the respective points and markers to record a 2D image of its position. Markers are often obscured and therefore it is necessary at least six cameras. When the visible labels are located in 2D camera images, the centroid

coordinates of each marker are noted and a series of intersection "rays" are designed mathematically to calculate the 3D coordinates of each marker. Thus, each marker is assigned a trajectory.

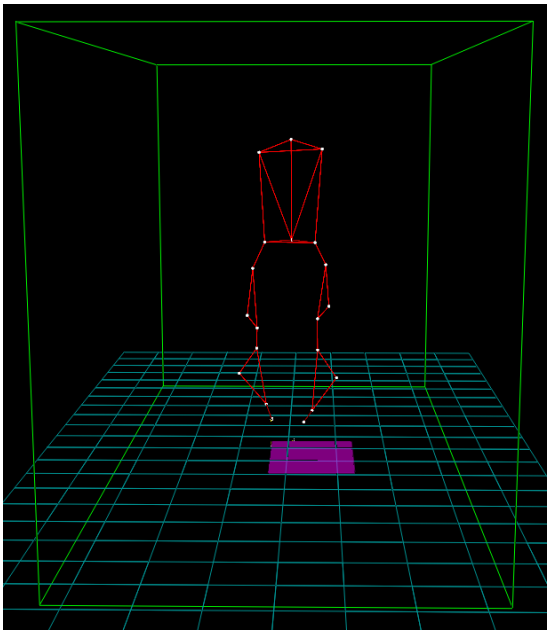


Figure 1.6 - Example of a movement capture of an individual using reflective markers.

1.4.3 3D kinematics

The markers form an "exo-skeleton" around the subject that is related to a model of "endo-skeleton" of the participant. The anthropometric data must be measured in each subject, and through a 3D motion analysis software system, it is possible to calculate the coordinates and the orientation of the segments of the external markers.

1.5 Anthropometry

Anthropometry is the science that studies the physical measurements of the human body in order to determine the differences between individuals (Winter, 1990).

1.5.1 The physical properties of the human body and its threads

The human body is considered as a system of mechanical linkages that have properties of form and size (for example: mass, center of mass, inertia, origin and insertion, muscle length, angle of pull, muscle cross-section). The length of the body segment is the most basic dimension of the human body and it can vary depending on several factors such as sex, race and age. In some cases, the length of certain body segments is determined from anatomical points determined from certain physical reference points. In other cases, there is a need to use indicators to measure the length of a segment from its joints (Rodacki).

Drillis and Contini (1966) have developed a set of average segment lengths expressed as a percentage of body height. These segment proportions serve as a good approximation, in the absence of better data, measured directly from the individual (Figure 1.7) (Winter, 1990).

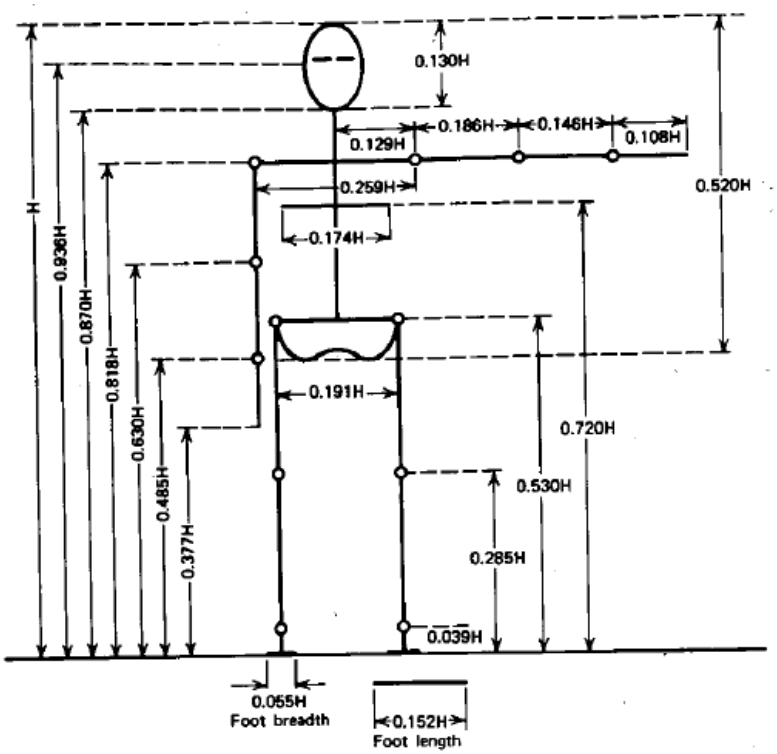


Figure 1.7 - Body segment lengths expressed as a fraction of body height H (Winter, 1990).

1.5.2 Segment Mass and center of mass

The terms *center of mass and center of gravity* are often used. The most general term is the center of mass, while the center of gravity refers to the center of mass in only one axis defined by the direction of gravity, the center of mass term is used in the two horizontal axes.

Table 1.1 expresses the mass of each segment as a percentage of the total mass of the body.

The location of the center of mass is also given as a percentage of segment length from either distal or proximal end.

Table 1.1 – Antropometric data (Winter, 1990).

Segment	Definition	Segment Weight /Total Body Weight	Center of Mass/ Segment Length		Radius of Gyration/ Segment Length			Density
			Proximal	Distal	C of G	Proximal	Distal	
Hand	Wrist axis/knuckle II middle finger	0.006M	0.506	0.494P	0.297	0.587	0.577M	1.16
Forearm	Elbow axis/ ulnar styloid	0.016M	0.430	0.570P	0.303	0.526	0.647M	1.13
Upper arm	Glenohumeral axis/ elbow axis	0.028M	0.436	0.564P	0.322	0.542	0.645M	1.07
Forearm and hand	Elbow axis/ ulnar styloid	0.022M	0.682	0.318P	0.468	0.827	0.565P	1.14
Total arm	Glenohumeral joint/ ulnar styloid	0.050M	0.530	0.470P	0.368	0.645	0.596P	1.11
Foot	Lateral malleolus/ head metatarsal II	0.0145M	0.50	0.50P	0.475	0.690	0.690P	1.10
Leg	Femoral condyles/ medial malleolus	0.0465M	0.433	0.567P	0.302	0.528	0.643M	1.09
Thigh	Greater trochanter/ femoral condyles	0.100M	0.433	0.567P	0.323	0.540	0.653M	1.05
Foot and leg	Femoral condyles/ medial malleolus	0.061M	0.606	0.394P	0.416	0.735	0.572P	1.09
Total leg	Greater trochanter/ medial malleolus	0.161M	0.447	0.553P	0.326	0.560	0.650P	1.06
Head and neck	C7-T1 and 1st rib/ear canal	0.081M	1.000	-PC	0.495	1.116	-PC	1.11
Shoulder mass	Sternoclavicular joint/glenohumeral axis	-	0.712	0.288	-	-	-	1.04
Thorax	C7-T1/T12-L1 and diaphragm	0.216PC	0.82	0.18	-	-	-	0.92
Abdomen	T12-L1/ L4-L5	0.139LC	0.44	0.56	-	-	-	-
Pelvis	L4-L5/ greater trochanter	0.142LC	0.105	0.895	-	-	-	-
Thorax and abdomen	C7-T1/ L4-L5	0.355LC	0.63	0.37	-	-	-	-
Abdomen and pelvis	T12-L1/ greater trochanter	0.281PC	0.27	0.73	-	-	-	1.01
Trunk	Greater trochanter/ glenohumeral joint	0.497M	0.50	0.50	-	-	-	1.03
Trunk head neck	Greater trochanter/ glenohumeral joint	0.578MC	0.66	0.34P	0.503	0.830	0.607M	-
HAT	Greater trochanter/ glenohumeral joint	0.678MC	0.626	0.374PC	0.496	0.798	0.621PC	-
HAT	Greater trochanter/ mid rib	0.678	1.142	-	0.903	1.456	-	-

The Center of Mass (COM) is an imaginary point at which the total body mass can be assumed to be concentrated (Mapelli *et al.,* 2014).

1.5.3 Center of mass of a multisegment system

With each body segment center of mass in motion, the centre of mass of the whole body is continuously changing with time. It is therefore necessary to recalculate after each time interval, and this requires knowledge of the trajectory of the center of mass of each body segment (Winter, 1990).

1.6 Trajectory of the centre of mass

The trajectory of the mass center reflects the movement of the entire body. An alteration in the trajectory of body mass center may indicate a clinical manifestation of an underlying pathology. The mass center may provide useful parameters for the assessment of the global motion, and in combination with other kinematic and kinetic data provide a more detailed analysis, thus allowing the practical application (Lulic *et al*., 2010).

The displacement of center of mass of the body (CMb) during walking, which represents and characterizes the whole body system in movement, is used to explain center of mass of the body mechanics, metabolic energy expenditure, postural adjustments, and dynamic equilibrium (Dierick *et al*., 2004).

1.7 Gait pattern

The movements of locomotion change from an individual to another because each one has a gait pattern with less physical effort and adequate stabilization (Estrázulas *et al*., 2005).

The pattern of the locomotor system presented by a child, adult or elderly results from the interaction of several factors, components of various fields of human behavior. Thus, as a child grows, and develops the quantitative somatic changes combined with the structural differentiation processes form a typical response for the walking pattern which makes motor pattern typical of each age group (Estrázulas *et al*., 2005).

The human being begins to develop the gait early in life, and the gait pattern is acquired in childhood at about 7 or 8, when the sensorimotor system becomes adapted to automatically generate a repetitive set of command of motor control to allow any person to walk without effort (Estrázulas *et al*., 2005).

In adults the gait pattern is characteristic of each individual and it is well defined, while in old age, one of the largest functional limitations is the fall giving way to changes in the gait pattern (Estrázulas *et al*., 2005).

Center of mass displacement during gait has frequently been used as an indicator of gait efficiency or as a complement to standard gait analysis (Gutierrez-Farewik *et al.*, 2006).

Locomotor development can result from a gradual multidimensional process involving not only musculoskeletal growth and biomechanical factors but also maturation of the central nervous system (Dierick *et al*., 2004).

1.8 Variability

Variability is inherent to human actions because the human being is unable to perform two equal motor gestures. Thus the variability may be subject to the context in which movement occurs. So we can define: the anatomical variability that is the number of degrees of freedom in the joints, does not imply a fixed relationship between agonist-antagonist (the same muscle group can perform the adduction and abduction - arm for example); the mechanical variability corresponding to the degree of muscle activation motion performed does not have a fixed relationship, that is, the same engine command may produce different

results (e.g. mobilization of biceps, isometry or in flexing the elbow); and also the physiological variability regarding noise between the emission of the cortical and cerebellar level command until arrival of the same effector organ (e.g. level of myelination, calcium concentration in muscle membrane). Over a movement we can still consider the variability of force involved in performing the task, the kinematic variability relating to changes in the execution of the movement, such as speed, time, space and acceleration and response variability and the variation the result obtained in the execution of a task (end position and movement time) (Junior).

The variability of some movement control parameters, as the phase relationships between members or segments, can be used to investigate their stability and control characteristics. It has been found that a low variability generally means greater stability however, the fact that variability is low might indicate a high level of movement control or a non-adaptive behavior (Mendes, 2005).

Those measures of gait parameters variability have great interest because it is an excellent predictor of falls and declining mobility as high variability in the walk values refer to fluctuation in the values of the gait parameters from one step to another and it is considered indicative of instability as it reflects motor control disorders of the central and peripheral nervous system. Thus, variability increase in the gait pattern can be caused by several situations, including the simultaneous execution of cognitive tasks while gait. With advancing age, these functions may deteriorate and be ineffective in responding to disturbances and restoration of functional gait (Mendes, 2005).

The gait kinematics stability requires proper motor pattern generation and effective responses to disturbances. Thus, since the muscles are responsible for generating the forces which govern the implementation of the gait, kinematic presumably reflects the muscle activation patterns (Mendes, 2005). However, the kinematic parameters are much less variable than electromyographic ones and kinematic patterns are more controlled than muscle activation. This can be primarily related to inertia and damping properties of body segments which explains the lower variability found in the kinematic data regarding electromyographic data.

So the increased variability in kinematic variables (stride length, double support time, the gait time and step time) is considered an indication that divided attention towards other tasks rather than their own march, requires more complex modulations of the neuromotor system than when gait is isolated from other stimuli (Hallal et al., 2013). Thus, control of balance is an essential component of human movements and these possible movements for the

control of balance are described in a three dimensional space related to the horizontal position of the body center of mass (Pai & Patton, 1997).

The variables such as step and COM positions are stabilized by motor-equivalent coordination among the major joints of the body during locomotion. Step-by-step fluctuations in joint angles at the time of heel strike covary turning task variability lower than it would be predicted from the variability in the individual joint angles (Verrel et al., 2012). When multiple functional constraints need to be integrated in a task, such as balance maintenance (stabilization of the COM position) and forward progression (regularity of the step pattern, e.g. step length control) during walking, reductions in coordinative skill may be reflected either in an general reduction in coordination indices across task variables, or in a selective reduction in coordination with respect to task variables that are functionally less relevant (Verrel et al., 2012).

Considering individual variability of the human body structure and complexity of locomotion, it can be concluded that the description of COM behaviours during walking is a complex task and basically impossible to implement without adequate and reasonably complex measuring apparatus (Staszkiewicz et al., 2010; Wurdeman et al., 2012). The amount of variation in motion has proven to be closely linked to the ability to maintain stability in the vertical position and in several studies, variability in gait speed between steps have proven to be the best predictor of falls among the elderly. Similarly, a study shows that an increase in amount of variation of the laying time is associated with a higher incidence of disability in the elderly. Thus, an assessment of the variability gives a solid foundation for understanding the stability in the vertical position of an individual during locomotion (Wurdeman et al., 2012). However, if the antero-posterior directional control is passive and medio-lateral directional control depends on the central nervous system, a change in the direction of progression should not affect the amount of variability in the anterior-posterior or medial-lateral directions. The medio-lateral direction has a greater amount of variability than the antero-posterior direction (Wurdeman et al., 2012).

A stable walking depends on the coordination of multiple biomechanical degrees of freedom (DOF) to ensure the dynamic maintenance of whole-body equilibrium as well as continuous forward progression (Verrel et al., 2012). Thus, the motor-equivalent coordination among joint angles contributes to the stabilization of COM position and foot placement during walking in young adults (Verrel et al., 2012). Both the COM position and foot placement depend on the configuration of many biomechanical DOF (e.g. joint angles) across the body. Due to motor-equivalent (the abundance of DOF over relevant task parameters), the

same COM or foot position can be achieved by a large variety of joint configurations. Relating variability in joint angles to variability in a hypothetic task variable (e.g. step length or COM position in the case of walking) has been proposed and validated as a way to formally capture the contribution of the central nervous system to the stabilization of this variable (Verrel et al., 2012).

1.9 Theories of human gait

The human gait results from a complex interaction of muscle strength, joint motion and neural motor commands. In clinical gait analysis, it is important to understand the mechanisms by which the body support and propulsion forward are obtained (Buczek *et al.,* 2006).

The theory of the six determining gait kinematic suggests a set of features that help to reduce the displacement from the body center of mass, meaning that the vertical and horizontal displacements are energetically exhausting. In contrast, the theory of inverted pendulum proposes that the march is energetically less costly if the member behaves like a pendulum in arc movement. However, these two theories report to the principle of reducing the energy expenditure in the opposition direction rather than in the sense of complementarity (Sousa, 2008; Sousa & Tavares, 2008).

1.9.1 Inverted Pendulum Theory

The human gait can be modeled as a pendulum system, the kinetic energy being converted to gravitational potential energy and vice versa, with retention of more than 60 to 70% of the required mechanical energy. The most decisive force in the inverted pendulum is gravity (F = mg, where m is the mass involved and g the gravitational constant) which must be at least equal to the centripetal force (= mv^2 / L, where L is the length of the leg and v the horizontal speed). The ratio between the two powers corresponds to the Froude number (= v^2 / gL).

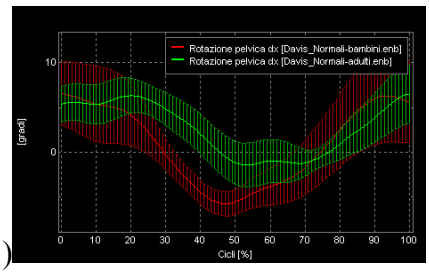
According to the model of the inverted pendulum, much of the work done during the march is not related to the active muscle work, but to a passive mechanism of kinetic energy and potential exchange, since the center of mass, by analogy with the inverted pendulum, varies depending on the limb in stance phase, thereby reducing the work needed to lift and accelerate the mass center. Similarly, the muscular effort required to swing the member is lowered due to a mechanism similar to a pendulum, where there are exchanges of kinetic and

potential energy as the member moves in the anterior direction (Sousa, 2008; Lee & Farley, 1998).

1.9.2 Theory of the six determinants of gait

Gait is characterized by the existence of a set of mechanisms that are considered determinant in gait pattern:

• Pelvic rotation: in a normal operation level the pelvic girdle runs interchangeably to the right and to the left relative to the line of progression. The magnitude of this rotation is approximately 8º (4º in the swing phase and 4º in the stance phase). The pelvic rotation lowers the arc passing through the center of mass by rising the edges of the arc, and consequently the turning angle at the intersection of successive arcs are less abrupt, and energy cost is lower. The potential energy loss is more gradual and the force required to change the direction of the mass center in the next arc is lower. The angular rotation of the hip, in flexion and extension, is reduced and the energy required for the inner oscillation of the member is maintained.

(1) 

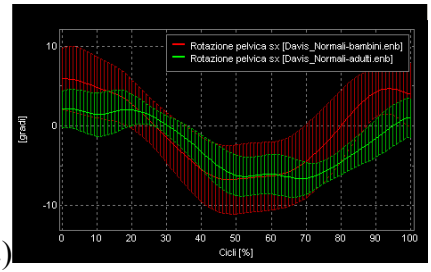
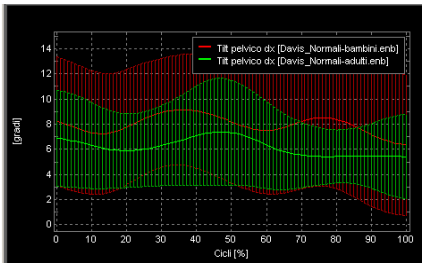
(2) 

Figure 1.8 - Example of normality between adults and children the right pelvic rotation (1) and left (2) based on Davis protocol and obtained through the software used in this work, SMART-DX, BTS.

- Pelvis inclination: the center of mass moves laterally over the load edge twice during one cycle. The lateral displacement is produced by tilting the pelvis opposite the supporting member. To allow the pelvic tilt, the member in the aerial phase must perform knee flexion. The pelvic tilt on the side of the swing phase occurs abruptly at the end of the dual phase support. The mass center path is shorter, pelvic path is smoothed, and through the knee flexion, energy is conserved due to the effective shortening of the pendulum.

(1) 

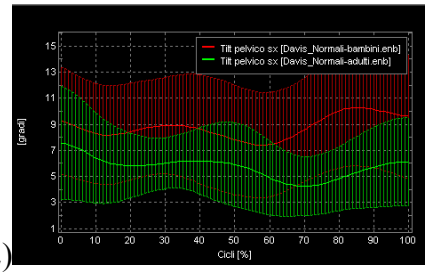
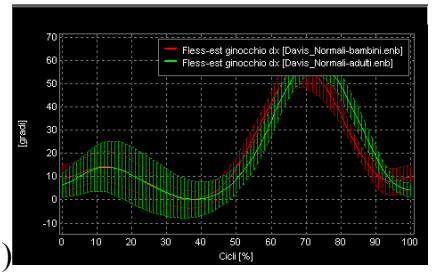
(2) 

Figure 1.9 - Example of normality between adults and children the right pelvic tilt (1) and left (2) based on the Davis protocol and obtained through the software used in this work, SMART-DX, BTS.

• Flexion of the knee in the stance phase: The passage of body weight over the end while the knee is in flexion is a characteristic of gait. The member in charge starts stance phase through the ground attack with the knee in full extension, then the knee begins to flex and continues until the foot gets to the ground. The average flexion is about 15º. Immediately prior to the complete medium load period, the knee goes again to length, which is immediately followed by terminal knee flexion. This support phase period occupies about 40% of the gait cycle and it is referred to as the double lock knee period since this is primarily locked in extension, unlocked in flexion and again locked in extension, followed by a final flexion.

(1) 

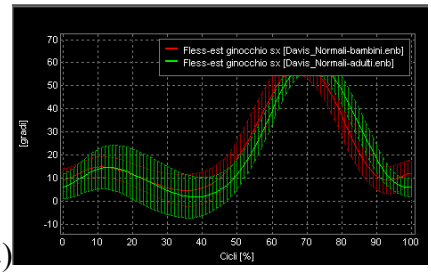
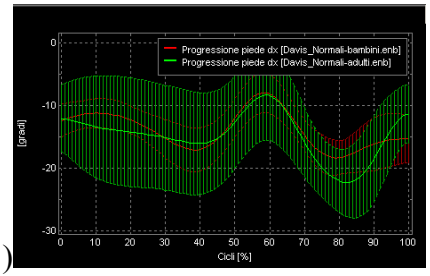
(2) 

Figure 1.10 - Example of normality between adults and children of flexion and extension of the right knee (1) and left (2) based on the Davis protocol and obtained through the software used in this work, SMART-DX, BTS.

These three determinants, rotation and pelvic tilt and knee flexion act to lower the bow of the center of mass. Pelvic rotation raises the ends of the bow while the pelvic tilt and knee flexion depress its peak.

• Foot and knee: There is a close relationship between angular leg and knee dislocations and may even be established two arcs that intersect during stance phase. The first occurs in the contact of the heel and is described by the radius formed by the calcaneus. The second arc is formed by standing on the center of rotation established in association with the forefoot propulsion. On heel contact, the foot is in dorsiflexion

and the knee is in full extension, so the tip is at its maximum length and the center of mass is at its lowest point of upward movement. The fast plantar flexion, associated with the onset of knee flexion, keep the center of mass in its progression at the same level for a while, by downloading and gently reversing the curvature at the beginning of his bow translation. The end of this arc is also flat and gently invert by the bending of the second knee associated with propulsion. The decrease in abrupt inflections at the intersection of the center of mass of the arches reduces energy costs.

(1) 

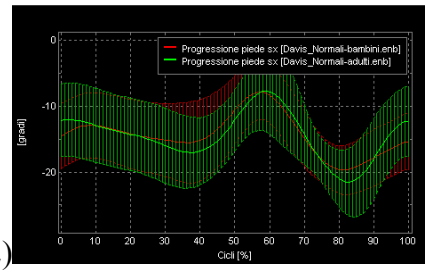
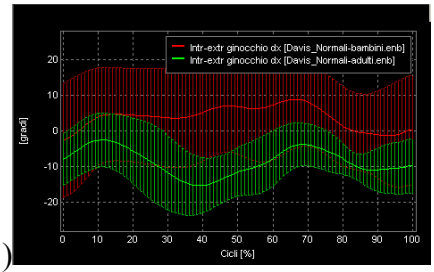
(2) 

Figure 1.11 - Example of normality between adults and children of the progression of the right foot (1) and left (2) based on the Davis protocol and obtained through the software used in this work, SMART-DX, BTS.

(1) 

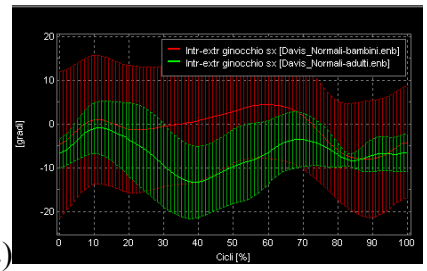
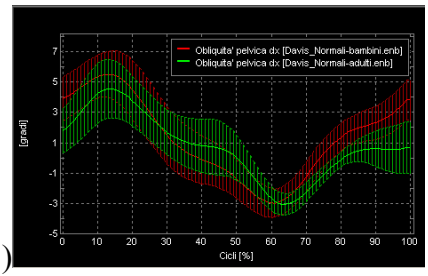
(2) 

Figure 1.12 - Example of normality between adults and children of intra and extra rotation of the right knee (1) and left (2) based on the Davis protocol and obtained through the software used in this work, SMART-DX, BTS.

- Pelvis lateral displacement: If the ends were parallel, the shift amount would be equal to half the interval of the axis passing through the hip joints, which is approximately equal to 3 cm. The excessive lateral displacement is corrected by the existence of the tibiofemural angle, which, together with the relative hip adduction, reduces to 1.75 cm displacement so as to approach the vertical position. In this sense, the center of mass deviation is most often symmetrical in horizontal and vertical plans. The factors that allow energy storage and its recovery involve the time required for muscle contraction in the displacement of the moving segments. As the center of mass moves along a sinusoidal path of low amplitude, energy is expended during lifting, and only a part of

the portion of this energy is recovered in its descent. The result is a continuous energy expenditure.

(1) 

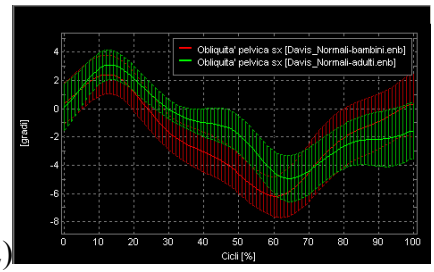
(2) 

Figure 1.13 - Example of normality between adults and children of the right pelvic obliquity (1) and left (2) based on Davis protocol and obtained through the software used in this work, SMART-DX, BTS.

2. Materials and methods

2.1 Participants

The sample consists of 20 individuals selected among Erasmus Portuguese students in Italy, Italian students and Italian children (divided into two groups). Fourteen young adults with a mean age of 23.07 ± 2.53 years, mean height of 165.29 ± 8.43 cm and mean body mass of 61.43 ± 9.45 kg, six children with a mean age of 6.00 ± 0.00 years, mean height of 121.00 ± 2.00 cm and mean body mass of 22.58 ± 0.38 kg. All participants were physically active and did not have any traumatic-orthopedic dysfunction, no known developmental delay and/or musculoskeletal pathology and no difficulties on independent gait. The criteria for children inclusion were that they walked independently before the age of 16 months and were able to perform the gross coordination exercises. The parents of the children involved signed a free and informed consent term that explained the procedures and the purpose of the study.

2.2 Instruments

3D-Kinematic (SmartD, Bts, Italy) and inertial sensor data (Opal, Apdm, US) were collected during the tests (sampling frequency respectively of 200Hz and 128Hz).

2.2.1 SMART-DX, BTS

SMART-DX, BTS is a set of high definition systems that have a calculation power and a fantastic versatility allowing you to make analysis even in difficult conditions. This device has the ability to capture very fast and imperceptible movements as it uses high resolution video cameras (up to 4 Megapixels) with highly sensitive sensors, and has a great power of irradiation. BTS SMART-DX supplements, through their systems, synchronize and manage the kinematic, kinetic, electromyographic and video data. This system offers features such as getting high frequency up to 2000 Hz, the resolution of 2048 × 2048 pixels, the identification of automatic marker, rapid multiple calibration and different volumes of dimensions, operation without any loss of precision and accuracy, even in environments with critical light conditions, and can be used outside under direct sunlight (playing fields, athletics tracks, etc.).

Table 2.1- Technical features of the BTS SMART-DX.

Infrared digital cameras	**Up to 4 for each datastation**
Multiple datastations connection capability	Yes
Sensor resolution	640×480
Acquisition frequency at maximum resolution	140fps
Maximum acquisition frequency	280fps
Accuracy	<0,2mm on a volume 2x2x2m
Preview	Full frame
Strobe LED wavelenght	850nm
Number of markers detected simultaneously	Unlimited
Data transmission technology	Gigabit Ethernet
TVC power	Directly supplied by the datastation
Lenses	Interchangeable C-mount
Datastation case	Slim
Passive and retro reflecting markers	Ø from 3 to 20 mm
Pre-installed software	BTS SMART-Suite

2.2.2 OPALs

The Opal™ is a miniature, wireless inertial measurement unit that can both log kinematic data and stream it in real-time continuously. Opals use a low-power wireless communication protocol to transmit data to the Access Point, which serves as an antenna for a local computer. Its main characteristics: wireless streaming, data logging, triaxial accelerometers, triaxial gyroscopes, triaxial magnetometers, precision of temperature calibration and body straps. It was designed to streamline gait and balance assessments by making it easy to collect, store, and analyze data involving human subjects and APDM's wireless Opal inertial sensors.

Table 2.2 - Opal sensor characteristics.

	Accelerometer	***Gyroscope***	***Magnetometer***
Axes	3 axes	3 axes	3 axes
Range	± 2g or ± 6g	± 2000 deg/s	± 6 Gauss
Noise	0.0012 m/s²/√Hz	0.05 deg/s/√Hz	0.5 mGauss/√Hz
Sample Rate	1280 Hz	1280 Hz	1280 Hz
Output Rate	20 to 128 Hz	20 to 128 Hz	20 to 128 Hz
Bandwidth	50 Hz	50 Hz	50 Hz
Resolution	14 bits	14 bits	14 bits

2.3 Procedures

Participants were asked to walk along the laboratory to make gait analysis at self-selected speed using swimwear or close-fitting shorts. Each participant performed 15 walks, divided in groups of 5. Every 5-walk-test, participants were asked to perform the following coordination exercises:

- standing on a foot for more than 8 seconds,
- ant step walking,
- tiptoe walking,
- jumping.

The performance of the coordination exercises led to obtain a 7 minute pause in between the walking tests.

Coordination exercises were used both for distracting participants from the walking tests and for evaluating children's level of development.

2.4 Experimental protocol

3D-Kinematic (SmartD, Bts, Italy) and inertial sensor data (Opal, Apdm, US) were collected during the tests (sampling frequency respectively of 200Hz and 128Hz). 18 reflective markers were positioned on anatomical landmarks according to Plug in Gait protocol (shoulders, neck, iliac crests, sacrum, trochanter, knee, ankle). The tree triaxial wireless inertial sensors were positioned on the lower back at approximately COM level (at L5 level) and on the legs using straps. For each walking test, joint angles, COM trajectory and COM acceleration were obtained.

2.5 Kinematic data acquisition

The movement performed by the subjects in the study in question is recorded by an optoelectronic and stereophotogrammetric vision system that has the ability to recognize and reconstruct the three-dimensional trajectory retroflectives markers that are placed in specific anatomical reference points. The opto-electronic system used for the experimental tests has the BTS Smart System which consists of six cameras, with illuminator equipped with a CCD (charge-coupled device) sensor sensitive to infrared light radiation. In particular, the cameras detect the reflections of the markers that are positioned over the subject and that are coated with reflective aluminum powder material. Its reflection properly processed enables the delivery of three-dimensional coordinates of each point of interest. Combining all this information with the position of the cameras, it is possible to get, through the stereoscopic

processing, the three-dimensional position of the markers. Noting the 3D position at all times, the trajectory can be obtained.

2.6 Calibration

The process by which, from bi-dimensional images, three-dimensional coordinates of the markers are extrapolated requires information related to the intrinsic and extrinsic properties of the cameras. The intrinsic parameters are related to the information given according to the focal length and aperture of the camera while the extrinsic parameters relate to the positioning and orientation of the cameras, and the position of the global reference system with which coordinates of the different markers will be calculated.

These parameters are acquired during an initial calibration by two special techniques: a static calibration and dynamic calibration.

The calibration volume, defined as the space in which the movement is carried out for the study should be calibrated to allow calculation of the positions in time of the coordinates of respective markers to a reference system, whose position will be calculated by the vision system, and storage.

In addition to the static acquisition, it is carried out a dynamic calibration that will outline the volume of calibration; this operation is performed with the use of a "wand" which is moved in acquisition volume dynamically creating a large number of two-dimensional coordinates acquired for each frame that, through a process known as "bundles fit" will determine the three-dimensional position and direction of the cameras relative to the global reference calibrated in the previous step.

2.7 Software

To acquire data on the kinematics of the movement we used a BTS Bioengineering software package which includes the following software:

- Smart Capture: it records the movement that allows synchronization and data correlation resulting from the kinematic motion of the markers in space.
- Smart Tracker: it allows, from the arrangement of markers, to rebuild from the computer, bone segments of the subjects through the union of the individual markers creating segments, such as the segment of the thigh, leg etc.
- Smart Analyzer: it allows the management of all types of data that can be of biomechanical interest such as distances, angles, speed, acceleration (linear and angular), forces, moments,

power and the ability to generate different reference systems and the creation of a virtual marker that allows the user to analyze and present data in different coordinate systems. It also allows the analysis of time signals acquired during testing.

2.8 Plug-in-Gait Marker Placement

Plug in gait marker protocol was used in this study, even if it was lightly adapted, as suggested by the software BTS Smart Tracker.

Table 2.3 - Description where the Plug-in-Gait markers should be placed on the subject.

Torso Markers	C7	7th Cervical Vertebrae	Spinous process of the 7th cervical vertebrae
Arm Markers	LSHOULD	Left shoulder marker	Placed on the Acromio-clavicular joint left
	RSHOULD	Right shoulder marker	Placed on the Acromio-clavicular joint left
Pelvis	LASI	Left ASIS	Placed directly over the left anterior superior iliac spine
	RASI	Right ASIS	Placed directly over the right anterior superior iliac spine
	SACR	Sacral wand marker	Placed on the skin mid-way between the posterior superior iliac spines (PSIS).
Leg Markers	LTHIGH	Left trochanter	Placed in region of the trochanter left
	RTHIGH	Right trochanter	Placed in region of the trochanter right
	LBAR1	Left femur wand marker	These are placed to form a plan determining the alignment of the left knee flexion axis
	RBAR1	Right femur wand marker	These are placed to form a plan determining the alignment of the right knee flexion axis
	LKNE1	Left knee 1	Placed on the lateral epicondyle of the left knee
	LKNE2	Left knee 2	Placed on the lateral epicondyle of the left knee
	RKNE1	Right knee 1	Placed on the lateral epicondyle of the right knee
	RKNE2	Right knee 2	Placed on the lateral epicondyle of the right knee
	LBAR2	Left tibial wand marker	These are placed over the lower 1/3 of the shank to determine the alignment of the left ankle flexion axis
	RBAR2	Right tibial wand marker	These are placed over the lower 1/3 of the shank to determine the alignment of the right ankle flexion axis
Foot Markers	LMET	Left met	Placed over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot
	RMET	Right met	Placed over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot
	LHEEL	Left heel	Placed on the lateral malleolus along an imaginary line that passes through the transmalleolar axis
	RHEEL	Right heel	Placed on the lateral malleolus along an imaginary line that passes through the transmalleolar axis
	LMALL	Left mall	Placed on the calcaneous at the same height above the plantar surface of the foot as the toe marker
	RMALL	Right mall	Placed on the calcaneous at the same height above the plantar surface of the foot as the toe marker

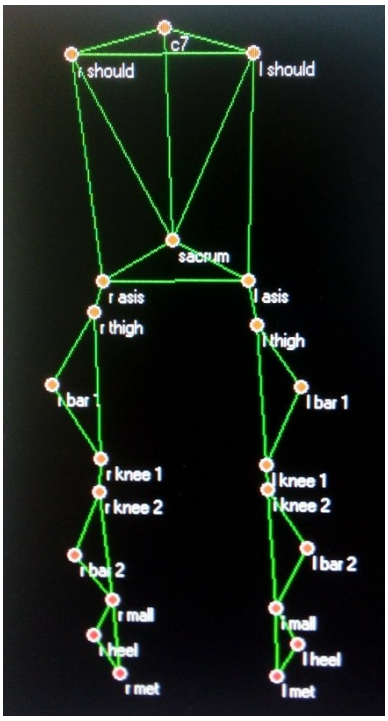


Figure 2.1 - Davis protocol – Model

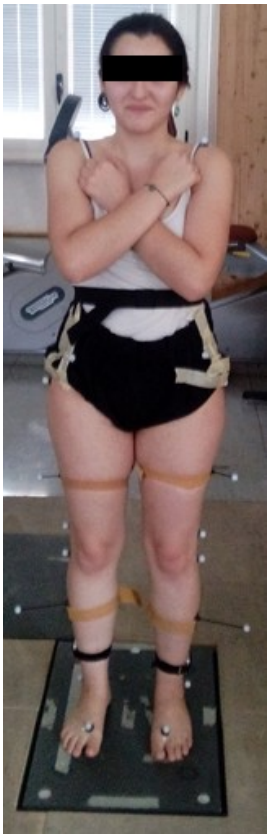


Figure 2.2 - Application of Davis protocol in an adult.

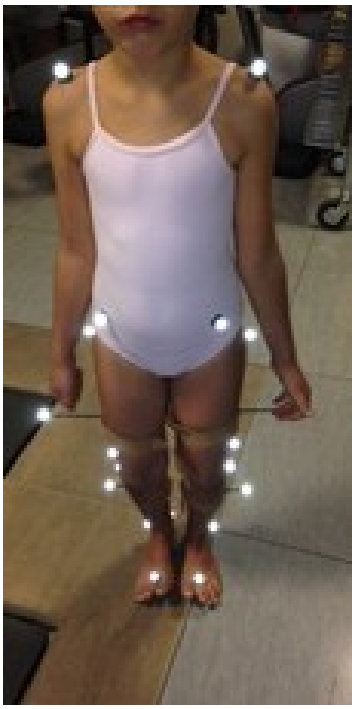


Figure 2.3 - Application of Davis protocol in a child.

2.9 Kinematic data elaboration

With the software BTS Smart Tracker it was possible to obtain the movement of the reflective markers in space (Figure 2.4).

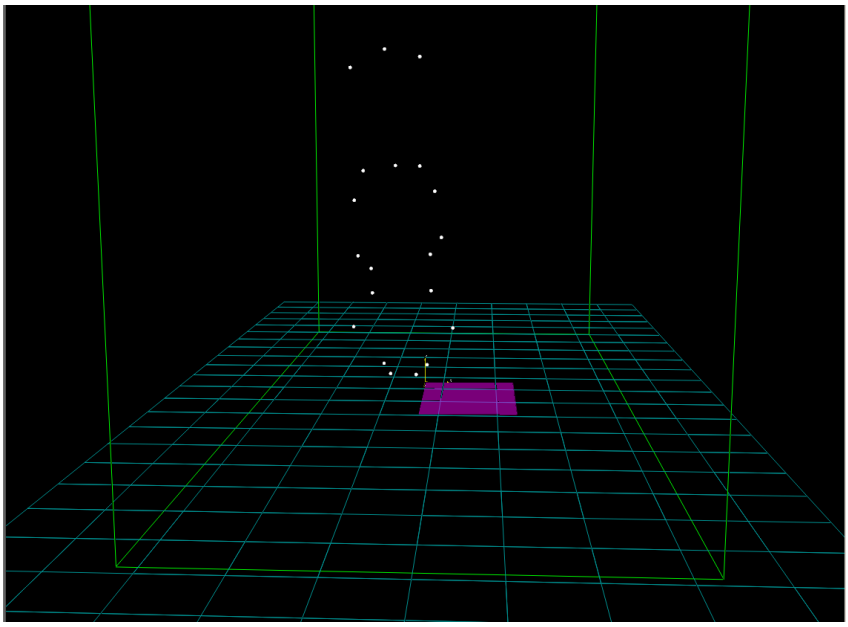


Figure 2.4 - Representation of reflective markers placed in a subject.

Through the software BTS Smart Tracker bone segments were reconstructed by connecting the reflective markers (Figure 2.5).

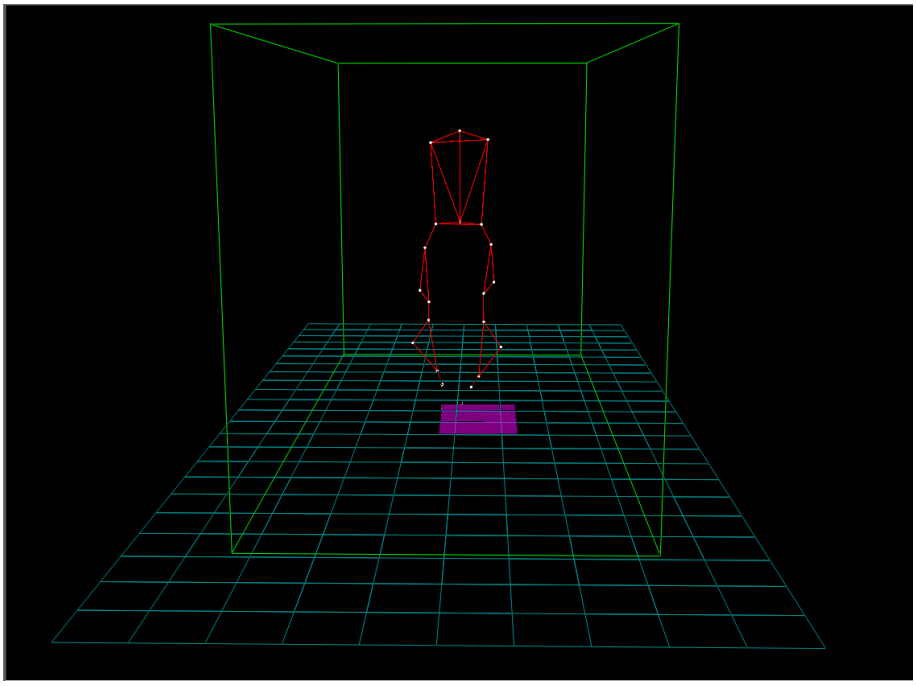


Figure 2.5 - Representation of the reflective markers placed in a subject after creating segments.

With the use of software BTS Smart Analyzer it is possible to obtain data of interest such as angles and positions of anatomical markers during the walk cycle or during the whole test. To get this you should indicate in the software all the supports and highlights on the soil of each subject in every walk (Figure 2.6).

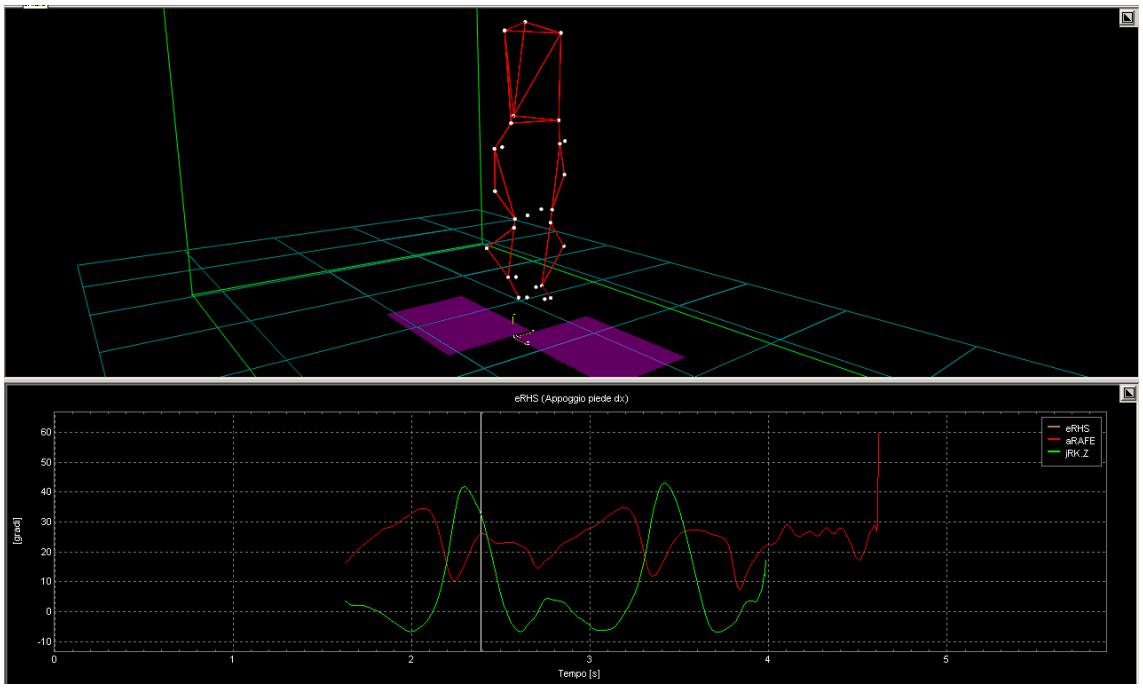


Figure 2.6 - A subject's support log representation in the soil.

The approximate center of mass was calculated between the points C7 and the sacrum and was posed in a local reference system corresponding to the sagittal plane of the subject: the y-axis was preserved during a step cycle and throughout the test.

With the use of Matlab by a function self customized by the University of Bologna, planax function, we can define a local coordinate system from the trajectories of the reflective markers (where: x = unit vector of the orthogonal plan-screw direction; y = unit vector of the projection; z = unit vector of the vectorial product x^y). It creates a rotation matrix of the local coordinate system defined after non-collinear coordinates of the reflective markers. Thus, we define the anatomical structure.

2.10 Inertial data elaboration

Stride detection for inertial sensors data was estimated from the angular velocity around the medio-lateral axis of the leg. COM acceleration along vertical, medio-lateral and antero-posterior direction was assumed to correspond at data collected from the inertial sensor mounted on the lower back during a step cycle or during the test.

2.10.1 Inertial sensors (Accelerometers and gyroscopes)

The mobile inertial measurement units APDM use MEMS technology (Micro-Electro-Mechanical Systems) recording accurately the movement with a complete set of kinematic sensors including triaxial accelerometers, gyroscopes and magnetometers. The sensors are APDM and continuously write information to 128 Hz.

In the study in question three inertial sensors were placed in the subjects. Two at the feet so that it is possible to mark the step and another sensor at the bottom of the trunk in a location close to the center of the body mass.

Figure 2.7 - The Opal movement monitor.

2.11 Data Analysis in Matlab

In order to evaluate intra-test and inter-test variability, the relative standard deviation (std%) of each estimated variable was calculated between the 5 walks of each test and among the 3 repetitions of the 5-walk-test.

Kinematic and acceleration data were exported through Matlab R2013b (MathWorks BV, EUA) and a program was developed to data processing and to perform the calculations of the variables analyzed.

Thus, we resorted to the use of MATLAB software through which it was possible to obtain for each walk the joint angles, the trajectory of the center of mass and acceleration. It was then possible to calculate the mean and standard deviation of each variable, evaluating inter-test and intra-test variability which was calculated after the five walking moments of each test and three replications of each of the five walking moments. Relative inter test and intra test variability of the analyzed variables were calculated: this allowed to compare the variability of different variables, that is, joint angles, COM trajectory and COM acceleration, both for adults and for children.

2.12 Statistical analysis

The mean and standard deviation were calculated for each group (adults and children) as the center of mass trajectory results and the acceleration of the center of mass respectively to the vertical axis (x), medio-lateral axis (y) and antero-posterior axis (z), and the kinematics respectively to the joint angles.

With the help of the SPSS software (v.21; SPSS Inc, Chicago, IL, USA) using nonparametric statistics because the data were obtained from randomly selected groups, it was necessary to verify if the data followed a normal distribution using the *Shapiro-Wilk* test as the data were less than 50. Once the variables did not show a normal distribution we turned to the processing of data through the LN (natural logarithm), thus not changing the results.

To compare the variables between adults and children t-Student test for independent samples was used, as this test is based on the difference between two sample means, allowing to check if there are significant differences between two distinct processes with the level of significance $\alpha = 0.05$. Still using *Levene* test it was possible to test the null hypothesis that the variance between groups is the same, so if this test shows a significance level $\alpha < 0.05$ it means there is homogeneity.

3. Results

3.1 Data

Before performing the tests, data were collected from the subjects so that they could then be used in the processing of the results. Thus, the age of each individual was asked, through a scale it was possible to obtain the body mass and measured, in centimeters, the height, pelvis width, right and left pelvis height, right and left leg length, right and left knee diameter and right and left ankle both in adults (Table 3.1) and children (Table 3.2).

- *Adults*

Table 3.1 - Data collected from the adults subjects.

Subject	Age (years)	Body mass (Kg)	Height (cm)	Width pelvis (cm)	Height pelvis right (cm)	Height pelvis left (cm)	Length leg right (cm)	Length leg left (cm)	Diameter knee right (cm)	Diameter knee left (cm)	Diameter ankle right (cm)	Diameter ankle left (cm)
A	30	72	175	26.5	13.5	13	79	80	10	10	7.5	7.5
B	23	58	159	28	11	11	72	71	11	11	6	6.5
C	21	57	163	28	9	9	75	76	12	12.5	7	7.5
D	23	50	162	23	9	9	77.5	77.5	9	9	7	7
E	20	58	167	30	12	13	77	77	12	11.5	7.5	7.5
F	22	66	170	28	16	15	76	76	12	11.5	8.5	8
G	27	70	170	29	15	14.5	75	75	11	11	8	8
H	22	48	158	30	10	11	74	73	12.5	13	7	7
I	23	80	185	28	14	14	83	83	11	11	7.5	7.5
J	23	60	162	23	9	9	77.5	77.5	9	9	7	7
K	23	56	156	30	10.5	11	75	72	11	12	7	7
L	22	60	157	26	7.5	8	73	73	9	9	7	7
M	22	73	170	23	12	12	70	72	10	10	7.5	7.5
N	22	52	155	49	16	15	74	72	12	12	8	8

- *Children*

Table 3.2 - Data collected from the children subjects.

Subject	Age (years)	Body mass (Kg)	Height (cm)	Width pelvis (cm)	Height pelvis right (cm)	Height pelvis left (cm)	Length leg right (cm)	Length leg left (cm)	Diameter knee right (cm)	Diameter knee left (cm)	Diameter ankle right (cm)	Diameter ankle left (cm)
A	6	22.5	123	18.5	10	10	51	50.5	7	7	6	6
B	6	23	122	19	9	8	52	51	9	9	7.5	7.5
C	6	22.5	123	18	10	10	52	52	7.5	7.5	6	6
D	6	23	120	20	9	9	49	49	8.5	8	6.5	6.5
E	6	22	118	20	10	10	45	47	8	8	7	7
F	6	23.5	120	17.5	7.5	8	55	55	8.5	8.5	6	6

Using the MATLAB software, codes have been developed that might allow to calculate the joint angles, the mass center trajectory and also to calculate the average and

standard deviation of each variable evaluating inter-and intra-assay variability for the 5 test walks of each test and between the 3 replications of five test walks.

We also used Matlab to calculate the percentage of variability of acceleration obtained from the inertial sensor Opal, and obtained variability of the mass center trajectory by the "markers", which is the most accurate one, and also the percentage of variability of the joint angles both for adults and children (Appendix I).

3.2 Trajectory of the Mass Center

To calculate the center of mass from the markers we established a midpoint between the neck (C7) and the sacrum and we got for correspondent to the average relative standard deviation for each 5 walk-test as well as for the set of all walks in adults (Table 3.3 and 3.4) and children (Table 3.5 and 3.6).

- *Adults*

Table 3.3 - Inter-test variability of the trajectory of the center of mass around x, y, z axes.

Subject	X	Y	Z
A	0,23	0,07	0,79
B	0,18	0,05	0,41
C	0,19	0,06	0,93
D	0,07	0,03	0,24
E	0,02	0,01	2,33
F	0,04	0,01	0,23
G	0,04	0,02	1,32
H	0,43	0,06	1,16
I	0,45	0,10	3,53
J	0,24	0,07	1,23
K	0,07	0,02	1,56
L	0,05	0,02	8,47
M	0,04	0,03	1,12
N	0,14	0,03	0,11
Mean	0,16	0,04	1,67
Standard deviation	0,14	0,03	2,16

Table 3.4 – Intra-test variability of the trajectory of the center of mass around x, y, z axes.

Subject	X	Y	Z
A	0,44	0,09	10,58
B	0,24	0,05	3,89
C	0,24	0,08	35,85
D	0,24	0,04	0,46
E	0,06	0,03	15,87
F	0,09	0,03	0,79
G	0,08	0,04	5,47
H	0,27	0,06	27,29
I	1,69	0,16	5,62
J	0,39	0,13	19,58
K	0,16	0,05	1,05
L	0,12	0,04	0,47
M	0,08	0,04	6,49
N	0,33	0,13	0,24
Mean	0,32	0,07	9,55
Standard deviation	0,41	0,04	11,17

- *Children*

Table 3.5 - Inter-test variability of the trajectory of the center of mass around x, y, z axes.

Subject	X	Y	Z
A	0,13	0,06	0,44
B	0,37	0,15	0,62
C	0,10	0,06	4,19
D	0,21	0,09	3,02
E	0,08	0,07	1,52
F	1,38	0,57	9,01
Mean	0,38	0,17	3,13
Standard deviation	0,50	0,20	3,22

Table 3.6 - Intra-test variability of the trajectory of the center of mass around x, y, z axes.

Subject	X	Y	Z
A	0,26	0,13	1,38
B	0,91	0,58	3,08
C	0,27	0,13	15,21
D	0,34	0,18	4,90
E	0,33	0,26	8,43
F	1,00	0,58	1,51
Mean	0,52	0,31	5,75
Standard deviation	0,34	0,21	5,32

3.2.1 Center of mass calculated from markers

To calculate the mass center from the markers we established a midpoint between the neck (C7) and the sacrum and we got the graphs (Figure 3.1; 3.2; 3.3 and 3.4) corresponding to the average relative standard deviation for each 5 walk-test as well as for the set of all walks.

- *Adults*

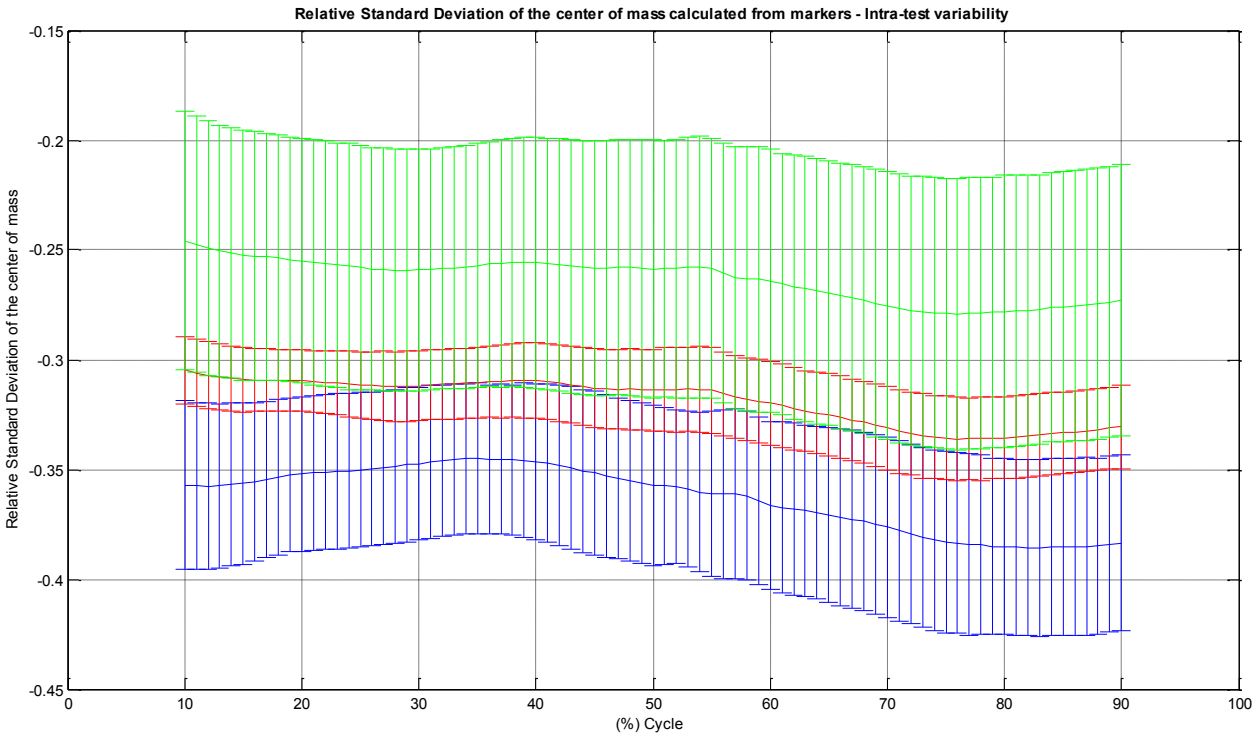


Figure 3.1 - Standard deviation representation of the center of the mass calculated from the midpoint between C7 and the sacrum for each walk-test.

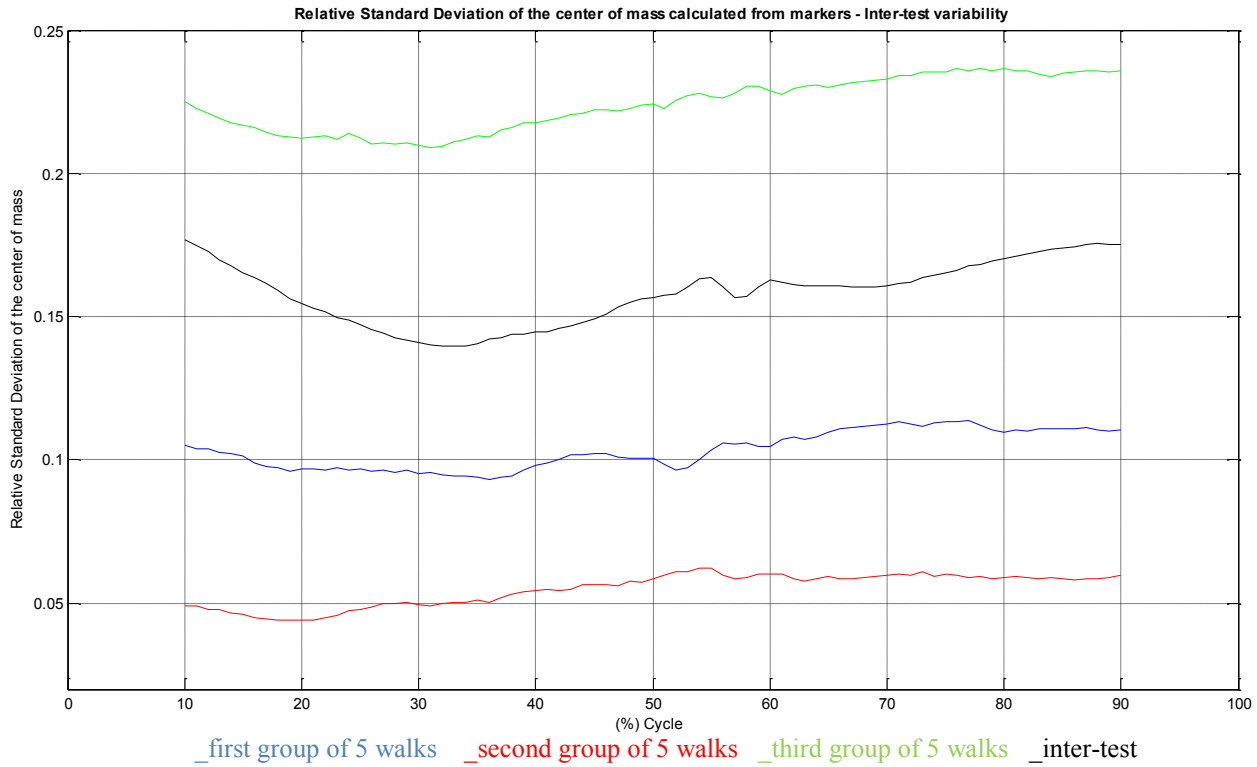


Figure 3.2- Standard deviation representation of the center of the mass calculated from the midpoint between C7 and the sacrum for all tests of a subject.

- *Children*

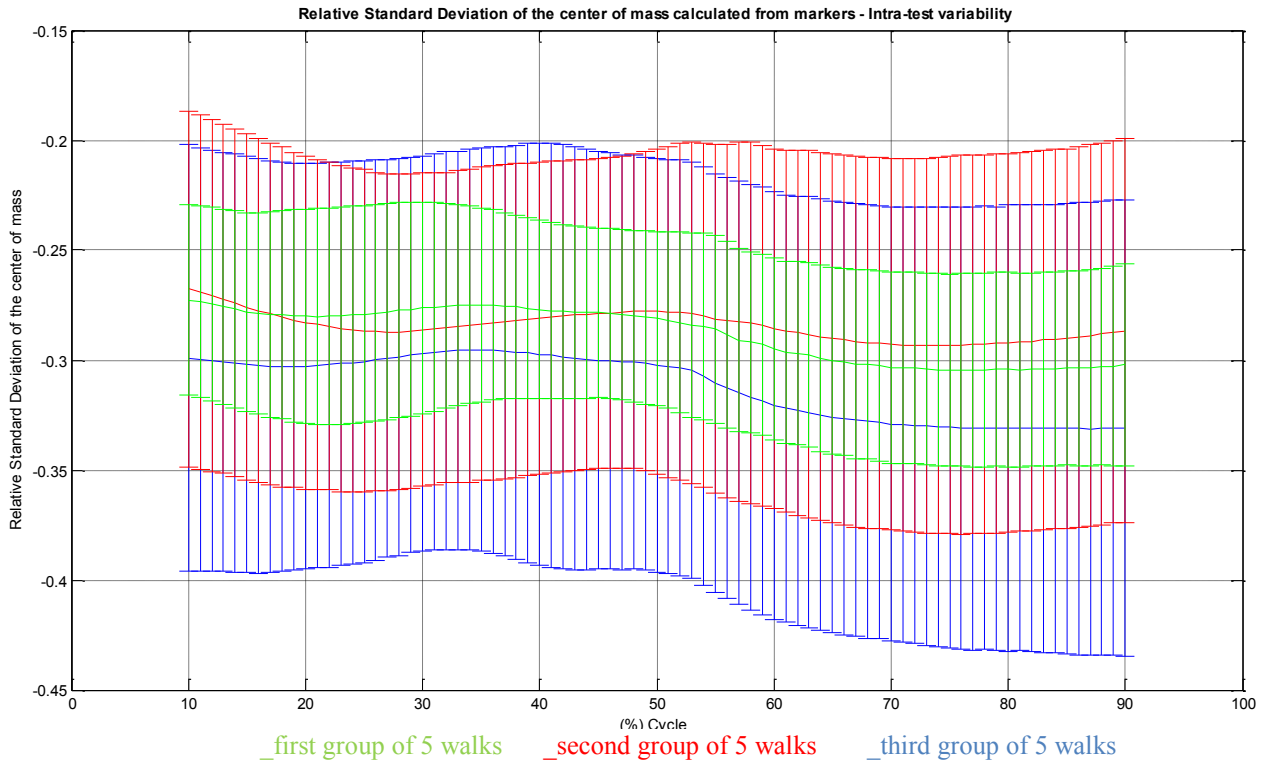


Figure 3.3 - Standard deviation representation of the center of the mass calculated from the midpoint between C7 and the sacrum for each walk-test.

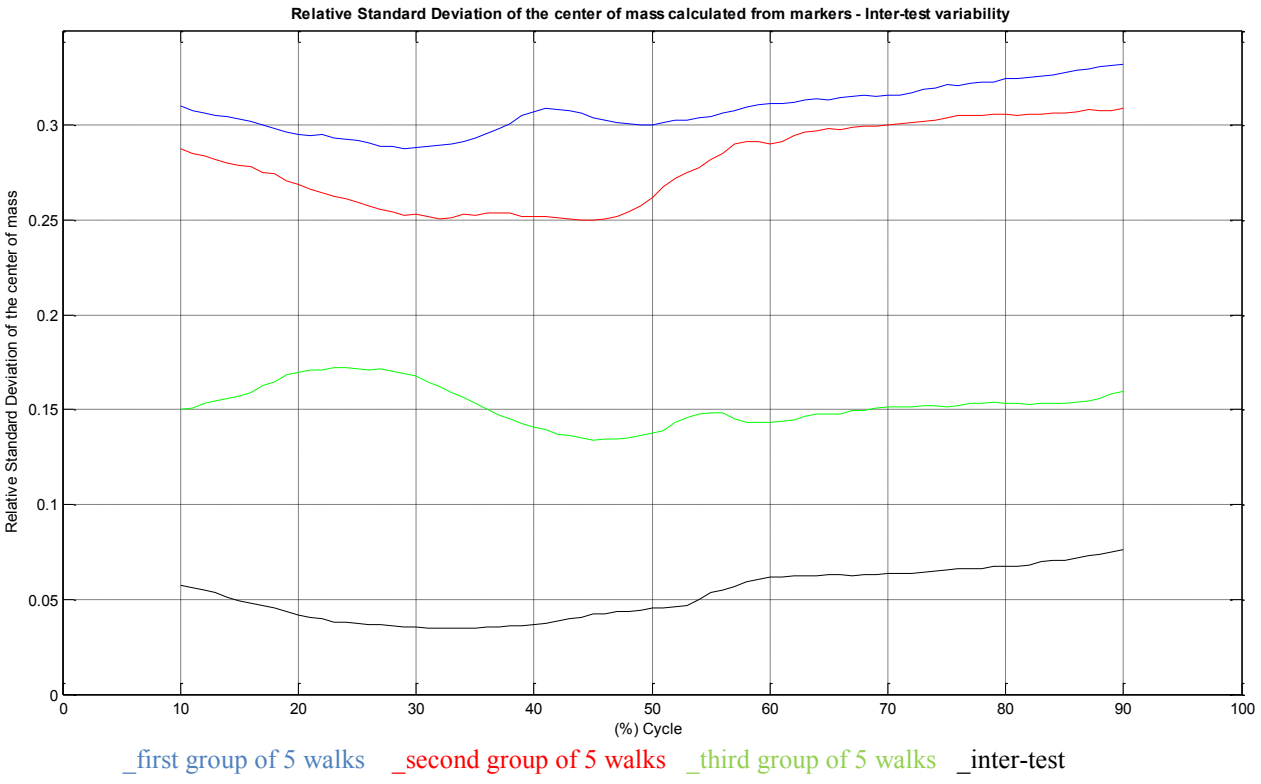


Figure 3.4 - Standard deviation representation of the center of the mass calculated from the midpoint between C7 and the sacrum for all tests of a subject.

After checking the normality of data by the *Shapiro-Wilk* test, that is, it was found that the significance level is greater than 0.05 (sig > 0.05) we proceeded to the analysis of *Levene* test and t-student test.

Table 3.7 - T-student test for inter-test variability of the trajectory of the center of mass around x, y, z axes.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TransfX	Equal variances assumed	,048	,828	-1,532	18	,143	-,74368	,48558	-1,76386	,27650
	Equal variances not assumed			-1,474	8,779	,175	-,74368	,50463	-1,88963	,40227
TransfY	Equal variances assumed	,028	,869	-3,322	18	,004	-1,23619	,37211	-2,01796	-,45441
	Equal variances not assumed			-3,073	8,120	,015	-1,23619	,40230	-2,16152	-,31085
TransfZ	Equal variances assumed	,061	,807	-1,261	18	,223	-,70962	,56280	-1,89203	,47279
	Equal variances not assumed			-1,259	9,495	,238	-,70962	,56377	-1,97490	,55566

Through *Levene* test it is noted that for the x axis sig = 0.828 > 0.05, for y axis sig = 0.869 > 0.05 and the z axis sig = 0.807 > 0.05, therefore it can be concluded that there are no significant differences in the variables of the two groups.

Analyzing the t-student test, it can be seen that the y axis (medio-lateral axis) has a sig value < 0.05, so it can be concluded that there are differences between adults and children.

Table 3.8 - T-student test for intra-test variability of the trajectory of the center of mass around x, y, z axes.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TransfX	Equal variances assumed	,512	,484	-1,940	18	,068	-,77234	,39819	-1,60890	,06423
	Equal variances not assumed			-2,258	13,837	,041	-,77234	,34208	-1,50684	-,03783
TransfY	Equal variances assumed	,223	,642	-4,991	18	,000	-1,47428	,29536	-2,09481	-,85374
	Equal variances not assumed			-4,652	8,237	,002	-1,47428	,31695	-2,20152	-,74704
TransfZ	Equal variances assumed	3,075	,097	-,087	18	,931	-,06384	,73168	-1,60105	1,47337
	Equal variances not assumed			-,108	16,063	,915	-,06384	,59033	-1,31488	1,18720

Through *Levene* test it is noted that for the x axis sig = 0.484 > 0.05, for y axis sig = 0.642 > 0.05 and the z axis sig = 0.097 > 0.05, therefore it can be concluded that there are no significant differences in the variables of the two groups.

Analyzing the t-student test, it can be seen that the y axis (medio-lateral axis) has a sig value < 0.05, so it can be concluded that there are differences between adults and children.

3.3 Kinematics

Through the Matlab it was also possible to calculate the kinematic average of angle cycle sequences: acRAFE (angle cycle right ankle flexion/extension) , acRAIE (angle cycle right ankle intra/extra rotation), acRKFE (angle cycle right knee flexion/extension), acRKAA (angle cycle right knee abduction/adduction), acRKIE(angle cycle right knee

intra/extra rotation), acRHPFE (angle cycle right hip flexion/extension), acRHPAA (angle cycle right hip abduction/adduction), acRHPIE (angle cycle right hip intra/extra rotation), acLAFE (angle cycle left ankle flexion/extension), acLAIE (angle cycle left ankle intra/extra rotation), acLKFE(angle cycle left knee flexion/extension), acLKAA (angle cycle left knee abduction/adduction), acLKIE (angle cycle left knee intra/extra rotation), acLHPFE (angle cycle left hip flexion/extension), acLHPAA (angle cycle left hip abduction/adduction), acLHPIE(angle cycle left hip intra/extra rotation), and acRPTILT, acRPOBLI, acRPROT, acPTILT, acPOBLI, acLPROT (three absolute angles).

- *Adults*

Table 3.9 - Inter-test variability of the angles cycles.

Subject	RAFE	RAIE	RKFE	RKAA	RKIE	RHPFE	RHPAA	RHPIE	LAFE	LAIE	LKFE	LKAA	LKIE	LHPFE	LHPAA	LHPIE	RPTILT	RPOBLI	RPROT	LPTILT	LPOBLI	LPROT
A	0,21	0,43	0,33	0,65	0,85	0,62	2,73	1,02	0,14	0,32	0,25	0,31	0,48	0,27	1,89	0,30	3,52	18,42	2,78	1,60	7,64	4,15
B	0,19	0,18	0,21	0,73	2,21	0,19	0,20	0,27	0,10	0,30	0,08	0,38	1,19	0,06	0,29	1,53	0,07	1,97	1,11	0,07	869,47	1,40
C	0,08	0,11	0,11	0,83	0,50	0,42	0,68	0,71	0,13	0,08	0,2	0,44	0,46	1,24	0,10	0,29	2,10	0,69	5,09	1,30	0,27	4,93
D	0,07	0,07	0,11	0,16	0,17	0,07	0,05	0,80	0,09	0,23	0,08	0,19	0,12	0,07	0,10	0,04	0,11	0,20	0,31	0,09	0,29	0,40
E	0,15	0,23	0,15	1,27	0,40	0,15	0,22	0,95	0,09	0,15	0,09	1,45	1,52	0,18	1,43	0,90	3,05	0,90	2,29	1,11	1,25	4,55
F	0,20	0,30	1,37	0,21	0,61	0,33	0,10	0,47	0,16	0,15	0,79	0,21	0,46	0,22	0,12	0,47	0,07	1,14	5,66	0,05	47,04	0,85
G	0,20	1,59	0,30	0,61	0,29	0,28	0,52	0,51	0,20	0,47	0,18	0,92	0,21	0,16	1,03	1,36	0,25	1,64	0,25	0,21	1,63	0,22
H	0,12	0,22	0,44	1,60	13,03	0,84	0,48	0,22	0,18	0,10	0,59	3,58	0,48	1,19	1,08	0,85	0,12	3,26	0,53	0,16	8,95	0,76
I	0,29	0,54	0,18	3,40	0,24	0,20	0,43	2,00	0,79	0,44	0,53	2,63	21,83	0,68	0,61	118,73	0,47	0,31	1,72	0,54	0,51	2,03
J	0,27	0,21	0,23	2,63	0,38	0,16	0,22	0,98	0,19	0,09	0,14	3,32	0,29	0,17	0,35	0,46	0,14	0,23	0,58	0,08	0,34	0,55
K	0,15	0,52	0,15	0,42	2,80	0,19	0,29	0,20	0,32	1,25	0,31	0,81	0,21	0,33	0,56	0,24	0,11	1,01	0,81	0,16	1,36	0,84
L	0,13	0,61	0,15	1,65	0,30	0,26	0,08	0,22	0,12	142,68	0,11	0,26	0,20	0,08	0,21	0,21	0,54	0,60	0,82	0,19	1,37	1,51
M	0,10	0,32	0,07	0,97	0,18	0,13	0,67	0,21	0,12	0,30	0,14	0,47	0,53	0,19	0,31	0,63	0,13	5,81	1,69	0,14	9,17	2,16
N	0,09	0,36	0,37	0,13	0,27	0,27	0,06	0,10	0,06	0,17	1,15	0,10	0,27	0,87	0,07	0,13	0,19	1,05	0,96	0,17	0,99	1,25
Mean	0,16	0,41	0,30	1,09	1,59	0,29	0,48	0,62	0,19	10,48	0,33	1,08	2,02	0,41	0,58	9,01	0,78	2,66	1,76	0,42	67,88	1,83
Standard deviation	0,07	0,38	0,33	0,96	3,39	0,21	0,68	0,51	0,18	38,05	0,32	1,21	5,72	0,41	0,57	31,58	1,19	4,78	1,70	0,52	231,04	1,58

Table 3.10 - Intra-test variability of the angles cycles.

Subject	RAFE	RAIE	RKFE	RKAA	RKIE	RHPFE	RHPAA	RHPIE	LAFE	LAIE	LKFE	LKAA	LKIE	LHPFE	LHPAA	LHPIE	RPTILT	RPOBLI	RPROT	LPTILT	LPOBLI	LPROT
A	0,28	0,43	0,55	1,30	1,47	1,10	5,60	2,09	0,51	0,59	0,93	0,56	0,94	1,36	16,55	0,86	10,58	8,27	2,87	11,01	30,95	9,94
B	0,35	0,27	0,44	1,04	4,07	0,25	0,37	0,32	0,29	0,28	0,3	0,63	2,61	0,20	0,33	2,00	0,15	2,66	4,14	0,11	22,11	2,56
C	0,16	0,36	0,28	2,62	1,22	1,79	1,47	1,28	0,23	0,23	0,53	1,17	1,06	4,38	0,23	0,74	15,54	1,72	55,65	5,71	0,70	35,82
D	0,16	0,31	0,30	0,41	0,62	0,25	0,22	1,87	0,19	0,63	0,27	0,83	0,29	0,18	0,34	0,11	0,24	0,55	0,76	0,21	0,47	0,78
E	0,27	0,52	0,31	3,19	0,80	0,26	0,43	1,48	0,32	0,33	0,32	2,54	1,93	0,43	10,94	1,51	3,39	1,90	12,72	5,61	3,45	12,86
F	0,63	1,14	6,20	0,95	3,58	1,31	0,43	1,20	0,51	0,34	3,5	0,53	1,09	1,18	0,40	1,29	0,14	3,84	78,58	0,16	51,00	1,49
G	0,47	5,70	0,29	0,66	0,59	0,38	0,69	0,74	0,44	1,26	0,28	1,29	0,42	0,32	1,89	2,80	0,59	2,38	0,50	0,70	3,62	0,60
H	0,14	0,32	0,56	2,39	17,19	2,00	0,80	0,38	0,30	0,27	0,56	69,75	0,55	1,40	2,23	0,95	0,24	5,50	0,72	0,27	26,29	0,96
I	0,57	1,44	0,41	7,51	0,63	0,33	0,74	5,92	0,59	0,64	1,22	15,59	6,95	0,99	1,42	20,93	0,91	0,35	3,42	0,73	0,61	5,61
J	0,46	0,43	0,43	7,31	1,06	0,39	0,51	2,31	0,36	0,36	0,51	5,00	0,68	0,56	0,71	0,59	0,18	0,72	1,77	0,17	0,67	1,34
K	0,37	1,39	0,32	0,89	5,64	0,40	0,59	0,48	0,28	49,53	0,3	0,73	0,47	0,34	1,26	0,35	0,58	2,65	1,09	0,23	4,35	1,34
L	0,24	1,47	0,33	4,64	0,51	0,75	0,22	0,39	0,33	55,32	0,33	0,53	0,62	0,47	0,42	0,33	1,25	1,26	2,71	0,88	1,95	5,94
M	0,16	0,87	0,26	4,29	0,23	0,24	1,26	0,31	0,24	0,88	0,44	1,54	1,35	0,30	0,45	1,20	0,36	21,43	5,81	0,29	105,21	355,98
N	0,25	0,72	0,60	0,17	0,58	0,48	0,20	0,19	0,17	0,41	4,86	0,29	0,78	3,98	0,12	0,23	0,41	1,69	6,66	0,38	1,54	4,55
Mean	0,32	1,10	0,81	2,67	2,73	0,71	0,97	1,35	0,34	7,93	1,03	7,21	1,41	1,15	2,66	2,42	2,47	3,92	12,67	1,89	18,07	31,41
Standard deviation	0,16	1,40	1,56	2,45	4,47	0,60	1,38	1,50	0,13	18,88	1,39	18,44	1,72	1,35	4,87	5,38	4,67	5,47	23,72	3,25	29,47	93,87

- *Children*

Table 3.11 - Inter-test variability of the angles cycles.

Subject	RAFE	RAIE	RKFE	RKAA	RKIE	RHPFE	RHPAA	RHPIE	LAFE	LAIE	LKFE	LKAA	LKIE	LHPFE	LHPAA	LHPIE	RPTILT	RPOBLI	RPROT	LPTILT	LPOBLI	LPROT
A	0,21	1,74	0,12	1,44	0,76	0,12	0,67	0,32	0,25	0,80	0,18	0,49	1,65	0,19	0,94	0,36	0,13	2,62	4,92	0,15	7,00	11,76
B	0,15	0,45	0,26	0,17	85,85	0,09	0,31	0,16	0,18	0,28	0,99	25,13	8,18	0,16	3,45	4,68	0,23	6,34	2,08	0,25	2,67	1,36
C	0,12	0,74	0,09	1,77	3,27	0,10	1,10	0,39	0,19	2,20	0,13	0,32	0,20	0,13	0,39	0,41	0,46	0,33	3,24	0,35	0,43	4,22
D	0,29	0,36	0,39	1,08	0,50	20,28	0,53	0,67	0,17	0,24	0,27	49,08	1,25	47,44	8,00	12,60	0,71	1,00	30,66	0,78	1,04	2,17
E	0,23	0,30	0,19	0,57	0,79	0,21	0,28	3,22	0,16	0,29	0,19	8,70	0,25	0,23	0,88	7,85	0,91	0,41	2,11	0,61	0,40	1,35
F	2,78	0,71	1,48	117,51	1,77	4,55	10,06	2,91	6,97	0,60	1,40	8,59	1,00	8,68	1,30	1,20	0,73	6,75	34,37	0,75	6,00	8,63
Mean	0,63	0,72	0,42	20,42	15,49	4,22	2,16	1,28	1,32	0,74	0,53	15,38	2,09	9,47	2,49	4,52	0,53	2,91	12,90	0,48	2,92	4,91
Standard deviation	1,05	0,53	0,53	47,57	34,48	8,06	3,88	1,39	2,77	0,75	0,54	18,81	3,04	18,91	2,90	4,93	0,31	2,94	15,27	0,27	2,91	4,34

Table 3.12 - Intra-test variability of the angles cycles.

Subject	RAFE	RAIE	RKFE	RKAA	RKIE	RHPFE	RHPAA	RHPIE	LAFE	LAIE	LKFE	LKAA	LKIE	LHPFE	LHPAA	LHPIE	RPTILT	RPOBLI	RPROT	LPTILT	LPOBLI	LPROT
A	0,34	34,14	0,23	3,60	1,47	0,35	1,23	0,65	0,39	1,44	0,45	1,58	172,90	0,51	4,75	1,09	0,45	142,78	13,37	0,44	18,77	175,64
B	0,36	1,27	0,50	0,57	120,27	0,35	0,94	0,44	0,41	0,97	5,49	6,61	8,75	0,50	10,81	8,30	0,30	12,94	5,65	0,28	103,05	8,64
C	0,43	3,98	0,30	3,46	17,41	0,32	2,77	0,89	0,33	4,96	0,30	0,44	0,37	0,43	0,84	0,52	2,25	0,91	5,12	1,31	0,77	113,61
D	0,90	1,48	0,70	2,39	1,69	2,87	0,75	1,76	0,38	1,21	0,55	7,24	5,12	3,47	3,32	5,38	0,95	11,58	9,51	1,42	20,74	11,30
E	0,44	0,82	0,45	1,23	2,45	0,53	0,38	14,27	0,34	0,83	0,48	61,07	0,43	0,54	4,41	68,68	2,10	1,61	5,86	2,09	1,51	11,78
F	32,96	2,92	5,27	217,39	7,27	28,93	14,38	5,88	49,68	3,08	5,39	35,35	4,07	69,91	12,72	6,01	2,61	4,97	8,92	2,95	3,19	471,94
Mean	5,90	7,44	1,24	38,11	25,09	5,56	3,41	3,98	8,59	2,08	2,11	18,72	31,94	12,56	6,14	15,00	1,44	29,13	8,07	1,41	24,67	132,15
Standard deviation	13,26	13,14	1,98	87,84	47,02	11,49	5,44	5,43	20,13	1,63	2,58	24,40	69,13	28,12	4,61	26,47	1,00	55,90	3,17	1,01	39,40	180,02

3.3.1 Angular variability

With the use of matlab and through sequences of angles cycles we got the graphs (Figure 3.5; 3.6; 3.7 and 3.8) corresponding to the average standard deviation relative for each 5 walk-test as well as for the set of all walks.

- *Adults*

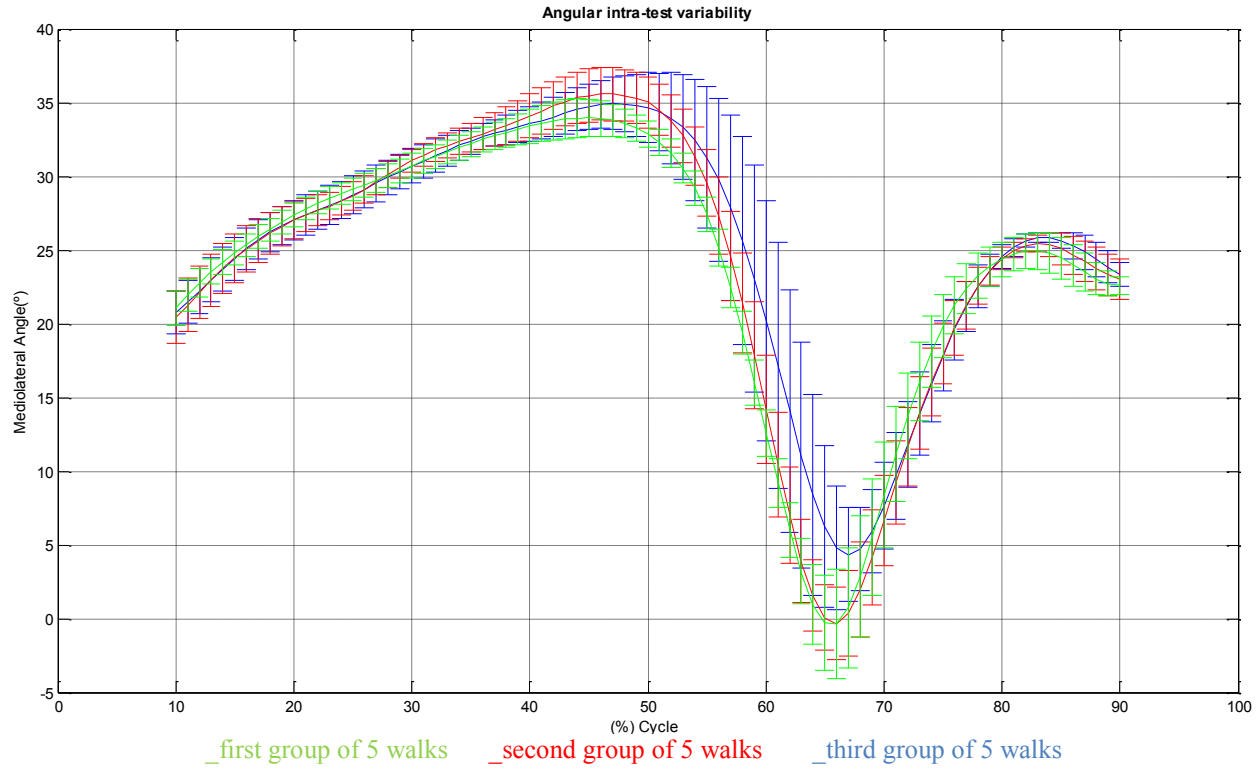


Figure 3.5 – Medio-lateral angle for each walk-test.

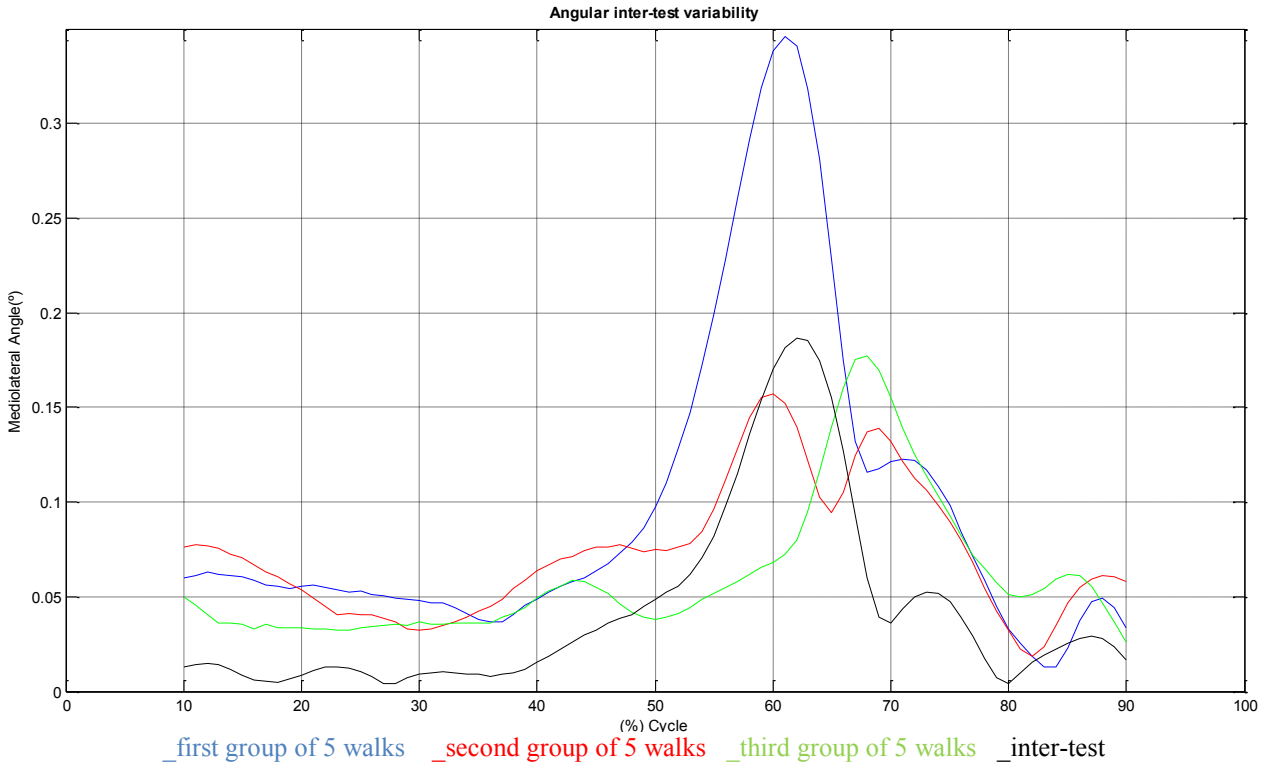
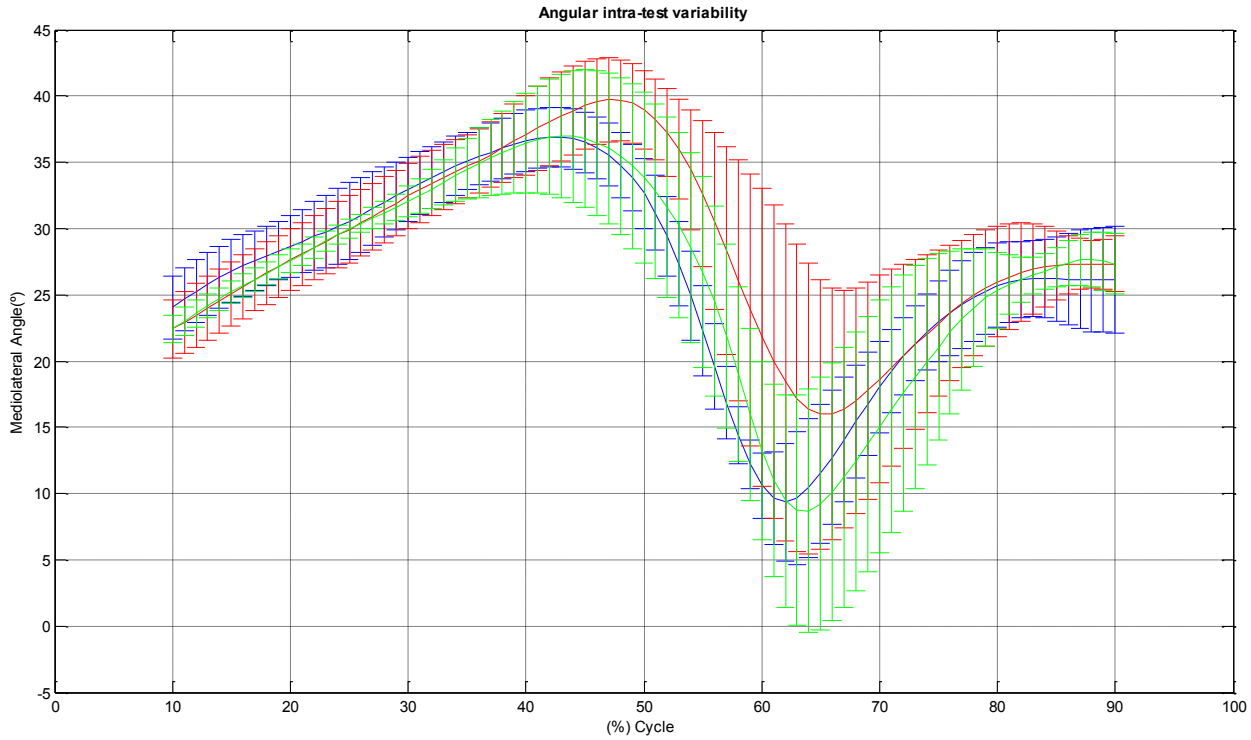


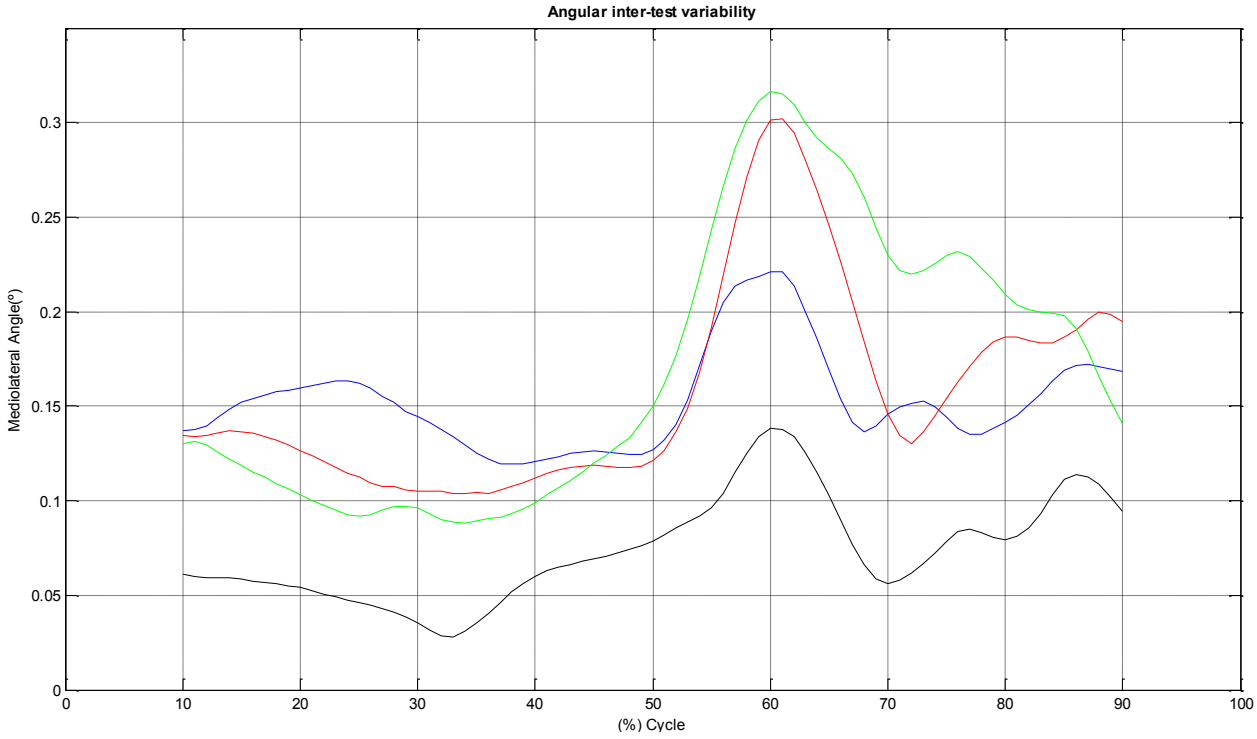
Figure 3.6 – Medio-lateral angle for all tests of a subject.

- *Children*



_first group of 5 walks _second group of 5 walks _third group of 5 walks

Figure 3.7 – Medio-lateral angle for each walk-test.



_first group of 5 walks _second group of 5 walks _third group of 5 walks _inter-test

Figure 3.8 – Medio-lateral angle for all tests of a subject.

After checking the normality of data by the *Shapiro-Wilk* test, that is, it was found that the significance level is greater than 0.05 (sig > 0.05) we proceeded to the analysis of *Levene* test and t-student test (only were chosen some angles cycles).

Table 3.13 - T-student test for inter-test variability of the angles cycles.

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TransfRAIE	,136	,716	-1,867	18	,078	-,66611	,35678	-1,41568	,08346
			-2,020	11,480	,067	-,66611	,32981	-1,38832	,05610
TransfRKFE	,424	,523	-,435	18	,669	-,17462	,40164	-1,01843	,66918
			-,385	7,492	,711	-,17462	,45408	-1,23423	,88498
TransfRHPAA	,032	,860	-2,015	18	,059	-1,14543	,56838	-2,33955	,04869
			-1,869	8,162	,098	-1,14543	,61281	-2,55370	,26284
TransfRHPIE	1,212	,285	-,969	18	,346	-,45768	,47248	-1,45032	,53496
			-,838	7,216	,429	-,45768	,54628	-1,74163	,82626
TransfLKFE	,195	,664	-,932	18	,364	-,41511	,44559	-1,35126	,52104
			-,888	8,608	,399	-,41511	,46754	-1,48014	,64993
TransfLHPAA	,031	,862	-2,728	18	,014	-1,43127	,52459	-2,53340	-,32914
			-2,716	9,437	,023	-1,43127	,52694	-2,61492	-,24762
TransfRPOBLI	,372	,549	-,500	18	,623	-,30881	,61764	-1,60644	,98881
			-,486	8,950	,639	-,30881	,63590	-1,74854	1,13091
TransfRPROT	1,515	,234	-3,328	18	,004	-1,70915	,51350	-2,78796	-,63033
			-2,929	7,426	,021	-1,70915	,58357	-3,07319	-,34510

By *Levene'*s test it is found sig > 0.05, so it can be concluded that there are no significant differences in the variables of the two groups.

Analyzing the t-student test, it can be seen that acLHPAA, and acRPROT have a sig value < 0.05, so it can be concluded that there are differences between adults and children in what concerns to joint angles.

Table 3.14 - T-student test for intra-test variability of the angles cycles.

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TransfRAIE	,693	,416	-2,823	18	,011	-1,38920	,49211	-2,42309	-,35532
			-2,352	6,809	,052	-1,38920	,59058	-2,79369	,01528
TransfRKAA	,800	,383	-1,276	18	,218	-,90142	,70629	-2,38527	,58243
			-1,005	6,291	,352	-,90142	,89680	-3,07148	1,26864
TransfRKIE	1,125	,303	-2,539	18	,021	-1,65613	,65231	-3,02657	-,28569
			-2,176	7,110	,065	-1,65613	,76116	-3,45036	,13810
TransfRHPAA	,977	,336	-1,891	18	,075	-,92927	,49155	-1,96198	,10343
			-1,626	7,150	,147	-,92927	,57158	-2,27511	,41656
TransfRHPIE	,818	,378	-1,409	18	,176	-,75767	,53760	-1,88712	,37179
			-1,236	7,381	,254	-,75767	,61313	-2,19243	,67710
TransfLHPAA	1,509	,235	-2,514	18	,022	-1,60062	,63664	-2,93816	-,26308
			-2,918	13,737	,011	-1,60062	,54849	-2,77914	-,42211
TransfLHPIE	,552	,467	-2,385	18	,028	-1,62941	,68330	-3,06497	-,19385
			-2,102	7,449	,071	-1,62941	,77514	-3,44018	,18135
TransfRPOBLI	1,833	,193	-1,875	18	,077	-1,20764	,64397	-2,56057	,14529
			-1,532	6,612	,172	-1,20764	,78847	-3,09448	,67920

By *Levene*'s test it is found sig > 0.05, so it can be concluded that there are no significant differences in the variables of the two groups.

Analyzing the t-student test, it can be seen that acRAIE, acRKIE, acLHPAA, acLHPIE have a sig value < 0.05, so it can be concluded that there are differences between adults and children in what concerns to joint angles.

3.4 Center of Mass Acceleration

With the use Matlab we calculated the center of mass by acceleration and we got for correspondent to the average standard deviation for each 5 walk-test as well as the set of all walks in adults (Table 3.15 and 3.16) and children (Table 3.17 and 3.18).

- *Adults*

Table 3.15 - Inter-test variability of the L5 acceleration around x, y, z axes.

Subject	X	Y	Z
A	0,05	1,25	0,15
B	0,02	0,67	0,07
C	0,02	0,51	0,08
D	0,01	0,84	0,37
E	0,05	4,18	0,26
F	0,03	5,11	0,13
G	0,05	0,93	0,18
H	0,10	3,42	0,13
I	0,03	0,46	0,24
J	0,14	12,36	0,73
K	0,04	3,04	0,20
L	0,04	2,43	0,23
M	0,02	1,73	0,59
N	0,05	0,45	0,20
Mean	0,05	2,67	0,25
Standard deviation	0,03	3,17	0,19

Table 3.16 - Intra-test variability of the L5 acceleration around x, y, z axes.

Subject	X	Y	Z
A	0,08	1,87	0,23
B	0,06	0,74	0,21
C	0,04	1,01	0,14
D	0,05	2,24	0,75
E	0,11	4,77	0,33
F	0,05	212,16	0,29
G	0,09	2,43	0,35
H	0,07	4,49	0,31
I	0,05	0,76	0,56
J	0,63	22,35	2,15
K	0,04	9,21	0,17
L	0,10	7,40	0,52
M	0,04	4,85	1,01
N	0,05	1,32	0,29
Mean	0,10	19,69	0,52
Standard deviation	0,15	55,68	0,53

- *Children*

Table 3.17 – Inter-test variability of the L5 acceleration around x, y, z axes.

Subject	X	Y	Z
A	0,09	2,96	1,99
B	0,06	1,61	1,46
C	0,09	1,36	0,34
D	0,11	11,71	0,81
E	0,08	0,42	0,87
F	0,14	6,98	0,40
Mean	0,09	4,17	0,98
Standard deviation	0,03	4,36	0,64

Table 3.18 - Intra-test variability of the L5 acceleration around x, y, z axes.

Subject	X	Y	Z
A	0,15	7,20	4,39
B	0,29	9,31	2,99
C	0,17	2,49	0,69
D	0,25	5,60	1,95
E	0,10	1,10	1,74
F	0,30	11,86	2,06
Mean	0,21	6,26	2,30
Standard deviation	0,08	4,07	1,26

3.4.1 Center of Mass calculated from acceleration (OPAL)

With the use of Matlab calculated the center of mass by acceleration and we got the graphs (Figure 3.9; 3.11; 3.12 and 3.13) corresponding to the average relative standard deviation for each 5 walk-test, as well as for the set of all walks.

- *Adults*

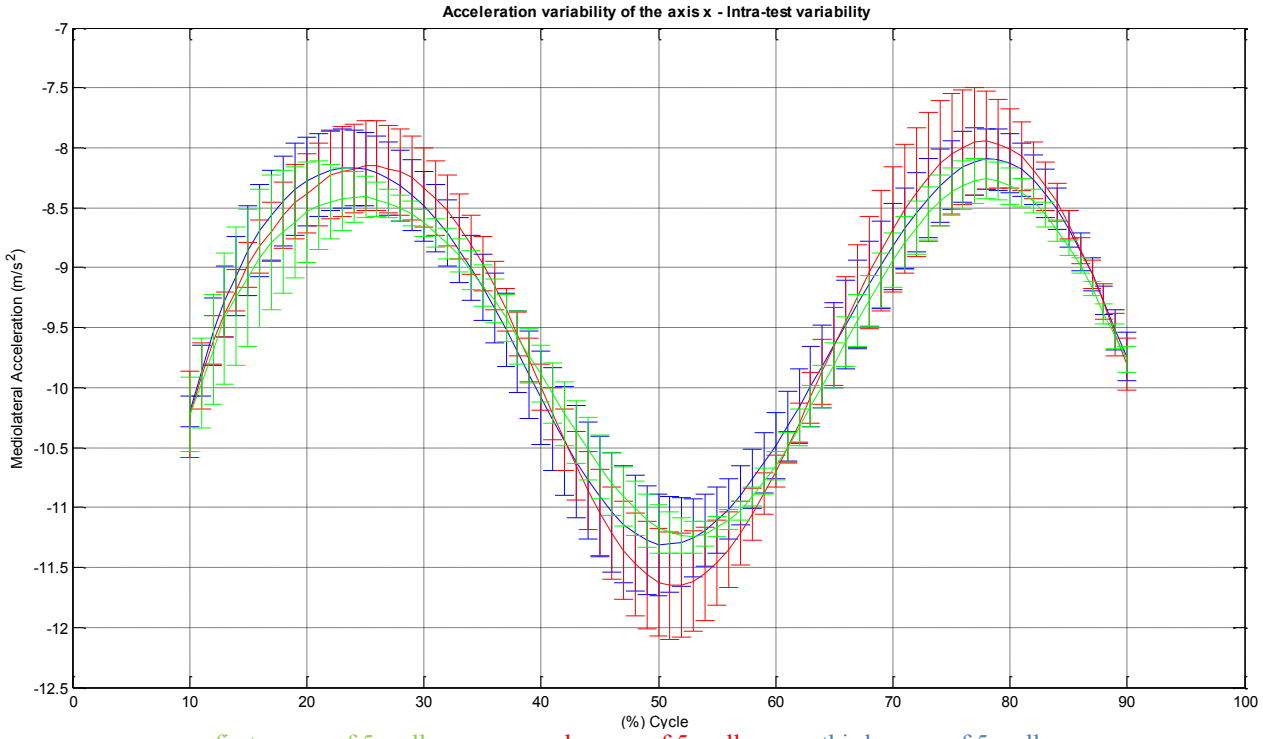


Figure 3.9 – Medio-lateral acceleration for each walk-test.

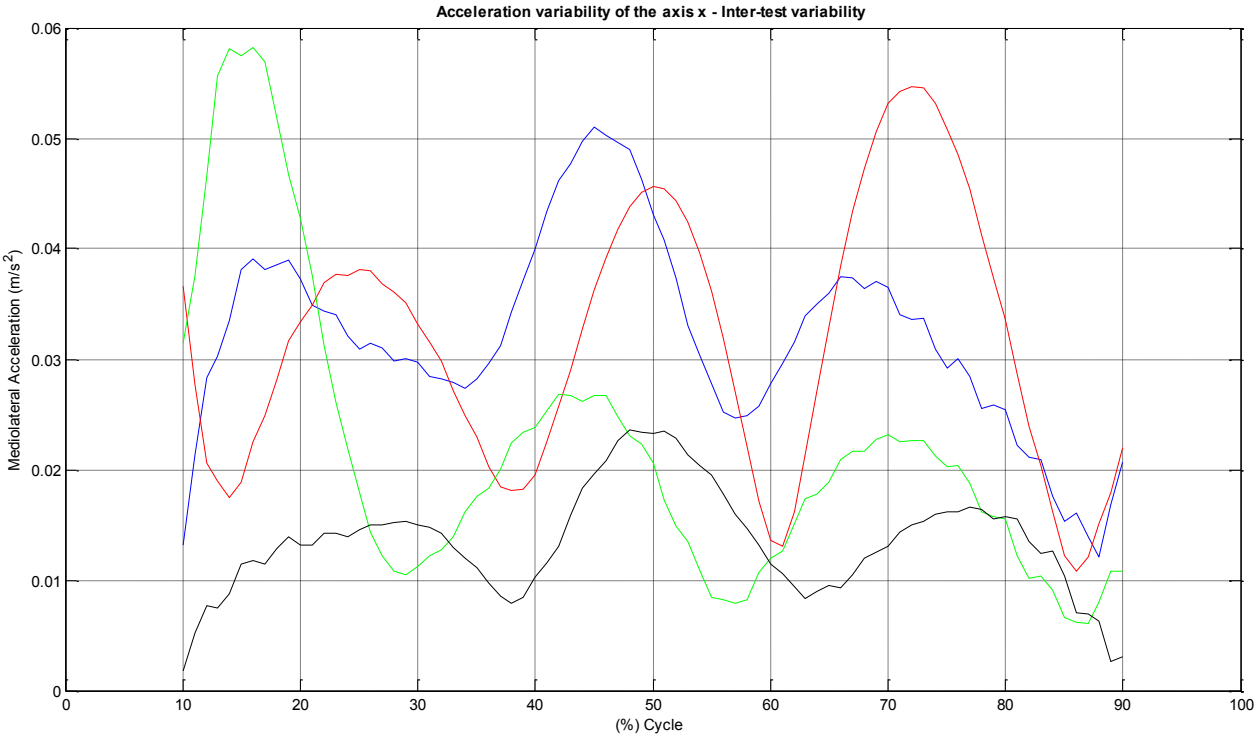


Figure 3.10 – Medio-lateral acceleration for all tests of a subject.

- *Children*

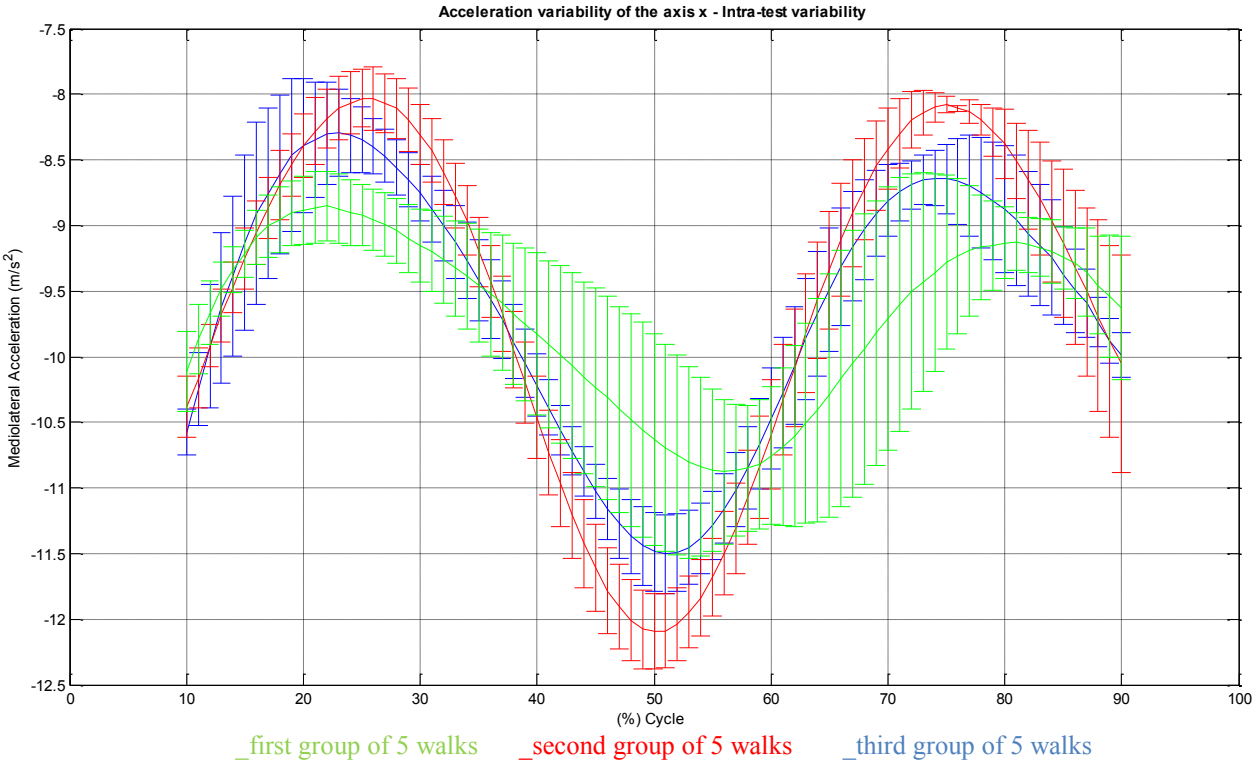


Figure 3.11 – Medio-lateral acceleration for each walk-test.

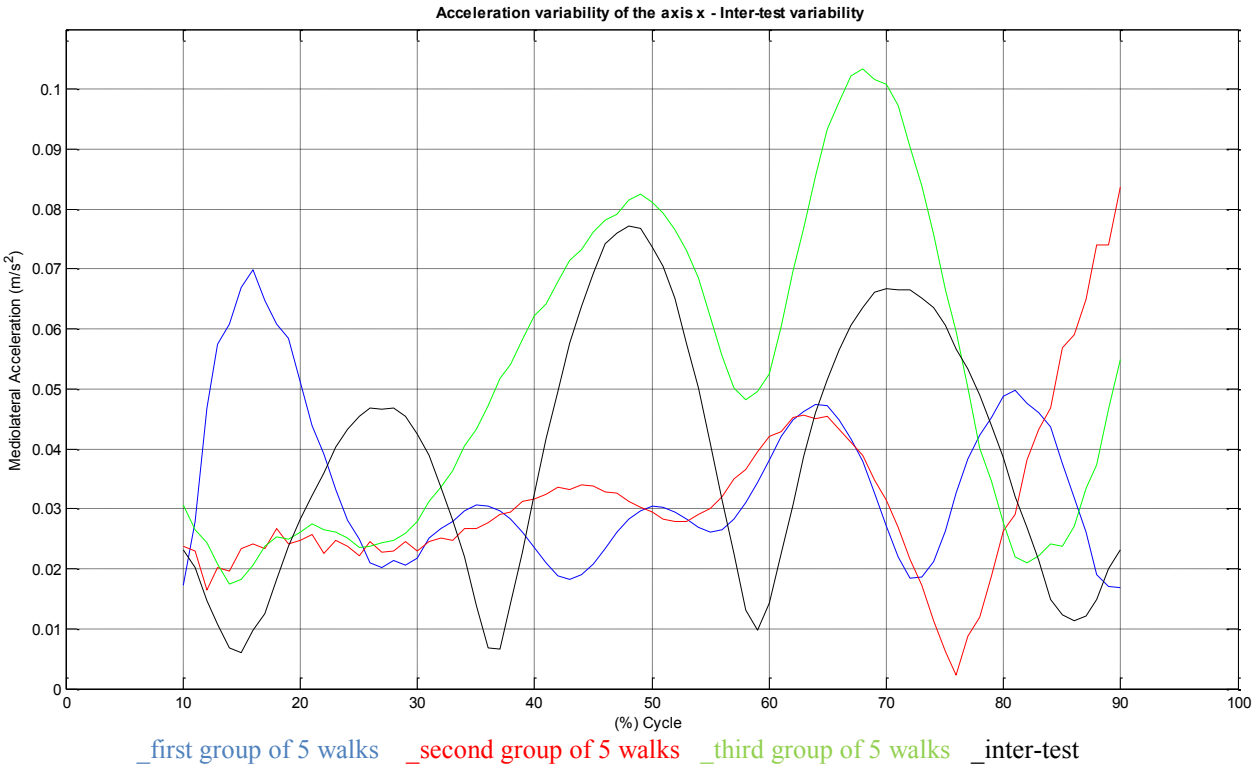


Figure 3.12 – Medio-lateral acceleration for all tests of a subject.

After checking the normality of data by the *Shapiro-Wilk* test, that is, it was found that the significance level is greater than 0.05 (sig > 0.05) we proceeded to the analysis of *Levene* test and t-student test.

Table 3.19 - T-student test for inter-test variability of the L5 acceleration around x, y, z axes.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TransfX	Equal variances assumed	2,612	,123	-3,149	18	,006	-,86429	,27445	-1,44089	-,28769
	Equal variances not assumed			-4,188	17,859	,001	-,86429	,20635	-1,29806	-,43051
TransfY	Equal variances assumed	,077	,785	-,800	18	,434	-,41994	,52468	-1,52226	,68238
	Equal variances not assumed			-,747	8,260	,476	-,41994	,56219	-1,70927	,86940
TransfZ	Equal variances assumed	,026	,874	-4,167	18	,001	-1,36828	,32835	-2,05811	-,67844
	Equal variances not assumed			-4,083	9,117	,003	-1,36828	,33512	-2,12489	-,61167

Through *Levene* test it is noted that for the x axis sig = 0.123 > 0.05, for y axis sig = 0.785 > 0.05 and the z axis sig = 0.874 > 0.05, therefore it can be concluded that there are no significant differences in the variables of the two groups.

Analyzing the t-student test, it can be seen that the x axis (vertical axis) and z axis (antero-posterior axis) have a sig value < 0.05, so it can be concluded that there are differences between adults and children.

Table 3.20 - T-student test for intra-test variability of the L5 acceleration around x, y, z axes.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TransfX	Equal variances assumed	,184	,673	-3,231	18	,005	-,99684	,30854	-1,64506	-,34863
	Equal variances not assumed			-3,920	15,320	,001	-,99684	,25428	-1,53785	-,45584
TransfY	Equal variances assumed	,790	,386	-,277	18	,785	-,18499	,66851	-1,58948	1,21950
	Equal variances not assumed			-,339	15,646	,739	-,18499	,54591	-1,34439	,97441
TransfZ	Equal variances assumed	,605	,447	-4,741	18	,000	-1,64318	,34661	-2,37138	-,91499
	Equal variances not assumed			-5,111	11,383	,000	-1,64318	,32150	-2,34791	-,93846

Through *Levene* test it is noted that for the x axis sig = 0.673 > 0.05, for y axis sig = 0.386 > 0.05 and the z axis sig = 0.447 > 0.05, therefore it can be concluded that there are no significant differences in the variables of the two groups.

Analyzing the t-student test, it can be seen that the x axis (vertical axis) and z axis (antero-posterior axis) have a sig value < 0.05, so it can be concluded that there are differences between adults and children.

4. Discussion

Through graphical analysis and statistical analysis we can observe that the trajectory of the center of mass, the acceleration of the center of mass and the joint angles are substantially different in adults and children.

Analysing the mass center trajectory in both inter-test condition and in intra-test condition it can be checked through the Tables 3.3, 3.4, 3.5 and 3.6 that the percentage of medio-lateral standard deviation was higher in the group of children, and together with the Figure 3.1, 3.2, 3.3 and 3.4, it is found that children have a standard deviation higher than adults. Confirming the results in statistical form (Table 3.7 and 3.8), it turns out that there really are differences in the medio-lateral axis.

The results of the joint angles have greater variability in children than in adults, both for intra-test and inter-test conditions (Table 3.9, 3.10, 3.11 and 3.12) For example: in particular children hip flexion / extension and intra / extra rotation, and ankle flexion / extension angles showed percentage standard deviation greater than adults' ones.

Analyzing graphically (Figure 3.5, 3.6, 3.7 and 3.8), it is found that the angular variability is also higher in children both the inter-test condition and in the intra-test condition.

Confirming the results in statistical form (Tables 3.13 and 3.14) and analyzing some angular cycles, it can be seen that, for example, in the intra-test condition the acRAIE (angle cycle right ankle intra / extra rotation) shows significant differences between adults and children.

In both intra-test and inter-test conditions, children COM acceleration showed percentage standard deviation higher on the antero-posterior axis. The percentage of standard deviation on the vertical axis is smaller in children in both inter-and intra- test condition,

Analyzing graphically (Figure 3.9, 3.10, 3.11 and 3.12), it is apparent that the variability of the acceleration is also higher in children in both the inter-test condition and in the intra-test condition.

Using statistics (Tables 3.19 and 3.20), it can be seen that there are relative differences between adults and children concerning the vertical and antero-posterior axes.

Due to two high values of two adults in the medial-lateral axis resulting of a possible inadequate movement during the execution of test, the result is slightly altered, because one would expect the percentage of the standard deviation of the medio-lateral axis in children to

be higher to adults. However, assessing the inter-test condition, despite similar values children present greater acceleration of the center of mass.

In studies carried out by Wurderman *et al.* (2012) the results for the absolute measure of variability have shown that during lateral gait, the antero-posterior direction had significantly greater variability than in the medio-lateral direction.

When comparing the standard deviation, the medio-lateral direction values were higher than in the antero-posterior direction, but a closer inspection of the group means showed that the medio-lateral direction had larger values because of the standard deviation rather than the particular main step. The delay step in the medio-lateral direction, however, is similar to the delay step and main step of the antero-posterior direction. This was confirmed by significant interactions. From the standard deviations, it is possible to conclude 1 of 2 things: (1) there is no difference in antero-posterior and medio-lateral control, or (2) the use of absolute variability to compare human movements of grossly different magnitudes is inappropriate.

The incoherence between lag and lead step standard deviations in the antero-posterior direction gives no insight into the directional control, but highlights the dependence of the standard deviation on the means. Thus, we should consider the normalized variation, which depicts a more detailed image of the control differences for antero-posterior and medio-lateral direction. Specifically, the change in the direction of gait progression resulted in a greater amount of variability in the antero-posterior direction than the medio-lateral direction.

The results of Wurderman *et al.* (2012) have shown that the antero-posterior direction had greater variability than the medio-lateral direction.

Control of the directions of movement are well defined, however it is thought that the amount of active control in any direction depends on the direction of progression. The increase in active control is assumed on the less beneficial direction of the impact of passive physical entities associated with motion such as momentum and inertia. The direction that is orthogonal to the progression will have the least amount of influence of these entities (for example, of inertia and momentum) and, therefore, are expected to have greater dependence on active neural control for foot placement (Wurderman *et al.* 2012).

According to Kang *et al.* (2007) the observed variability in gait of adults is a result of loss of strength and flexibility rather than slower speed. Therefore, changes in gait variability exist in healthy normal aging, and this increase in variability was perceptible through the

trunk roll angle. This is supported by the literature where the roll motion is not stable in gait and fall risk was predicted by step width variability.

According to the study of Estrázulas *et al.* (2005) the group of children presented higher values than adults, which may be related to the lack of maturation of this group when executing the march. Therefore, they concluded that these groups have distinct characteristics of locomotion and, although some variables are similar, one can verify the specificity of each group studied.

5. Conclusions and Future Research

5.1 Conclusions

The results of this study support the hypothesis that the trajectory of the COM is one of the main factors of gait control dynamics of the Central Nervous System (CNS): children showed less variability in COM kinematics (trajectory and acceleration) than in joint angles. Thus, it can be argued that, during operation, the control CNS is focused on the progression of the COM and not on its lateral stabilization, therefore we can conclude that in children variability in the medial-lateral axis is greater than in adults.

Understanding the dynamics of control while walking is of fundamental importance both to improve the basic knowledge and to improve rehabilitation techniques in neurological and / or elderly patients.

Considering the individual variability of human body structure and complexity of locomotion, it can be concluded that description of COM behaviours during walking is a complex task.

5.2 Future work

The research time of this work, though enough to draw the conclusions described above, could be extended to enable an increased number of study participants.

The kinematic and dynamic studies of human locomotion are of major interest for the study of injury, disease or the aging process. Thus, in the future, the same study might be taken, but applied to a wider age diversity, comparing different age groups, resorting to individuals with certain pathologies, or subjecting individuals to weight transport, in order to study the gait when they are in physical effort.

Therefore, in the future, it would be important to analyze the trajectory of the COM at various ages (so, its performance) to see what is the mechanism of the pendulum, and it would also be important to use other software to acquire data on the kinematics of the movement, in order to improve the quality of the results.

6. Appendix

6.1 Appendix I - Matlab code

elaboraAngoli

```
clear
clc
close all

n=5;
for i =2:n
currentFile = sprintf('ARwalking_0%d.mat',i)

load(currentFile)
%clear SEQcicliANG
SEQcicliANGOLI0(:,:,i)=[SEQcicliANG];
end
media0=nanmean(SEQcicliANGOLI0,3);
devst0=nanstd(SEQcicliANGOLI0,0,3);
devstREL0=devst0/mean(media0);

n=5;
for i =1:n
currentFile = sprintf('ARwalking_1%d.mat',i)

load(currentFile)
%clear SEQcicliANG
SEQcicliANGOLI1(:,:,i)=[SEQcicliANG];
end
media1=nanmean(SEQcicliANGOLI1,3);
devst1=nanstd(SEQcicliANGOLI1,0,3);
devstREL1=devst1/mean(media1);

n=5;
for i =1:n
currentFile = sprintf('ARwalking_2%d.mat',i)

load(currentFile)
%clear SEQcicliANG
SEQcicliANGOLI2(:,:,i)=[SEQcicliANG];
end
media2=nanmean(SEQcicliANGOLI2,3);
devst2=nanstd(SEQcicliANGOLI2,0,3);
devstREL2=devst2/mean(media2);

%Variabilità inter test
mediaTOT(:,:,1)=media0;
mediaTOT(:,:,2)=media1;
mediaTOT(:,:,3)=media2;
mediaInter=nanmean(mediaTOT,3);
stdInter=nanstd(mediaTOT,0,3);
devstInterREL=stdInter/mean(mediaInter);

%save ARwalkingANGLES media0 devst0 devstREL0 media1 devst1 devstREL1
media2 devst2 devstREL2
```

```
k=1;
figure(1)
errorbar([1:101],media0(:,k),devst0(:,k))
hold on
errorbar([1:101],media1(:,k),devst1(:,k),'r')
errorbar([1:101],media2(:,k),devst2(:,k),'g')

figure(2)
plot([1:101],devstREL0(:,k))
hold on
plot([1:101],devstREL1(:,k),'r')
plot([1:101],devstREL2(:,k),'g')
plot([1:101],devstInterREL(:,k),'k')

save ARwalkingANGLES_std devstREL0 devstREL1 devstREL2 devstInterREL
```

Elaboramarker3D

```
clear
close all
clc

% indici (se presenti tutti i marker, quindi tracce [numFrame*85]
% sacro = 2,3,4
% C7= 44 45 46

n=5;
for i =1:n
currentFile = sprintf('ARwalking_0%d.mat',i)

load(currentFile)
i1=round(EVENTI(1,2)*200);
i2=round(EVENTI(2,2)*200);

Sa=interpft(tracce3D(i1:i2,2:4),101);
C7=interpft(tracce3D(i1:i2,44:46),101);


% DA MODIFICARE IN BASE A POSIZIONE L5! COSTRUIRE SDR TRONCO PER VALUTARE
A(:,:,1)=Sa;
A(:,:,2)=C7;
L5g=mean(A,3);
%L5(:,:,i)=prova2-Sa;

O=[0 0 0];
R=planax(C7(10,:)', C7(90,:)', Sa(10,:)', O', [0 10 0]');

for k=1:101
L5(k,:,i)=planloca(R,O',L5g(k,:)');
end

% A(:,:,1)=Sa;
% A(:,:,2)=C7;
% mediaZero=Sa(1,:);
% prova=[mediaZero(1).*ones(101,1) mediaZero(2).*ones(101,1)
mediaZero(3).*ones(101,1)];
% prova2=C7-Sa;
```

```
% L5(:,:,i)=C7-Sa;

end
mediaL5_0=nanmean(L5,3);
devstL5_0=nanstd(L5,0,3);

for i=1:3
devstREL0(:,i)=devstL5_0(:,i)/abs(mean(mediaL5_0(:,i)));
end

n=5;
for i =1:n
currentFile = sprintf('ARwalking_1%d.mat',i)

load(currentFile)
i1=round(EVENTI(1,2)*200);
i2=round(EVENTI(2,2)*200);

Sa=interpft(tracce3D(i1:i2,2:4),101);
C7=interpft(tracce3D(i1:i2,44:46),101);

% DA MODIFICARE IN BASE A POSIZIONE L5! COSTRUIRE SDR TRONCO PER VALUTARE
A(:,:,1)=Sa;
A(:,:,2)=C7;
L5g=mean(A,3);
%L5(:,:,i)=prova2-Sa;

O=[0 0 0];
R=planax(C7(10,:)', C7(90,:)', Sa(10,:)', O', [0 10 0]');

for k=1:101
L5(k,:,i)=planloca(R,O',L5g(k,:)');
end

end
mediaL5_1=nanmean(L5,3);
devstL5_1=nanstd(L5,0,3);
for i=1:3
devstREL1(:,i)=devstL5_1(:,i)/abs(mean(mediaL5_1(:,i)));
end

n=[1 3 4];
for i =1:3
currentFile = sprintf('ARwalking_2%d.mat',n(i))

load(currentFile)
i1=round(EVENTI(1,2)*200);
i2=round(EVENTI(2,2)*200);

Sa=interpft(tracce3D(i1:i2,2:4),101);
C7=interpft(tracce3D(i1:i2,44:46),101);

% DA MODIFICARE IN BASE A POSIZIONE L5! COSTRUIRE SDR TRONCO PER VALUTARE
A(:,:,1)=Sa;
A(:,:,2)=C7;
L5g=mean(A,3);
%L5(:,:,i)=prova2-Sa;

O=[0 0 0];
```

```
R=planax(C7(10,:)', C7(90,:)', Sa(10,:)', O', [0 10 0]');

for k=1:101
L5(k,:,i)=planloca(R,O',L5g(k,:)');
end

end
mediaL5_2=nanmean(L5,3);
devstL5_2=nanstd(L5,0,3);
for i=1:3
devstREL2(:,i)=devstL5_2(:,i)/abs(mean(mediaL5_2(:,i)));
end

%Variabilità inter test
mediaTOT(:,:,1)=mediaL5_0;
mediaTOT(:,:,2)=mediaL5_1;
mediaTOT(:,:,3)=mediaL5_2;
mediaInter=nanmean(mediaTOT,3);
stdInter=nanstd(mediaTOT,0,3);

for i=1:3
devstInterREL(:,i)=stdInter(:,i)/abs(mean(mediaInter(:,i)));
end

k=1;
figure(1)
errorbar([1:101],mediaL5_0(:,k),devstL5_0(:,k))
hold on
errorbar([1:101],mediaL5_1(:,k),devstL5_1(:,k),'r')
errorbar([1:101],mediaL5_2(:,k),devstL5_2(:,k),'g')

figure(2)
plot([1:101],devstREL0(:,k))
hold on
plot([1:101],devstREL1(:,k),'r')
plot([1:101],devstREL2(:,k),'g')
plot([1:101],devstInterREL(:,k),'k')

save ARwalkingCOM_std devstREL0 devstREL1 devstREL2 devstInterREL
```

letturaDati_emt2mat

```
clear
close all
clc

% % DA USARE PER PROVE 01---05
% numFiles = 2;
for n = 1:5

   currentFile = sprintf('MMwalking_0%d_ciclidiangoli1D.emt',n);
   cicliANG = dlmread(currentFile,'',8,0);

   currentFile = sprintf('MMwalking_0%d_sequenzediciclidiangoli1D.emt',n);
   SEQcicliANG = dlmread(currentFile,'',8,1);
```

```
    currentFile = sprintf('MMwalking_0%d_sequenzedieventi.emt',n);
    EVENTI = dlmread(currentFile,'',8,0);


    currentFile = sprintf('MMwalking_0%d_traccePunti3D.emt',n);
    tracce3D = dlmread(currentFile,'',11,1);

    myFile=sprintf('MMwalking_0%d.mat',n);
    save(myFile,'cicliANG','SEQcicliANG','EVENTI','tracce3D')

end

% DA USARE PER PROVE 11---25

numFiles = [11 12 13 14 15 21 22 23 24 25];
for n = 1:10

    currentFile = sprintf('MMwalking_%d_ciclidiangoli1D.emt',numFiles(n));
    cicliANG = dlmread(currentFile,'',8,0);

    currentFile =
sprintf('MMwalking_%d_sequenzediciclidiangoli1D.emt',numFiles(n));
    SEQcicliANG = dlmread(currentFile,'',8,1);

    currentFile = sprintf('MMwalking_%d_sequenzedieventi.emt',numFiles(n));
    EVENTI = dlmread(currentFile,'',8,0);

    currentFile = sprintf('MMwalking_%d_traccePunti3D.emt',numFiles(n));
    tracce3D = dlmread(currentFile,'',11,1);

    myFile=sprintf('MMwalking_%d.mat',numFiles(n));
    save(myFile,'cicliANG','SEQcicliANG','EVENTI','tracce3D')

end
```

risultatiACC

```
clear
close all
clc

load SCwalkingACC_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(1,:)=max(stdMAXintra);
stdMAXinter(1,:)=max(devstInterREL(10:90,:));

load IAwalkingACC_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));
```

```
stdMEANintra(2,:)=max(stdMAXintra);
stdMAXinter(2,:)=max(devstInterREL(10:90,:));

load BAwalkingACC_std
stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(3,:)=max(stdMAXintra);
stdMAXinter(3,:)=max(devstInterREL(10:90,:));

load CGwalkingACC_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(4,:)=max(stdMAXintra);
stdMAXinter(4,:)=max(devstInterREL(10:90,:));

load MMwalkingACC_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(5,:)=max(stdMAXintra);
stdMAXinter(5,:)=max(devstInterREL(10:90,:));

load DBwalkingACC_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(6,:)=max(stdMAXintra);
stdMAXinter(6,:)=max(devstInterREL(10:90,:));

load ARwalkingACC_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(7,:)=max(stdMAXintra);
stdMAXinter(7,:)=max(devstInterREL(10:90,:));

load MAMwalkingACC_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(8,:)=max(stdMAXintra);
stdMAXinter(8,:)=max(devstInterREL(10:90,:));

load MBwalkingACC_std
```

```
stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(9,:)=max(stdMAXintra);
stdMAXinter(9,:)=max(devstInterREL(10:90,:));

load MBAwalkingACC_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(10,:)=max(stdMAXintra);
stdMAXinter(10,:)=max(devstInterREL(10:90,:));

MEANintra=mean(stdMEANintra);
MEANinter=mean(stdMAXinter);

[SUCCESS,MESSAGE]=xlswrite('risACC.xlsx',MEANintra,'MeanIntra','2')
[SUCCESS,MESSAGE]=xlswrite('risACC.xlsx',MEANinter,'MeanInter','2')
```

risultatiCINE_adulti

```
clear
close all
clc

load SCwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(1,:)=max(stdMAXintra);
stdMAXinter(1,:)=max(devstInterREL(10:90,:));

load IAwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(2,:)=max(stdMAXintra);
stdMAXinter(2,:)=max(devstInterREL(10:90,:));

load BAwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(3,:)=max(stdMAXintra);
stdMAXinter(3,:)=max(devstInterREL(10:90,:));

load CGwalkingANGLES_std
```

```
stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));
stdMEANintra(4,:)=max(stdMAXintra);
stdMAXinter(4,:)=max(devstInterREL(10:90,:));

load MMwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(5,:)=max(stdMAXintra);
stdMAXinter(5,:)=max(devstInterREL(10:90,:));

load DBwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(6,:)=max(stdMAXintra);
stdMAXinter(6,:)=max(devstInterREL(10:90,:));

load ARwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(7,:)=max(stdMAXintra);
stdMAXinter(7,:)=max(devstInterREL(10:90,:));

load MAMwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(8,:)=max(stdMAXintra);
stdMAXinter(8,:)=max(devstInterREL(10:90,:));

load MBwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(9,:)=max(stdMAXintra);
stdMAXinter(9,:)=max(devstInterREL(10:90,:));

load MBAwalkingANGLES_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));
```

```
stdMEANintra(10,:)=max(stdMAXintra);
stdMAXinter(10,:)=max(devstInterREL(10:90,:));


MEANintra=mean(stdMEANintra);
MEANinter=mean(stdMAXinter);

[SUCCESS,MESSAGE]=xlswrite('risCINE.xlsx',MEANintra,'MeanIntra','3')
[SUCCESS,MESSAGE]=xlswrite('risCINE.xlsx',MEANinter,'MeanInter','3')
```

risultatiCOM_adulti

```
clear
close all
clc

load SCwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(1,:)=max(stdMAXintra);
stdMAXinter(1,:)=max(devstInterREL(10:90,:));

load IAwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(2,:)=max(stdMAXintra);
stdMAXinter(2,:)=max(devstInterREL(10:90,:));

load BAwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(3,:)=max(stdMAXintra);
stdMAXinter(3,:)=max(devstInterREL(10:90,:));

load CGwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(4,:)=max(stdMAXintra);
stdMAXinter(4,:)=max(devstInterREL(10:90,:));

load MMwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
```

```
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(5,:)=max(stdMAXintra);
stdMAXinter(5,:)=max(devstInterREL(10:90,:));

load DBwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(6,:)=max(stdMAXintra);
stdMAXinter(6,:)=max(devstInterREL(10:90,:));

load ARwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(7,:)=max(stdMAXintra);
stdMAXinter(7,:)=max(devstInterREL(10:90,:));

load MAMwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(8,:)=max(stdMAXintra);
stdMAXinter(8,:)=max(devstInterREL(10:90,:));

load MBwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(9,:)=max(stdMAXintra);
stdMAXinter(9,:)=max(devstInterREL(10:90,:));

load MBAwalkingCOM_std

stdMAXintra(1,:)=max(devstREL0(10:90,:));
stdMAXintra(2,:)=max(devstREL1(10:90,:));
stdMAXintra(3,:)=max(devstREL2(10:90,:));

stdMEANintra(10,:)=max(stdMAXintra);
stdMAXinter(10,:)=max(devstInterREL(10:90,:));

MEANintra=mean(stdMEANintra);
MEANinter=mean(stdMAXinter);

[SUCCESS,MESSAGE]=xlswrite('risCOM.xlsx',MEANintra,'MeanIntra','3')
[SUCCESS,MESSAGE]=xlswrite('risCOM.xlsx',MEANinter,'MeanInter','3')
```

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