Vestibular dysfunctions and their impact on gait in primary school children: a review of research from 2010 to 2024

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Review paper

VESTIBULAR DYSFUNCTIONS AND THEIR IMPACT ON GAIT IN PRIMARY SCHOOL CHILDREN: A REVIEW OF RESEARCH FROM 2010 TO 2024

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Abstract
The vestibular system plays a key role in maintaining balance and coordinating movement, and its optimal function is especially important for children in development. In elementary school-aged children, vestibular dysfunction can result in various difficulties in maintaining balance and proper gait, which can further impact their physical activities and overall quality of life. Research shows that vestibular dysfunction can lead to serious motor skill disturbances, including unsteady gait, frequent falls, and poor postural control. These symptoms are often associated with issues in spatial perception, reduced coordination between the visual and motor systems, as manifested by challenges in maintaining static and dynamic balance. The aim of this scientific paper is to provide an overview of the latest insights into the relationship between vestibular dysfunction and gait and balance disorders in children of elementary school age. Through the review and analysis of existing studies from 2010 to 2024, we aim to clarify the impact of vestibular dysfunction on children's motor development, identify the latest diagnostic procedures, and the most recent scientific and professional insights applicable in kinesiology. By better understanding this connection, we can develop more effective methods for early detection and treatment of children with vestibular disorders, significantly improving their health and encouraging them to lead a more active and healthier lifestyle.

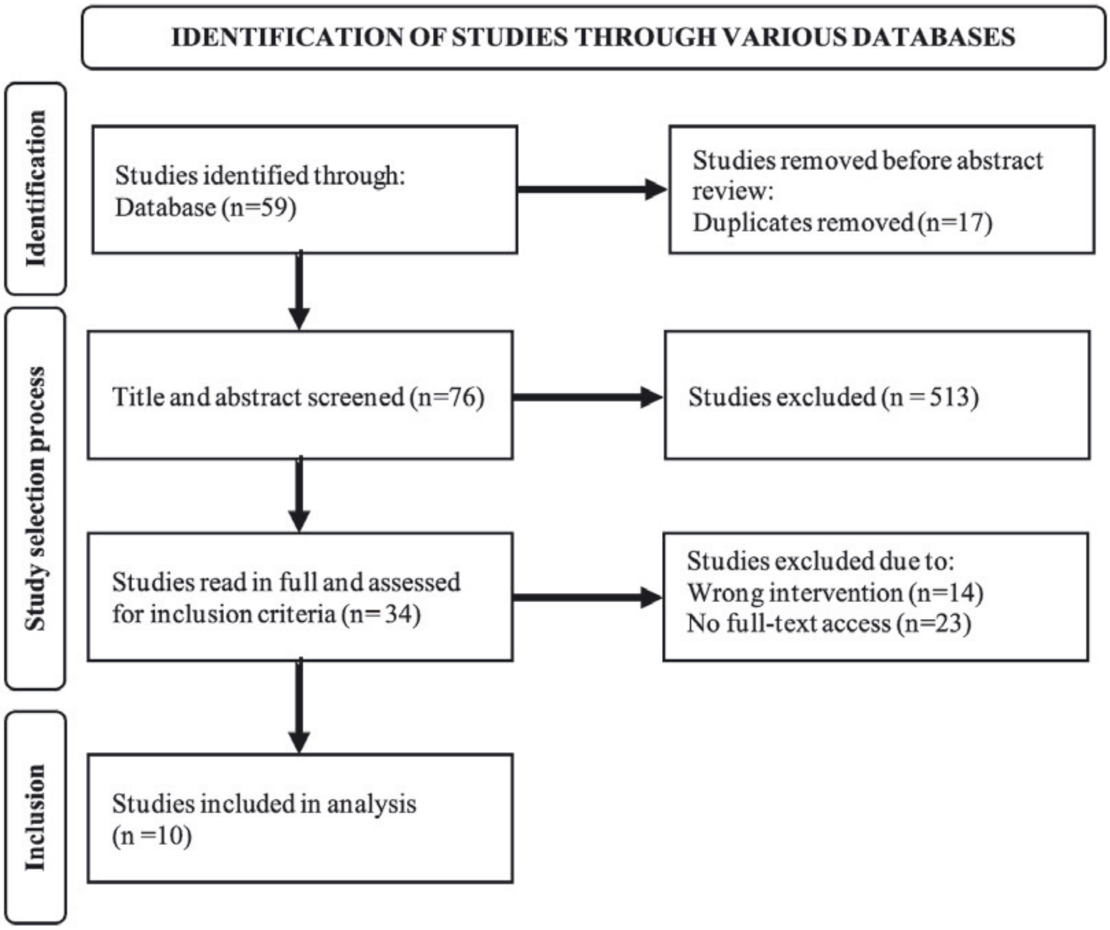
Key words: vestibular dysfunction, gait biomechanics, children

1. Introduction

The vestibular system is a key component of human perception of balance and spatial orientation and plays a crucial role in maintaining postural stability and coordinating movements. Located in the inner ear, the vestibular system sends information to the brain about the position and movement of the head, enabling appropriate body adjustments to maintain balance. In children who are in a phase of intense development, dysfunction of the vestibular system can have significant consequences on their motor skills and ability to walk. Vestibular dysfunction refers to any disorder or impairment of the vestibular system. It can be caused by various factors including genetic predispositions, infections, trauma, or neurological diseases. In children, vestibular dysfunction can be particularly concerning as it can affect their motor development and overall physical activity. Symptoms of vestibular dysfunction can include dizziness, a sense of instability, balance difficulties, and problems with movement coordination. Gait is an individualized, highly coordinated, and complex process that requires the integration of various bodily systems (1). It is a complex biomechanical process that requires the synchronization of the musculoskeletal, neuromuscular, and, of course, vestibular systems. In children, it continually develops and improves throughout primary school age, becoming increasingly complex and efficient. The research problem is the insufficiently explored area of the impact of vestibular dysfunctions on the biomechanics of gait and motor skills in primary school children. There is a lack of information on how gait patterns and their biomechanical parameters change under the influence of vestibular dysfunctions (2).

2. Methodology

The aim of this scientific paper is to provide an overview of the latest findings on the relationship between vestibular dysfunction and gait and balance disorders in primary school children, and to detect the most common disorders that can be identified by kinesiologists to aid in early intervention. Gait analysis is recognized as a powerful clinical tool for exploring the connections between brain function and motor control (1,2,3). This paper relies on literature that investigates the relationship between vestibular dysfunction and its negative impact on gait characteristics and how these can progress from early to late childhood. It is especially important to note that studies have shown that the interference of vestibular dysfunction and gait is greater in children compared to adults, but differences can vary according to age and type of disorder (1,2,3). Included are scientific papers from eminent journals that examined the impact of vestibular dysfunction on the gait of primary school children, published between 2010 and May 2024 in English. Studies without peer review were excluded. The databases PubMed and SPORTDiscus were searched using keywords: “Vestibular System,” “Children,” “Adolescents,” “Biomechanics,” “Kinematics,” “Kinetics,” “Electromyography,” “Gait,” and “Gait Analysis.” Data were extracted using a standardized form that included information such as author, year, aim, population, methods, results, and conclusion (Figure 1).



Melo and colleagues in 2021 investigated the static balance of children with sensorineural hearing loss in relation to the degrees and function of the vestibular system. The subjects were children aged 7-11 years (n=130). Static balance was assessed using stabilometric analysis with a force platform that measured the displacement of the center of pressure in three positions: bipedal stance with feet together, natural parallel stance, and single-leg stance. All positions were performed in two ways or under two sensory conditions, with eyes open and eyes closed. The results showed that children with severe and profound sensorineural hearing loss have lower static balance than children with normal hearing in all positions. The conclusion is that the greater the degree of sensorineural hearing loss, the greater the instability in children's balance (4).

Ayanniyi and colleagues in 2014 investigated the static and dynamic balance of primary school children with and without hearing impairment. The sample consisted of children aged 8-17 years (n=160). To assess static and dynamic balance, they used the single-leg stance test and the functional reach test in two sensory conditions, with eyes open and eyes closed. The results showed that static balance with eyes closed and open was significantly lower in children with hearing impairment compared to those with normal hearing. Dynamic balance was higher in children with hearing impairment, but it was not statistically significant. No significant correlation was found between static balance with eyes closed and open in children with hearing impairment and those with normal hearing. No significant correlation was found between dynamic and static balance in children with hearing impairment and those with normal hearing. Children with hearing impairment performed worse on static balance tests compared to those with normal hearing, while dynamic balance was similar between both groups (5).

Melo and colleagues in 2017 investigated the static and dynamic balance of students with normal hearing and sensorineural hearing loss. The sample consisted of children aged 7-18 years (n=96). To assess static balance, the Romberg, Romberg-Barré, and Fournier tests were used, and for dynamic balance, the Unterberger test was applied. Students with hearing impairment showed more changes in static and dynamic balance compared to healthy subjects in all the tests used. The same difference was observed when the subjects were grouped by gender. They concluded that students with hearing impairment showed more changes in static and dynamic balance compared to healthy children of the same gender and age group (6).

In 2017, Melo compared the gait performance between children with normal and impaired hearing, considering the gender and age of the sample. He analyzed gait according to degrees of hearing loss and etiological factors in the group. The sample consisted of children aged 7-18 years (n=96). For gait analysis, the Brazilian version of the Dynamic Gait Index (DGI) was used, and for statistical analysis, the Mann-Whitney test was applied. The results showed that the group with hearing impairment had a poorer gait pattern compared to the healthy group. The same was observed when the children were grouped by gender, both females and males (p=0.000). The same difference occurred when the children were stratified by age group: 7-18 years (p=0.000). The group with severe and profound hearing loss showed poorer gait performance than those with mild and moderate loss (p=0.048). Children born earlier with severe and profound hearing loss showed the poorest gait results (7).

Gouleme and colleagues in 2014 investigated the development of postural control in completely healthy children. The sample consisted of children aged 4-16 years (n=58). Postural stability was tested on an unstable platform under three different visual conditions: with eyes open fixing a target, under optokinetic stimulation, and with eyes closed. The results showed a significant decrease in the area and the mean velocity of the center of pressure during childhood. As children grew, spectral power indices significantly decreased, and time significantly increased. Such improvement in postural control could be the result of better use of sensory input information and cerebellar integration during development, allowing subjects to achieve more efficient postural control (8).

In 2015, Ezane and colleagues analyzed the postural control of healthy elementary school children and children with strabismus in stable and unstable situations. The sample consisted of elementary school children (n=52, 26 with and 26 without strabismus). Postural control was assessed using the Framiral® platform. Posture was recorded in the following conditions: eyes open fixing a target and eyes closed on a stable and unstable platform. For children with and without strabismus, the values of the center of pressure area and mean velocity were significantly higher in conditions with eyes closed on the unstable platform, but this was much more pronounced in subjects with strabismus. Spectral power index and time also showed poorer values in children with strabismus compared to children without strabismus. These data demonstrate poor postural stability for both groups on the unstable platform with eyes closed. However, children with strabismus exhibited significantly worse performance than children without strabismus. Children with strabismus also utilize more energy to stabilize their posture using visual-vestibular sensory inputs to compensate for altered vision due to strabismus, compared to children without strabismus (9).

In 2015, Gouleme and colleagues investigated the issue of postural control in children with dyslexia using both spatial and temporal analysis. The sample consisted of elementary school children (n=60, 30 with and 30 without dyslexia). Postural stability was evaluated using the Multitest Equilibre system from Framiral®. Posture was recorded under the following conditions: eyes open fixing on a target and eyes closed on a stable and unstable platform. The results of this study showed poor postural stability in children with dyslexia compared to children without dyslexia, confirmed by both spatial and temporal analysis. In both groups of children, postural control was dependent on conditions and improved when eyes were open on a stable platform. Children with dyslexia had higher spectral power indices than children without dyslexia and demonstrated shorter testing times. Poor postural control in children with dyslexia could be due to a lack of sensory information, possibly caused by impaired cerebellar activity (10).

3. Discussion

The analysis of all results and conclusions from the presented research shows that vestibular dysfunction can significantly disrupt motor skills and the biomechanics of walking, manifesting through: unsteady gait, compromised postural control or stability, and the emergence of compensatory movement patterns.

3.1. Unsteady gait is a common occurrence in children with vestibular dysfunction. The vestibular system plays a crucial role in stabilizing the head and body during walking. When the system is not functioning properly, children may walk with a wider stance to increase their base of support and ensure better stability. This can result in a wider gait, slower walking speed, and visibly awkward or uncoordinated movements. A wider stance or increased foot separation may help maintain balance but could also limit walking efficiency. Children move slower to maintain control over their movements, which can negatively impact their engagement in physical activities that require quick movements. Lack of coordination can lead to awkward, uncoordinated movements that increase the risk of falls.

3.2. Compromised postural control is the diminished ability to maintain a stable body position, whether in a static resting state or dynamically while in motion. Vestibular dysfunction can lead to issues with postural control, manifested through unstable posture, movement inconsistencies, and increased muscle tension. Children may struggle to maintain an upright body position, resulting in frequent swaying or body shifting to maintain balance. Problems with the vestibular system can lead to body movement inconsistencies during walking, such as leaning forward or backward to compensate for a sense of instability. Children may increase muscle tension to maintain stability, leading to rapid fatigue and reduced mobility.

3.3. Compensatory movement patterns are created and adapted movements that involve modifications to the normal gait pattern to reduce the risk of balance loss and falls. They often manifest in shortened steps, reduced movement amplitude, increased need for visual control, and the appearance of asymmetrical movements. Children may shorten step length to increase control over each step and reduce feelings of insecurity. Arm and leg movements may be restricted to reduce vestibular system load and enhance stability. Children may focus on visual cues to compensate for the lack of vestibular information, such as looking down while walking.

Many scientists agree that vestibular dysfunction can negatively impact a primary school child's gait by disrupting the natural development of walking in children, with far-reaching consequences on their motor skills and daily activities. Children with vestibular dysfunctions may later develop the ability to walk securely in comparison to their peers. During growth and development, occasional regressions in gait are normal. However, in children with vestibular disorders, these regressions may be more frequent and prolonged. Difficulties in walking can affect a child's self-confidence and willingness to participate in physical activities, further limiting their physical and social development.

4. Conclusion

Vestibular dysfunction can have a serious impact on the biomechanics of walking and overall motor skills in primary school children. Understanding these impacts enables kinesiologists to identify abnormalities in gait and intervene in a timely manner. Early identification and targeted interventions, such as vestibular therapy, can help minimize the harmful effects of vestibular dysfunction and improve motor abilities and the quality of life for children.

5. Literature

1. Kasović, M., Štefan, L. & Petrić, V. (2021) Normative data for the 6-min walk test in 11–14 year-olds: a population-based study. *BMC Pulm Med 21*, 297. https://doi.org/10.1186/s12890-021-01666-5
2. Kasović, M., Štefan, L. & Zvonár, M. (2020) Foot characteristics during walking in 6–14- year-old children. *Sci Rep 10*, 9501. https://doi.org/10.1038/s41598-020-66498-5
3. Kraan, C. M., Tan, A. H. J., & Cornish, K. M. (2017). The developmental dynamics of gait maturation with a focus on spatiotemporal measures. *Gait & posture, 51*, 208–217. https://doi.org/10.1016/j.gaitpost.2016.10.021
4. Melo, R. S., Lemos, A., Raposo, M. C. F., Monteiro, M. G., Lambertz, D., & Ferraz, K. M. (2021). Repercussions of the degrees of hearing loss and vestibular dysfunction on the static balance of children with sensorineural hearing loss. *Physical Therapy, 101*(10), pzab177.
5. Ayanniyi, O., Adepoju, F. A., & Mbada, C. E. (2014). Static and dynamic balance in school children with and without hearing impairment. *J Exp Integr Med, 4*, 245-8.

6. Melo, R. D. S., Marinho, S. E. D. S., Freire, M. E. A., Souza, R. A., Damasceno, H. A. M., & Raposo, M. C. F. (2017). Static and dynamic balance of children and adolescents with sensorineural hearing loss. *Einstein* (São Paulo), 15, 262-268.
7. Melo R. S. (2017). Gait performance of children and adolescents with sensorineural hearing loss. *Gait & posture, 57*, 109–114. https://doi.org/10.1016/j.gaitpost.2017.05.031
8. Gouleme, N., Ezane, M. D., Wiener-Vacher, S., & Bucci, M. P. (2014). Spatial and temporal postural analysis: a developmental study in healthy children. *International journal of developmental neuroscience : the official journal of the International Society for Developmental Neuroscience, 38*, 169–177. https://doi.org/10.1016/j.ijdevneu.2014.08.011
9. Ezane, M. D., Lions, C., Bui Quoc, E., Milleret, C., & Bucci, M. P. (2015). Spatial and temporal analyses of posture in strabismic children. *Graefe's archive for clinical and experimental ophthalmology = Albrecht von Graefes Archiv fur klinische und experimentelle Ophthalmologie, 253*(10), 1629–1639. https://doi.org/10.1007/s00417-015-3134-8
10. Gouleme, N., Gerard, C. L., Bui-Quoc, E., & Bucci, M. P. (2015). Spatial and temporal analysis of postural control in dyslexic children. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology, 126*(7), 1370–1377. https://doi.org/10.1016/j.clinph.2014.10.016