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Pilot Study on Gait and Postural Symmetry Assessment Using Baropodometric and Stabilometric Analyses

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Abstract

Gait and postural symmetry are fundamental aspects of motor control, with particular relevance for rehabilitation and pediatric development. Asymmetries in plantar loading and balance regulation may reflect normal maturation or early signs of dysfunction. This pilot study aimed to assess plantar pressure distribution and postural stability in healthy pediatric subjects using baropodometric and stabilometric analyses. A single participant (male, 8 years old) with normal motor development underwent static and dynamic baropodometric tests and stabilometric evaluations under both eyes-open and eyes-closed conditions. Static analysis showed a slight predominance of left-foot loading (51%) and a posterior support tendency, while dynamic gait assessment revealed a longer stance duration on the left side and greater propulsion forces on the right. Stabilometric tests demonstrated increased sway and a Romberg index >2.0 in visual deprivation, confirming strong reliance on vision for balance control. These findings indicate that functional asymmetries can be detected even in healthy children and highlight the feasibility of baropodometric and stabilometric tools as objective measures. This pilot study provides preliminary evidence supporting their application in developmental assessment, rehabilitation monitoring, and preventive care in pediatric populations.

Keywords: gait symmetry; pediatric biomechanics; rehabilitation; baropodometry; stabilometry; motor recovery; postural control; plantar pressure; balance assessment

1. Introduction

Symmetry and asymmetry in gait and postural control are fundamental aspects of biomechanics, rehabilitation, and motor recovery. Balanced plantar pressure distribution and stable postural sway represent efficient motor strategies, whereas asymmetries may denote compensatory mechanisms, musculoskeletal dysfunctions, or neuromotor impairments [1–3].

Recent studies have emphasized the role of objective methods, such as baropodometry and stabilometry, in evaluating motor symmetry. Doshi et al. [4] showed that wearable inertial sensors can differentiate gait and postural features in populations at risk of falls. Baropodometric methods have been applied in hemiparesis [1], multiple sclerosis [5], low back pain [2], and scoliosis [3], whereas stabilometry is frequently used to quantify center of pressure (CoP) oscillations and postural sway [14,17]. Pediatric studies have confirmed that plantar loading and postural strategies differ significantly from those of adults, reflecting ongoing maturation [9–11,16,29].

Baropodometric and stabilometric analyses represent two of the most widely used noninvasive techniques for quantifying gait and postural control. Baropodometry refers to the assessment of plantar pressure distribution during the static stance and dynamic gait. This method provides detailed information on weight-bearing patterns, foot loading symmetry, propulsion forces, and gait phases [1,9,10]. Clinically, baropodometry has been used to monitor alterations in plantar support in patients with hemiparesis [1], multiple sclerosis [5], and scoliosis [3] as well as to evaluate the relationship between foot type and postural control in children [9]. In rehabilitation, it is often used to track the evolution of motor recovery and guide interventions aimed at redistributing plantar loads [2,8,20].

In contrast, stabilometry focuses on the analysis of center of pressure (CoP) oscillations when an individual stands on a force or pressure platform. It quantifies postural sway using parameters such as path length, ellipse area, and sway velocity, thereby reflecting sensory integration and balance control strategies [14,17]. Stabilometric evaluation has proven useful in detecting increased visual dependence in children [29], monitoring motor recovery after musculoskeletal injuries [31], and assessing proprioceptive training effects [7,25]. Its sensitivity to changes in visual, vestibular, or proprioceptive inputs makes it particularly relevant in pediatric populations, where balance control is still developing [10,16].

Taken together, baropodometry and stabilometry provide a complementary view of motor function; while the former captures plantar loading and gait mechanics, the latter reflects postural regulation and sensory integration. Their integration allows for a more holistic evaluation of symmetry and asymmetry in human movement, with applications ranging from sports sciences to preventive pediatric care and clinical rehabilitation [6,13,18].

Within *Symmetry*, multiple studies have addressed gait and postural asymmetries. Monteiro-Rodrigues et al. [6] identified plantar pressure asymmetries in healthy adults, whereas Shibata and Yoshida [7] demonstrated that targeted mobilization improved stability under visual deprivation. Other studies have explored gait symmetry after trauma [31], plantar pressure indices in musculoskeletal disorders [20,23], and computational analyses of plantar loading [17,18]. Furthermore, recent pediatric studies have highlighted asymmetries in gait with prostheses [8], foot type differences [9], and the impact of high-intensity training on neurodivergent children [13].

Despite these advances, no study has systematically applied baropodometric or stabilometric methods to quantify symmetry in healthy children. Pediatric literature outside of *Symmetry* highlights that children often exhibit posterior loading, increased sway, and visual dependence for balance [10,11,16,25,26]. These asymmetries diminish with age but may persist or become maladaptive in conditions such as idiopathic toe walking [27], developmental coordination disorder [28], or neuromuscular disease [27,29]. Thus, establishing normative pediatric data is essential.

In this context, we formulated several working hypotheses to guide the pilot investigation. We expected that the analyses would reveal subtle but measurable asymmetries, even in healthy pediatric subjects, and that these methods would prove feasible for application in preventive and rehabilitation-oriented pediatric assessments.

HW1: Baropodometric analysis will reveal subtle asymmetries in plantar load distribution, even in healthy pediatric subjects.

HW2: Stabilometric testing indicates increased postural sway and a higher Romberg index under visual deprivation, reflecting children's developmental reliance on vision for balance control.

HW3: The combined use of baropodometric and stabilometric methods will demonstrate feasibility as complementary tools for early screening and preventive assessment of gait and postural asymmetries in pediatric populations.

The present pilot study aimed to evaluate gait and postural symmetry in a healthy pediatric subject using baropodometric and stabilometric analyses. By documenting subtle asymmetries, this study contributes to the understanding of developmental motor control and offers perspectives for early rehabilitation monitoring.

2. Materials and Methods

To explore these working hypotheses (HW1–HW3), this pilot study employed a baropodometric platform and stabilometric system to quantify plantar pressure distribution and postural sway in healthy pediatric subjects. The experimental design was structured to capture both static and dynamic load patterns, as well as balance control under visual and non-visual conditions.

2.1. Participants

The study involved a single healthy pediatric participant (male, 8 years old) with no history of neuromotor or orthopedic disorders and exhibiting normal motor development. Participation was voluntary, and written informed consent was obtained from the parents prior to enrollment. The experimental protocol adhered to the principles of the Declaration of Helsinki and was conducted in a private rehabilitation clinic in Bucharest, where participants were regularly engaged in a preventive motor activity program.

2.2. Measurement Instruments

Evaluation was performed using a baropodometric platform (FreeMed®, Sensor Medica, Guidonia, Italy) and a computerized stabilometric system (FreeMed® Stabilometry Module, Sensor Medica, Italy), capable of recording plantar pressure distribution and center of pressure (CoP) oscillations in real time.

Baropodometric analysis included:

- Static test: assessment of plantar load distribution between the left and right foot, and between the forefoot and rearfoot.
- Dynamic test: Analysis of successive footprints during gait, including stance and propulsion phases.

Stabilometric analysis included:

- Romberg test (eyes open and closed) was used to evaluate postural control and visual dependence.
- Computation of the sway ellipse area and CoP trajectory (path length and area) as indicators of balance stability.

2.3. Experimental Protocol

The participant performed all trials barefoot, with the arms relaxed alongside the body:

- Static analysis: upright stance for 30 s while focusing on a fixed visual target at the eye level.
- Dynamic analysis: walking across the platform at a self-selected pace, repeated three times; mean values were used.
- Stabilometric analysis (Romberg test): bipodal stance for 30 s with eyes open, followed by 30 s with eyes closed.

All trials were automatically recorded and processed using proprietary software.

2.4. Parameters Analyzed

- Plantar load distribution: % load on the left vs. right foot; % load on the forefoot vs. rearfoot.
- Dynamic gait parameters: step length (cm), contact time (ms), and peak propulsion pressure (kPa).
- Stabilometric parameters:

1. CoP sway area (mm^2) and path length (mm)
2. Anteroposterior and mediolateral oscillations (mm)
3. Romberg index (ratio of eyes closed to eyes open).

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Table 1. Parameters analyzed in baropodometric and stabilometric assessments.

Category	Parameter	Unit	Description
Static plantar pressure	Left vs. right load distribution	%	Relative distribution of plantar load between left and right foot
Static plantar pressure	Forefoot vs. rearfoot load distribution	%	Relative distribution of plantar load between forefoot and rearfoot
Dynamic gait	Step length	cm	Distance between two successive steps
Dynamic gait	Contact time	ms	Duration of foot–ground contact
Dynamic gait	Peak propulsion pressure	kPa	Maximum plantar pressure generated during propulsion
Stabilometry	CoP sway area	mm^2	Area covered by center of pressure oscillations
Stabilometry	CoP path length	mm	Total length of the CoP trajectory during test
Stabilometry	Romberg index	ratio (eyes closed/open)	Ratio of postural stability with eyes closed vs. eyes open

These tests and parameters were selected because they are widely validated as reliable indicators of gait and postural symmetry in pediatric and clinical populations [1,5,7,14,25].

3. Results

The results are presented in relation to the working hypotheses formulated in the introduction.

- HW1 (Baropodometric analysis): Static plantar pressure distribution indicated a slight left–right asymmetry, with a predominance of left-foot loading (51%) compared to the right (49%), and a posterior tendency with greater rearfoot support (62%). Dynamic analysis confirmed this pattern, with the left side contributing to a longer stance duration, while the right side generated higher propulsion forces. These findings support HW1 by demonstrating detectable asymmetries, even in a healthy subject.
- HW2 (Stabilometric analysis): Stabilometric testing revealed increased postural sway under visual deprivation, with a larger sway ellipse area and a Romberg index exceeding 2.0. These results are consistent with those of HW2, indicating that children exhibit a strong reliance on vision to maintain balance.
- HW3 (Combined feasibility): Together, the baropodometric and stabilometric results demonstrate the feasibility of integrating these complementary methods for symmetry and asymmetry assessment in pediatric populations, supporting HW3.

3.1. Static Baropodometric Analysis

The static baropodometric assessment revealed an overall balanced distribution of plantar loads, with a slight predominance in the left foot (51%) compared to the right foot (49%). Analysis of the anterior–posterior distribution showed that the rearfoot supported the majority of the load (62%),

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while the forefoot accounted for 38%. These findings indicate a mild asymmetry characterized by a posterior loading tendency, which may reflect the developmental features of pediatric posture. The detailed values are presented in Table 1, and the distribution of plantar loads between the left and right feet is graphically represented in Figure 1.

Table 1. Static baropodometric data. Distribution of plantar load between left and right foot, and between forefoot and rearfoot.

Foot	Load (%)	Forefoot (%)	Rearfoot (%)
Left	51	37	63
Right	49	39	61

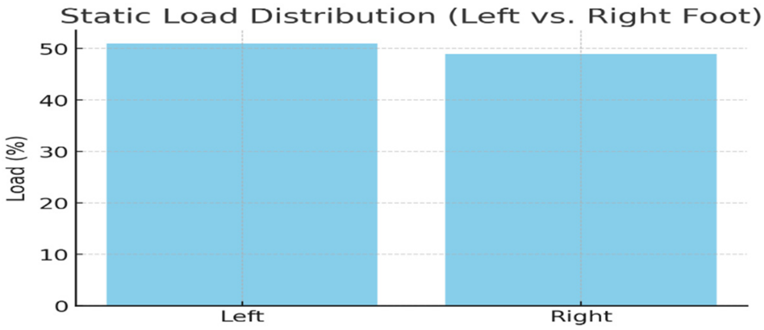

Figure 1. Static load distribution**.** Percentage of plantar load between the left and right foot, as measured in the static baropodometric test.

3.2. Dynamic Baropodometric Analysis

During the dynamic assessment of gait, successive footprints demonstrated consistent sequencing; however, subtle asymmetries were observed between the two limbs. The left foot exhibited a slightly longer step length (52 cm vs. 50 cm) and a longer stance duration (0.72 s vs. 0.68 s), suggesting its role in contributing to overall stability. In contrast, the right foot generated higher peak propulsion forces (240 N vs. 220 N), reflecting a greater contribution to the forward progression. These complementary asymmetries illustrate a functional differentiation between stability and propulsion during gait, which has been described as a characteristic of pediatric motor development. The specific values are summarized in Table 2, and the comparison of step length, stance duration, and propulsion forces between the left and right sides is illustrated in Figure 2.

Table 2. Dynamic gait data. Comparison of step length, stance duration, and propulsion force between the left and right foot.

Parameter	Left Foot	Right Foot
Step length (cm)	52	50
Stance duration (s)	0.72	0.68
Peak propulsion (N)	220	240

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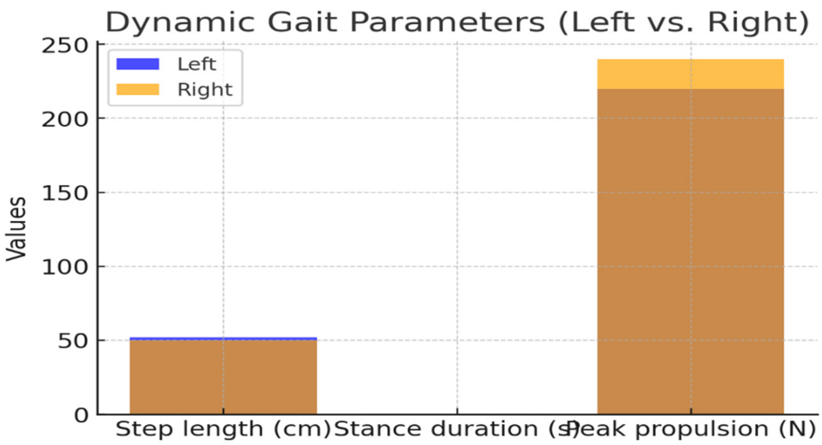

Figure 2. Dynamic gait parameters**.** Comparison of step length, stance duration, and peak propulsion force between the left and right foot.

3.3. Stabilometric Analysis

The stabilometric evaluation highlighted an increase in postural sway when the visual input was removed. With eyes open, the center of pressure (CoP) path length was 210 mm, and the sway ellipse area was 180 mm², values that remained within the expected range for a stable stance, although mediolateral oscillations were evident. With eyes closed, both parameters increased markedly (340 mm for path length and 320 mm² for ellipse area), indicating reduced postural stability in the absence of visual guidance. The Romberg index exceeded 2.0, confirming a strong reliance on visual input for balance control, which is consistent with the pediatric postural strategies described in the literature. The corresponding stabilometric values are reported in Table 3, and the differences between the eyes-open and eyes-closed conditions are depicted in Figure 3.

Table 3. Stabilometric data. Center of pressure (CoP) trajectory, ellipse area, and Romberg index under eyes-open and eyes-closed conditions.

Condition	**CoP Path Length (mm)**	**Ellipse Area (mm²)**	**Romberg Index**
Eyes Open	210	180	1.0
Eyes Closed	340	320	2.1

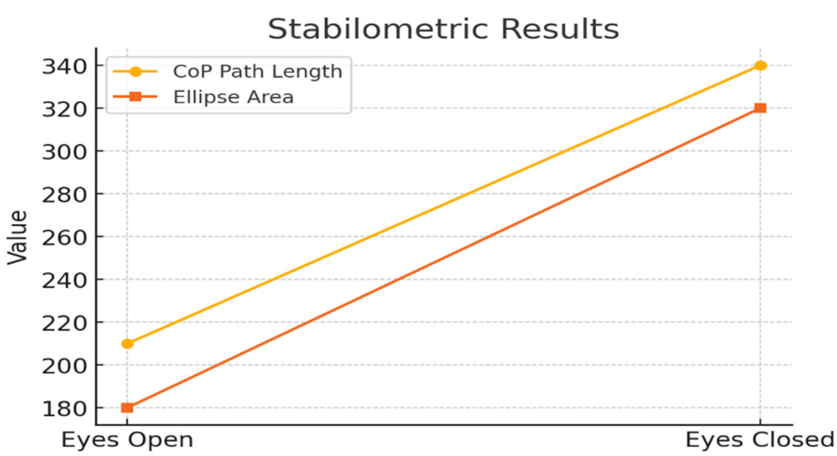

Figure 3. Stabilometric results**.** Center of pressure (CoP) trajectory length and sway ellipse area under eyes-open and eyes-closed conditions.

In summary, the static analysis revealed a mild left–right asymmetry in plantar loading, with the left foot supporting 51% of body weight compared to 49% on the right, and a predominance of rearfoot loading (62%) relative to the forefoot (38%) (Table 1, Figure 1). This posterior loading strategy is commonly described in children, as the maturation of gait is associated with the progressive redistribution of plantar pressures toward a more balanced forefoot–rearfoot pattern. Previous pediatric studies have shown that younger children exhibit greater variability and asymmetry in static support, which tends to decrease with age as motor control improves.

Dynamic assessment further highlighted subtle gait asymmetries (Table 2 and Figure 2). The left foot demonstrated a slightly longer step length (52 cm vs. 50 cm) and stance duration (0.72 s vs. 0.68 s), suggesting a stabilizing role, whereas the right foot exhibited higher peak propulsion forces (240 N vs. 220 N), reflecting a greater contribution to forward progression. Such side-specific differences are consistent with developmental gait patterns, where one limb often provides stability, while the contralateral limb contributes more to propulsion. Pediatric gait literature describes these asymmetries as part of a transitional process toward a mature, more symmetrical gait pattern typically reached in late childhood.

Stabilometric evaluation confirmed increased postural sway under visual deprivation (Table 3, Figure 3). With eyes open, the CoP path length was 210 mm and the sway ellipse area was 180 mm^2; with eyes closed, these values increased to 340 mm and 320 mm^2, respectively. The Romberg index exceeded 2.0, indicating a strong dependence on visual input for balance control. This finding is in line with prior research showing that children rely more heavily on visual cues for maintaining postural stability, as proprioceptive and vestibular integration remains less efficient than in adults. Pediatric stabilometric studies have consistently reported larger sway amplitudes and higher Romberg indices, suggesting that balance control mechanisms are still maturing throughout early and middle childhood.

Taken together, these results demonstrate that even in healthy pediatric subjects, objective baropodometric and stabilometric analyses can identify functional asymmetries and developmental characteristics of gait and posture. The combination of mild plantar asymmetry, complementary gait dynamics, and visual dependence for balance illustrates typical variability in pediatric motor control. Supported by both numerical data (Tables 1–3) and graphical representations (Figures 1–3), these findings emphasize the feasibility of detecting relevant asymmetries in pediatric populations and highlight the potential role of these tools in rehabilitation and developmental monitoring.

4. Discussion

This pilot study examined gait and postural symmetry in a healthy pediatric subject, guided by three working hypotheses (HW1–HW3). The discussion is therefore organized around these hypotheses, emphasizing the consistency of the findings with the existing literature and their relevance for pediatric assessment and rehabilitation. The results demonstrated subtle but measurable asymmetries in plantar pressure distribution, gait parameters, and postural control. These observations suggest that asymmetry in childhood should not be regarded solely as a pathological marker, but may also reflect normal developmental variability in motor strategies.

4.1. HW1 – Baropodometric Analysis and Plantar Load Asymmetries

Static analysis revealed a slight predominance of left-foot loading and posterior distribution of plantar pressure. This pattern is consistent with the findings of Monteiro-Rodrigues et al. [6], who reported rearfoot dominance in adults, and with pediatric studies demonstrating posterior support strategies during growth [9,10]. Dynamic analysis further emphasized the complementary roles of the limbs: the left foot primarily contributed to stability, whereas the right foot generated greater propulsion forces. Similar asymmetric contributions have been described in both healthy children [12,16] and pathological contexts, such as idiopathic toe walking [27]. These results support HW1 by showing that baropodometry can detect subtle but measurable asymmetries, even in children without clinical pathology. While such asymmetries may represent adaptive mechanisms facilitating motor development, their persistence could predispose to musculoskeletal imbalance, underscoring the preventive value of baropodometric assessments in pediatric populations.

4.2. HW2 – Stabilometric Analysis and Visual Dependence in Postural Control

Stabilometric assessment revealed strong reliance on visual input, with enlarged sway areas and a Romberg index greater than 2.0 under eyes-closed conditions. These results confirm HW2 and are in line with previous studies showing that children rely more heavily on vision to maintain balance than adults [25,29]. Shibata and Yoshida [7] similarly reported that targeted rehabilitation could reduce postural instability under visual deprivation, supporting the importance of sensory training in balance development. Further evidence from VR-based postural control interventions [28] and EMG-based gait analyses [12] highlights the role of multimodal sensory integration in pediatric motor control. Moreover, exaggerated visual dependence has been observed in children with developmental coordination disorders or neuromuscular impairments [27,28], suggesting that stabilometry is a valuable diagnostic and monitoring tool in both healthy and clinical populations.

4.3. HW3 – Combined Feasibility of Baropodometric and Stabilometric Assessment

The integration of baropodometric and stabilometric findings provides strong support for HW3, demonstrating the feasibility of these complementary methods in pediatric evaluation. Baropodometry offers detailed information on plantar load distribution, gait phases, and propulsion, whereas stabilometry captures postural sway and sensory reliance. Together, they provide a holistic picture of motor function and symmetry, aligning with prior work that has emphasized the need for multimodal assessment in rehabilitation and sports science [2,6,18]. In the pediatric context, this combined approach has significant potential for early screening, preventive interventions, and individualized rehabilitation strategies, particularly for children with orthopedic or neuromotor vulnerabilities. By highlighting both functional asymmetries and sensory integration patterns, this methodology contributes to a more comprehensive understanding of motor development and its clinical application.

4.4. Clinical Implications

Although the participant was healthy, the findings were clinically significant. Baropodometry and stabilometry have been validated in hemiparetic [1], MS [5], and scoliosis populations [3]. Extending their application to pediatric practice may help detect early asymmetries and monitor rehabilitation effects. Foot type differences [9], prosthesis use [8], and pathological gait conditions [27,28] all demonstrate the value of plantar pressure analysis in guiding interventions.

Additionally, reliability studies have confirmed that baropodometric measures are valid for children aged 4–12 years [26], supporting the feasibility of their integration in pediatric care.

4.5. Gait and Postural Symmetry Assessment in Pediatric Prevention and Rehabilitation

The assessment of gait and postural symmetry is not only of scientific relevance but also of clinical and preventive importance. In children, asymmetries may initially appear as functional adaptations during growth; however, if not identified early, they can predispose children to postural deviations, musculoskeletal imbalances, or inefficient motor patterns [9,10,29]. Baropodometric and stabilometric analyses, by providing objective and quantifiable data, enable clinicians to detect such deviations at a subclinical stage before they evolve into overt pathology.

From a *preventive perspective*, integrating these methods into routine pediatric evaluations may support the identification of children at risk of developing postural or gait abnormalities, such as flatfoot, idiopathic toe walking, or balance deficits associated with poor sensory integration [11,16,27]. Early detection can guide targeted interventions, including proprioceptive training, corrective exercise, and adapted motor activity programs in schools or community health initiatives [2,25,28].

From a *rehabilitation perspective*, these tools have the advantage of objectively monitoring treatment progress. They can quantify changes in plantar load redistribution, improvements in balance control, and reductions in asymmetry following interventions such as manual therapy, perceptive rehabilitation, or VR-based balance training [5,7,13,28]. For pediatric populations recovering from orthopedic injuries or neuromotor disorders, baropodometric and stabilometric assessments offer outcome measures and motivational feedback to both families and therapists.

Ultimately, combining prevention and rehabilitation approaches based on gait and postural symmetry analyses may contribute to promoting healthier motor development trajectories, reducing long-term risks, and enhancing children's quality of life.

4.6. Future Research Directions

Although this pilot study demonstrated the feasibility of detecting functional asymmetries in a healthy pediatric subject, its single-case design represents an obvious limitation. Therefore, future research should prioritize larger age-stratified cohorts to establish normative datasets of plantar pressure distribution and stabilometric indices across different stages of development. Such reference values are essential for distinguishing normal developmental variability from pathological asymmetries.

Comparative studies between healthy children and those with neuromotor or orthopedic conditions, such as idiopathic toe walking, developmental coordination disorder, or neuromuscular diseases, would further clarify whether the observed asymmetries are adaptive or maladaptive. Longitudinal designs could provide valuable insights into how gait and postural symmetry evolve over time and whether specific asymmetries predict later motor impairments or postural deficits.

In parallel, future studies should examine the effectiveness of targeted rehabilitation programs, such as proprioceptive training, sensorimotor stimulation, or VR-based therapies, in reducing maladaptive asymmetries and enhancing balance control. Combining baropodometric and stabilometric analyses with advanced technologies, including wearable sensors, machine learning algorithms, and real-time biofeedback systems, may offer new opportunities for continuous monitoring and personalized intervention. Moreover, integrating these approaches into school or preventive health programs could support the early identification of children at risk of developing motor dysfunction.

Ultimately, interdisciplinary collaboration between clinicians, biomechanists, engineers, and educators is essential to expand the scope of research from single-case pilot studies to comprehensive frameworks that address both fundamental developmental processes and applied rehabilitation strategies.

These findings reinforce the idea that functional asymmetries are integral to motor development. Distinguishing developmental variability from maladaptive asymmetry is essential for timely rehabilitation. By extending *the scope of symmetry* to pediatric populations, this study emphasizes the importance of early screening and objective monitoring of gait and postural symmetry.

5. Conclusions

This pilot study demonstrated that baropodometric and stabilometric analyses can successfully identify subtle functional asymmetries in gait and postural control, even in healthy pediatric subjects. Static plantar loading revealed a mild left–right imbalance with posterior predominance, dynamic testing highlighted differentiated roles of the limbs in stability and propulsion, and stabilometric measures confirmed strong reliance on visual input for balance. Together, these findings support the feasibility and clinical potential of symmetry assessment tools in pediatric populations.

Although limited by its single-case design, this study provides a methodological framework and preliminary evidence that may inform larger investigations. Establishing normative pediatric data, comparing healthy and pathological groups, and integrating advanced monitoring technologies are essential for advancing research in this area. Beyond its scientific contribution, the present study underscores the relevance of symmetry assessment in rehabilitation and preventive care, highlighting its potential to guide early intervention and promote optimal motor development in children.

The results support HW1 by demonstrating detectable plantar load asymmetries, HW2 by confirming visual dependence in postural control, and HW3 by validating the combined feasibility of baropodometric and stabilometric assessments as complementary tools for pediatric evaluation.

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Abbreviations

The following abbreviations are used in this manuscript:

CoP	Center of Pressure

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