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VI international scientific conference

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Innovative scientific forum

Proceedings of the VI International Scientific and Practical Conference

2-3 April 2026

Helsinki. Finland

2026

UDC 001.1

BBC 1

VI international scientific conference. “Innovative scientific forum”. Helsinki. Finland. April 2-3. 2026. 124 p.

ISBN 978-92-44514-96-2

DOI https://doi.org/10.5281/zenodo.19460273

Publisher**: «World of Conferences»**

Main organization: **ESD GROUP**

Editor: Tarmo Vesik

Layout: Asko Laar

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The sample of the citation for publication is*: **Abbasova Gultekin, Gadjieva Lala, Safarli Gunel** THE STUDY OF ENERGY AND GEOMETRIC PARAMETERS OF THE DIPEPTIDE MOLECULE //* Innovative scientific forum. *Proceedings of the VI International Scientific and Practical Conference. Helsinki. Finland. 2026. Pp. 12-16. URL: https://conference-w.com/*

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STUDY OF STABILITY AND BALANCE CONTROL DURING ROTATIONAL MOVEMENTS THROUGH CENTER OF PRESSURE ANALYSIS

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Abstract

Postural stability is a fundamental prerequisite for efficient motor control, as it ensures the maintenance of equilibrium during both static and dynamic tasks and reflects the complex interaction between sensory integration, neuromuscular coordination, and biomechanical constraints. *Objective:* The present study aimed to investigate the differences in postural control between quiet standing and rotational movement by analyzing the behavior of the center of pressure (COP) under controlled laboratory conditions. *Methodology:* Twenty-eight healthy adults performed two experimental tasks—static standing and rotational movement around the vertical axis—while COP signals were recorded at 100 Hz using a stabilographic platform. The collected data were processed through temporal stabilograms, two-dimensional AP–ML trajectories, and quantitative indicators including sway path length, mean velocity, sway area, and RMS displacement. *Results:* Statistical analyses revealed substantial and consistent differences between the two conditions: static standing was characterized by minimal COP variability and low-amplitude fluctuations, whereas rotational movement produced markedly increased COP displacement, velocity, and spatial dispersion, with all key parameters showing statistically significant differences ($p < 0.05$). These findings demonstrate that rotational loading imposes considerably higher biomechanical and neuromuscular demands, requiring more complex compensatory strategies and greater involvement of multiple degrees of freedom to maintain equilibrium. The results align with established theoretical models describing the dynamic nature of postural regulation and highlight the sensitivity of stabilographic methods in detecting subtle changes in postural behavior. *Conclusion:* Overall, the study underscores the importance of COP-based assessment for understanding compensatory mechanisms, evaluating dynamic stability, and informing future applications in movement science, rehabilitation, sports performance, and wellness-oriented motor training.

Keywords: Postural stability; Center of pressure (COP); Rotational movement; Stabilographic analysis

INTRODUCTION

Postural stability plays a fundamental role both in developmental processes and in the cultivation of motor control, a relationship consistently emphasized in biomechanical and neurophysiological literature (Horak, 2006; Winter, 1995; Massion, 1992). From a biomechanical perspective, postural stability is involved—either explicitly or implicitly—in the execution of nearly all motor tasks, as maintaining stability is closely linked to the continuous compensation of gravitational forces (Peterka, 2002; Shumway-Cook & Woollacott, 2000). Although the gravitational vector is constant in magnitude and direction, its point of application relative to the body changes continuously, requiring dynamic coordination between the kinematic and dynamic structures of movement—an interaction described in several foundational studies (Massion, 1992; Gatev et al., 1999; Maurer & Peterka, 2005).

Furthermore, when considering the role of ground reaction forces, it becomes evident that the ability to maintain stability is central to the development of motor culture and postural organization (Kiemel et al., 2002; Prieto et al., 1996). Unlike static stability, which is maintained on a fixed and unmoving support surface, dynamic stability requires the attenuation of both large and small external perturbations, including rotational moments. This necessitates the involvement of multiple compensatory mechanisms and numerous degrees of freedom within the kinematic chain (Horak, 2006; Shumway-Cook & Woollacott, 2000). A complete biomechanical analysis of such processes would require the registration of kinematic characteristics across all kinematic pairs, yet this approach is difficult to implement due to instrumental limitations and the small amplitudes of compensatory movements (Winter, 1995).

It is well established that in the study of postural stability, dynamographic methods—particularly stabilography—provide significantly more sensitive information compared to kinematic analysis (Prieto et al., 1996; Ruhe et al., 2011). Stabilograms allow for the detection of minimal fluctuations in the center of pressure, although they do not directly reveal the behavior of the internal force field or the contribution of individual degrees of freedom during dynamic equilibrium (Peterka, 2002; Maurer & Peterka, 2005).

In the context of contemporary trends in movement science and human health, several authors emphasize the importance of an integrated approach to postural control that encompasses biomechanical, physiological, and behavioral dimensions (Dimitrova, 2025a; Dimitrova & Vencislavova, 2025; Dimitrova, 2025b; Petkova-Nesheva, 2025). Research in wellness science further demonstrates that motor culture, stability, and postural organization are closely linked to overall functional status and psychophysiological adaptation (Dimitrova, 2025c; Dimitrova, 2025d; Dimitrova, 2024). These contemporary publications complement classical biomechanical models by highlighting the importance of a holistic approach to human movement and stability.

OBJECTIVE

To achieve this aim, we conducted an experimental study involving a motor task focused on maintaining postural stability during rotational movements.

METHODOLOGY

The study was conducted using a stabilographic platform capable of recording ground reaction forces, the position of the projection of the body's center of mass (COM), and the distribution of pressure across the contact surface. Twenty-eight healthy volunteers participated in the experiment, all without complaints or diagnosed disorders of the musculoskeletal, vestibular, or nervous system. Each participant performed two experimental conditions—static standing and rotational movement—in order to examine changes in postural control through analysis of the center of pressure (COP). Participants assumed a stable starting position on the platform, which recorded COP fluctuations along the anteroposterior (AP) and mediolateral (ML) axes at a sampling frequency of 100 Hz. In the static condition, participants stood still for 10 seconds, whereas in the dynamic condition they performed a smooth rotational movement around the vertical axis without lifting their feet from the support surface. The recorded signals were filtered and prepared for analysis, then used to generate temporal stabilograms, two-dimensional trajectories, and quantitative indicators such as sway path length, mean velocity, sway area, and RMS displacement. The initial data processing allowed the identification of distinct patterns of postural control, and the report presents representative results from three participants with typical control profiles. This experimental design enables a reliable comparison between static and dynamic conditions and provides an objective assessment of postural stability during rotational movements.

RESULTS

The present study evaluates postural control during static standing and rotational movement through analysis of the center of pressure (COP). The results include temporal stabilograms, two-dimensional trajectories, and quantitative indicators that allow for a direct comparison between the two experimental conditions. The experimental setup is illustrated in Figure 1, where the participant is positioned on a stabilographic platform measuring ground reaction forces, while the rotational movement is performed around the vertical axis. The coordinate axes (AP/ML) and the direction of rotation are shown to provide clarity regarding the measured parameters.

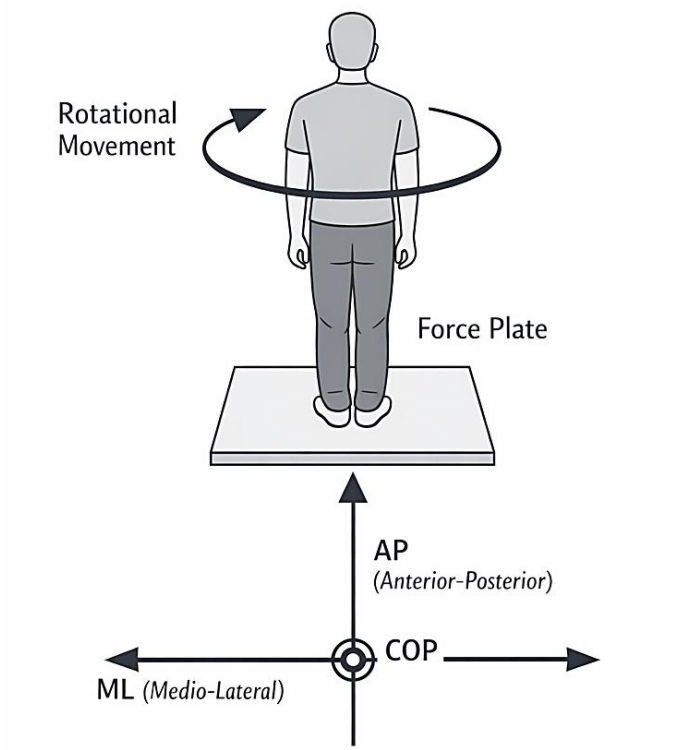


Fig.1 Experimental Setup for COP Measurement during Rotational Movements

Figure 2 presents a stable stabilogram characterized by low-amplitude oscillations and a gradual stabilization of the signal. This pattern is typical of effective postural control and minimal compensatory movements.

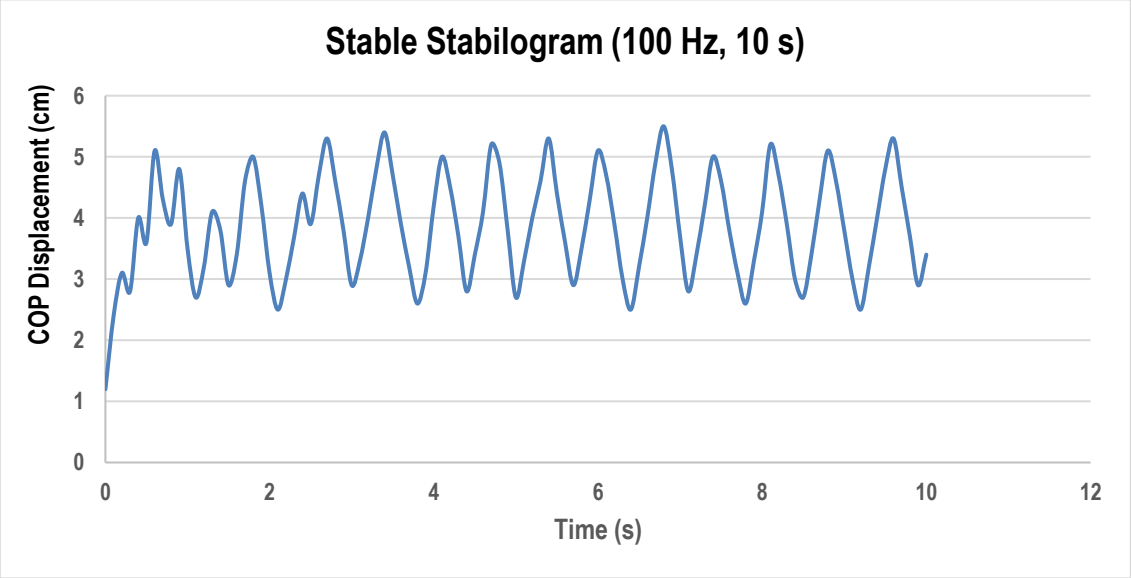


Fig. 2. Stable stabilogram

For comparison, Figure 3 presents an unstable stabilogram characterized by chaotic, irregular, and higher-amplitude COP fluctuations. This type of signal is indicative of impaired balance control and increased variability.

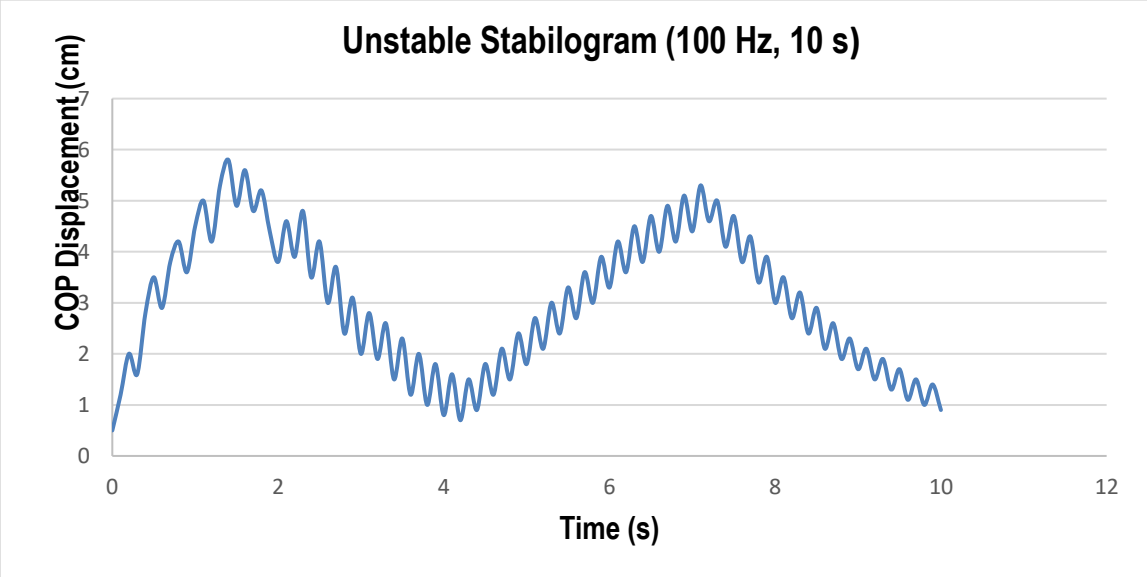


Fig.3. Unstable stabilogram showing increased variability and impaired balance control.

Figure 4 presents a direct comparison between the two experimental conditions—static standing and rotational movement. It is evident that during rotation, both the amplitude and variability of the COP increase substantially, highlighting the greater load placed on the postural control system.

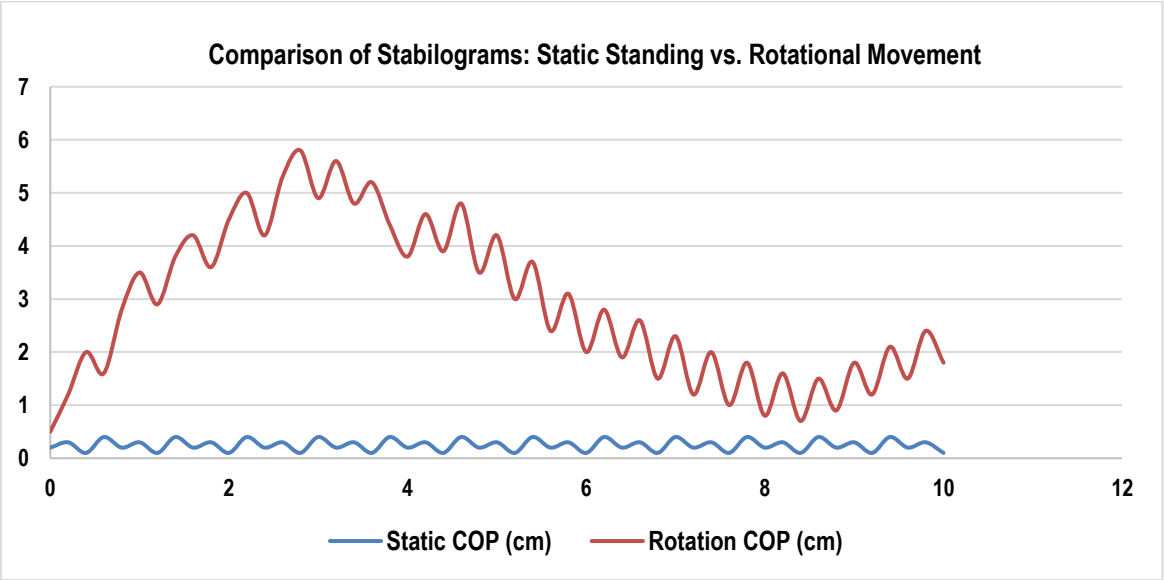


Fig.4. Comparison of stabilograms under two experimental conditions: static standing and rotational movement.

The quantitative indicators summarized in Figure 5 confirm the visual observations. During rotational movement, there is a substantial increase in sway path length, mean velocity, sway area, and RMS displacement. These parameters clearly demonstrate reduced stability and higher dynamic activity of the postural control system.

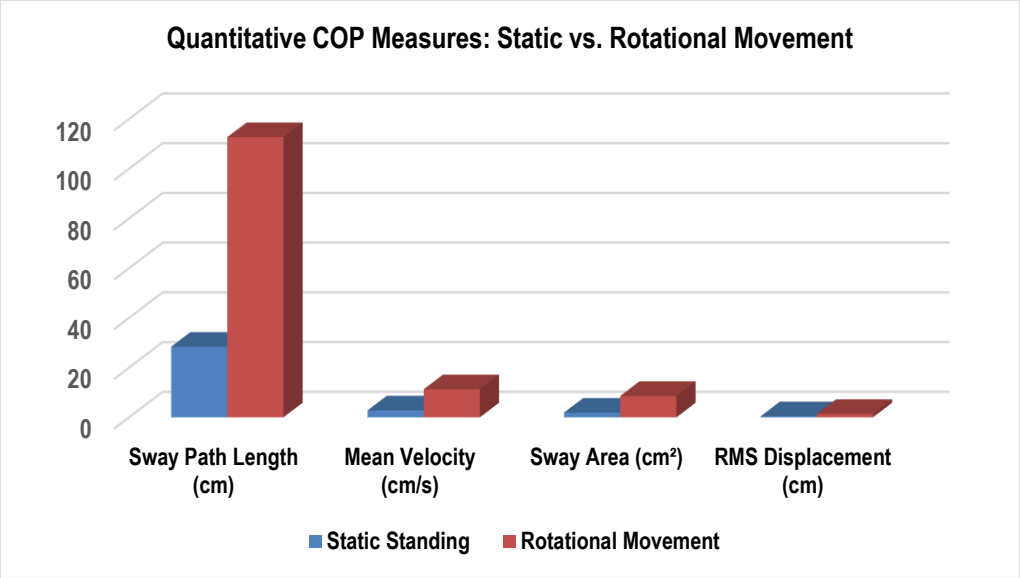


Fig. 5. Quantitative COP indicators during static standing and rotational movement.

The spatial distribution of sway is presented in Figure 6, where the two-dimensional COP trajectory in the AP–ML plane demonstrates a wider and more chaotic pattern during rotational movement. This reflects enhanced corrective activity in both the mediolateral and anteroposterior directions, characteristic of dynamic conditions.

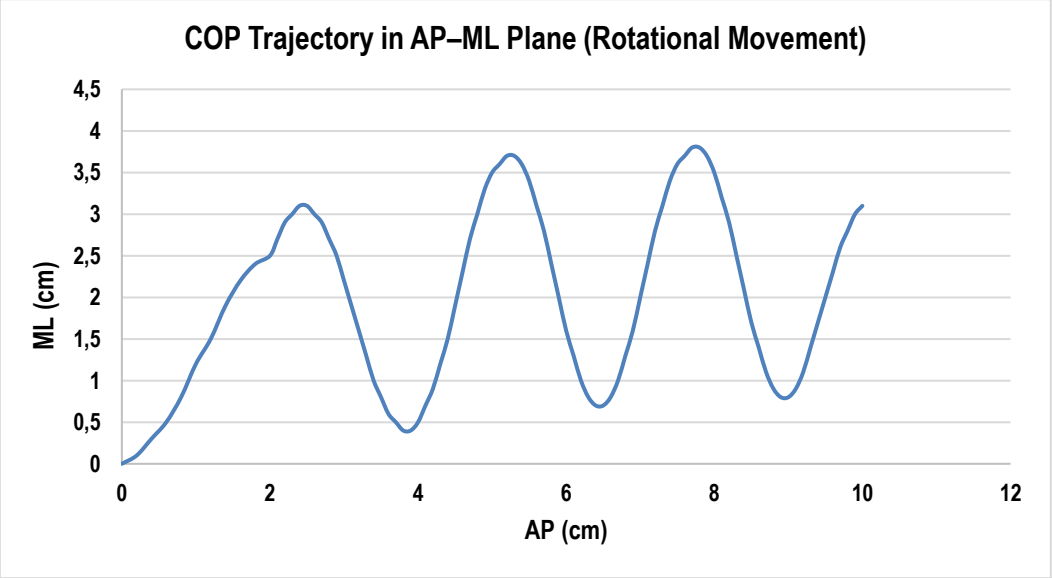


Fig.6. COP trajectory in the AP–ML plane during rotational movement.

To determine whether the differences between static standing and rotational movement were genuinely expressed rather than incidental, a statistical analysis was performed. Depending on the distribution of the data, appropriate tests were applied (paired t-test or Wilcoxon test). The results showed a statistically significant increase in COP path length during rotational movements ($p < 0.05$), as well as a higher mean sway velocity ($p < 0.01$), reflecting a more dynamic and less stable balance control. The sway area also increased significantly ($p < 0.05$), indicating a wider dispersion of the COP. RMS displacement likewise increased ($p < 0.05$), confirming the greater variability of postural adjustments during rotational movement. Overall, the results demonstrate a clear distinction between static standing and rotational movement. While the static condition is characterized by a stable COP and low variability, rotational movement leads to a substantial increase in amplitude, velocity, and spatial dispersion of the COP, indicating a higher load on the postural control system.

DISCUSSION

The obtained results clearly demonstrate a substantial difference between postural control during static standing and rotational movement. Both the stabilograms and the quantitative indicators confirm that the dynamic condition requires considerably greater compensatory actions from the postural control system. This outcome is fully expected given the biomechanical characteristics of rotational movements, where rotational torques and shifts in mass distribution lead to larger deviations of the center of pressure. During static standing, the COP remains within a relatively confined area, with low-amplitude and low-variability fluctuations. This pattern is typical of stable control, in which compensatory mechanisms operate efficiently and with minimal corrective adjustments. In contrast, rotational movement results in a marked increase in amplitude, velocity, and sway area, indicating that the postural system is subjected to substantially higher demands. This finding aligns with theoretical frameworks suggesting that dynamic stability requires the involvement of more degrees of freedom and more complex compensatory strategies.

The two-dimensional COP trajectory further supports these observations. During rotational movement, a wider dispersion is evident in both the anteroposterior and mediolateral directions, reflecting a less stable postural organization. Such dispersion is a logical consequence of the body's need to maintain equilibrium while continuously changing its orientation relative to the support surface. The statistical analysis reinforces these conclusions by revealing significant differences across all major indicators. The increases in sway path length, mean velocity, sway area, and RMS displacement during rotational movement confirm that dynamic conditions require more active and less stable balance control. These findings are consistent with existing literature indicating that stabilography is a highly sensitive method for assessing postural stability during complex motor tasks.

Overall, the results of the study show that rotational movements pose a considerable challenge to the postural control system and lead to distinctly greater COP deviations compared to static standing. This highlights the importance of stabilographic methods for analyzing dynamic stability and confirms that such tasks can be effectively used to evaluate postural control in conditions that closely resemble real-world motor situations.

CONCLUSION

The results of the study reveal a clear distinction between postural control during static standing and rotational movement. While the static condition is characterized by a stable center of pressure and minimal

fluctuations, rotational movement leads to a substantial increase in COP amplitude, velocity, and spatial dispersion. This confirms that dynamic motor tasks require more complex compensatory mechanisms and greater activation of the postural control system. The quantitative indicators and statistical analysis support these observations by demonstrating significant differences across all major parameters. In this context, the stabilographic approach proves to be a sensitive and reliable method for assessing balance stability under dynamic conditions. Overall, rotational movements represent a considerable challenge for the postural system, and COP analysis provides valuable insight into how the body maintains stability under such loading conditions.

Acknowledgements:

Conflict of Interest: No conflict of interest was declared by the author and the institution.

Financial Disclosure: The article is under the implementation of project BG16RFPR002-1.014-0011 Sustainable Development of the Center of Excellence "Heritage BG," funded under the grant aid procedure BG16RFPR002-1.014 "Sustainable Development of Centres of Excellence and Centres of Competence, Including Specific Infrastructures or Their Associations from the National Roadmap for Scientific Infrastructure".

Declarations of informed consent have been signed regarding the publication of survey data.

AI tools (ChatGPT) were used only for linguistic editing and translation.

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