

Influence of anthropometric factors on postural control in school-aged children: A stabilometric evaluation

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Abstract:

Problem Statement: The gradual development of postural conditions during the school years progresses through a series of rapidly developing phases, including improvements in stability, balance, and coordination. The use of evaluation methods such as baropodometry allows to analyze foot dysfunctions by mapping plantar surface pressure, thereby indicating important postural anomalies. The aim of the study was to highlight the values of the center of pressure (COP) in relation to anthropometric parameters in children between 5 and 13 years of age. **Approach:** Children from the primary and lower secondary school in Italy (n = 141) and a subgroup (n = 35) using a stabilometric platform. Data acquisition lasted 10 seconds from the moment the participant positioned themselves on the evaluation platform. The study allowed us to highlight the values of the center of pressure in the developmental age with the influence of anthropometric factors. **Results** The results showed that height and weight influence front load percentages ($p = 0.035$) and center of pressure oscillations ($p = 0.039$) with an increase in both parameters. The average rearfoot load percentage among all study participants reached 62.7%. At the forefoot level, it reached an average of 37.3%. **Conclusions:** In children aged 5–13 years, a clear rearfoot predominance was observed (about 63%), with lower forefoot loading. As height and body mass increase, loading tends to shift forward, and COP sway becomes wider. These data point to postural control that is still maturing and support the value of early screening and targeted motor practice within school settings for children.

Key Words: - Posture, Center of Pressure, Motor Development

Introduction

The progressive development of postural conditions in school age goes through a series of phases that develop rapidly, such as the improvement of stability, balance, and coordination (Brzęk et al., 2017). Postural structure in children aged five undergoes marked developmental changes influenced by physical activity and lifestyle transitions, particularly with the onset of formal schooling. The quality of posture at this age is linked to physical fitness and coordination potential (Górniak et al., 2024). Postural control is defined as the ability to control the center of mass (COM) in relation to the base of support (Shumway-Cook & Woollacott, 2012). In children, it is closely linked to motor development and fundamental movement skills (Fisher et al., 2005). The human foot is the base of support and propulsion for walking and provides support and flexibility for weight transfer (Orlin & McPoil, 2000; Vianna & Greve, 2006). Moreover, correct foot biomechanics is responsible for maintaining body posture and symmetrical plantar pressure distribution (Vianna & Greve, 2006), exerting an important effect on postural control during standing and walking (Lafond et al., 2004). However, the presence of school weights such as backpacks and asymmetry in backpack straps could affect posturometric parameters (Bubanj et al., 2012), causing anomalies in thoracic rotation, decreased lumbar lordosis, and increased thoracic kyphosis in school age (Cardon et al., 2002). In fact, it is hypothesized that excessively heavy backpacks may contribute to high cases of back pain, poor posture, frequent causes of discomfort for students (Negrini & Carabalona, 2002), and significant static and dynamic oscillations while carrying the school backpack (Bjorklund & Beers, 2016).

Balance can be seen as a skill acquired through training and play, which develops during childhood and is influenced by factors including gender, height, weight, and leisure activities such as martial arts and basketball (Fong et al., 2012). In line with this perspective, previous work from our group reported that body weight can be associated with measurable changes in posture and performance-related outcomes, supporting the rationale for investigating weight-related effects on postural control and plantar load distribution during development (Mazzei, 2025). A comprehensive understanding of motor situations during team sports, particularly basketball, plays a crucial role in developing balance, coordination, and posture among youth, as these activities constantly stimulate adaptive postural capabilities (Altavilla & Raiola, 2014).

The environmental context also plays a crucial role in the development of balance. Children's exposure to adventurous motor experiences in natural environments enhances not only their integrated motor and cognitive skills but also encourages stronger postural self-regulation through risk perception and adaptation to

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terrain and external conditions (Coco et al., 2021). The postural system allows us to maintain balance when standing and during motor activities, such as walking (Bellizzi et al., 2011). As we age, postural control becomes of primary importance for performing daily activities (Van Wilderode et al., 2024). The study of static and dynamic balance is often useful for determining the state of neuromuscular control following range of motion, muscle strength, and endurance (Paterno et al., 2007). Incorrect postural attitudes in modern times are increasingly common due to the use of smartphones and prolonged sitting positions, which cause an increase in the physiological curves of the spine, especially at the thoraco-lumbar level, even more evident in adolescents who already present Low Back Pain (LBP) (Jung & In, 2020) and which can lead to very common conditions in adolescence such as forward head posture with consequent cervical pain (Ruivo et al., 2014). The use of evaluation methods such as baropodometry allows for the analysis of foot dysfunctions by mapping the pressure of the plantar surface, indicating important postural anomalies (Bellizzi et al., 2011; Kaercher et al., 2011), allowing for the understanding of incorrect postural adaptations (Bricot, 2008; Kaercher et al., 2011). Studies also highlight the key role in stabilometric rehabilitation (Roy et al., 2019) and athletic training. The aim of the study was to highlight the values of the center of pressure (COP) with the stabilometric platform, in relation to anthropometric factors during the developmental age.

Influence of anthropometric factors on posture control

In overweight individuals, the load on the medial longitudinal arch is approximately three times greater than in those of normal weight, leading to negative biodynamic changes that may restrict both quality of life and physical activity (Hills et al., 2001). Neri et al. (2019) emphasized the relationship between obesity, posture, fear of falling, and fall risk, noting that obesity contributes to an increased risk of falls due to impaired postural balance and heightened fear of falling. Similarly, Rezaeipour (2018) confirmed that weight gain is associated with balance disturbances in overweight and obese men, while Rosso et al., (2016) and Thiese et al. (2015) demonstrated that excess weight has a detrimental effect on body stability. Furthermore, Hue et al. (2007) found that increased weight causes a forward shift in the body's center of gravity, which directly influences postural control and foot loading. Research highlights that postural control is affected by anthropometric factors, with height being the most significant variable influencing this ability (Alonso et al., 2015). Additionally, children with higher levels of adiposity or a predominantly endomorphic body composition tend to perform worse in static and dynamic postural balance tests (Guzmán-muñoz, 2018).

Influence of age and gender on posture control

Adolescents demonstrate better balance performance compared to children (Schedler et al., 2019). However, discrepancies exist among studies concerning balance performance and its relation to age. Some research indicates that peak performance is achieved by the age of 10 (Riach & Starkes, 1993; Wollacott & Shumway-Cook, 1990), coinciding with a transitional phase in postural control (Shumway-Cook & Woollacott, 1985; Steindl et al., 2006) due to enhanced sensory integration (Bair et al., 2007; Barela et al., 2003). Conversely, other studies suggest that balance performance may continue to improve during adolescence (Schedler et al., 2019), demonstrating the dynamic nature of postural control development. The differences in maturation between boys and girls extend not only to physical, hormonal, and sexual development but also to the central nervous structures (Malina et al., 2004). These differences are also reflected in the psychological response to physical effort. Competitive anxiety in female soccer players differs significantly depending on their field position, affecting motor response and postural stability in high-pressure performance contexts, especially in tasks requiring spatial awareness and body control (Trandafirescu et al., 2024). A review of the literature highlighted that girls may perform better in static stationary balance tasks, such as standing on one leg, which require greater sensory input. In contrast, proactive balance, such as shifting the body to the limits of stability, appears to yield better results in boys due to greater muscular strength output (Schedler et al., 2019). Anthropometric and physiological differences between males and females manifest in variations in motor performance and posture, affecting both static and dynamic balance and influencing how body load is managed during postural control tasks (Altavilla et al., 2017).

Material & methods

Participants

One hundred and forty-one children (83 boys and 58 girls) from the Giovanni Falcone Comprehensive Institute in Rende-Quattromiglia (Cosenza, Calabria) primary and lower secondary school, aged between 5 and 13 years without neurological disorders and past interventions (Mean $\pm$ SD: age 10.7 ± 1.99 , weight 43.3 ± 13.9 , height 1.45 ± 0.152 , foot size 36.9 ± 3.39) participated in this study. Further analysis was carried out on a subsample of 35 children (21 boys and 14 girls) from the same school (Mean $\pm$ SD: age 10.1 ± 2.05 , weight 38.7 ± 12 , height 1.42 ± 0.14 , foot size 36 ± 3.18) to analyze the speed of oscillation of the COP.

Measurements system

The height was acquired with the stadiometer (SECA GmbH & Co. KG, Hamburg, Germany) while the weight was acquired with the digital scale (Zephyr ZHS809, Westim SpA, Roma, Italy). Initially, posture was assessed in a standing position with a forward gaze and relaxed posture to respect the participant's normal stance. The postural evaluation was performed using the 40x40 Baropodometric Platform (MotusTech Beyond, Guidonia Montecello, Italy), on which it was possible to perform the stabilometric test, monitoring the

oscillations of the COP and the percentage amount of weight distributed anteriorly, posteriorly, and laterally in bipodal support. The platform features gold-coated resistive sensors, which ensure precise and reliable measurements over an extended lifespan of up to 1,000,000 cycles. Its adjustable sampling rate, ranging from 5 Hz to 400 Hz, allows it to handle both static and dynamic assessments with ease. The resolution is fine-tuned to capture spatial details at 2.5 dpi horizontally and pressure variations at 8-bit vertically. Additionally, the platform can accommodate pressures of up to 150 N/cm², making it versatile for various clinical and research applications. The different color tones determine the amount of pressure exerted on the plantar areas. The colors can vary from dark red (greater pressure load exerted on a specific plantar area) to blue (less pressure load exerted on a specific plantar area).

Examination procedure

Participants arrived for evaluation in school clothing and were positioned on the platform only after removing their shoes. Before data acquisition, study participants were given the opportunity to stabilize their balance on the platform and once the test began, it lasted 10 seconds, during which the student had to keep their gaze oriented forward, without getting distracted. The anterior-posterior and right-left lateral oscillations of the COP with standard deviation were acquired from the platform. Data on the speed of oscillation of the COP, anterior-posterior oscillation speed, and medial-lateral oscillation speed were acquired (Figure 1). Participant recruitment for screening was allowed following communication through a school circular. The parents of the children had to give their consent to perform data acquisition.

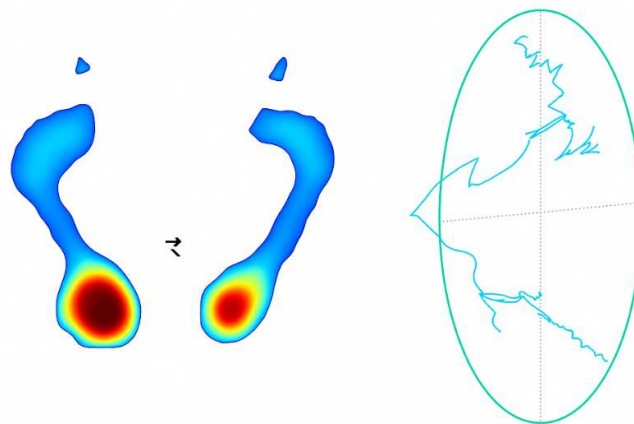


Figure 1. Visualization of Center of Pressure (CoP) trajectory and plantar pressure distribution areas obtained through stabilometric analysis, referring to a representative participant.

Statistical Analysis

The statistical analysis of this study included several tests to examine the relationships between anthropometric factors and postural control in school-aged children. Descriptive statistics were calculated to summarize the demographic characteristics of the participants, including age, weight, height, and foot size. The normality of continuous variables was assessed using the Shapiro–Wilk test, which confirmed a normal distribution ($p > 0.05$). To compare plantar load distribution between boys and girls, an independent-samples *t*-test was applied. A one-way analysis of covariance (ANCOVA) was conducted to examine the effect of height on front pressure, controlling for sex and weight as covariates. A linear regression analysis was conducted to investigate the association between height and anterior plantar pressure, as well as between body weight and anterior-posterior oscillation speed of the COP. Finally, to ensure that the sample size was adequate and to guarantee the statistical power of the study, a G-Power analysis was performed. The statistical analysis was conducted using the Jamovi 2.3.28 software, ensuring accurate computations and reliable results. Results were shown with mean value ($\bar{X}$) and standard deviation (SD). A *p*-value of < 0.05 was considered statistically significant.

Results

Of the one hundred and forty-one study participants, 87 participants (52 boys and 35 girls), exerted more than 60% of the load on the rearfoot. The average rearfoot load percentage among all study participants reached 62.7%. At the forefoot level, it reached an average of 37.3%. The average load percentage distributed laterally to the left and laterally to the right was 52.7% and 47.3%, respectively. The plantar pressure load between boys and girls did not reveal significant differences between the two groups (see Figure 2).

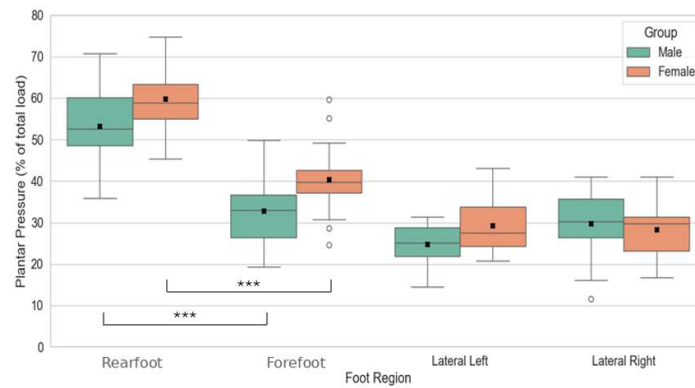


Figure 2. Differences of average and standard deviation of the stabilometric pressure between male (83) and female (58) groups. *** denotes a statistically significant difference ($p < 0.001$).

Gender comparison

Figure 2 highlights the differences in anterior, posterior, left lateral, and right lateral pressure load between the male and female groups. The comparison of the two genders did not lead to any significant differences ($p \geq 0.05$).

An ANCOVA on anterior load (%) with sex as fixed factor and height as covariate showed a significant effect of height, $F(1,138)=4.699$, $p=0.032$, $\eta^2=0.033$, whereas sex was not significant after adjustment for height, $F(1,138)=0.290$, $p=0.591$, $\eta^2=0.002$ (see figure 3).

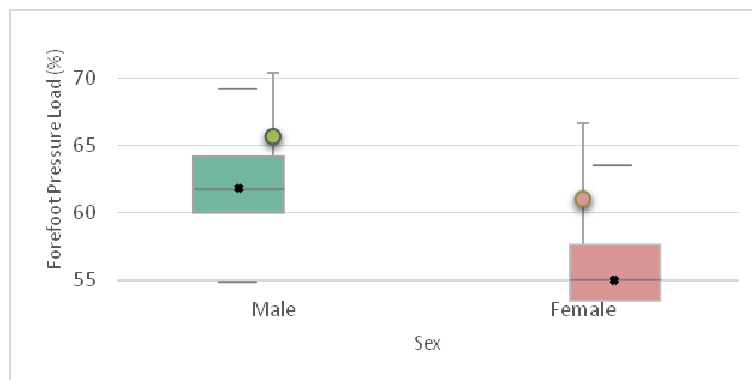


Figure 3. Anterior plantar load (%) by sex, adjusted for height (ANCOVA). The comparison between males and females did not reach statistical significance ($p > 0.05$).

A simple correlation analysis was performed to examine the association between front load and height ($SE = 6.22$, $p = 0.035$, $r = 0.387$). In fact, as height increases, anterior load increases (Figure 4.)

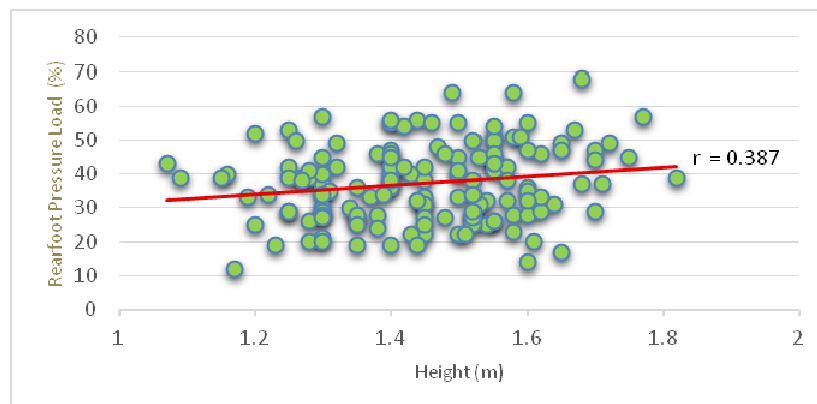


Figure 4. Correlations between the height of participants with front pressure in the stabilometric platform.

The correlation analysis to examine the association between oscillation speed and body weight showed a SE = 0.00367, $p = 0.039$ and $r = -0.178$, indicating a moderate impact in fact, weight seems to affect greater postural instability with higher anterior-posterior oscillation speed (see figure 5).

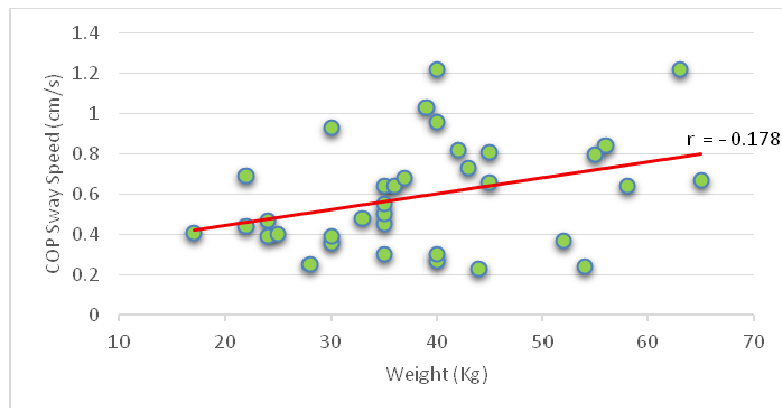


Figure 5. Correlations between the weight of participants and COP speed on the stabilometric platform.

Discussion

The study involved 141 children (83 boys and 58 girls) aged between 5 and 13 years from primary and lower secondary school. In this age range, postural control is still developing and reference values can vary widely depending on maturation and task conditions; therefore, collecting stabilometric data in school-aged samples may be particularly informative for interpreting balance behavior during growth (Verbecque et al., 2016). The study highlights the correlation between anthropometric parameters (height and weight) and postural characteristics. The results show that, as height increases, there is an increase in anterior load, while weight seems to negatively affect postural stability, favoring a more pronounced oscillation of the COP. This pattern is consistent with evidence showing that anthropometric characteristics significantly influence balance outcomes in children, supporting the interpretation that body size can modulate stabilometric parameters even in typically developing populations (Turon-Skrzypinska et al., 2020). In addition, pediatric plantar pressure research suggests that bodyweight categories can be associated with measurable differences in plantar pressure distribution, which helps contextualize the forward load shift observed in our sample as a plausible biomechanical adaptation accompanying growth and increased body mass (Feka et al., 2020).

Similar increases in CoP excursion across tasks of escalating difficulty have also been reported in adults, supporting the sensitivity of these stance conditions in identifying postural control challenges (Tsabalaki et al., 2023). These findings support existing literature, as indicated by Hue et al., (2007), who observed a negative effect of increased weight on body stability and an alteration in plantar load distribution. Importantly, studies comparing normal-weight and obese children report poorer balance control and altered CoP behavior in heavier groups, reinforcing our finding that weight is associated with greater postural instability (Turon-Skrzypinska et al., 2020; Villarrasa-Sapiña et al., 2016). Similarly, Enache et al., (2025) reported a decline in motor performance among ninth-grade students, with increased BMI and reduced coordination compared to previous cohorts in 2012, reinforcing the need for early postural screening and structured physical education. Because our stabilometric assessment was performed in a real school context, our results also align with school-based evidence indicating that overweight/obese children may present different postural control strategies and may be more challenged when additional school-related loads (e.g., backpacks) are introduced (Pau et al., 2012). Physical workload and functional demands vary considerably depending on the role occupied by athletes within a team, significantly impacting postural setup, plantar pressure distribution, and muscular compensations used to maintain balance (Altavilla et al., 2018). Guzmán-muñoz, (2018) also emphasizes that children with higher levels of adiposity tend to perform worse in static and dynamic balance tests. Borgogni & Agosti, (2021), note that hostile urban environments limit children's spontaneous movement, potentially worsening postural deficits in less active or overweight individuals.

Moreover, the relationship between plantar load and pressure distribution has been studied in depth by researchers such as Lafond et al., (2004) and Vianna & Greve, (2006), who confirm that foot biomechanics play a crucial role in neuromuscular control. Based on the results of the study and comparing them with data from the literature, a clear difference emerges in the values of plantar load distribution and postural control between school-aged children and adults. The study highlights a rearfoot load distribution of 62.7% and a forefoot load of 37.3%. Age-dependent differences in forefoot versus rearfoot loading have been documented in healthy individuals, with younger groups typically showing distinct distributions compared with adults; this supports the plausibility of the rearfoot predominance observed in our cohort and strengthens the interpretation of our values as developmentally meaningful (Pomarino & Pomarino, 2014). Recent pediatric plantar pressure studies in

school-age children further support the clinical relevance of reporting static plantar pressure patterns during development, reinforcing the value of our dataset as an additional school-aged reference point derived from stabilometric evaluation (Cuevas-Martínez et al., 2023). Finally, given that balance training interventions in healthy children can improve balance performance in a dose-responsive way, our findings provide an applied rationale for integrating early screening with targeted motor practice within school settings to support postural development (Schedler et al., 2019). These values differ significantly from those observed in adults, where the load distribution tends to be more balanced, as reported by Ohlendorf et al., (2020), who identified standard reference values in adult individuals with greater symmetry in plantar load distribution. The importance of targeted interventions to optimize postural development emerges from studies like those by Anwer et al., (2015), which propose specific exercises to prevent adverse postural conditions during adolescence, such as idiopathic scoliosis. Movement education programs focused on coordination have shown significant improvements in both balance and attentional performance in preschool children, supporting the integration of motor and cognitive training in early developmental stages (Esen et al., 2023). Targeted programs such as the Five-Step Boxing routine have been shown to significantly enhance postural engagement and exercise intensity in elementary school children, suggesting their efficacy in improving stability and motor control (Zhu et al., 2025). This perspective aligns with the findings of Di Palma & Agosti (2020), who emphasize that motor and sports activities, even in non-formal educational settings, can serve as powerful educational tools. Specifically, they highlight how involving students in the evaluation process alongside teachers fosters formative growth and body awareness, transforming assessment into a pedagogical moment rather than a purely technical one. These findings contribute to a broader understanding of the relationship between physical attributes and postural control, emphasizing the need for tailored interventions to enhance balance and motor skills during development.

Limitations

This study provides valuable insights into postural control during school age, yet certain limitations should be noted. The small sample size for stabilometric evaluation may constrain the generalizability of the findings, and the lack of longitudinal follow-up limits the ability to observe developmental changes over time. Future research should consider long-term designs and incorporate behavioral and environmental factors to offer a more holistic understanding of postural dynamics in children.

Conclusions

The study highlighted the increase in rearfoot load in school age, specifically between the ages of 5 and 13. Standard anterior and posterior load parameters in adulthood are significantly different from those presented in the study (Ohlendorf et al., 2020). The reason for such a significant difference between adolescence and adulthood could be attributed to an unestablished postural control process. These findings may serve as a reference point for understanding how plantar pressure evolves with age, highlighting developmental characteristics that could inform future comparative studies or targeted postural interventions. In these age phases, using an approach aimed at developing conditional and coordinative abilities is fundamental not only for the psychophysical well-being of young people but also for providing a solid foundation for an active lifestyle.

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Declaration of generative AI and AI-assisted technologies in the writing process

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