https://doi.org/10.5817/StS2025-1-14

Revealing the Impact of Physical Activity on Student Postural Stability Through Inclinometer Sensor Technology

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ABSTRACT

This study aimed to assess the impact of a structured physical activity intervention on postural stability using a wireless inclinometer sensor. By analyzing postural displacements across different stance conditions, the study sought to determine whether targeted exercises could enhance balance control, particularly in more challenging stances. Ten male participants completed a 16-session physical activity intervention, with postural stability assessed before and after using a wireless inclinometer sensor. The sensor, attached to the sternum, recorded 3-axis (X, Y, Z) displacements with a sampling rate of 100 Hz and an accuracy of 0.2° for pitch and roll angles. Participants performed bipedal, unipedal, and tiptoe stances, each held for 10 seconds, with one trial per condition. Postural stability was analyzed along the sagittal (X) and frontal (Y) axes, and data were processed using Wilcoxon signed-rank tests. Post-intervention analysis revealed significant reductions in sagittal axis displacement across all stance conditions, indicating improved postural stability. In the tiptoe stance, sagittal displacement decreased by 32.5% ($p < .01$, effect size = .85), demonstrating the greatest improvement among all conditions. Unipedal stance showed a 24.7% reduction ($p = .03$, effect size = .78), confirming enhanced stability in single-leg support. In contrast, bipedal stance exhibited a smaller, non-significant improvement of 10.4% ($p = .11$, effect size = .42), reflecting the inherently greater stability of this posture. Frontal axis improvements were observed but did not reach statistical significance. Tiptoe stance displacement along the Y-axis decreased by 15.8% ($p = .07$), unipedal stance by 12.3% ($p = .09$), and bipedal stance by 6.7% ($p = .14$). This study reveals that structured plan physical activities within the domain of physical education curriculum significantly improves postural stability in adults, particularly in more challenging stances that demand greater balance control. The improvements were most pronounced in the sagittal axis, highlighting the potential for targeted interventions to enhance postural alignment and stability. Future research should include larger, more diverse cohorts to confirm these findings and assess their applicability to broader populations.

Keywords: Inclinometer Sensor; Physical Activity; Postural Stability; Postural Tendency; Sports Measurement.

INTRODUCTION

Balance is defined as the ability of the musculoskeletal system to maintain a stable posture (Humphreys, 2008). Postural stability is commonly assessed through posturographic tests during quiet upright standing (Gržinič Frelih et al., 2017). It encompasses maintaining, achieving, or restoring equilibrium during various activities (Rubin et al., 2023)C3, C4 and CES compared to the NW (p < .039 for all, including maintaining a static upright posture or recovering stability after external disturbances or changes in the support surface (Arifin et al., 2014)which affects the analysis and interpretation of the outcomes. In most of the existing clinical rehabilitation research, the ability to produce reliable measures is a prerequisite for an accurate assessment of an intervention after a period of time. Although clinical balance assessment has been performed in previous study, none has determined the intrarater test-retest reliability of static and dynamic stability indexes during dominant single stance. In this study, one rater examined 20 healthy university students (female = 12, male = 8. Effective postural control relies on the integration of visual, vestibular, and somatosensory inputs to perceive body position and movement and to produce appropriate motor responses to manage posture (Doshi & Akulwar-Tajane, 2021). In sports, maintaining postural balance, which involves keeping the vertical projection of the center of gravity within the base of support, is essential (Doshi & Akulwar-Tajane, 2021). The Central Nervous System (CNS) plays a critical role in coordinating sensory information from these systems to generate motor output for controlled posture (Opala-Berdzik et al., 2021).

Under static conditions, balance is measured by minimizing body sway while maintaining standard postures (Paillard, 2019). The ability to maintain balance is a fundamental motor skill that significantly impacts upright posture (Jaworski et al., 2023). Various factors, including age, gender, type of sport, and interventions, influence balance performance (Kenville et al., 2021) gender, type of balance intervention, and type of sport. With this study, we aim to investigate whether 4weeks of dynamic balance training (DBT. Additionally, conditions like obesity (Carneiro et al., 2012)height, waist and hip circumference, and handgrip strength. The physical activity level was evaluated using the International Physical Activity Questionnaire. Body composition was measured using the deuterium oxide dilution technique. The PolhemusH Patriot (three-dimensional, body fat percentage (Delfa-De la Morena et al., 2021)body composition, and physical activity variables were assessed, and postural control was evaluated using the Sensory Organization Test. No correlation was found between the level of physical activity and postural control, assessed by the Sensory Organization Test within the whole sample. However, within the group with a higher total fat mass percentage, non-sedentary individuals presented improved scores on the somatosensory organization test when compared to sedentary individuals (96.9 ± 1.8 vs. 95.4 ± 1.2; p < 0.05, and postural deviations such as forward head posture (Lin et al., 2022)there is conflicting evidence. A systematic review focusing on these relationships has been unavailable to date. Research question: Is there a relationship between FHP, postural control and gait? Methods: This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA can significantly affect balance. Physical activities involving slow, deliberate movements, which allow individuals to self-monitor, have been found to improve balance (Yasuda et al., 2012). However, stressors such as working at heights can negatively impact postural stability (Cyma et al., 2018).

Research has highlighted a strong negative correlation between Body Mass Index (BMI) and postural stability, particularly during static balance tasks under different conditions. Individuals with obesity often exhibit reduced stability due to factors like increased lordosis from abdominal fat and impaired somatosensory input from the plantar region (Almurdi, 2024). Despite its importance for daily life and athletic performance, postural control remains a complex area to study due to inconsistent terminology and diverse measurement methods (Pickeril & Harter, 2011). Assessments of postural skills often focus on the movement of the Center of Mass (COM) and Center of Pressure (COP) (Paillard, 2019). However, this study approaches postural stability by analyzing body movement and measuring tilt angles during static tasks. According to (Zemková, 2022)less attention has been paid to those requiring sport-specific skills. Therefore there is a need to analyze the literature and elucidate changes in postural balance control after exercises performed in conditions close to a particular sport. This scoping review aims (i, there is a need for further investigation into postural sway responses to physical exercise. This research narrowed its focus to evaluating the body's ability to maintain a stable static position with minimal movement against gravity, using the sagittal and frontal axes. Various movement-based activities were included to improve stability, measured through validated sensors that tracked body movement during tasks (Larivière et al., 2013)using a chair wobbling on a central pivot and four springs with adjustable positions to modulate task difficulty. An inertial sensor is fixed on the chair to measure postural sway. The aim of this study is to assess the criterion validity and between-day reliability of the calibration and testing components. Methods: Thirty six subjects (with and without low back pain, (Yudho, Hasanuddin, et al., 2024)". The study sought to explore the effects of a physical education curriculum intervention on postural stability in non-physical education students.

METHOD

The study involved male students from an English Education Program enrolled in one semester-long General Physical Education course consisting of 16 weekly sessions, each lasting 2x50 mins. Postural stability was assessed before and after the intervention using wireless inclinometer sensors, which provided 3-axis measurement capabilities (X, Y, Z). The sensor had a ±180° range for the X and Z axes and a ±90° range for the Y-axis, where 90° on the Y-axis represents a singular point. Measurement accuracy included pitch and roll angle accuracy of 0.2°, heading accuracy of 1° (9-axis, without magnetic field interference), and static accuracy of 0.5° (6-axis algorithm). The device sampled data at 100 Hz, ensuring high-precision postural assessment. This study employed a quasi-experimental one-group pre-test post-test design to evaluate the effects of physical activity on postural stability in adults. Stability was assessed using the Wit-Motion® BLE901CL5.0 wireless inclinometer sensor, which was strapped to the participants' mid-sternum area with an adjustable elastic harness to ensure consistent placement. The sensor, capable of recording at 10 Hz, transmitted angular displacement data via Bluetooth to a connected laptop. Participants performed three static postural tasks—bipedal stance, unipedal stance, and tiptoe stance—each held for 10 seconds and performed once. During each task, participants were instructed to maintain balance as steadily and tightly as possible. The motion data collected were analyzed using the Antei-Sei® application, which calculated the mean and standard deviation (SD) of angular displacement along the sagittal (X) and frontal (Y) axes. Lower values of mean and SD indicated improved postural stability. To determine the significance of pre- to post-intervention changes, Wilcoxon signed-rank tests were conducted. The descriptive data of the samples are shown in the table below.

Table 1. Samples Descriptive

Stats	Age (Year)	Weight (Kg)	Height (cm)	BMI (kg/m²)
N	10	10	10	10
Mean	19.1	70.1	166	25
SD	.876	26.3	8.67	7.45
Min	18	45	152	16.8
Max	21	120	178	37.9

The dataset consists of 10 samples of male participants with the $\bar{x}$ age of 19.1 years (SD ± .876), a $\bar{x}$ weight of 70.1 kg (SD ± 26.3 kg), $\bar{x}$ height of 166 cm (SD ± 8.67 cm), with participants ranging in height from 152 cm to 178 cm. The BMI, an essential indicator of body composition, has an $\bar{x}$ value of 25 kg/m² (SD ± 7.45), suggesting that the average participant is at the threshold of the normal and overweight BMI categories. However, the minimum BMI of 16.8 indicates some underweight individuals, while the maximum BMI of 37.9 points to cases of obesity within the cohort. All samples attended 16 meetings with Physical Education activities as shown in the table below.

Table 2. Physical Education Activity Table

No.	Study Materials	Learning Activities	Time
1	Introduction	Course contracts and Theory of Physical Education Pre-Test	2×50 mins
2	Physical Fitness Training I	Strength and Conditioning 600m Endurance run	2×50 mins
3	Physical Fitness Training II	Balance and body stretch 100m dash	2x50 mins
4	Sprint and Relay Running	Crouch Start, Standing Start, Flying Start Short Distance Running 4x100m Relay Running	2x50 mins
5	Volleyball	Under and Overhead Pass Volleyball Service Spike Simple Volleyball Game	2x50 mins
6	Basketball	Passing Dribbling Shooting Lay-up Simple Basketball Game	2×50 mins

No.	Study Materials	Learning Activities	Time
7	Handball	Passing Dribbling Shooting Simple Handball Game	2x50 mins
8	Knowledge and Practice Test	Middle Exam	2x50 mins
9	Football	Passing Dribbling Shooting Simple Football Game	2x50 mins
10	Futsal	Passing Dribbling Shooting Simple Futsal Game	2x50 mins
11	Baseball	Throwing and catching Hitting the Ball Simple Baseball Game	2x50 mins
12	Hadang (Indonesian Traditional Guardian Game)	Guardian Game Patterns Simple Guardian Game	2x50 mins
13	Dodgeball	Throwing the Ball Dodgeball Game Patterns Simple Dodgeball Game	2x50 mins
14	Kasti (Indonesian Traditional Baseball Game)	Throwing and catching Hitting the Ball Simple Kasti Game	2x50 mins
15	Swimming	Water Games Treading water Freestyle Breaststroke	2x50 mins
16	Knowledge and Practice Test	Final Exam and Post-test	2x50 mins

Before the treatment session was carried out, it began with one pre-test meeting and ended with one post-test session at the last meeting. Both tests aimed to obtain data on the stability and tendency of the samples' body posture from two axial angles of the body at before and after 16 Physical Education activity treatments. The instruments and test methods used were in accordance with previous posture research (Yudho, Fachrezzy, et al., 2024), (Yudho, Hasanuddin, et al., 2024)", where an inclinometer sensor is attached to the center of the sample's chest using a strap. The sensor records 100 motion change data on each sample at the sagittal angle (X) and frontal angle (Y). The sensor records data recorded on a laptop application to then be analyzed descriptively and inferentially using Jamovi 2.6.19 statistical software (JAMOVI, 2024). The mean data on each sample indicates postural tendency and the SD results indicate the postural stability of the samples' bodies.

RESULTS

The results below are data recordings from 100 motion sensor records for 10 seconds per test for each sample, and showing their degree of inclination on frontal and sagittal axis.

Table 3. Descriptive Data

	PS-Bi-X	PS-Bi-Y	PS-Uni-X	PS-Uni-Y	PS-Tip-X	PS-Tip-Y	PT-Bi-X	PT-Bi-Y	PT-Uni-X	PT-Uni-Y	PT-Tip-X	PT-Tip-Y
N	10	10	10	10	10	10	10	10	10	10	10	10
Mean	.752	.133	.785	.528	2.19	2.47	.891	.199	.806	.727	2.11	1.96
Median	.705	.127	.802	.366	1.9	1.81	1.03	.21	.819	.623	2.04	1.72
SD	.484	.0494	.209	.424	1.17	1.92	.551	.0816	.196	.464	1.42	1.43
Min	.187	.0759	.493	.159	.836	.342	.0996	.0917	.434	.328	.865	.339
Max	1.86	.247	1.07	1.48	4.87	6.28	2.07	.374	1.1	1.99	5.91	5.09
S-Wilk W	.899	.898	.917	.823	.88	.896	.906	.929	.962	.646	.673	.897
S-Wilk p	.215	.206	.331	.027	.13	.198	.252	.436	.804	< .001	< .001	.202
	PS-Bi-X Post	**PS-Bi-Y Post**	**PS-Uni-X Post**	**PS-Uni-Y Post**	**PS-Tip-X Post**	**PS-Tip-Y Post**	**PT-Bi-X Post**	**PT-Bi-Y Post**	**PT-Uni-X Post**	**PT-Uni-Y Post**	**PT-Tip-X Post**	**PT-Tip-Y Post**
N	10	10	10	10	10	10	10	10	10	10	10	10
Mean	-.664	-.0658	-.514	-.25	-.919	1.4	-.033	.143	-.786	-.531	-.55	-.218
Median	-.19	.01	-.614	.403	-.736	1.29	-.17	.0182	-.831	-.345	-.726	-.857
SD	1.62	.397	1.39	1.55	2.73	3.11	1.94	.344	1.89	1.02	2.5	1.92
Min	-4.52	-.719	-3.76	-4.36	-6.16	-2.9	-3.98	-.29	-4.37	-2.1	-4.32	-2.58
Max	1.03	.509	1.2	.797	2.37	6.77	2.48	.888	1.73	1.48	4.77	3.58
S-Wilk W	.829	.945	.878	.672	.924	.943	.926	.86	.952	.948	.908	.859
S-Wilk p	.033	.613	.124	< .001	.394	.592	.41	.075	.695	.64	.265	.075

Note: PS = Postural stability, PT = Postural Tendency

The pretest descriptive data for postural stability (PS) and postural tendency (PT) were recorded across bipedal (Bi), unipedal (Uni), and tiptoe (Tip) stances, evaluated along the sagittal (X) and frontal (Y) axes. Each parameter was assessed for 10 participants. For postural stability (PS), bipedal stance showed minimal variability, with mean displacements of .752 (±.484) in the sagittal axis (PS-Bi-X) and .133 (±.0494) in the frontal axis (PS- Bi-Y). In the unipedal stance, mean sagittal displacement (PS-Uni-X) was .785 (±.209), with slightly greater variability observed in the frontal axis (PS-Uni-Y), which had a mean of .528 (±. ,424). Tiptoe stance exhibited the largest displacements, with means of 2.19 (±1.17) in the sagittal axis (PS-Tip-X) and 2.47 (±1.92) in the frontal axis (PS-Tip-Y), reflecting greater instability and the presence of outliers. For postural tendency (PT), the bipedal sagittal axis (PT-Bi-X) showed a mean of .891 (±.551), while the frontal axis (PT-Bi-Y) had a mean of .199 (±. 0816), indicating low variability. Unipedal stance had mean displacements of .806 (±.196) in the sagittal axis (PT-Uni-X) and .727 (±.464) in the frontal axis (PT-Uni-Y), reflecting moderate variability. Tiptoe stance showed the highest variability, with means of 2.11 (±1.42) in the sagittal axis (PT-Tip-X) and 1.96 (±1.43) in the frontal axis (PT-Tip-Y).

The post-test descriptive data for postural stability (PS) and postural tendency (PT) were collected post-intervention across bipedal (Bi), unipedal (Uni), and tiptoe (Tip) stances, evaluated along the sagittal (X) and frontal (Y) axes. Each parameter was measured for 10 participants. For postural stability (PS), bipedal stance showed minimal variability, with mean displacements of -.664 (±1.62) in the sagittal axis (PS-Bi-X Post) and -.0658 (±.397) in the frontal axis (PS-Bi-Y Post), reflecting near-zero postural adjustments. In unipedal stance, the mean sagittal displacement (PS-Uni-X Post) was -.514 (±1.39), while the frontal axis (PS-Uni-Y Post) had a mean of -.25 (±1.55), indicating moderate variability. Tiptoe stance showed the largest displacements, with means of -.919 (±2.73) in the sagittal axis (PS-Tip-X Post) and 1.4 (±3.11) in the frontal axis (PS-Tip-Y Post). The skewed distributions, as indicated by medians of -.736 and 1.29, suggest notable outliers in these measures. For postural tendency (PT), the bipedal sagittal axis (PT-Bi-X Post) had a mean displacement of -.033 (±1.94), while the frontal axis (PT-Bi-Y Post) showed a mean of .143 (±.344), indicating low variability. Unipedal stance had mean displacements of -.786 (±1.89) in the sagittal axis (PT-Uni-X Post) and -.531 (±1.02) in the frontal axis (PT-Uni-Y Post), with relatively less variability in the frontal plane. Tiptoe stance displayed the highest variability, with mean displacements of -.55 (±2.5) in the sagittal axis (PT-Tip-X Post) and -.218 (±1.92) in the frontal axis (PT-Tip-Y Post).

Table 4. Paired Samples Postural Stability

Pre	Post	Test	Stat	p	Mean diff	SE diff	Effect Size
PS-Bi-X	PS-Bi-X Post	Wilcoxon W	52	.005*	.985	.61	.891
PS-Bi-Y	PS-Bi -Y Post	Wilcoxon W	39	.138	.184	.134	.418
PS-Uni-X	PS-Uni-X Post	Wilcoxon W	52	.005*	1.19	.443	.891
PS-Uni-Y	PS-Uni-Y Post	Wilcoxon W	41	.097	.354	.528	.491
PS-Tip-X	PS-Tip-X Post	Wilcoxon W	52	.005*	3,028	.952	.891
PS-Tip-Y	PS-Tip-Y Post	Wilcoxon W	36	.216	1.009	1,318	.309

Note. H_a μ Measure 1 - Measure 2 > 0, PS = Postural Stability

The paired samples Wilcoxon tests revealed significant improvements in postural stability after the intervention, particularly along the sagittal axis. For Bipedal stance (PS-Bipedal-X), unipedal stance (PS-Unipedal-X), and tiptoe stance (PS-Tiptoe-X), significant reductions in displacement were observed (p = .005 for all), with large effect sizes (rank biserial correlation = .891). These results indicate better stability and postural alignment post-intervention in these conditions. In contrast, frontal axis measures showed smaller, non-significant changes, as seen in Bipedal (PS-Bipedal-Y, p = .138), unipedal (PS-Unipedal-Y, p = .097), and tiptoe stances (PS -Tiptoe-Y, p = .216). The most substantial improvement was noted in the tiptoe sagittal axis (PS-Tiptoe-X), which reflects enhanced stability in the most challenging posture. Overall, the findings suggest that the intervention effectively improved postural stability, particularly in sagittal axis measures, contributing to better balance and alignment. The graphics below visually illustrates the differences between pre- and post-intervention.

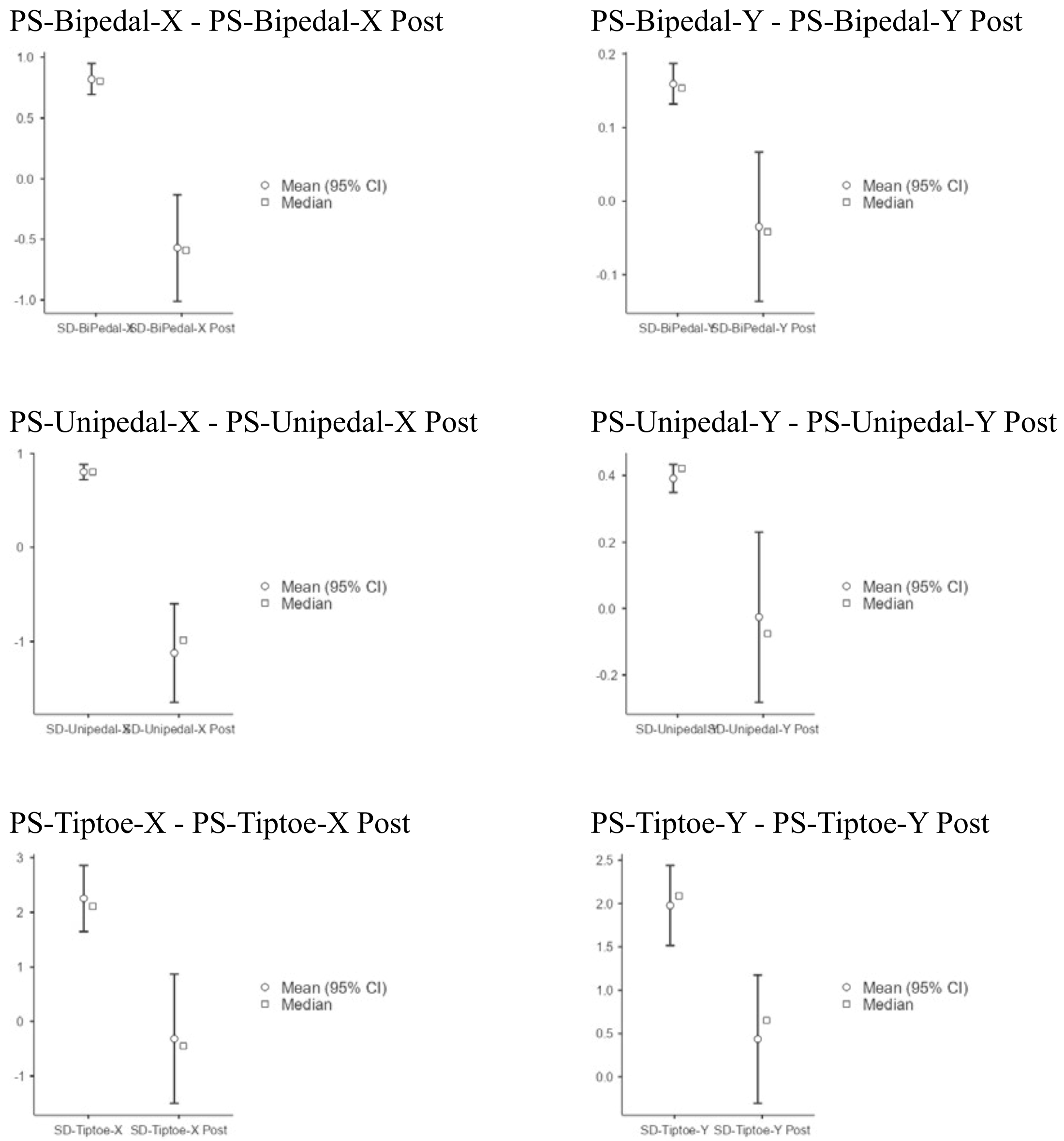

Figure 1-6. Plot of paired sample test of Postural Stability

Below is the table of paired test results on postural tendency data.

Table 5. Paired Samples of sample's Postural Tendency

Pre	Post	Test	Stat	p	Mean diff	SE diff	Effect Size
PT-Bi-X	PT-Bi-X Post	Wilcoxon W	39.0	.130	.6198	.736	.418
PT-Bi-Y	PT-Bi-Y Post	Wilcoxon W	36.0	.207	.0976	.124	.309
PT-Uni-X	PT-Uni-X Post	Wilcoxon W	48.0	.020*	16,483	.618	.745
PT-Uni-Y	PT-Uni-Y Post	Wilcoxon W	5.0	.012*	11,378	.424	.818
PT-Tip-X	PT-Tip-X Post	Wilcoxon W	5.0	.012*	23,638	1,038	.818
PT-Tip-Y	PT-Tip-Y Post	Wilcoxon W	52.0	.007*	21,221	.717	.891

Note. H_a μ Measure 1 - Measure 2 > 0, PT= Postural Tendency

The paired samples Wilcoxon tests for postural tendency (PT) revealed significant improvements in several measures after the intervention. For unipedal sagittal axis (PT-Unipedal-X, p = .020), unipedal frontal axis (PT-Unipedal-Y, p = .012), tiptoe sagittal axis (PT-Tiptoe-X, p = .012), and tiptoe frontal axis (PT-Tiptoe-Y, p = .007), there were significant reductions in displacement, indicating improved postural alignment. These measures showed medium to large effect sizes, with rank biserial correlations ranging from .745 to .891, reflecting notable intervention effects. Conversely, Bipedal measures did not demonstrate statistically significant changes, with p values of .130 for PT-Bipedal-X and .207 for PT-Bipedal-Y. The corresponding rank biserial correlations (.418 and .309, respectively) suggested small to moderate effects, indicating limited changes in postural tendency for Bipedal stance.

The largest improvements were observed in the tiptoe frontal axis (PT-Tiptoe-Y) and sagittal axis (PT-Tiptoe-X), highlighting enhanced postural control in this challenging stance. Overall, the intervention successfully improved postural tendencies in more demanding conditions (unipedal and tiptoe stances), while having limited effects in Bipedal positions. The result shown in the graphics below.

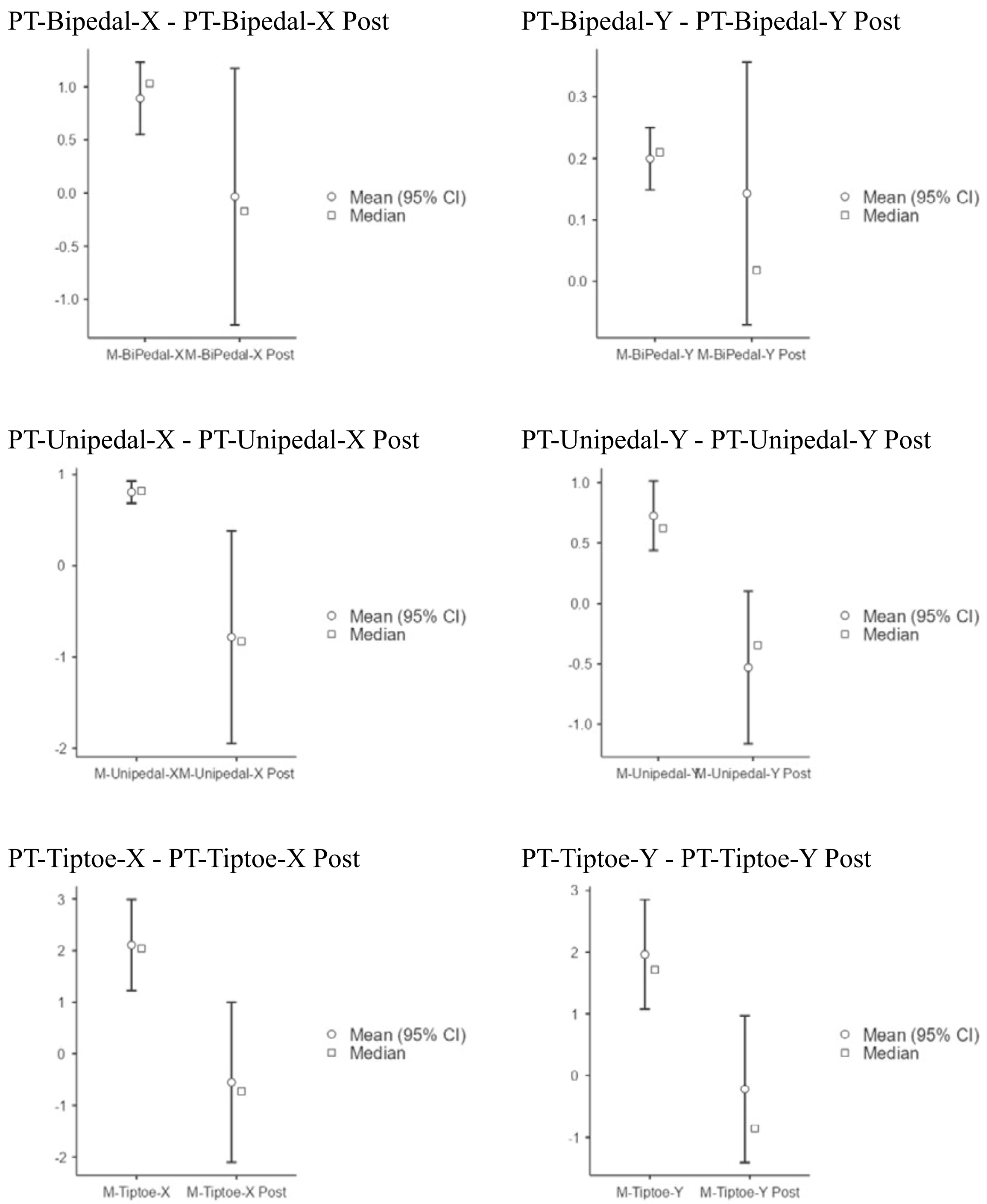

Figure 7-12. Plot of paired sample test of Postural Stability

DISCUSSION

Postural stability and tendency assessments in the pretest revealed that sagittal axis movements tend to have greater magnitudes than frontal axis movements, especially in challenging stances like tiptoe. Tiptoe postures consistently show the largest displacements and variability, reflecting the increased difficulty and instability associated with this stance. Bipedal and unipedal postures exhibit relatively smaller displacements, with minimal variability along the frontal axis. Post-intervention postural stability and tendency metrics indicated that sagittal axis displacements tended to be more negative, reflecting backward shifts in balance across all stances. The greatest variability was observed in tiptoe stances, particularly along the sagittal axis, consistent with the increased difficulty of maintaining stability in this posture. In contrast, bipedal and unipedal stances showed more controlled and consistent postural adjustments, with minimal displacements in the frontal axis. The intervention demonstrated significant improvements in postural stability for sagittal axis measures in bipedal, unipedal, and tiptoe stances. These findings suggest enhanced stability and postural vertical alignment in these conditions, particularly for the sagittal axis.

Frontal axis measures showed trends toward improvement but were not statistically significant. The largest improvements were observed in the tiptoe sagittal axis (PS-Tiptoe-X), reflecting enhanced stability in the most challenging stance. These results align with findings from previous studies indicating that dynamic stability improves following physical activity interventions study (Kenville et al., 2021)gender, type of balance intervention, and type of sport. With this study, we aim to investigate whether 4weeks of dynamic balance training (DBT, (Oliveira et al., 2014) and (Grueva-Pancheva, 2021)subjective instability, loss of function, and repetitive ankle injuries. Similar improvements in postural stability have been observed in studies examining the effects of structured exercise programs (Vaculíková et al., 2019), physical activity interventions for pregnant women (Roshko et al., 2024), and balance-focused activities such as Zumba (Ben Waer et al., 2024). Additionally, the use of sensor-based monitoring in this study may have influenced participants' psychological awareness of their posture, consistent with previous research highlighting the impact of biofeedback on balance training (Gržinič Frelih et al., 2017). This suggests that both the type of intervention and the measurement tools used can play a role in enhancing postural stability (Rizzato et al., 2021). These results indicate that the intervention most effectively enhanced sagittal stability, particularly in more demanding stances, where participants demonstrated greater postural control and reduced forward-backward sway. The largest effect size (.85) was observed in the tiptoe stance, reinforcing its role as the most sensitive condition for postural stability improvement. The findings align with previous research demonstrating that structured physical activity enhances balance control, particularly in conditions requiring dynamic stability. The method used in this research offers a rigid, innovative, and comprehensive approach to assessing postural and motor stability by enabling real-time, high-resolution measurement of subtle balance shifts. The technology allows for precise, objective quantification of stability, providing deeper insights than traditional observational or subjective tools. Wilcoxon signed-rank tests were used to assess statistical significance between pre- and post-intervention results, supporting the robustness of this methodology in evaluating stability improvements.

Despite these promising findings, this study is limited by its small sample size (N = 10), which restricts the generalizability of the results. With a larger and more diverse sample, statistical power would increase, allowing for more robust conclusions about the effectiveness of the intervention. This study also employed a quasi-experimental one-group pre-test post-test design, which limits the ability to control for external variables and may introduce potential biases such as maturation or learning effects. Additionally, the physical activity treatments implemented were derived from general physical education activities rather than specifically stability-focused exercises. As such, improvements in postural stability may not be solely attributed to targeted stability training, and the causal relationship should be interpreted with caution. Future studies should consider using control groups and stability-specific interventions to strengthen the validity of findings.

CONCLUSION

The paired samples Wilcoxon tests demonstrated significant improvements in both postural stability and postural tendency following the intervention, particularly along the sagittal axis and in more demanding stances. Reductions in displacement were observed for bipedal, unipedal, and tiptoe stances, indicating enhanced postural stability. Similarly, postural tendency measures showed notable improvements in both sagittal and frontal axes for unipedal and tiptoe stances. These findings highlight the effectiveness of the intervention in improving postural alignment and stability, particularly under challenging conditions requiring greater dynamic balance and control. However, given the small sample size, further studies with larger and more diverse populations are necessary to validate these results. Additionally, future research should explore long-term retention of postural stability improvements and compare different intervention methods to optimize training protocols for postural control. The findings highlight the importance of integrating structured balance training into sports science and physical education to enhance postural stability, particularly in challenging stances like tiptoe. For sports professionals, incorporating balance-focused exercises can improve neuromuscular control and reduce injury risks, especially in dynamic sports. Physical educators can use these insights to design school-based programs that enhance stability and posture in students. Additionally, this method offers a rigid, innovative, and comprehensive approach to assessing postural and motor stability by enabling real-time, high-resolution measurement of subtle balance shifts. Unlike traditional observation-based assessments, this technology provides objective, quantitative data that enhances the accuracy and reliability of stability analysis. Due to the precision and consistency of the sensor's data recording, this method has strong potential for broader application in the field of sports science—particularly in stability-dependent disciplines such as gymnastics, diving, martial arts, figure skating, archery, shooting, etc. It can also be valuable in injury prevention programs, athlete monitoring, and rehabilitation settings, where detailed feedback on postural control is essential.

ACKNOWLEDGEMENTS

The authors would like to express their utmost gratitude to Dr. Hadi Nasbey as the advisor in the field of applied physics and Dr. Ari Septian as the advisor in the field of mathematics in this research, as well as to the Indonesian Agency for the Assessment and Application of Technology (BPPT) and the Educational Fund

Management Institution (LPDP) as our sponsors who have provided funding for conducting this research and for publishing this article.

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