ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 12, Issue, 03, pp. 54814-54818, March, 2022
https://doi.org/10.37118/ijdr.24182.03.2022

REVIEW ARTICLE

OPEN ACCESS

GAIT INITIATION AND BIOMECHANICAL METHODS OF ANALYSIS AND INVESTIGATION: A LITERATURE REVIEW

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ARTICLE INFO

Article History:
Received 07th January, 2022
Received in revised form
18th January, 2022
Accepted 09th February, 2022
Published online 28th March, 2022

Key Words:
Biomechanics, Children, Dynamometry, Gait initiation, Kinemetry.

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ABSTRACT

The study of analysis and description of human gait encompasses clinical and biomechanical data regarding the locomotor system, motor control and movement mechanisms. Gait initiation surveys provide information on gait recognition, diagnosis, follow-up and, when necessary, establishment of appropriate physical therapy and/or surgical treatment. The present study aims to identify the biomechanical methods and their respective techniques used to assess and understand the mechanisms of gait initiation in children. Anthropometry, kinemetry, dynamometry and electromyography are the biomechanical methods used in the literature to investigate gait initiation. The combination of one or more methods to meet the needs of researchers is predominant. The tests are applied in laboratory or hospital environments, mainly studies that combine one or more biomechanical methods. By associating the specificity of each method with a particular case study, they intensify the reliability of the results.

Citation: *JACOB, Thamara Cardoso. NORA, Fernanda Grazielle da Silva Azevedo.* "Gait Initiation And Biomechanical Methods Of Analysis And Investigation: A Literature Review*", International Journal of Development Research*, 12, (03), 54814-54818.

INTRODUCTION

Gait is an activity that involves complex interactions between the nervous system and the entire musculoskeletal system. With a sequence of cyclical, coordinated, consistent, economical, smooth, and repetitive movements of the joints, the bipedal gait is the basic form of human locomotion (SHUMWAY-COOK, WOOLLACOTT, 2010; PIETRASZEWSKI, WINIARSKI, JAROSZCZUK, 2012). Efficient walking requires the maintenance of balance in static and dynamic conditions, coordination between posture, support, and control in the foot trajectory during the development of the phases of the gait cycle, in varied support situations (PERRY, 1992). Therefore, for the initiation of a step and a new gait cycle, a transition from the standing position to the first step must occur, this phenomenon is named gait initiation. The normal gait cycle is a sequence of progressive movements involving muscular and gravitational forces, starting from the standing position, with the cyclic movement of support and advancement of the lower limbs, with displacement of one foot on the ground that culminates in one step forward, until the foot touches the ground again (ISHIDA apud SAAD, BATISTELLA, 1997). The initial contact of the foot on the ground is made by the heel, however, Sutherland, Kaufman and Moitoza (1998) call attention to the particularities of pathological gait, in which other areas of the foot may first touch the ground. The movement of the normal gait cycle is described by two phases: 1) stance phase and; 2) swing phase (PERRY, 1992; SHUMWAY-COOK, WOOLLACOTT, 2010). The stance phase is described by the period between the foot touching the ground to the release of the opposite foot, which corresponds to about 60% of the movement. In this phase, horizontal forces are generated against the support surface to move the body in one direction, while vertical forces are responsible for supporting the body mass against gravity. The swing phase is the period in which the foot is not in contact with the ground, corresponding to the remaining 40% of the movement. For authors such as Sutherland, Kaufman, Moitoza (1998) and Shumway-Cook, Woollacott (2010), the gait cycle can be described from several variables: by the decomposition of the movement in the duration of the stance and swing phases; by the cadence calculated from the step frequency in a time interval (steps/minute); step length calculated from the distance between the same reference points on each foot during the stance phase; stride length, which is acquired from the distance covered during the time of two successive touches of the same and by the gait speed, which is the average speed after three steps (meters/second). The child, from a bipedal posture, begins its first steps at approximately one year of age. At four years of age, the child exhibits some gait patterns, close to those of an adult. Around 7-8 years of age, the typical child can walk without conscious effort (OKAMOTO, KUMAMOTO, 1972; FORSSBERG, NASHNER, 1982 and SHUMWAY-COOK, WOOLLACOTT, 1985 apud LEDEBT, BRENIÈRE, 1994; LONG, CINTAS, 1994; LONG, CINTAS, 1995 and SUTHERLAND, KAUFMAN, MOITOZA, 1998; TAWEETANALARP, 2011). For the acquisition of stable gait patterns, time, practice and adequate environmental stimuli are necessary, involving the use of sensory information, both reactively and proactively (SHUMWAY-COOK, WOOLLACOTT, 2010, p. 331).

According to Valentin-Gudol et al. (2013), the acquisition of independent gait in children favors the development of the spatial notion, stimulating the active exploration of the environment. These conditions and skills are necessary to perform daily activities that involve locomotion. With the maturation of motor control and sensorimotor experiences that come with time and stimuli, the child reaches maturity, autonomy and refines the gait pattern. Abilities to adjust, dimension and prepare the movements together with the experiences acquired with walking during childhood, to (re)modulate the movement, according to the demands requested in different environments, the act of walking becomes a task of easy execution. According to Morais Filho, Reis and Kawamura (2010), the age of acquisition of gait maturity is an object of discussion in the literature, because it can vary from 3.5 to 11 years, according to the method of analysis used (SUTHERLAND et al., 1980; SUTHERLAND, 1997; BACH, DAFERTSHOFER, DOMINICI, 2021; FOSTER, DRUMMOND, JANDIAL, 2021). In understanding and studying gait initiation, functional problems related to the locomotor system, motor control and biomechanical mechanisms of movement are identified. Four methods are recognized in the literature and used to investigate human gait: 1) electromyography (EMG), with the recording of muscle activity through electromyographic signals; 2) kinemetry using video and placing markers at anatomical points; 3) dynamometry with the analysis of the forces arising from the individual/ground interaction, being monitored by the ground reaction forces and other components of the movement, such as displacement - velocities and accelerations; 4) anthropometry through the physical characteristics of the segments (WHITTLE, 1996; AMADIO, DUARTE, 1998; ÁVILA et al., 2002; WINTER, 2009; SHUMWAY-COOK, WOOLLACOTT, 2010; CORRÊA, 2014; KILANI, VIETEN, 2018). The parameters obtained through one or a combination of the methods mentioned above are used to analyze and describe the gait. By understanding the mechanisms of normal human gait, its possible alterations can be evaluated. With the assessment, the child can benefit because, based on the gait description, the type of gait is recognized, as well as the diagnosis, follow-up, and establishment of an appropriate treatment, whether physical therapy and/or surgical ─ when any pathology or disturbance in the gait pattern was detected; and provide clinical and biomechanical gait data for research development. Gait analysis is often used in laboratory settings, specializing in biomechanics. Several studies have been dedicated to investigating gait to describe and compare pathological gait parameters in different populations, which differentiate or resemble the normal gait of a typical individual. Gait studies with children are compared with other populations – young adults and/or the elderly. Studies with children in the same age group, being typical and/or pathological, are relevant because the gait pattern in children suggests a significant difference in kinetic and spatio-temporal characteristics during gait when compared to an adult and/or elderly person (ESTRÁZULAS et al., 2005; MORAIS FILHO, REIS, KAWAMURA, 2010). It is pertinent to investigate the biomechanical methods of gait analysis and their use in children. Is there a standardization of a method? What techniques or procedures predominate to analyze, evaluate, and describe the acquisition of gait in children? Thus, the purpose of this review is to identify which are the biomechanical methods and their respective techniques used to assess and understand the mechanisms of gait initiation in children.

METHODOLOGY

This review was carried out using the following descriptors: “gait initiation” AND “children”; “gait initiation” AND “children”. The time frame was not established, as this study aims to identify the biomechanical methods used to analyze, evaluate, and describe the initiation of gait in children. This literature review is not focused on presenting companies, technical specifications and/or trademarks of the equipment used, but on the function, it performs to achieve the objectives proposed by the researchers investigated here. From the searches, texts were selected that contained one or more descriptors present in the titles, abstracts and/or keywords related to the initiation of gait in typical children and in children with pathologies. Experimental articles and/or case studies on gait initiation with children up to 12 years old, typical or with pathologies, published in Portuguese and English were included in the research. Review articles, abstracts of scientific events, course conclusion works (monographs, dissertations and/or theses) and works carried out with adolescents in which the age group was over 12 years were excluded. The present study is a narrative literature review, where the selection of articles/studies provided information about the biomechanical methods used in the assessment of gait initiation.

RESULTS AND DISCUSSION

The main methods used by biomechanics to analyze and understand the different forms of human movement are anthropometry, kinemetry, dynamometry and electromyography (AMADIO et al., 1999). Therefore, the results will be divided into studies that used the biomechanical methods mentioned above.

Anthropometry: It is responsible for investigating the characteristics and properties of the investigated segment to determine models that can represent the body. The parameters analyzed using anthropometric models, based on the individual's weight and height, are position of the Center of Gravity (CG), distribution of body mass, greetings, circumferences, etc. (AMADIO, DUARTE, 1998; ÁVILA et al., 2002 CORRÊA, 2014). Inman, Ralston and Todd (1998) emphasize individual variations and question the usefulness of data and anthropometric averages for understanding human gait. For the authors mentioned above, although it is possible to find means capable of developing a relationship between the segments of the lower limbs, people with different anatomical profiles will present a different gait pattern from one another. Therefore, for this method of biomechanical analysis, no study was found that used anthropometry as an exclusive tool to assess gait initiation in typical or pathological children.

Electromyography: Electromyography (EMG) is a method commonly used to measure the electrical signals produced by muscle activity (GRONLEY, PERRY, 1984; HAMILL, KNUTZEN, 1993; WINTER, 2009; SHUMWAY-COOK, WOOLLACOTT, 2010). These electrical signals are captured through electrodes placed on the skin, on top of the muscle to be investigated, to provide information about the muscles that are activated, the intensity of muscle contraction and the occurrence of antagonistic or synergistic muscle activity. Throughout history, this method has had several influences on the study of muscle function and the recruitment of motor units for clinical studies, however, there were limitations in recording this information while the individual was walking: this technique was invasive, impractical, and generated painful discomfort in the individual (JOHANSON, 1998). With advances in technology, the technique began to be performed with surface electrodes. It is important to emphasize that EMG is a method that requires precision when fixing the electrodes under the skin, along the muscle, because, during its execution, there may be failures in the reading of the signals due to poor positioning, sweating and/or poor adherence to the skin. For this method of biomechanical analysis, no study was found that used EMG as a unique tool to assess gait initiation in typical or pathological children.

Kinemetry: It is a set of methods that aim to measure the kinematic parameters of movement through displacement, velocity, and linear and angular accelerations (AMADIO, DUARTE, 1998; ÁVILA et al., 2002; SUTHERLAND; KAUFMAN; MOITOZA, 1998 apud MAGANHOTO et al., 2004). To reconstruct the movements, calculate the position and orientation of each body segment, as well as observe the stage of gait maturity, simple techniques of visual observation and recordings are used with electronic techniques such as cinematography, chronophotography, videography and/or optoelectronic systems to analyze the parameters of interest (GRONLEY, PERRY, 1984; WINTER, 2009; TREW, EVERETT, 1997 apud MAGANHOTO et al., 2004). Movement measurements are performed through the joint centers, thus, information about the displacement can be measured through markers that are placed at anatomical points and recorded in relation to a joint angle of the investigated limbs. Other instruments, such as goniometers, are used to measure the joint angle, when attached to the joint under study. Accelerometers, in turn, are responsible for measuring the reaction forces associated with the acceleration of a body segment TREW, EVERETT, 1997 apud MAGANHOTO et al., 2004; SHUMWAY-COOK, WOOLLACOTT, 2010). The resources provided by kinematics were used in the study by Boonyong et al,2012 in which he investigated the development of postural control during gait with cognitive tasks - walking and crossing obstacles associated with the Stroop Test - comparing typical younger children (5-6 years old) and typical older children (7-16 years old). years of age) with healthy young adults (19-26 years of age). Using a motion analysis system with eight cameras to capture the trajectories of three-dimensional markers, the authors suggest a trend in the development of attentional resources used to control gait in typical children. Similar studies of gait initiation associated with a second task were performed using kinemetry as a method. Postural control during gait in dual-task conditions improves when children are more mature, as attentional resources increase with age.

Dynamometry: It is responsible for describing human movement through the analysis of internal forces (from muscle activity) and external forces (external loads) that produce or modify movement. With this study, it is possible to understand how and why the movement happens and to analyze the causes of the movement, the movement pattern, its mechanisms, and the compensations. External forces are classified as: ground reaction force (FRS), forces transmitted through joints and other forces generated by other people, loads or resistance (CAPOZZO, 1984; AMADIO, DUARTE, 1998; ÁVILA et al., 2002; WINTER, 2009; TREW, EVERETT, 1997 apud MAGANHOTO et al., 2004). Instruments such as a force plate and a plantar pressure plate are equipment used to measure the forces applied by the feet on the ground in relation to body movement. According to Johanson (1998) and Lucareli (2004, p. 2), Jules Amar (1916) was one of the pioneers in the use of kinematics techniques to evaluate and measure the Ground Reaction Forces (FRS), through computational resources, with the aim of improving the understanding of gait kinetics. Unlike kinematics that refer to joint centers, in kinetics it is possible to analyze the trajectory of the Center of Mass (COM), determined by meeting the average weight of the center of mass of each body segment, based on the progression of the body in space; the CG which is the location of the COM in a vertical direction; and the Center of Pressure (COP) which is the location of the vertical reaction force to the ground that is equal and opposite to all forces acting downwards (GRONLEY, PERRY, 1984; WINTER, 2009).

In this way, knowing the gravitational, velocity and displacement forces acting on the body is necessary. According to Inman, Ralston and Todd (1998), cited in the review by Maganhoto et al. (2004), the analysis of forces is described by three components: the magnitude indicating the intensity of the force; the direction through the coordinate system and the direction of displacement. These components are used to facilitate the movement and prevention of falls, alteration of loads during the exercise, postural control and to inform evaluation parameters of performance (SMITH, WEISS, LEHMKUHL, 1997). Ledebt and Brenière (1994) used as a biomechanical method, the force plate from the inverted pendulum theory (BRENIERE, DO, 1986, 1991 apud LEDEBT, BRENIÈRE, 1994) to analyze the effect of anatomical changes - mass, height and inertia – and environmental characteristics at gait initiation in children aged between 4 and 8 years and compare them with children aged 15 to 18 months who are in the independent gait acquisition phase (BRENIÈRE, DO, 1986 apud LEDEBT, BRENIÈRE, 1994) and with adults (BRENIÈRE et al., 1989 apud LEDEBT, BRENIÈRE, 1994). From this study, it was confirmed that "[...] the ability to combine and adapt properties of the body, with the dynamics of the context, is acquired through the practice of independent walking". At each stage of their development, the child uses different strategies to remain stable when starting and during the gait movement, as suggested by the study by Nora, Jacob and Paiva (2021) with children aged between 1.7 and 3 years, by verifying how the independent walking experience adjusts the transition from standing posture to cyclic walking. In the anticipatory phase, younger children and less experienced with walking present more oscillations in the displacement of the COM. The study by Da Silva Azevedo Nora et al. (2020) with children aged 1.3 years to 4 years, presented the relationship between gait experience and COP behavior during gait initiation, suggesting that the more experienced the child is, the greater the anteroposterior and mediolateral displacement amplitude of the gait. COP Children who are more experienced with walking have greater speed when performing the first step, therefore, older children do not need to maintain the balance of the bipedal posture, they do not require more time, as younger children do to balance and preserve the stability of the standing position, in the execution of the movement. In children aged 5 to 6 years, compensatory movement pattern strategies were observed for the recovery of postural control during step initiation. In the study by Stania et al. (2017) found that both children with postural problems and healthy children exhibited a greater amplitude and displacement speed of the COP, in the execution of the task step, in this case, it had the complexity of going down a step.

Combined Biomechanical Methods: Anticipatory postural adjustments (APA) maintain body dynamics, balance, and create the propulsive forces to move the COM forward. APAs begin to develop around 3 years of age and complete their maturation well after 8 years (LEDEBT, BRIL, BRENIÈRE, 1998; ASSAIANTE, WOOLLACOTT, AMBLARD, 2009; FARINELLI et al., 2020). Malouin and Richards (2000) studied adjustments related to gait initiation by comparing a group of typical children aged 4 to 6 years with a group of adults aged 50 to 61 years, to demonstrate whether motor behavior anticipatory response is consistent and whether the gait initiation process has characteristics like those of an adult. For this, they used a combination of three biomechanical methods: kinemetry to calculate the COM when using images obtained from a 2D camera; electromyographic signals from the soleus muscle (SOL), tibialis anterior (TA) and gluteus medius (GM); and dynamometry, to calculate the COP two force platform were used. Data were synchronized using a computer program. Based on the experimental protocol developed by these authors, the existence and functionality of gait control mechanisms is confirmed, even if they have limitations due to biomechanical restrictions of the musculoskeletal system. The authors report that the children investigated showed greater lateral sway, suggesting that this strategy would be used to maintain balance instead of generating impulse to move frontally. The anticipatory gait initiation behavior develops first in the frontal plane and that to achieve full control, as expected by an adult, and thus, more time to experience walking and better postural stability is needed. To conclude the study, Malouin and Richards (2000) state that the temporal organization, similar to adults, is in the consolidation phase in children aged 4 to 6 years. Postural control during gait initiation is generated from the interaction of COP and COM, in which there is an increase in the backward displacement of COP, resulting in greater forward speed. Based on these variables, Taweetanalarp et al. (2011) compared COP and COM characteristics during the gait initiation process between typically developing 7–10-year-olds and children with diplegia. Anthropometric data from the children (leg length, wrist, knee, and ankle width) and the fixation of reflective markers were collected. The characteristics of the gait initialization were obtained by the force platform and with the video system composed of six cameras. In this study by Taweetanalarp et al. (2011) there were no significant differences when comparing the anthropometric data of the investigated children. The COP data obtained suggest that the group of typical children use the strategy that shifts the COP backwards to generate momentum and the groups with diplegia use the lateral strategy to maintain stability. For children with diplegia who cannot walk independently, using the walker increases the base of support which helps to increase lateral stability. When examining the APAs associated with gait initiation, Isaias et al. (2014) applied the tests to eleven girls with Rett Syndrome (mean age 9 years) and ten healthy children of both sexes (mean age 10 years). The tests involved spontaneous walking on the force platform to obtain data regarding the FRS and CoP, muscle activity data were recorded using electrodes fixed on the SOL and TA muscles, while six video cameras recorded the images.

In this experimental protocol, researchers used retroreflective markers to analyze head, trunk, upper and lower limb movements to calculate global CoM and anthropometric data. Isaiah et al. (2014) reported patterns with a shorter time interval between SOL inhibition and TA excitation and concluded that the findings are relevant with respect to rehabilitation and physical therapy work due to postural limitations, the abnormality of abnormal SOL muscle activation and TA. and the impairment in the temporal organization of all phases of PAC in the group with Rett Syndrome. Farinelli et al. (2020), reproduced the methodology of Isaias et al. (2014) and added electrodes to collect information from the contraction activity of the rectus femoris, biceps femoris, and erector spinae muscles. To investigate the role of the cerebellum in the development of postural control, the researchers evaluated postural control during standing and gait initiation in children (mean age 12 ± 3 years) with Cerebellar Ataxia (slow generalized cerebellar atrophy). progressive and with non-progressive vermian hypoplasia - Joubert syndrome), compared to healthy children (mean age 10 ± 3 years). Through this study, Farinelli et al. (2020) concluded that children with slow progressive generalized cerebellar atrophy showed instability when standing still and the first step was significantly shorter and slower than the group of healthy children. Therefore, the cerebellum plays an important role in the phase of human maturation, specifically, in the construction of internal models of gait initiation. The protocols that were used and mentioned during this literature review in the studies are experimental, with an experimental design applied to the specificity of the investigated population. Research subjects are recruited for convenience, in the case of healthy children with typical development and/or participate in treatment/therapy at teaching clinics and research centers. The tests are applied in laboratory or hospital environments, mainly studies that combine one or more biomechanical methods. The logistics of transport, assembly, and preparation of equipment to be used can be an impact factor for which children travel to laboratories and/or research centers. Another possibility is that data collection is carried out in the same environment where the children undergo medical and/or therapeutic follow-up. Anthropometry and electromyography are methods that have their significance despite not being found in research as a single method but combined with other method(s) to better qualify and give robustness to the studies. Each of the biomechanical methods discussed in this review has its advantages and disadvantages. From this, the researcher must choose the one that best suits his objectives, the population that will be evaluated and, in his research, /intervention proposal.

Children use several postural control strategies to perform the steps of an independent walk. The construction and adoption of a particular movement strategy for gait initiation is related to age, experience with walking, a second task associated with walking and environmental factors, selecting a better strategy at each stage than the previous one. Regardless of the biomechanical methods applied with the aim of investigating gait initiation and its particularities, studies indicate that gait initiation presents certain patterns of execution that are often compared to adults. When there are changes in this pattern, such as a shorter step length, faster gait speed, and a longer period of limb support, it suggests physical therapy treatment for the development of the skill to improve the performance of independent walking.

CONCLUSION

From the analysis and study of gait in children, the type of gait is recognized, which allows for a more detailed diagnosis for the follow-up and establishment of a treatment (physiotherapeutic and/or surgical), in addition to providing clinical and gait biomechanics for equipment development and research. In this narrative literature review, the objective was to investigate the main biomechanical methods of gait analysis found in the literature and their use in children. Based on the information obtained through the articles and experimental studies, four methods of analysis and understanding were identified: anthropometry, kinemetry, dynamometry and electromyography. Through techniques to measure the human body and its segments, anthropometry was mentioned in the studies, but not as a protagonist of the methodology used. It appears as a complement to applied studies with children. Its means and variations are often used to characterize the study sample, due to individual variations. Among the four methods of analysis, anthropometry offers low cost and can be applied in laboratory environments and/or meet the child's location.

Initially performed with needles, an invasive and impractical method, but currently performed with electrodes that adhere to the skin surface, EMG records electrical signals during a muscle contraction to detect the beginning and end of muscle activity during muscle contraction. gait initiation. This provides information on the recruitment of motor units and nerve impulses (action potential) while the individual performs a certain task, such as walking. As with anthropometry, EMG was not found in studies that used it as a unique tool to assess gait initiation, but rather as an aid in the characterization of the study sample, in the diagnosis and treatment of various orthopedic conditions and gait disorders. EMG offers medium cost, and can be applied in laboratory environments, requiring a qualified professional to operate and fix the electrodes along the musculature to be investigated, since it may have errors in the execution (sweat, changes in temperature, bad positioning, among others). others), causing errors in diagnosis and interpretation of results. From the kinemetry, values of the displacements are obtained during the initialization of the gait. The analysis techniques include records using video cameras, sensors, and other electronic equipment for photos and/or videos, and can be done in two or three dimensions, with or without contact with the individual. The variables obtained through kinemetry can describe gait patterns that are difficult to observe visually, with the naked eye, as well as in the assessment of movements before and after therapeutic and/or surgical intervention. These patterns may or may not be associated with gait disorders. Because it is a controlled environment, with the use of electronic imaging equipment and motion sensors, techniques for studying gait initiation are applicable in laboratory environments. To assess the forces acting on the human body and thus understand how gait initiation occurs, dynamometry can estimate the force that the muscle of a body segment needs to produce to perform a given movement. When the variables from the force platform are obtained, the forces that cause the gait initialization movement are identified. Although the cost of the equipment (power platform) is high, it is possible to carry out the tests both in the place where the child is and in laboratory environments. By associating the specificity of each method of biomechanical analysis to a specific case study, they intensify the reliability and precision of the results.

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