

THE INTERACTION BETWEEN STATIC AND DYNAMIC BALANCE PARAMETERS AND GENERAL AND SPECIFIC COGNITIVE SKILLS IN MOTOR ACTIVITIES IN PREADOLESCENTS

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ABSTRACT. Introduction: Balance and cognitive abilities share common neural structures and processing areas, especially within the cerebellum and prefrontal cortex. **Objective:** The objective was to analyze the relationship between general and specific cognitive skills related to motor activities and balance in preadolescents. **Material and Methods:** This research included children aged 10-13 years (N=116) from a middle school in Iași, Romania. The subjects performed static balance tests on a force plate and a dynamic balance test. The cognitive skills specific to motor activities were evaluated using the Witty Sem device, while general cognitive skills were assessed using the Raven Progressive Matrices. **Results:** A series of good correlations were observed between the parameters of static balance and the results of attention, working memory, visual memory, and IQ tests. After linear regression, some static balance parameters and the force applied on the support leg explained over 30% of the variance in cognitive abilities. **Discussion:** The findings of this research are consistent with previous studies highlighting the interdependence between balance control and cognitive functions, particularly in relation to executive abilities and processing speed. **Conclusions:** The correlations obtained support the hypothesis that both balance and cognition rely on shared neural mechanisms located in the cerebellum and prefrontal cortex. Also, the identified associations between applied force and IQ could represent an additional research topic, as we have not found studies in the specialized literature that investigate this link.

Keywords: Static balance; IQ; attention; visual memory; working memory.

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INTRODUCTION

Physical and sports activities manage to improve certain cognitive abilities such as working memory (Biino, et al., 2021), attention, memory (Sumińska, 2021), academic performance (Lambert, Ford, & Jeanes, 2022), and can also enhance processing speed after engaging in a moderate to high-intensity activity before taking a cognitive test (Kekäläinen, et al., 2023).

Certain authors (Divandari et al., 2023; Meunier, et al., 2021; Yan, et al., 2022) report that both static and dynamic balance can require different cognitive processes, such as executive functions, episodic memory, processing speed, and cognitive decline, these results being obtained on elderly subjects.

Yan et al. (2022), following the results of a study conducted on 8,499 adults over the age of 45, concluded that good static balance was significantly associated with higher cognitive function (episodic memory, mental state, and global cognition) and lower cognitive decline. Meunier and his collaborators (2021) also found an association between low balance ability and poorer cognition in a cross-sectional analysis of 4,811 adults aged over 76.

The cerebellum, an area of the brain heavily involved in both balance and cognitive abilities such as visual-spatial attention, working memory, and language (Zhang et al., 2023), undergoes substantial development in early life and continues to mature until approximately 15 years of age (Tiemeier et al., 2010).

Additionally, the prefrontal cortex is involved in attention, motor planning, and executive functions (Sugihara et al., 2021), and at the same time, certain studies demonstrate activation of the prefrontal cortex during the performance of a static and dynamic balance task (Wittenberg et al., 2017). Moreover, it is known that postural control and cognitive performance are affected during dual-task paradigms, suggesting that they use common areas of the brain.

Therefore, childhood can represent a sensitive period necessary for the development of important synapses and neuronal connectivity involved in the systems on which the optimal achievement of balance depends, and the evolution of cognitive capacity in childhood represents the beginning of a lifelong cognitive path (Hurst et al., 2013).

In children, positive correlations were found between static balance and attention at the age of 4-5 years (Abuin-Porras et al., 2018), with academic performance at the age of 5-6 years (de Waal, 2019), and additionally links were observed between dynamic balance, concentration ability, and academic performance in mathematics in 12-year-old children (Bataineh et al., 2017). At the same time, during adolescence (15 years old), higher cognition was associated with better midlife balance performance, with associations decreasing with age (Blodgett et al., 2018).

Additionally, performance IQ and visual-motor IQ had a strong association with static balance for the ages 7-13 years and 11-18 years. The weakest (insignificant) association of static balance was with verbal IQ. Moreover, a very strong association was found between the ability to maintain static balance at 7 years old and performance IQ at 16 years old (Jenni et al., 2013).

A similar result in the study conducted by Rigoli and colleagues (2012) was the specific link found between balance ability and total errors in the inhibition test in subjects aged 12-16 years. This link supports the accumulation of evidence for the attentional demands of children during postural tasks. The same result was observed in children aged 5-7, finding a link between static balance and the ability to switch attention, inhibition, and the capacity to update within working memory (Oberer et al., 2017).

Certain studies have not obtained results that demonstrate a correlation between balance and certain cognitive aspects, such as working memory, academic performance, and executive functions at the age of 12-16 years (Rigoli et al., 2012), cognitive development in children aged 1 year and 6 months (Veldman et al., 2019), and with the results on the Raven's Progressive Matrices test in children with an average age of 6 years and 4 months (Sadri et al., 2021).

Research interested in the correlation between static balance, dynamic balance, and cognitive abilities is numerous for elderly subjects. In contrast, studies conducted on subjects in childhood, preadolescence, and adolescence are found in a smaller number.

The purpose of this research was to verify whether certain balance variables correlate with general cognitive abilities and specific motor activity skills in preadolescents based on age and gender. We hypothesized that there would be certain correlations between the variables of static and dynamic balance and IQ, attention, visual memory and working memory in children aged 10-13 years.

MATERIAL AND METHODS

Participants

In this study, 116 subjects participated, students of the "George Călinescu" Middle School in Iași County, Romania, school for which we received the approval of the school management to conduct the tests. Inclusion criteria for subjects: to be aged between 10 years and 13 years and 11 months, to be clinically healthy, not to have a certificate of students with special educational needs, and to have parental consent. Exclusion criteria: to have physical or mental medical issues that may disrupt balance or cognitive abilities and to not complete all administered tests.

The subjects were divided into two groups, 10-11 years old (30 girls/30 boys) and a group of 12-13 years old (27 girls/29 boys), and within each group, a separate statistical analysis was conducted on female and male subjects.

We chose this age group for subjects because the cerebellum and prefrontal cortex (areas of the brain involved in both balance and cognitive skills) continue to mature during this period. Regarding cognitive skills specific to motor activities, attention matures around the age of 12, while memory and working memory mature around the age of 14.

Thus, considering that the psychomotor component, balance, is at the end of the developmental period, we divided the subjects into 2 groups because we wanted to observe at which age group (10-11 years or 12-13 years) we would identify the most significant correlations between balance components and cognitive abilities.

The study was approved by the Ethics Committee of Scientific Research of the Faculty of Physical Education and Sport at “Alexandru Ioan Cuza” University of Iași.

Procedure

The research was conducted in November 2023 at the “George Călinescu” Middle School in Iași, Romania. Participants were divided into two age groups (10–11 years and 12–13 years) and were tested while well rested, in the school’s sports hall. The testing sessions were performed during the morning hours, in small groups, under the supervision of the research team.

Before testing, participants and their parents were informed about the purpose and objectives of the study and were assured of the confidentiality of their data and the right to withdraw at any time.

Materials

The evaluation of static balance was carried out using the Desmotec E-Board force plate. The balance maintenance task was performed on one leg (right and left) both with eyes open and closed, while the subject kept their hands on their hips. Desmotec E-Board measures the area encompassed within an ellipse of pressure points on each foot, the maximum and average force applied on the right/left side of the foot, and the percentage of unbalance.

To evaluate dynamic balance, we used the Bass test (Johnson & Leach, 1986; Rami, 2019). In the context of this test the subject has 10 squares (2.5 cm²) stuck to the ground in front of it. The subject is on the starting line with the right foot. At the evaluator’s signal, the subject jumps on the square number 1 with the left foot and maintains balance for 5 seconds while looking forward. After 5

seconds, the subject jumps with the right foot onto square number 2, maintaining their balance for the same number of seconds. The same thing is done on each square, jumping from one foot to the other. The evaluator will count the seconds on the stopwatch aloud to help the subject orient themselves temporally. If the subject puts their heel down or any other part of their body (foot, hand), the counting stops and the seconds maintained correctly by the subject are recorded. He receives 5 points if he covered the entire square with the ping pong ball, 3 points if he covered half of the square, 0 points if he didn't cover the square at all, and 1 point for each second the ping pong ball is held.

Specific cognitive abilities were evaluated using the Witty-SEM device: 2.1.11. We used the Divided Attention test to evaluate attention as well as response time. The subject has 4 traffic lights arranged in a line on a frame with distance between them in front of him. Two geometric shapes of different colors will be displayed on the two middle traffic lights. The traffic light on the left side has a "Y" on it, representing the answer "Yes," and the one on the right side has an "N," representing the answer "No." The subject stands in front of the frame where the traffic lights are located and must press "Y" if the two geometric shapes have the same color and "N" if the geometric shapes have different colors.

For visual memory, we used the Eye for Detail test. The subject is 2 meters away from the device and has 8 traffic lights arranged in an oval shape in front of them on the frame. On 3 of the traffic lights, 3 butterflies will appear in random order, 2 of which are identical, and one is different. After all 3 butterflies have appeared, a green dot will light up on the traffic lights where these shapes have appeared. The subject must move as quickly as possible and touch the green point on the traffic lights that showed the two identical butterflies, and then move back to the starting point.

For working memory, we used the Juggle test. The subject is 2 meters away from the device and has 8 traffic lights arranged in an oval shape in front of them on the frame. Numbers from 1 to 3 will appear on the traffic lights in ascending order and arranged randomly. After this, a green dot will appear on all the traffic lights, and the subject must press the corresponding traffic lights in the order the numbers appear (1, 2, 3...). After the first 3 repetitions, if the subject answers correctly, 4 numbers will appear, with the maximum number of numbers that can appear on the traffic lights being 6, but it depends on the correctness of the answers. In case the subject answers incorrectly repeatedly, the number of digits displayed will decrease to 2.

The Raven Progressive Matrices test was used to assess the intelligence quotient. The test includes 60 items, which the subjects received individually on sheets. Each item consists of an abstract drawing, often from a grouping of figures ("matrix"), from which a part is missing an element. The subject must

decide, after examining the matrix, which is the unique figure (from the 6 or 8 offered on the same board under the matrix) suitable for the correct “completion” of the matrix. Simple trials are grouped into series of 12 matrices each, with the series being labeled from “A” to “E.”

Data analysis

Within the statistical-mathematical method, we used the following: Mahalanobis distance - to identify data that exhibit an aberrant distance from the mean of the evaluated parameters; Shapiro-Wilk - analysis of the normality of data distribution in groups with fewer than 50 subjects; Pearson correlation - to establish the correlations between the mentioned parameters and cognitive abilities that exhibited a normal distribution of results; Spearman correlation - to establish the correlations between the mentioned parameters and cognitive abilities that do not have a normal distribution of results; Linear regression - to identify the degree of influence that balance parameters can have on general and specific cognitive abilities. Statistical significance was set at $p < 0.05$.

RESULTS

Correlations performed in the 10-11 year age group

In the group of 10-11-year-old boys, a good association was observed between a greater static imbalance on the left foot with eyes open and a smaller number of correct responses on the attention test ($r=-0.576$), and between a larger integrated surface of pressure points on the left foot with eyes closed and a better response time on the working memory test ($r=-0.573$).

A good correlation was also observed between a greater maximal force applied to the left side of the right leg with eyes closed and a slower response time on the working memory test ($r=0.530$) (Table 1).

In the group of 10-11 year old girls, a good association was observed between a low IQ and a larger integrated area of pressure points on the right foot with eyes closed ($r=0.538$) and between a greater maximum force applied to the right side of the left foot with eyes closed and a higher IQ score ($r=0.566$).

In contrast, the other parameters of static and dynamic balance showed a weak correlation with general cognitive abilities and those specific to motor activities (Table 2).

Following the use of linear regression, we were able to observe how much cognitive abilities are influenced by balance parameters. It was found that in the case of 10-11-year-old boys, static balance on the left foot with eyes open

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influenced the correct response results in the attention test by 33%, while the response time in the working memory test was influenced by 34% by the integrated surface of pressure points on the left foot with eyes closed and by 30% by the maximum force applied on the left side of the right foot with eyes closed (Table 1).

Table 1. Good correlations between balance parameters and cognitive abilities and linear regression results in the group of boys aged 10-11 years

Variable	Correlation Parameter	R/p	R squared
UN_Lfoe (%)	CA_A (score)	-.576/.006	.330
A_Lfce (cm ²)	RT_WM (score)	-.573/.032	.346
MForce_LSide_RFce (Kg)	RT_WM (score)	.530/.011	.307

Legend: R - correlation coefficient; p - threshold of significance; UN - unbalance; Lfoe - left foot open eyes; A - area encompassed within an ellipse of pressure points; LFce - left foot closed eyes; MForce - maximum force applied; LSide - left side; RFce - right foot closed eyes; RA - correct answers; A - attention test; RT - response time; WM - working memory test.

In the case of the group of girls aged 10-11, the IQ results were influenced by 28% by the integrated area of pressure points on the right foot with eyes closed and by 32% by the maximum force applied on the right side of the left foot with eyes closed. Thus, the R-squared values indicate a fairly good influence in the case of boys to predict that these balance parameters have influenced the results of cognitive abilities, but also in the case of girls regarding the maximum force applied on the right side on the left foot with eyes closed (Table 2).

Table 2. Good correlations between balance parameters and cognitive abilities and linear regression results in the group of girls aged 10-11 years

Variable	Correlation Parameter	R/p	R squared
A_RFce (cm ²)	IQ (score)	.538/.021	.289
MForce_RSide_LFce (Kg)	IQ (score)	.566/.006	.307

Legend: R - correlation coefficient; p - threshold of significance; A - area encompassed within an ellipse of pressure points; RFce - right foot closed eyes; MForce - maximum force applied; RSide - right side; LFce - left foot closed eyes; IQ - intelligence quotient.

Correlations performed in the 12-13 age group

In 12-13-year-old boys, a good association was observed between a higher integrated surface area of pressure points on the right foot with eyes open and a lower number of correct responses on the working memory test ($r=-0.578$).

Regarding the maximum and average force applied to each side of the leg in 12-13-year-old boys, good correlations were observed between a higher IQ and greater force applied to certain strength parameters with r values between 0.519 and 0.697 (Table 3).

In 12-13-year-old girls, it was observed that there is a good correlation between higher static balance on the left leg with eyes open and a lower number of correct responses on the visual memory test ($r=-0.511$), and between higher static balance on the right and left legs with eyes closed and better response speed ($r=-0.551$) and a decrease in correct responses on the attention test ($r=-0.500$), as well as a slower response time on the visual memory test ($r=0.505$).

Regarding the maximum and average force applied on each side of the leg, a good association is observed between a high IQ and a lower average force applied on the left side of the right leg with eyes closed ($r=-0.687$) and the average force applied on the right side of the left leg with eyes closed ($r=-0.616$). Good correlations were also observed between a slower response time on the visual memory test and greater force applied to certain strength parameters, with an r value between 0.507 and 0.581.

Good associations were also observed between the increase in correct responses on the visual memory test and the lower force applied on certain strength indices with an r value between -0.510 and -0.604, while a slower response time on the working memory test showed a good association with higher maximal force applied on the right side of the right leg with eyes closed ($r=0.504$) (Table 4).

In contrast, the scores on the dynamic balance test showed no correlation with general cognitive abilities or specific motor activity skills in either 12-13-year-old girls or boys.

Following the use of linear regression, the highest values of r -squared were observed in the case of 12-13-year-old boys, where IQ results were influenced by 46% by the average force applied to the right side of the left foot with eyes closed and by 48% by the maximum force applied to the left side of the right foot with eyes closed. In the case of 12-13-year-old girls, IQ scores were influenced by 47% by the average force applied to the left side of the right foot with eyes closed (Table 3).

However, more significant and numerous influences of balance parameters on cognitive abilities were observed in the group of boys aged 12-13 than in girls, where in many associations the R -squared value is between 0.202 and 0.28 (Table 4).

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Table 3. Good correlations between balance parameters and cognitive abilities and linear regression results in the group of boys aged 12-13 years

Variable	Correlation Parameter	R/p	R squared
A_RFoe (cm ²)	CA_WM (score)	-.578/.006	.320
mForce_LSide_RFoe (Kg)	IQ (score)	.573/.016	.328
mForce_LSide_RFce (Kg)	IQ (score)	.519/.016	.245
MForce_LSide_RFce (Kg)	IQ (score)	.697/.000	.486
MForce_RSide_RFce (Kg)	IQ (score)	.538/.010	.289
mForce_RSide_LFce (Kg)	IQ (score)	.675/.002	.466

Legend: R - correlation coefficient; p - threshold of significance; A - area encompassed within an ellipse of pressure points; RFoe – right foot open eyes; mForce – medium force; LSide – left side; RLoe – right leg open eyes; RFce – right foot closed eyes; MForce – maximum force; RSide – right side; LFce – left foot closed eyes; CA – correct answers; WM – working memory test; IQ – intelligence quotient.

Table 4. Good correlations between balance parameters and cognitive abilities and linear regression results in the group of girls aged 12-13 years

Evaluated Parameter	Correlation Parameter	R/p	R squared
UN_Lfoe (%)	CA_VM (score)	-.511/.015	.246
UN_Rfce (%)	RT_A (score)	-.551/.012	.236
UN_LFce (%)	RT_VM (score)	.505/.028	.230
	CA_MV (score)	-.500/.028	.238
MForce_RSide_RFoe (Kg)	RT_VM (score)	.507/.019	.202
mForce_RSide_RFoe (Kg)	RT_VM (score)	.507/.016	.223
MForce_LSide_LFoe (Kg)	CA_VM (score)	-.510/.018	.227
mForce_LSide_LFoe (Kg)	RT_VM (score)	.562/.010	.227
	CA_VM (score)	-.604/.005	.288
mForce_LSide_RFce (Kg)	IQ (score)	-.687/.002	.472
MForce_RSide_RFce (Kg)	RT_WM (score)	.504/.020	.207
mForce_RSide_RFce (Kg)	RT_VM (score)	.581/.006	.270
	CA_VM (score)	-.523/.015	.236
mForce_LSide_LFce (Kg)	CA_VM (score)	-.520/.023	.255
mForce_RSide_LFce (Kg)	IQ (score)	-.616/.008	.379

Legend: R - correlation coefficient; p - threshold of significance; UN – unbalance; LFoe – left foot open eyes; RFce – right foot closed eyes; LFce – left foot closed eyes; MForce – maximum force applied; RSide- right side; RFoe – right foot open eyes; mForce – medium force applied; LSide – left side; CA – correct answers; VM – visual memory test; RT – response time; A – attention test; WM – working memory test; IQ – intelligence quotient.

DISCUSSION

In comparison with the results from the specialized literature, it should be noted that the subjects in other research studies did not perform the same balance or cognitive ability tests as the subjects in our research. Thus, some researchers have found an association between performance IQ and visual-motor IQ, inhibition capacity, and the ability to maintain balance on one leg for 60 seconds in subjects of a similar age to those in our study (Jenni et al., 2013; Rigoli et al., 2012).

Regarding our study, we obtained results similar to those of Jenni and colleagues (2013), as the IQ scores showed an association with the area of pressure points encompassed within an ellipse of the foot on which the balance maintenance task was performed in 10-11-year-old girls.

Certain correlations between lower results in terms of response time and accuracy of responses on the attention test, working memory test, and visual memory test, and higher values on static balance tests obtained by the subjects of our research were in line with certain studies that focused on preschool-aged subjects (Abuin-Porras et al., 2018; Bataineh et al., 2017; de Waal, 2019; Frick and Möhring, 2016). At the same time, certain studies on subjects of a similar age to those in our study did not find associations between balance and fluid intelligence, working memory, and inhibition (Rigoli et al., 2012).

However, regarding the multiple associations between general and specific cognitive abilities and the force applied on the side of the leg where the balance maintenance task was performed by the subjects of our research, certain authors (Amenya et al., 2021; Zeng et al., 2022) have found associations between certain indicators of strength (palmar strength, the number of pull-ups and trunk raises from a supine position performed, and the long jump) executive functions, and IQ in preadolescents.

An association between lower limb strength and cognitive function has been observed only in studies on adults, and it was mediated by neuromuscular function (Frith and Loprinzi, 2018; Storoschuk et al., 2023), and also, deficient muscle strength has been associated with cognitive decline (Esmaeilzadeh et al., 2022; Herold et al., 2019; Tessier et al., 2022).

At the same time, these results suggest that the force applied on the opposite side of the support leg only during the eyes-closed maintenance task influences IQ scores to a greater extent in boys. Additionally, the positive relationship between these parameters may indicate that 12-13-year-old boys who apply greater force on the opposite side of the balance-maintaining leg, both with eyes open and closed, have a higher IQ due to the mechanisms involved in balance regulation that may require the subject's ability to convey correct

information for task resolution, considering that balance regulation and cognitive abilities are carried out in common areas of the brain, namely the prefrontal cortex and cerebellum (Sugihara et al., 2021; Zhang et al., 2023).

The limitation in conducting this research was the low number of subjects, most often determined by the parents' reluctance regarding the participation of students in a research study.

CONCLUSIONS

The study identified clear associations between balance parameters and cognitive abilities in preadolescents. Greater stability and balance control were generally linked to faster responses in attention test, and higher working memory performance. Additionally, increased force and pressure values recorded during balance tasks correlated positively with IQ. These results suggest that postural control and cognitive functioning develop in close interaction during this age period.

Following the linear regression analysis, it was observed that the mentioned cognitive abilities, which showed associations with balance parameters, were influenced by them in over 30% of the cases. At the same time, the identified associations between applied force and IQ could represent an additional research topic, as we have not found studies in the specialized literature that investigate this link.

Additionally, in the case of boys, the greatest influences of balance parameters on cognitive abilities were observed, while in girls, more numerous associations with these parameters were noted, but most of them had an influence on cognitive abilities that was slightly below 30%.

As a result of the findings obtained in this study, we aim to implement an intervention program based on balance exercises and identify the influence it will have on the level of cognitive abilities.

AUTHOR CONTRIBUTIONS

Bianca Georgiana Mihaș and Adrian Cojocariu contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

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