

Evaluating and measuring proprioception levels to optimize motor skills in 10-year-old children

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Abstract:

Proprioception, a vital physiological process driven by neural activity, is enhanced by activating proprioceptors in muscles, tendons, joints, ligaments, and internal organ feedback, collectively shaping the body's internal environment. Within the comprehensive framework of physical exercises for 10-year-old children, the psycho-neuro-motor aspect plays a pivotal role in regulating and providing feedback in response to stimuli from both external and internal bodily environments. This study aimed to assess the efficacy of specific testing methods for evaluating proprioceptive aspects related to body orientation, balance, and coordination. **Materials and Methods:** Twelve subjects (6 boys and 6 girls), aged 10 years and enrolled in the 4th grade at a public primary school, underwent testing utilizing two protocols: the hexagon and circle tests. Objective measurements were obtained using the Optojump Next-test equipment from MICROGATE. The resulting data were analyzed using statistical-mathematical methods, including descriptive analysis and the Kolmogorov-Smirnov test for normality assessment. The data were normally distributed ($p > 0.05$) in the hexagon and circle tests. Additionally, the independent samples t-test was conducted for comparison, revealing no statistically significant differences between the hexagon and circle tests [on the x-axis: $t(22) = .173$; $p > 0.05$; on the y-axis: $t(22) = .375$; $p > 0.05$; and for the average landing distance: $t(22) = .382$; $p > 0.05$]. **Results:** Despite observable differences in execution difficulty, the obtained results did not reveal a significant disparity between the hexagon and circle tests in assessing proprioceptive capabilities. **Conclusions:** Increasing task complexity during proprioceptive testing of body orientation, balance, and coordination did not yield divergent results when employing the same testing equipment. Therefore, future research endeavors should prioritize identifying testing modalities that offer significantly distinct outcomes.

Keywords: balance, body orientation, coordination, evaluating proprioception, motor skills, neuromotricity

Introduction

Participating in physical education through consistent physical exercise is a way to activate proprioceptors. The surge in sedentary behaviors, linked to the increased usage of advanced communication technologies such as smartphones, electronic tablets, computers, and laptops, compounded by the inefficiency of online physical education systems during the pandemic (Mujiono & Gazali, 2020), may contribute to the onset of locomotor deficiencies and a decline in overall motor skills among children. As noted by McCloy (cited in Ehrlich, 1942, p.8), a child is more than just a body or a mind; rather, a child is an organic unity encompassing the body, mind, emotions, spiritual appreciations, and vegetative visceral functions. Understanding the functions of this organic unity is imperative for designing activities tailored to a child's holistic needs.

The cerebellum plays a pivotal role in predictive and inhibitory functions associated with proprioception, facilitating the anticipation and regulation of body movements (Robănescu, 2001). Additionally, proprioceptive information is crucial in cognitive actions, body image, control of body movements and its segments, balance, and coordination, contributing to performance enhancement (Rapotan et al., 2022).

Acknowledging the significance of psycho-neuro-motor qualities in physical activities (Geantă & de Hillerin, 2023), our study explores proprioceptive components in 10-year-old children using the hexagon and circle tests. Moreover, previous studies have indicated that balance and proprioception training can improve performance in specific components of physical fitness and certain technical skills, albeit with a limited focus on volleyball (Achilleopoulos et al., 2022).

Motor skills, integral to human physical activity, enhance bodily functions and facilitate specific physical endeavors and are interconnected with sensory, emotional, and intellectual aspects (Butu, 2017). Recognizing the importance of a comprehensive exploration, we advocate for a thorough analysis of motor actions, considering the entire motor chain from cerebral command to muscles and back (Geantă & de Hillerin, 2023).

Children's motor behavior often operates on anticipatory mechanisms driven by predictive processes that transform motor commands into anticipated sensory outcomes (Rosen, 2012; Wolpert, 2013). Anticipation, distinct from reaction, precedes events and requires understanding body actions and limb awareness, with a processing time of up to 400 ms (Aman, 2015; Carter, 2019).

Youth Exercise Training (2020) suggests that 6–10-year-old children are particularly receptive to developing long-term qualities, highlighting the importance of maintaining balanced joint mobility. Movement, encompassing posture, locomotion, and transformation, involves closed feedback loops across various levels, representing a multifaceted approach from molecular to global levels (Gagea, 2010).

Neuromuscular control, intertwined with sensory information processing, influences balance, posture, and coordination, with proprioception serving as a regulator and a means of perceiving temporal regularities (Tironi, 2009; Baci, 1972; Fleishman, 1963).

Children often concentrate on the external environment while performing motor tasks, often overlooking internal reactions (Camenidis & Geantă, 2022). Proprioceptive field information, comprising passive and active exercises, is beneficial because muscular activity mirrors external manifestations of cerebral activity (Sherrington, 1906; Secenov, 1954; Carter, 2019).

Sherrington's conceptualization of the nervous system as the highest expression of the internal environment underscores the continuous connection between the external and internal environments through reflex actions (Sherrington, 1906). Claude Bernard's idea of the internal environment and its constancy, elaborated by Henderson (1949), shaped the understanding that variations in internal properties are functional rather than random. Studies over time indicate that exercise induces cortical reorganization, highlighting the significance of proprioceptor stimulation for enhancing motor function (Secenov, 1954; Schmidt, 1991; Aman, 2015; Repciuc, 1966).

Based on these insights, our study postulates that dedicated exercises stimulating proprioceptors in children will improve their proprioceptive function.

Materials and methods

The examinations were performed using specialized equipment and corresponding software modules, facilitating the recording, processing, and consolidation of data for each participant. To assess participants' proprioceptive levels, two simultaneous two-legged jump tests were conducted using the OptoJump Next equipment, a cutting-edge tool for analyzing perceptual–motor coordination. This system, equipped with advanced sensors and software, accurately captured and evaluated various aspects of human movement. Specifically, it assessed the synchronization between sensory perception and motor responses, offering invaluable insights (Roșu et al., 2024). The specific tests employed (hexagon and circle tests) focused on demonstrating certain components of psychomotricity and motor skills.

A cohort of 12 subjects, consisting of 6 boys and 6 girls, all aged 10 years, was chosen to participate in the study. Before participation, students were briefed on the nature of the research and provided a signed written consent document from their parents after receiving relevant information.

Test Protocols

The Hexagon Test:

1. Participants performed 16 simultaneous jumps on both legs.
2. Jumps were performed within a hexagon, proceeding clockwise: 0 = initial position inside the hexagon, 1 = forward, 2 = oblique forward to the right, 3 = oblique backward to the right, 4 = backward, 5 = oblique backward to the left, 6 = oblique forward to the left, and 7 = final position identical to the initial one.
3. Jumps were performed with participants' eyes open.
4. Each participant's activity was recorded for 15 s.

The Circle Test:

1. Four OptoJump Next bars were arranged to create a square. Inside this square, a circle with a diameter of 60 cm was drawn on the ground. The circle was divided into four quadrants using four lines of paper tape, where jumps were executed.
2. The starting position was within the circle, with feet close together, knees slightly bent, and arms bent beside the body. The first jump moved forward, followed by subsequent jumps in a clockwise direction.
3. Participants performed 16 jumps on both legs, moving from inside the circle to outside it in different directions clockwise: 0 = initial position inside the circle, 1 = forward, 2 = movement to the right, 3 = backward motion, 4 = movement to the left, and 5 = final position identical to the initial one.
4. Jumps were executed with participants' eyes open, and after each jump, participants returned inside the circle. Rotating the body during jumps was prohibited, and participants were instructed to maintain a frontal orientation with each jump.
5. Physical education teachers provided guidance on proper jumping techniques.
6. Before testing, an accommodation period was provided, during which participants practiced the exercise.
7. Each participant's activity was recorded for 15 s.

Data Collection and Statistical Analysis

Statistical analysis was performed using SPSS version 23, and the chosen statistical indicators comprised the following:

1. Descriptive analysis: This entailed examining distributions focusing on the arithmetic mean and standard deviations.
2. Normality assessment: The Kolmogorov–Smirnov test was employed to assess the normality of distributions. This step was pivotal in deciding whether to employ a parametric or non-parametric comparison test.
3. Independent samples t-test: This test was chosen based on the interpretation of the Kolmogorov–Smirnov test results, which indicated that all distributions were normal.
4. Levene test: The Levene test was utilized to determine the variances of the distributions analyzed in conjunction with the independent samples t-test.

These statistical procedures were employed to ensure robust data analysis and interpretation in the study.

Results

To emphasize improved balance, coordination, and laterality, 12 students participated in the hexagon test, requiring simultaneous jumping on two legs with eyes open.

The dots in the models (Figures 1–4) serve as visual cues, representing the organized or disorganized manifestation of the test subjects' proprioceptive ability within the landing zones of the 6 quadrants, numbered 1 through 6.

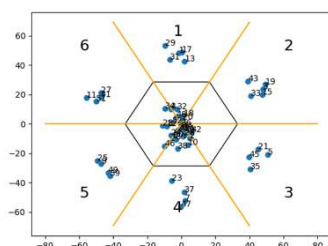


Figure 1. Model no 1

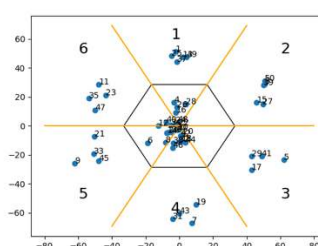


Figure 2. Model no 2

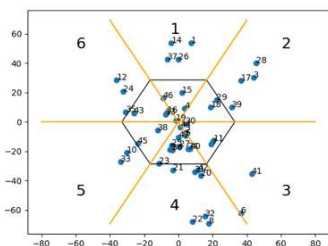


Figure 3. Model no 3

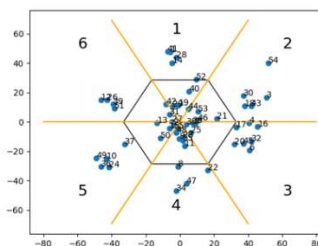


Figure 4. Model no 4

Figures 1–4 provide insights into how participant landings are represented, suggesting potential variations in orientation and movement control, likely linked to proprioception.

Participants demonstrate disordered movement patterns with centrally located landings. Notably, Figures 3 and 4 exhibit weaker manifestations in the anterior–posterior direction than Figures 1 and 2, indicating nuanced movement control, which we interpret as correlated with proprioception quality in both mediolateral and anteroposterior directions.

Jump distances were measured from the central point within the hexagon to each landing point in the outer quadrants, facilitating the assessment of children's awareness of their body's positioning. This methodology validated the accuracy of landings concerning motor control across all six quadrants (Table 1).

To enhance balance, coordination, and laterality, 12 students participated in the circle test involving simultaneous jumping on two legs. Dots in the patterns represent landing zones in the circle's four internal and external quadrants. Distinct movement patterns among the tested subjects are observed:

- Figure 1: The subject demonstrates deviations in mediolateral and anteroposterior directions, with landing points dispersed across all four quadrants and around the circle.
- Figure 2: The subject jumps more towards the left side and forward, deviating from an even distribution among all four quadrants.
- Figure 3: Uncontrolled jumps in the anteroposterior direction are observed, contrasting with the mediolateral direction, where landing points should be evenly distributed between the right and left quadrants.

- Figure 4: The subject exhibits controlled movements, with landing points observed in all four quadrants in mediolateral and anteroposterior directions. This indicates a superior proprioception manifestation compared to the previous figures.

These findings suggest possible individual disparities in proprioceptive abilities among the subjects, with some demonstrating proficiency in perceiving forward jumps while others excel in backward jumps or lateral movements to the right or left.

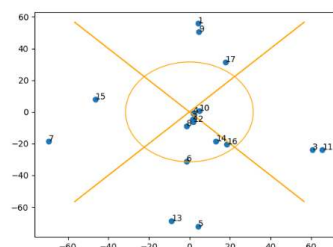


Figure 5. Model no 1

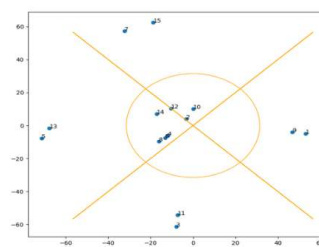


Figure 6. Model no 2

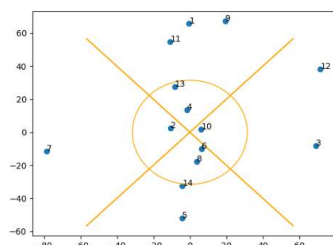


Figure 7. Model no 3

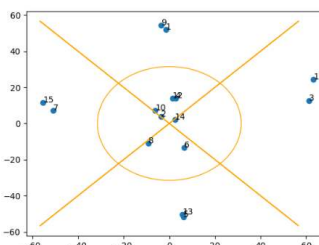


Figure 8. Model no 4

The jump distances were measured in the presented models, representing the perpendicular length from the landing point on the ground to the circle's circumference. This measurement aimed to assess whether there was a deliberate control of the body schema among the children. Subsequently, the accuracy of the landings in terms of motor control was confirmed across all four quadrants, as detailed in Table 1.

Table 1. Results from the hexagon and circle tests

ID	X-axis measurements		Y-axis measurements		Average landing distance	
	Hexagon test	Circle test	Hexagon test	Circle test	Hexagon test	Circle test
1	2.21	3.32	0.98	-11.49	20.63	21.71
2	4.37	-10	-0.54	1.58	20.92	20.16
3	-0.24	1.88	2.91	5.54	23.87	24.81
4	-3.33	-0.89	-4.98	-14.33	19.58	18.05
5	3.06	-6.36	-7.86	2.35	16.00	16.90
6	-0.26	3.75	-0.87	-10.03	20.24	12.14
7	4.34	0.98	6.69	7.19	15.49	16.55
8	1.58	6.41	5.29	2.15	21.98	18.64
9	4.00	-6.10	0.06	1.175	19.51	15.91
10	8.86	-1.18	-4.47	-1.95	14.70	21.07
11	-1.67	-0.68	1.99	-5.2	15.54	12.305
12	-0.42	0.86	-2.78	-0.59	16.81	11.13

Participants executed jumps within the quadrants of the circle. The obtained values reflect the quality of coordination in the frontal plane (where positive values indicate movement toward the front and negative values indicate movement toward the back) and the sagittal plane (where positive values signify movement to the right and negative values denote movement to the left).

In this study, the definition of the frontal plane is synonymous with the mediolateral direction. In contrast, the sagittal plane corresponds to the anteroposterior direction of the participants' movement during the test. Negative values do not indicate errors in participants' coordination during jumps; rather, they represent body displacements to the left or back from the zero point of the initial test position. Conversely, positive values indicate body displacements to the right or forward from the zero point of the initial test position.

The distance values are expressed as the total length of the movement within the test surface delimited by the equipment bars used for participant evaluation. The X-axis illustrates participants' movement to the right side (following the zero-plus digit) and to the left side (following the zero-minus digit). Meanwhile, the Y-axis represents participants' movement forward (above zero plus) and backward (below zero plus minus).

Table 2. Testing the normality of distributions and selecting the appropriate statistical test to compare the outcomes of the hexagon and circle tests

Measurements	df	Kolmogorov–Smirnov statistic	Sig. Kolg–Smirn.	Interpretation p	Findings/ status of distributions	Appropriate statistical test
Hexagon test on the X-axis	12	.155	.200	p > 0.05	Two normal distributions	Independent samples t-test
Circle test on the X-axis	12	.114	.200	p > 0.05		
Hexagon test on the Y-axis	12	.181	.200	p > 0.05	Two normal distributions	Independent samples t-test
Circle test on the Y-axis	12	.206	.168	p > 0.05		
Average hexagon test landing distance	12	.176	.200	p > 0.05	Two normal distributions	Independent samples t-test
Average circle test landing distance	12	.141	.200	p > 0.05		

The results of the Kolmogorov–Smirnov test suggest that the data are normally distributed ($p > 0.05$) in both the hexagon and circle tests. Consequently, we have two normal distributions for each measured variable.

Thus, in future assessments of proprioception ability among subjects, we can apply either the hexagon or circle tests individually because there are no statistically significant differences between the two tests based on the obtained data (Table 3).

Table 3. The significance of differences between distributions assessed through the independent samples t-test

Measurements	Test ¹	Mean	Std. deviation	Levene test F	Levene sig.	t	df	Sig. (2-tailed)	p
X-axis	H	1.69	3.359	.201	.658	1.408	22	.173	p > 0.05
	C	-.66	4.734						
Y-axis	H	.19	4.641	1.867	.186	.906	22	.375	p > 0.05
	C	-1.97	6.872						
Average landing distance	H	18.77	2.970	.883	.358	.892	22	.382	p > 0.05
	C	17.45	4.184						

¹H – hexagon test; C – circle test

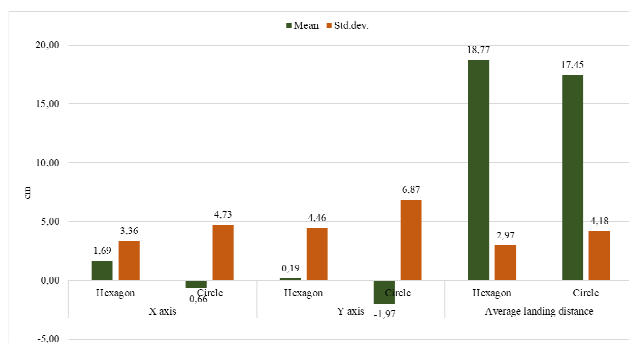


Figure 9. Mean and standard deviation values

Discussion

The objective of our study was to assess and measure proprioceptive levels in 10-year-old children using the OptoJump Next system, employing both hexagon and circle tests. During the tests, intriguing situations arose, likely owing to the students' unfamiliarity with such evaluations.

The results highlighted statistically insignificant aspects regarding proprioceptive development at this age. Our observations suggest that 10-year-old children may encounter difficulties adapting to proprioceptive assessments, possibly owing to the novelty of the tests. We found no statistically significant differences when employing the hexagon and circle tests for proprioceptive evaluation. Hence, focusing on a single test with a larger sample size is recommended to mitigate potential negative influences on results.

We observed that some participants performed below expectations on the hexagon test, indicating a potential misunderstanding of the requirements or slower adaptation to spatial aspects. This underscores the importance of subjects' familiarity with the tests, which can impact proprioceptive result interpretation.

Limitations of our study include the small sample size and, consequently, limited generalizability of results. Further exposure to such tests or interventions may lead to significant changes in children's proprioceptive performance, which is essential for everyday activities and physical education tasks. External factors such as extracurricular physical activity, medical history, and socioeconomic status can influence results and should be considered in future research. Because adequate postural control is essential for independent standing and walking (Carzoli & Enoka. 2023), choosing appropriate tests to observe conscious control of the body schema among children is crucial. Moreover, dynamic balance and coordination play vital roles in children's motor skills and significantly impact performance in team sports (Pontaga et al., 2024).

To enhance balance and coordination and mitigate falls and sports-related injuries, it may be necessary to implement an ameliorative intervention aimed at stimulating proprioceptors.

In this study, proprioception tests were evaluated and measured. It was revealed that there are no statistically significant differences between the hexagon and circle tests when applied individually rather than simultaneously. The statistical analysis comparing the results of both tests, conducted on the same 12 subjects, yielded the following findings:

a. On the x-axis, no statistically significant differences were observed between the hexagon and circle tests [$t(22) = .173$; $p > 0.05$]. b. Similarly, on the y-axis, there were no statistically significant differences between the two tests [$t(22) = .375$; $p > 0.05$]. c. Regarding the average landing distance, no statistically significant differences were found between the hexagon and circle tests [$t(22) = .382$; $p > 0.05$].

However, the sensitivity of the tests employed in the study may facilitate clearer measurements of future performances by the subjects. Although the initial hypothesis posited that dedicated exercises targeting proprioceptor stimulation in children would enhance their proprioceptive function, the absence of statistically significant differences between the two tests suggests the need for a new ameliorative intervention. Subsequent evaluations using different tests than those utilized in this study may be warranted.

Conclusions

In the developmental progression of a child's motor skills, advancements occur, potentially influencing the quality of exercise (Avramescu, 2006, p.240). These advancements stem from neuromuscular learning and neural adaptations (Kaufman, 2007).

There is a need for physical education teachers to have access to measurement and research facilities in schools. This ensures that students can learn to differentiate between objects and actions, a perception that may not always be immediately evident owing to response times extending beyond the operation itself (Nadin, 1988, p.279). Effective communication of verbal instructions by teachers, combined with guiding children to sense and visualize their movements during practice, can enhance the quality and efficiency of motor control. Improved proprioception function in children can positively impact body schema development, balance, mobility, and coordination. Results from testing proprioceptive components of body schema awareness, balance, and coordination via similar tests show negligible differences without statistical significance ($p > 0.05$). In the current comparison between the hexagon and circle tests, increasing testing complexity does not yield different results in measuring test subjects' abilities. This suggests that individuals demonstrate distinct ways of manifesting proprioceptive abilities, such as excelling in forward jumps, backward jumps, or lateral movements to the right or left. Given these findings, researchers may find value in exploring significantly different testing methods, such as assessments conducted with eyes closed.

Author contributions

All authors contributed equally to this work.

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Conflicts of interest

The authors declare no potential conflict of interest. All authors have reviewed and approved the final version of the manuscript. This study did not receive any financial support.

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