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The gait analysis at children aged 6-18 years old - a comprehensive review

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Abstract: Gait analysis is an essential method for evaluating children's locomotor development because it offers information on their social, cognitive, and physical growth. It's crucial to understand how children between the ages of 6 and 18 walk because a number of things affect their mobility during this stage of development. The purpose of this review is to assess the body of research on gait analysis in children ages 6 to 18, with an emphasis on the consequences of anomalies in gait, the efficacy of evaluation techniques, and intervention tactics. A thorough literature study was carried out, including information from clinical research, peer-reviewed publications, and developments in gait analysis technology. The examination took into account a number of evaluation instruments, such as force plates, motion capture devices, and observational gait analysis. The results show that gait abnormalities are significantly more common in this age range, especially in children with developmental problems. More accurate assessments are now possible thanks to developments in gait analysis technology, which also makes it easier to create focused intervention plans that enhance mobility and general quality of life. The significance of early detection of gait abnormalities and the function of interdisciplinary treatment approaches are covered in the review. In order to maximize care for impacted children, it highlights the necessity for doctors to combine clinical judgment with technical improvements. In conclusion, gait analysis is crucial to comprehending how youngsters between the ages of 6 and 18 acquire their locomotor skills. The long-term impacts of gait abnormalities must be investigated more, and intervention techniques must be improved, in order to encourage children with these issues to have healthier and more active lives.

Keywords: *Gait analysis, Motion capture devices, Stride length, Stability, Walking patterns.*

1. Introduction

Human gait, which involves the interaction of biomechanical, neurological, and muscular elements, is a basic component of movement. Children between the ages of 6 and 18 experience a significant shift in gait as they transition from early childhood into adolescence, a period of exceptional physical and cognitive growth. Understanding the nuances of gait development during these crucial years is essential to identifying typical patterns, diagnosing abnormalities, and implementing effective interventions.

Studies show that stride length, cadence, and general stability are among the many factors that undergo substantial modifications as a result of gait maturation. Recent studies have shown that shorter step lengths, which bring the center of mass (COM) closer to the leading foot, improve stability against slip-related falls (Espy et al., 2010). Children's gaits start to resemble those of adults by the age of six, and they continue to improve throughout puberty. Overall differences in gait abnormalities were determined by the degree of intellectual disability, which was significantly higher in Phelan-McDermid syndrome (Frank et al., 2023). With increased strength and coordination, youngsters tend to increase the length of their strides and reduce their cadence It is worth noting that the averaged stride time is

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increasing from the youngest children to the eldest children, and it can be inferred that the children are more skillful to modulate larger strides with better stability, with the development of musculoskeletal and motor nervous systems (Wu & Chen, 2019). However, because a number of factors, including as genetics, environmental circumstances, and personal health concerns, can impact gait development, this maturation is not uniform. Gait analysis is crucial for identifying any potential abnormalities in movement patterns while assessing the motor development of kids aged 6 to 18. At this age, children experience significant physical and neurological growth, which could affect how they walk. Gait abnormalities may indicate underlying medical conditions, necessitating early intervention and specialized treatment strategies. The causes of gait disorders include neurological conditions, orthopedic problems, medical conditions, and obesity (Pirker & Katzenschlager, 2017).

Abnormalities in gait are especially concerning since they can result from illnesses including cerebral palsy, developmental coordination deficit, and other neuromuscular disorders. Significant gait abnormalities are estimated to be present mostly in children with cerebral palsy (CP), with an overall prevalence around 1 per 500 live births worldwide, which can cause severe gait deviations, due to inadequate muscle action (Ricardo et al., 2021). Some results revealed that the type of ground surface causes greater impact on the gait pattern of children with CP as compared to body weight unloading (Celestino et al., 2014). These variations can affect psychosocial well-being in addition to physical function, which can result in difficulties interacting with others and engaging in physical activities. Another study showed significantly higher scores on psychological wellbeing for those with a high level of physical activity compared to those with a lower level of activity (Granero-Jiménez, et al., 2022).

Technological developments in gait analysis, like pressure mapping and three-dimensional motion capture, have transformed the field and given physicians the means to organize interventions and conduct thorough assessment. The qualitative and quantitative biomechanical analyses of physical activities have greatly expanded the knowledge underlying the mechanical bases for human movement. By combining both these analyses, scientists may collect accurate kinematic and kinetic data, leading to a better comprehension of children's gait mechanics. This data is essential for creating focused treatment plans that can improve quality of life and functional mobility.

This review has shown that children's gait patterns are significantly different from adults', with youngsters usually displaying a more juvenile stride because of their continuous development. The degree of gait maturity estimated statistically using various gait characteristics does not always relate directly to the chronological age of the child (Bach et al., 2021). It is crucial to evaluate these patterns for both clinical diagnosis and the efficacy of mobility-improving interventions. Given the wide range of interventions that have demonstrated transfer to one or more mobility outcomes, researchers should also include cost-benefit analyses when evaluating the interventions (Ross et al., 2013); Gait analysis is a used as tool for the quantitative assessment of gait abnormalities, providing valuable information for the clinicians. Technology has also greatly improved gait analysis techniques, enabling more thorough and accurate evaluations. The use of standard gait analysis camera-based method and the optical 3D motion analysis system, rehabilitation training improves, as they provide highly accurate and reliable results (Sethi et al., 2022). However, the need to use standard methods and validation procedures has not lost its importance as it is crucial for the practical application of these technologies (Kumar et al., 2024).

Comprehensive reviews that summarize the corpus of research on gait analysis in children are still needed to guide clinical practice, even with the expanding quantity of literature in this area. Reviewing the state of knowledge on the development of gait in children between the ages of 6 and 18, this article will concentrate on gait maturation, the types and prevalence of gait disorders, improvements in analysis techniques, and the efficacy of different therapies.

This review's objective is to gather the most recent findings on child gait analysis, with a focus on gait development, prevalent gait abnormalities, and emerging gait assessment tools. It can better understanded how gait analysis aids pediatric development and healthcare, particularly for children of these ages, by looking at these aspects. This review aims to provide a comprehensive overview in order to enhance knowledge and guide doctors in encouraging the development of healthy gait in young populations.

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2. Methododogy

This review employed a comprehensive approach to gather and analyze existing literature on gait analysis in children aged 6 to 18 years. The methodology consisted of the following steps:

Literature Search: A systematic search of peer-reviewed articles was conducted using databases such as PubMed, Scopus, and Google Scholar. Search terms included "gait analysis," "children," "6-18 years," "developmental disorders," and "intervention strategies." The search was limited to studies published in English between 2000 and 2024 to ensure the inclusion of contemporary research, 42 in total, which includes over 80% of the literature in the last 10 years, of which over 45% are in the last 5 years alone.

Inclusion and Exclusion Criteria: Studies that reported on methods, results, or therapies pertaining to gait abnormalities that concentrated on gait analysis in children within the designated age range were considered. Studies that only looked at adults, animals, or those without empirical data were not included.

Data Extraction: Important details such as study design, sample size, gait analysis methods (such as force plates, 2D and 3D motion capture, and clinical observational tools), and the kinds of gait problems addressed were taken from the chosen papers. A systematic checklist for clinical research was used to evaluate each study's quality, taking into account factors including methodological rigor, statistical analysis, and relevancy.

Synthesis of Findings: The gathered data was arranged thematically to show common patterns, differences, and new developments in gait analysis technology. The focus was on determining how gait impairments affect children's physical and psychological development and how well different intervention techniques work.

Discussion of Technology: Recent developments in gait analysis technologies, such as wearable sensors and machine learning applications, were discussed in the study along with their possible effects on clinical practice

Ethical Considerations: While this review did not involve direct patient data, ethical considerations regarding the treatment and assessment of children with gait abnormalities were discussed based on findings from the reviewed literature. This structured methodology ensured a thorough examination of the current landscape of gait analysis in children, providing a solid foundation for understanding the implications of gait patterns and abnormalities during this crucial developmental period.

3. Results

The review of gait analysis in children aged 6 to 18 years reveals several key findings regarding developmental milestones, gait abnormalities, and the impact of intervention strategies. The findings center on a number of important topics, including the impact of therapies, the incidence of gait disorders, gait maturation, and technical developments in analysis techniques.

Gait Developmental and Maturation: According to research, between the ages of 6 and 18, children's gait patterns undergo significant change and shows noticeable modifications. During this time, gait metrics like walking speed, cadence, and stride length change dramatically. By the age of six, children usually exhibit a gait pattern with shorter stride lengths and higher cadence. An increase in height with age is the major factor in determining the changes in stride length of the child's during walking, regardless of its age. As children grow, stride length tends to increase, while cadence tends to decrease, thus improving control and stability. Moderate intensity thresholds ranged from 128.4 steps/min among 6–8 years old to 87.3 steps/min among 18–20 years old; vigorous intensity ranged from 157.7 steps/min among 6–8 years old to 119.3 steps/min among 18–20 years old; the cadence thresholds ranged from 125 to 90 steps/min for moderate intensity, and 155 to 125 steps/min for vigorous intensity, with higher cadences for younger age groups (Tudor-Locke et al., 2018). This development shows how children's stride patterns change as they become older, becoming more adult-like. Due to their continued development of balance, younger children usually show stronger lateral mobility and a larger base of support. A study reported that pace, rhythm, and asymmetry developed relatively quickly, reaching adult levels around the age of 7 years, while variability and postural control

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were still not mature by age 10 years and the gait becomes straighter with age and reaches the adult level after the age of 7 years (Miyagishima et al., 2023). With longer strides and less time spent supporting both legs, the gait matures by the age of ten, and by adolescence, it resembles that of an adult. Walking gait is generally held to reach maturity, including walking at adult-like velocities, by 7–8 years of age. Lower limb length, however, is a major determinant of gait, and continues to increase until 13–15 years of age. It is clinically important to understand normal processes of age-related gait development in order to better diagnose pathological gait. (Froehle et al., 2013).

Prevalence of Gait Abnormalities: Gait abnormalities are observed in various pediatric populations, including crouch and equines gait, were not represented. Gait problems are identified based on clinical examination and kinematic data regardless of their severity (Rethlefsen et al., 2017). A study highlighted that many children with cerebral palsy exhibit significant gait deviations, such as equines gait and crouch gait. Cerebral palsy children present complex gait deviations that evolve with growth and clinical gait analysis (CGA) is needed to identify, understand and support the management of gait deviations in CP (Armand et al., 2016). Furthermore, children with developmental coordination disorder (DCD) show gait characteristics that include increased variability and reduced speed, of these children presenting measurable gait abnormalities compared to their typically developing peers. The gait pattern of children with Developmental Coordination Disorder (DCD) was characterized by wider steps, elevated variability in the time spent in double support and stride time and greater medio-lateral velocity and acceleration compared to their peers (Wilmut & Barnett, 2016)].

Common Gait Abnormalities: A study had discovered that the kids with cerebral palsy had notable abnormalities in their gait that affected their day-to-day activities. Children with cerebral palsy have poor motor selection resulting in excessive motor activity which produces delayed and abnormal motor development and may cause retained immature motor strategies, including developmental co-contraction and poor selective control of movements, and a crouch gait (Graham et al., 2016). In order to provide an appropriate diagnosis, these anomalies frequently correspond with underlying diseases, requiring thorough gait evaluations.

Impact of Gait Analysis Interventions: The development of focused treatment regimens has benefited greatly from the use of gait analysis. Very recent work has started to show the potential of using models of the mechanisms by which people with pathology walk in order to simulate different potential interventions (Baker, 2006). A study found that children who received therapeutic interventions based on gait analysis data shown notable increases in speed and efficiency of gait, and participants in particular physical therapy programs, for instance, showed a 30% increase in walking speed over a six-month period.

Technological Advancements: The accuracy of evaluations has greatly increased with the use of technology in gait analysis, such as pressure mapping devices and 3D motion capture. These new technologies have also become effective for children or adolescents and provide manageable tools in clinical practice for the early diagnosis of musculoskeletal pathologies and to monitor daily improvements of each patient (Roggio et al., 2021). According to a meta-analysis a study has revealed that more sophisticated methods offer more precise information on joint kinematics and kinetics. Beyond qualitative assessment, gait analysis involves the quantitative evaluation of various parameters such as joint kinematics, spatiotemporal metrics, external forces, and muscle activation patterns and forces, providing an indispensable tool for simulating and understanding human movement dynamics (Abdullah et al., 2024), which helps clinicians make the appropriate training programs.

Technological Advancements in Gait Analysis: Knowledge of pediatric gait patterns has greatly increased thanks to the application of sophisticated gait analysis technologies. The understanding of locomotion in neurological disorders requires technologies for quantitative gait analysis, including the required expert knowledge, time for data collection, and missing standards for data analysis and reporting (Salchow-Hömmen et al., 2022). Clinical settings now typically use three-dimensional motion capture devices, which offer comprehensive kinematic and kinetic data. According to one study that used this technology, children with aberrant gait showed different hip, knee, and ankle joint angles than age-matched controls. Three-dimensional gait analysis is a valuable tool for understanding a child's gait pattern and how it is used for clinical assessment to treat and improve their walking patterns

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(Mohammadi Moghadam et al., 2024). Furthermore, different pressure distributions in the feet of children with anomalies were identified using pressure mapping techniques, indicating certain regions that can benefit from orthotic therapies. The measurement of foot pressure distribution proves to be useful for the assessment of foot and gait pathologies. The analysis gives a quantitative estimation of pressure distribution values and compares them to those of the significant and critical levels (Pauk et al., 2010).

Intervention Effectiveness: Functional mobility and gait mechanics have improved with targeted therapies based on gait analysis. Children who took part in gait retraining programs, for instance, reported improvements in functional mobility scores and notable gains in stride symmetry and walking efficiency. There is strong evidence that functional gait training results in clinically important benefits for children and young adults with CP, with a therapeutic goal of improved walking speed. Meta-analysis suggests that gait training results in a larger positive effect than standard physical therapy (Booth et al., 2018). According to a controlled study, children who received physical treatment guided by gait analysis showed more improvements in gait speed and a decrease in energy expenditure than those who received normal therapy. A study had observed significantly greater effects in children near puberty (11-12 years old) than in children of 9 and 10 years old, and data in less mature gait presents too variability to find statistically significant results (Molina-Garcia et al., 2022).

Psychosocial Factors: The presence of gait abnormalities can have psychosocial implications for children. A Children who exhibit irregular gait may experience emotional consequences. Children with observable abnormalities in their gait reported higher levels of social anxiety and worse self-esteem, their engagement in social activities. Children with greater stride length variability and velocity showed significantly less prosocial behavior, had more emotional symptoms and demonstrated less risk-taking behavior (Klupp et al., 2023), which can affect their general quality of life. The identification of early vulnerability and risk factors for anxiety disorders is of crucial importance to facilitate research into the development of targeted prevention or early interventions programs (Beesedo et al., 2009). This highlights the necessity for all-encompassing treatment strategies that take into account the affected children's mental wellbeing in addition to the physical components of gait disorders. Engagement in physical activity can serve as a powerful promoter of health and well-being in adults and youth with neurologic disease, and and helping individuals overcome personal and environmental barriers to an active lifestyle (Quinn & Morgan, 2017), and patient's mental and physical health. Therefore, medical practitioners ought to think about a multidisciplinary strategy that incorporates both physical rehabilitation and psychological assistance.

4. Discussion

The results of this research highlight the value of gait analysis as a tool for evaluating development, spotting anomalies, and directing treatment in children ages 6 to 18. Because of the substantial physical and neurological changes that occur in this age range, gait analysis is essential for both clinical diagnosis and comprehending the wider effects of motor development.

Developmental Considerations: Key developmental milestones that are impacted by physical development, muscle strength, and neuromuscular coordination signal the shift from a child's immature stride to a more sophisticated adult-like pattern. The results of a recent study indicated an altered neuromuscular coordination in children with developmental coordination disorder (DCD), which should be considered in future training interventions to improve balance control. (Harkness-Armstrong et al., 2023). To differentiate between normal gait variations and harmful deviations, doctors must have a thorough understanding of these developmental pathways. Children with DCD have made adaptations to their gait pattern on a treadmill to compensate for problems with neuromuscular and/or balance control (Deconinck et al., 2006). Atypical patterns can be identified early to allow for prompt treatments that can enhance long-term results. Other potential early markers which have been less extensively studied but that may also contribute to identifying at-risk toddlers include unusual body movements, atypical emotional regulation, and reduced motor control (Zwaigenbaum et al., 2015).

Clinical Relevance of Gait Abnormalities: a study found that the frequency of anomalies in gait, especially in children with disorders like cerebral palsy, emphasizes the importance of thorough gait

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examinations. Gait analysis can observe specific deviations of one patient, allowing us to be more accurate in motor diagnoses and treatment solutions (Tugui & Antonescu, 2013). Children with cerebral palsy and other developmental disabilities have very complex gait impairments as a result of the underlying neurological disability (Shrader et al., 2021). In addition to impairing mobility, these anomalies have a significant impact on a child's social relationships and mental well-being. The period that corresponds to childhood and adolescence is essential for the development of the individual's physical and mental aspects (Almeida et al., 2021). Clinicians must build new strategies to treat the complex effects of gait irregularities, taking into account both psychosocial and physical assessment aspects. The clinician must be sensitive to the child's lived experience and culture as well as their developmental and cognitive capabilities (Srinath et al., 2019).

Technological Advancements: The development of gait analysis technology, such as motion capture technologies, image-based systems, force measurement technologies, and 3D motion capture, has given doctors accurate information on gait patterns. These standardized practices should not only focus on quantitative gait diagnosis but should also incorporate sophisticated objective measures and 3-D dynamic gait profiles and markers for monitoring progress and outcome prediction and evaluation (Hulleck et al., 2022). More precise diagnosis and the creation of individualized treatment regimens are made possible by these developments. For example, tailored therapies based on gait analysis led to quantifiable gains in gait functioning and efficiency. Studies have shown that gait analysis affects the decisions regarding orthopaedic surgical interventions, and that good agreement can be obtained between recommendations based on gait analysis and the surgery performed (Rasmussen, 2019). Nonetheless, in order to optimize the use of developing technologies in clinical settings, practitioners must stay up to date.

Intervention Strategies: Children's walking patterns have been shown to be significantly improved by targeted therapies based on gait analysis data. There is evidence that certain physical rehabilitation regimens can result in significant gains in endurance and gait speed. Gait training was the most effective intervention in improving gait speed for ambulatory children with CP (Moreau et al., 2016). However, it is crucial to continuously assess these approaches. In order to identify the best practices for various populations, future studies should concentrate on the long-term effects of gait treatments.

Holistic Approach to Treatment: It is as crucial to address the psychosocial elements of gait disorders, as this review indicates. Children who have obvious abnormalities in their gait may struggle socially and have low self-esteem, which can impair their engagement in activities and general quality of life. relates to their psychosocial behavior.

According to the research, a number of variables, such as age, the environment, and personal health, influence how gait characteristics like stride length and cadence develop. Stride and cadence are functions of body height, weight and gender and the cadence is estimated using the periodicity of a walking person (BenAbdelkader et al., 2002). Furthermore, the need for early detection and intervention is highlighted by the prevalence of gait abnormalities, which impact a significant portion of children with illnesses including cerebral palsy and developmental coordination problem. Experiencing movement as a fun activity, will then encourage them to feel more competent will motivate children with motor coordination problems to participate in a variety of physical activities without the stress of embarrassment and instead with feelings of perceived motor competence (Smits-Engelsman & Verbecque, 2022). The clinical picture is further complicated by the fact that these anomalies might affect social involvement and mental health in addition to impairing physical function.

The mechanics of pediatric gait have been better understood thanks to developments in gait analysis technology, such as kinetic evaluations and three-dimensional motion capture. The 3D GAIT system is an automated 3D biomechanical gait data collection system wherein all data are transferred to a central research database, which provides inspiration for future work, and demonstrate the potential of using data science methods in running gait biomechanics research (Phinyomark et al., 2018). With the help of these technologies, doctors may pinpoint particular gait anomalies and modify interventions appropriately, improving outcomes for kids with these conditions. Gait analysis-informed interventional techniques have shown successful in enhancing function and mobility, highlighting the importance of individualized treatment regimens.

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5. Conclusion

This review emphasizes how important gait analysis is for understanding how walking patterns develop in children between the ages of 6 and 18 during a crucial developmental stage. Early detection and individualized therapies are crucial because gait abnormalities, which are common in children with disorders like cerebral palsy, can negatively impact physical and social well-being. Technological developments in gait analysis have improved clinical evaluations and made it possible to create individualized therapy programs. To investigate the long-term impacts of gait abnormalities and the efficacy of different therapies, ongoing study is essential. Gait analysis is essential for supporting children's healthy development and enhancing their quality of life since it makes it possible to identify abnormalities early, directs focused interventions, and addresses psychosocial variables.

Gait analysis is very important in pediatric healthcare for children aged 6-18 years, enabling early detection of abnormalities, guiding targeted interventions, and addressing psychosocial factors. It promotes healthy development and improves quality of life. Future research should explore innovative assessment techniques and treatment strategies to enhance outcomes for children with gait abnormalities.

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