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PHYSIOTHERAPY THROUGH EXERGAMES – INFLUENCE IN THE DEVELOPMENT OF STATIC BALANCE FOR CHILDREN WITH NEUROMOTOR DISABILITIES

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ABSTRACT. *Objective:* This study investigates the effectiveness of an innovative therapeutic protocol aimed at enhancing static balance of children with neuromotor disabilities. Exergames and proprioceptive neuromuscular facilitation methods are to be combined and applied as a physiotherapeutic technique to improve standard deviations of the center of pressure (CoP) in different planes and axes. *Method and materials:* The therapeutic program involved the application of proprioceptive neuromuscular facilitation techniques using repeated stimulation, performed concurrently with interactive exergaming tasks on the MIRA Rehab digital platform. Exercises were conducted on an unstable support surface (balance board) to stimulate postural adjustment. Quantitative measurements of postural control were collected using BTWalk software, focusing on CoP variability. *Results:* Comparative analysis of pre- and post-intervention data indicated a statistically significant reduction in the standard deviation values of CoP displacement in both the antero-posterior and medio-lateral directions. These findings support an improvement in static postural stability following the intervention. *Discussion:* Improvements observed are attributed to various factors: the engaging, gamified MIRA Rehab system boosted motivation; motor tasks across multiple planes enhanced neuromuscular activation; and a task-oriented approach facilitated sensorimotor learning through repetition and feedback. Although minor improvements in CoP control on a fixed surface were noted, they were not statistically significant, indicating that children with NMD might benefit more from dynamic stimuli that challenge balance and sensorimotor integration.

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These findings support previous research on the advantages of interactive virtual rehabilitation in pediatric neurorehabilitation, showing that exergames enhance balance control and improve therapy adherence. *Conclusions:* This study demonstrates that an exergame-based balance training program using the MIRA Rehab platform can produce statistically significant improvements in postural stability on unstable surfaces in children with neuromotor disabilities. The intervention was effective in reducing CoP displacement in both sagittal and frontal planes, indicating better control of the center of gravity during challenging postural tasks.

Keywords: physiotherapy, static balance, exergaming, neuromotor rehabilitation

INTRODUCTION

Exergame-Based Rehabilitation Platforms: Mechanisms and Clinical Effectiveness

The Role of Gamification and MIRA Rehab Technology

Gamification is becoming increasingly common within the field of rehabilitation, where it is viewed as a beneficial strategy to enhance patient engagement, enthusiasm, and overall involvement in therapy. The MIRA Rehab platform is an exergame rehabilitation tool that requires specific hardware, including a computer and a motion tracking sensor. This system is implemented in physiotherapeutic approaches for various physical deficiencies to improve physical coordination, stability, gross motor skills in the upper and lower limbs, attention, eye-hand coordination, and sensorimotor abilities.

Hardware Capabilities and Application Across Populations

The Kinect 360 Xbox sensor is frequently incorporated into these systems due to its excellent accuracy in recognizing joint movements. Consequently, this sensor is often utilized as a reliable tool for assessing the range of motion (ROM) of both the lower and upper limbs (Guess et al., 2016; Seo et al., 2016; Lahner et al., 2015; Hawi et al., 2014). This specific exergame hardware integrates virtual reality and is applicable across all ages and genders for rehabilitation programs treating either orthopedic or neurologic deficiencies.

Clinical Effectiveness in Adult and Pediatric Rehabilitation

Applications in Stroke and Fall Prevention

Games-based exercises, or 'Exergames,' have demonstrated clinical efficacy in multiple domains. A systematic review and meta-analysis conducted by Corbetta et al. (2015) provided supporting evidence that these exercises help improve balance and reduce variables related to falls risk following a stroke by enhancing mobility and walking speed. Furthermore, clinical interventions have indicated that exergame programs successfully assist older community-dwelling individuals in improving their balance after experiencing a stroke (Koh et al., 2020). MIRA Rehab exergames also represent a cost-effective strategy for preventing falls in assisted living facilities for people aged 55 years or older, showing improvements in balance, pain, and fear of falling (Stanmore et al., 2019).

Treatment for Children with Cerebral Palsy (CP)

Low-cost technology video games hold potential as valuable rehabilitation resources for children, particularly those with cerebral palsy. A gaming system based on non-immersive virtual reality (Xbox 360 KinectTM) showed gains in the independence of activities of daily living when used as a supplement to traditional rehabilitation treatment for children with CP (Luna-Oliva el al., 2013). Additionally, customized interactive video games provided by MIRA Rehab, used in conjunction with the Kinect 360 Xbox sensor, have served as an occupational therapy scoring system for evaluating bilateral upper limb performance and function in children with cerebral palsy (Moldovan et al, 2014).

Neuromotor Principles and Mechanism of Action

Postural Stability and Reflexes

Research has been conducted to analyze the effect on static balance when applying a proprioceptive neuromuscular facilitation (PNF) technique during a physiotherapeutic program utilizing Mira Exergames for orientation development in children with neuromotor disabilities. Maintaining the body on the vertical axis—a state defined as stabilizing the body—requires aligning the entire body such that the projection of the Center of Pressure (CoP) falls within the body's supporting base (Yoshida et al, 2022). When imbalances or deviations occur in the latero-lateral or antero-posterior planes, the cortex involuntarily executes the postural recovery reflex (Macie, 2021; Promsri, Mohr, & Federolf, 2021).

Neuroplasticity and Motor Learning

Conscious neuro-muscular activity facilitates recovery when the body is stimulated through conscious, induced imbalance (Sandoval-Munoz & Haidar, 2021; Sousa et al, 2023). For individuals with special educational needs (SEN) who exhibit reduced motor skills, learning is promoted by stimulating the cortex

through imitation. Furthermore, motor skills are created through neuroplasticity, which is encouraged by the frequent repetition of a movement or repeated reflex stimulation achieved via proprioceptive neuromotor facilitation (PNF).

Benefits of Isometric Training

Isometric exercise is beneficial for managing imbalance and improving overall well-being (Šarabon & Kozinc, 2020). Its effectiveness is linked to its capacity to increase muscle strength, improve blood flow regulation, boost cardiovascular fitness, and support the adjustment of autonomic function (Zhao et al, 2022). Therapeutic programs that incorporate optimal and customized isometric training techniques based on individual needs can enhance cardiovascular health and stability (Kounoupis et al, 2020; Azeem & Zemková, 2022), providing patients with increased comfort and confidence to manage their daily activities.

The research studied the effect on static balance applying a proprioceptive neuromuscular facilitation technique during the performance of a physiotherapeutic program for orientation development using Mira Exergames on children with neuromotor disabilities.

METHODS AND MATERIALS

This study was conducted on a group of 10 children with neuromotor disabilities (NMD) and special educational needs (SEN), each with different diagnoses but all meeting the eligibility criteria for participation. These included:

- the ability to maintain balance for at least one minute on a balance board,
- the ability to sustain a static posture for a minimum of 10 seconds,
- the capacity to focus visual attention on a screen placed approximately 1.5 meters away for at least one minute, and
- the cognitive ability to perceive and process visual instructions.

The intervention focused on eliciting reflexive, uncontrolled postural rebalancing through combined motor, cognitive, and spatial orientation tasks, integrated into a rehabilitation program using the MIRA Rehab exergame platform. These tasks were performed on an unstable support surface (balance board), which added a proprioceptive challenge to the motor training (Sousa et al., 2023; Luna-Oliva et al., 2013).

Assessment Tools and Parameters

To evaluate static balance, we used the BTS P-Walk system, a validated gait and posture assessment tool based on plantar pressure sensors (Macie, 2021; Yoshida et al., 2022). The system allows detailed analysis of:

- static and dynamic plantar pressure,
- center of pressure (CoP) trajectory,
- postural asymmetries, and
- rotational displacements during stance.

The stabilometry module of the BTS P-Walk provides insights into the postural control mechanisms, particularly by measuring deviations in the sagittal (OX) and frontal (OY) planes. The test was administered under both eyes-open and eyes-closed conditions, enabling the analysis of oculomotor, vestibular, and proprioceptive contributions to balance.

This technology allows clinicians to compare patient data with normative reference values, providing an immediate interpretation of deviations in postural stability and plantar pressure distribution (Stanmore et al., 2019; Zhao et al., 2022).

Stabilometric Analysis Parameters

The key stabilometric parameters included:

- Standard deviation of CoP trajectory on the OX and OY axes,
- Total sway area, represented by an ellipse covering 90% of CoP points,
- Balance density curves in the sagittal and frontal planes.

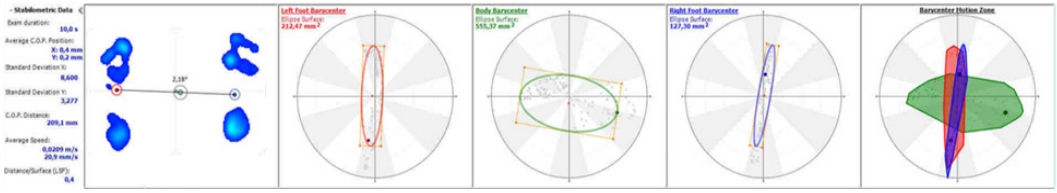


Fig. 1. Stabilometric evaluation with BTS P-Walk

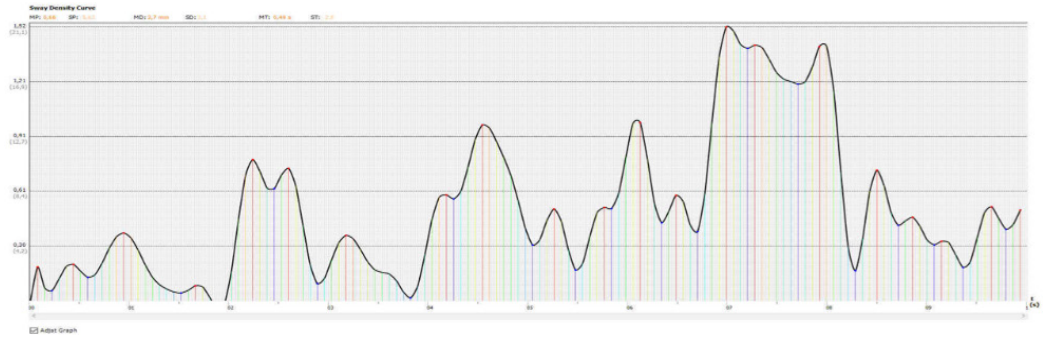


Fig. 2. Density balance curve on the OX and OY axes

Rehabilitation Protocol

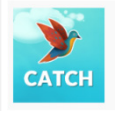
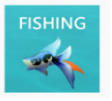
Each child participated in 10 therapy sessions over a period of one month (three sessions per week). Each session consisted of static balance training through MIRA Rehab exergames, conducted on the balance board to enhance proprioceptive feedback and neuromotor control (Tyng et al., 2017; Sattelmayer et al., 2016).

The exergames were designed to require multi-directional upper body movements, including:

- Shoulder flexion/extension,
- Shoulder abduction/adduction,
- Spinal lateral flexion and forward bending,
- Hip abduction.

These movements were tailored to the objectives of the games (Table 1), promoting engagement, motor learning, and reflexive balance recovery (Behan et al., 2022).

Table 1. Types of Combined Movements and MIRA Rehab Exergames applied in the research

Movement	MIRA games	Game Objective
 Shoulder abduction		Catch different images appearing on screen
 Hip abduction		Same game, performed using lower limb movements
 Shoulder flexion		Identify and select animals according to specific sounds
 Spine flexion		Catch as many fish as possible while avoiding traps
 Lateral spine flexion		Navigate a submarine to catch treasures and avoid bombs

Note: Combination of games and movements preset in MIRA Rehab to implement the program for each session - same game executed with one or two types of body movements, performed correctly, on maximum amplitude

Each game was executed with maximum movement amplitude and included preset combinations of body movements provided by MIRA Rehab.

Pre- and Post-Test Evaluation

The pre-test and post-test evaluations were conducted under identical conditions (time, place, equipment) to ensure measurement validity and reliability. Each participant's static balance was tested:

- First, on a fixed surface (ground), and
- Then, on a mobile surface (balance board).

Data were collected from the results generated by the BTS P-walk balance assessment software, for each member of the experimental trial group, following the pre and posttest static balance assessment - by pre and post evaluation. These results include objective stabilometric data obtained after evaluations that were performed by placing the software sensor on two surfaces - on the ground - considered the fixed surface and on the balance plate, considered the mobile surface. By comparing the two evaluations, a favorable evolution of the stabilometric data according to the provided data is observed (Figure 3a. and Figure 3b. for fixed surface and Figure 4a.and Figure 4b for mobile surface).

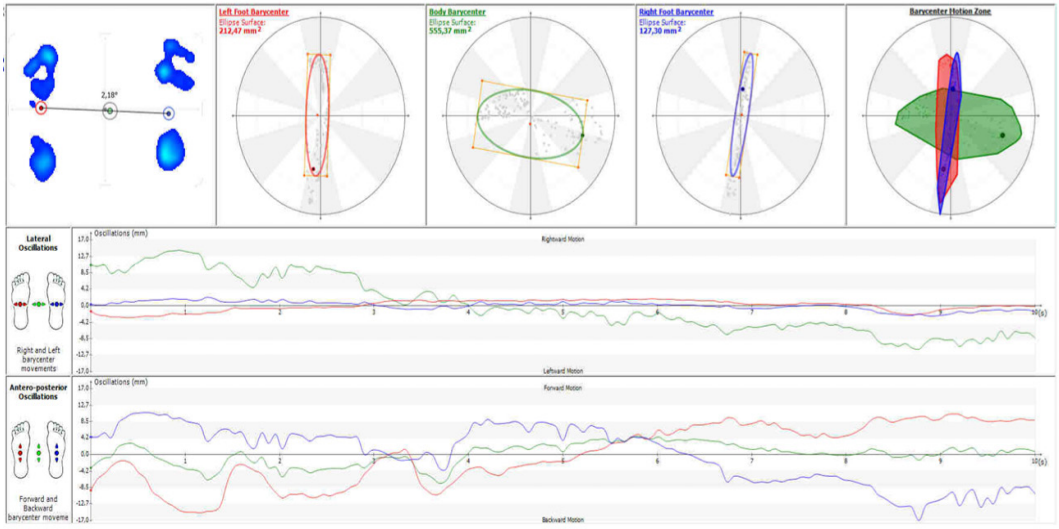


Fig. 3a. Pre-test static balance evaluation on fixed surface - results obtained from the BTS P-walk software

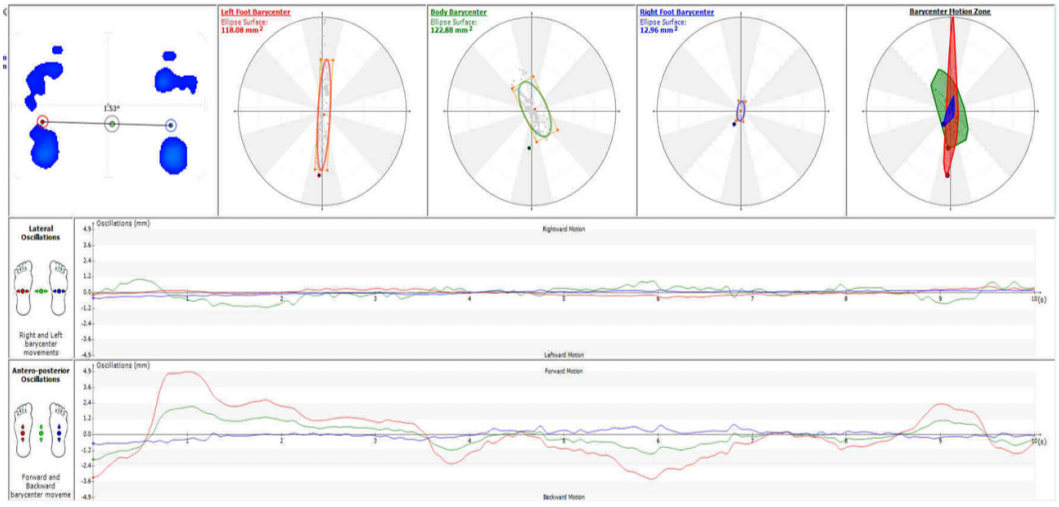


Fig. 3b. Post-test static balance evaluation on fixed surface - results obtained from the BTS P-walk software

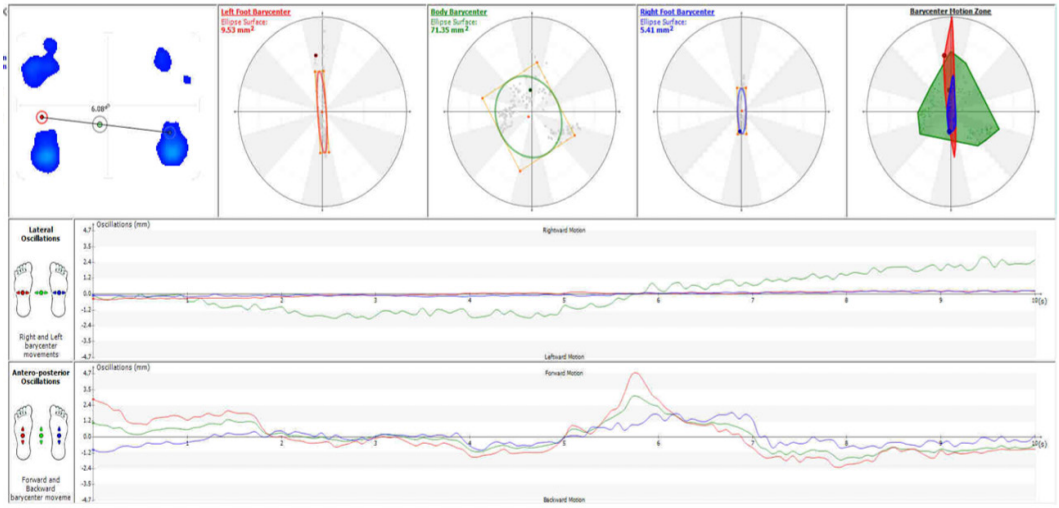


Fig. 4a. Pre-test static balance evaluation on mobile surface - Results obtained from the BTS P-walk software

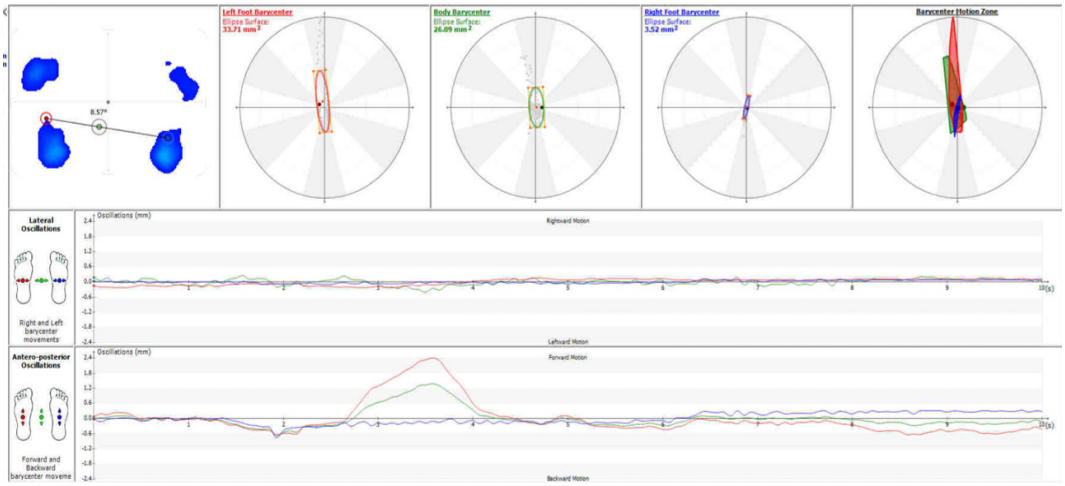


Fig. 4b. Post-test static balance evaluation on mobile surface - Results obtained from the BTS P-walk software

RESULTS

The data obtained from the BTS P-Walk balance assessment software were statistically analyzed using the Paired Samples T-test, in order to examine the differences between pre-test and post-test scores across multiple stabilometric parameters. The primary dependent variables were the standard deviations of Center of Pressure (CoP) displacements on both the sagittal (X-axis) and frontal (Y-axis) planes, recorded on both fixed and mobile surfaces.

Descriptive Statistics

Descriptive statistics, including means and standard deviations, were calculated for all measured variables. Table 2 presents the results of the pre- and post-test evaluations for each parameter.

Table 2. Descriptive Statistics of Pre-Test and Post-Test CoP Standard Deviations on Fixed and Mobile Surfaces

Pair	Condition	Mean	N	Std. Deviation	Std. Error Mean
1	Pre-test fixed X-axis SD	2.27	10	2.99	0.95
	Post-test fixed X-axis SD	1.39	10	1.41	0.45
2	Pre-test fixed Y-axis SD	2.63	10	2.25	0.71
	Post-test fixed Y-axis SD	2.11	10	1.63	0.52

Pair	Condition	Mean	N	Std. Deviation	Std. Error Mean
3	Pre-test mobile X-axis SD	8.08	10	3.0	0.95
	Post-test mobile X-axis SD	4.66	10	3.42	1.08
4	Pre-test mobile Y-axis SD	8.67	10	3.81	1.21
	Post-test mobile Y-axis SD	3.98	10	1.74	0.55

Note. N = number of participants; SD = standard deviation; Std. Error Mean = standard error of the mean.

Inferential Statistics

To determine the significance of the differences between pre-test and post-test scores, a **Paired Samples T-test** was performed for each variable. The results are summarized in Table 3.

Table 3. Paired Samples T-Test Results Comparing Pre-Test and Post-Test CoP Standard Deviations

Pair	Mean Difference	T	df	p (2-tailed)	95% CI of the Difference
1	0.88	1.1	9	.298	[-0.93, 2.70]
2	0.51	0.76	9	.469	[-1.02, 2.05]
3	3.43	4.35	9	.002	[1.64, 5.21]
4	4.69	4.12	9	.003	[2.11, 7.26]

Note. CI = confidence interval; df = degrees of freedom; p values are two-tailed.

Statistically significant differences ($p < .05$) were found for Pair 3 (mobile X-axis) and Pair 4 (mobile Y-axis), indicating a meaningful improvement in balance control on the mobile surface following the intervention.

For Pair 3, the mean post-test score ($M = 4.66$, $SD = 3.42$) was significantly lower than the pre-test score ($M = 8.08$, $SD = 3.00$), $t(9) = 4.35$, $p = .002$.

For Pair 4, the post-test score ($M = 3.98$, $SD = 1.74$) was also significantly lower than the pre-test score ($M = 8.67$, $SD = 3.81$), $t(9) = 4.12$, $p = .003$.

In contrast, Pairs 1 and 2, which correspond to standard deviations on the fixed surface (X-axis and Y-axis, respectively), showed a decrease in post-test values, but these differences were not statistically significant ($p > .05$).

Interpretation

These results suggest that the use of MIRA Rehab exergames performed on a balance board significantly improved postural control on unstable surfaces, particularly by reducing CoP variability in both sagittal and frontal planes. Improvements on stable surfaces were observed, but not at a statistically significant level.

DISCUSSION

The findings of this study support the efficacy of an exergame-based rehabilitation program using the MIRA Rehab system in improving static balance control in children with neuromotor disabilities (NMD) and special educational needs (SEN). The most notable outcome is the significant reduction in Center of Pressure (CoP) standard deviations on the mobile surface, both in the sagittal (X-axis) and frontal (Y-axis) planes, after ten intervention sessions.

As illustrated in Figure 5, a clear downward trend in CoP variability was observed between the pre-test and post-test assessments, with greater reductions in the mobile surface conditions. Specifically, post-intervention measurements showed significant improvements in postural control when balance was challenged by instability, reflecting increased proprioceptive responsiveness and motor coordination.

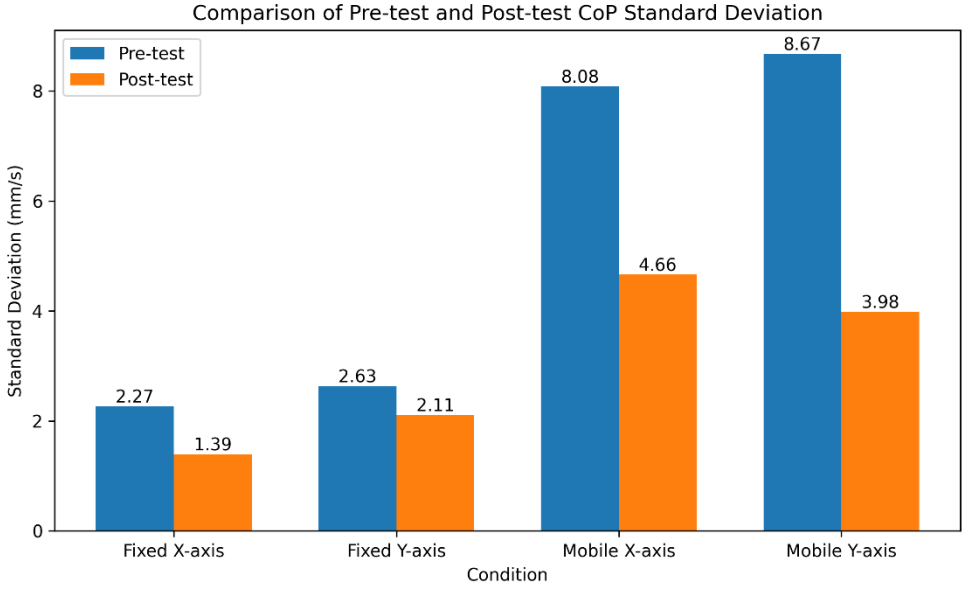


Fig. 5. Comparative Analysis of Pre-Test and Post-Test Center of Pressure (CoP) Standard Deviations on Fixed and Mobile Surfaces

These improvements are likely the result of multiple factors:

- The interactive, gamified format of the MIRA Rehab system enhanced engagement and motivation.

- The motor tasks performed in multiple planes (sagittal and frontal) likely promoted comprehensive neuromuscular activation.
- The task-oriented structure of the exercises encouraged sensorimotor learning through repetition, feedback, and real-time correction.

In contrast, although minor improvements were noted in CoP control on the fixed surface, these were not statistically significant ($p > .05$). This outcome suggests that postural systems in children with NMD may respond more readily to dynamic or unstable stimuli, where greater demand is placed on sensorimotor integration and balance adjustment.

These results align with previous research highlighting the benefits of interactive virtual rehabilitation platforms in pediatric neurorehabilitation. Several studies have reported that exergames not only stimulate balance control and postural symmetry but also improve adherence to therapy protocols due to their engaging and adaptive nature.

CONCLUSIONS

This study demonstrates that an exergame-based balance training program using the MIRA Rehab platform can produce statistically significant improvements in postural stability on unstable surfaces in children with neuromotor disabilities. The intervention was effective in reducing CoP displacement in both sagittal and frontal planes, indicating better control of the center of gravity during challenging postural tasks.

Although improvements on fixed surfaces were also noted, these did not reach statistical significance, suggesting that the intervention's benefits are more pronounced under dynamic balance conditions.

These findings support the integration of interactive digital tools in pediatric rehabilitation, offering a motivating, measurable, and adaptive approach to motor recovery. Further research with larger cohorts and controlled study designs is necessary to confirm these outcomes and explore additional benefits in functional mobility, daily living activities, and long-term motor autonomy.

RESEARCH LIMITATIONS

One of the main limitations encountered in this research was the difficulty of involving certain students in therapeutic programs that incorporate virtual materials. This was primarily due to challenges related to spatio-temporal orientation, visual processing disorders, and attention deficits, particularly among participants diagnosed with autism spectrum disorders, hyperkinesia, or ADHD.

FUTURE RESEARCH DIRECTIONS

The effectiveness of static balance training through repetitive stimulation of postural righting reflexes—using the balance board in conjunction with MIRA Rehab software—on improving functional independence in activities of daily living (ADLs) in children with neuromotor disabilities will be further investigated in the first author's doctoral thesis, involving a larger and more diverse sample of participants.

CONFLICT OF INTEREST

None declared.

AUTHORS CONTRIBUTION

All authors designed the study, contributed to the data collection, analyzed, accessed and verified the data. All authors drafted the initial manuscript, interpreted the data and approved the decision to submit the manuscript.

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REFERENCES

Azeem, A. A., & Zemková, E. (2022). Isometric exercises and their clinical implications. *European Journal of Translational Myology, 32*(2), 10384. https://doi.org/10.4081/ejtm.2022.10384

Behan, J., Colreavy, M., Furlong, B. A., Healy, A., & Kenny, I. C. (2022). Validity of the Xbox Kinect™ and wearable sensors for balance and mobility assessment in older adults. *Sensors, 22*(15), 5704. https://doi.org/10.3390/s22155704

Corbetta, D., Imeri, F., & Gatti, R. (2015). Rehabilitation that incorporates virtual reality is more effective than standard rehabilitation for improving walking speed, balance and mobility after stroke: A systematic review. *Journal of Physiotherapy, 61*(3), 117–124. https://doi.org/10.1016/j.jphys.2015.05.017

Guess, T. M., Plummer, H. A., & Sherman, D. (2016). Validity of Kinect-based motion tracking for measuring gait parameters in children with cerebral palsy. *Gait & Posture, 48*, 165–170. https://doi.org/10.1016/j.gaitpost.2016.05.013

Hawi, N. S., Al-Jumeily, D., & Hussain, A. (2014). A comparative study of Kinect and Vicon systems for gait analysis: Practical issues and challenges. *Procedia Computer Science, 37*, 90–97. https://doi.org/10.1016/j.procs.2014.08.017

Koh, G. C. H., Chua, R. A. G., Toh, S. A. E., & Lee, T. S. (2020). Effectiveness of Kinect-based virtual rehabilitation on post-stroke balance: A randomized controlled trial. *Journal of Rehabilitation Medicine, 52*(5), jrm00065. https://doi.org/10.2340/16501977-2670

Kounoupis, D., Koutsoubi, F., & Bogdanis, G. C. (2020). Effects of isometric strength training on balance and postural control in older adults: A systematic review. *Journal of Aging and Physical Activity, 28*(3), 343–352. https://doi.org/10.1123/japa.2019-0015

Lahner, M., Lehmann, M., Höher, J., & Wülker, N. (2015). Validity and reliability of the Kinect for measuring shoulder joint angles: A comparison with a 3D motion analysis system. *Physiotherapy, 101*(S1), e792. https://doi.org/10.1016/j.physio.2015.03.1495

Luna-Oliva, L., Ortiz-Gutiérrez, R. M., Cano-de-la-Cuerda, R., Martínez-Piédrola, R., Alguacil-Diego, I. M., Sánchez-Camarero, C., & Cuesta-Gómez, A. (2013). Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study. *NeuroRehabilitation, 33*(4), 513–521. https://doi.org/10.3233/NRE-130993

Macie, K. M. (2021). Assessment of balance and center of pressure using force platforms in clinical settings. *Physiological Reports, 9*(6), e14789. https://doi.org/10.14814/phy2.14789

Moldovan, A., Stan, T., Cristea, A., & Gavrila, A. (2014). The use of Kinect-based games in pediatric occupational therapy for children with cerebral palsy. *Journal of Physical Education and Sport, 14*(1), 107–112. https://doi.org/10.7752/jpes.2014.01017

Promsri, A., Mohr, M., & Federolf, P. (2021). Postural control as a function of task difficulty in healthy individuals: A principal component analysis. *PLOS ONE, 16*(1), e0244573. https://doi.org/10.1371/journal.pone.0244573

Sandoval-Muñoz, A. I., & Haidar, S. (2021). Neuroplasticity and balance training: Linking mechanisms to rehabilitation. *Frontiers in Human Neuroscience, 15*, 628096. https://doi.org/10.3389/fnhum.2021.628096

Šarabon, N., & Kozinc, Ž. (2020). Isometric exercise and balance: A review. *European Journal of Sport Science, 20*(8), 1053–1062. https://doi.org/10.1080/17461391.2019.1682274

Seo, N. J., Kosmopoulos, M. L., Enders, L. R., & Hur, P. (2016). Kinect-based exergaming for functional balance training: A study in children with cerebral palsy. *Gait & Posture, 44*, 242–247. https://doi.org/10.1016/j.gaitpost.2015.11.023

Sousa, C. O. M., Silva, J. M. D., & Silva, T. B. D. (2023). Effectiveness of proprioceptive neuromuscular facilitation in balance rehabilitation. *Brazilian Journal of Physical Therapy, 27*(1), 101–109. https://doi.org/10.1016/j.bjpt.2022.100467

Stanmore, E. K., Mavroeidi, A., de Jong, L. D., Skelton, D. A., Sutton, C. J., Benedetto, V., & Todd, C. (2019). The effectiveness and cost-effectiveness of strength and balance exergames to reduce falls risk for people aged 55 years and older in UK assisted living facilities: A multi-centre, cluster randomized controlled trial. *BMC Medicine, 17*(1), 49. https://doi.org/10.1186/s12916-019-1278-9

Tyng, C. M., Amin, H. U., Saad, M. N. M., & Malik, A. S. (2017). The influences of emotion on learning and memory. *Frontiers in Psychology, 8*, 1454. https://doi.org/10.3389/fpsyg.2017.01454

Yoshida, A., Takeda, Y., & Yamaguchi, T. (2022). Center of pressure displacement and balance strategies in children with motor impairments. *Research in Developmental Disabilities, 121*, 104134. https://doi.org/10.1016/j.ridd.2021.104134

Zhao, M., Ma, H., Li, H., & Zhang, X. (2022). The role of isometric exercise on autonomic function and cardiovascular control: A review. *Frontiers in Physiology, 13*, 835207. https://doi.org/10.3389/fphys.2022.835207