

DEVELOPMENT OF EXECUTIVE FUNCTIONS AND MOTOR COORDINATION: PEDAGOGICAL PERSPECTIVES AND EDUCATIONAL IMPLICATIONS

SVILUPPO DELLE ABILITÀ ESECUTIVE E COORDINAZIONE MOTORIA: PROSPETTIVE PEDAGOGICHE E IMPLICAZIONI DIDATTICHE



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ABSTRACT

Cognitive-motor training is an innovative methodology aimed at enhancing cognitive and motor skills through the integration of physical exercises and stimulus processing activities. This study analyzes the effectiveness of a cognitive motor training program, involving secondary school students. The goal was to improve visuospatial memory, reaction speed, selective attention, and motor coordination. By employing standardized tests and specific motor activities, the study explores the relationships between cognitive processing, decision-making speed, and movement control. Data analysis allows for an assessment of the role of combined training in improving students' cognitive and physical abilities, also considering individual differences in performance. The findings highlight the potential of this methodology for optimizing learning and motor performance, suggesting possible applications in educational and sports settings. The integration of motor strategies into school curricula could contribute to the development of essential skills for students' improving their well-being and their school performance, fostering a holistic approach to education.

L'allenamento cognitivo-motorio è una metodologia innovativa che mira a potenziare le abilità cognitive e motorie attraverso l'integrazione di esercizi fisici e attività di elaborazione degli stimoli. Questo studio analizza l'efficacia di un programma sperimentale applicato a studenti della scuola secondaria, con l'obiettivo di migliorare la memoria visuo-spaziale, la velocità di reazione, l'attenzione selettiva e la coordinazione motoria. Attraverso l'impiego di test standardizzati e attività motorie specifiche, vengono esplorate le relazioni tra elaborazione cognitiva, rapidità decisionale e controllo del movimento. L'analisi dei dati consente di valutare il ruolo dell'allenamento combinato nel miglioramento delle capacità cognitive e fisiche degli studenti, considerando anche le differenze individuali nelle prestazioni. I risultati evidenziano il potenziale di questa metodologia per l'ottimizzazione dell'apprendimento e delle prestazioni motorie, suggerendo possibili applicazioni in ambito educativo e sportivo. L'integrazione di strategie motorie nei programmi scolastici potrebbe contribuire allo sviluppo di competenze essenziali per il benessere e il rendimento degli studenti, favorendo un approccio globale alla formazione.

KEYWORDS

Cognitive-motor training, executive functions, selective attention, physical education, decision-making speed, cognitive development Allenamento cognitivo-motorio, funzioni esecutive, attenzione selettiva, educazione motoria, rapidità decisionale, sviluppo cognitivo

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Pedagogical Approaches to Body–Mind Integration

In the contemporary educational context, characterized by the increasing complexity of the skills required of students, there is a renewed interest in integrated teaching approaches that simultaneously foster the development of both cognitive and motor skills. This interest has led to an evolution of traditional pedagogical paradigms, which are increasingly incorporating practices that enhance the body-cognitive dimension of learning (García-Hermoso et al., 2021). Within this framework, cognitive-motor training emerges as an innovative methodology capable of synergistically promoting the enhancement of executive functions and motor skills through the structured integration of physical activities and cognitive tasks (Morsanuto et al., 2023).

The theoretical foundation of this approach is rooted in the paradigm of embodied cognition, according to which mind and body are not autonomous entities (Gomez-Paloma, 2013), but are deeply interconnected through shared neural circuits that simultaneously and reciprocally orchestrate cognitive and motor functions (Diamond & Ling, 2019; Leisman et al., 2016). This paradigm represents a conceptual shift from more traditional perspectives that viewed the body merely as a "container" or vehicle for mental activity (Iavarone, 2021). On the contrary, the embodied perspective highlights how bodily movement, spatial orientation, and environmental interaction are constitutive elements of cognition itself. Cognitive-motor combined training is therefore based on a robust body of scientific literature that emphasizes the functional connections between cognitive and motor systems, supporting the need for interdisciplinary educational strategies to foster students' holistic development (Best, 2010; Albuquerque et al., 2022).

Executive functions – including response inhibition, selective attention, working memory, and cognitive control – play a crucial role in learning processes, behavioral regulation, and the ability to adapt to complex contexts (Viarouge et al., 2023; Miyake & Friedman, 2012). At the same time, physical activity, particularly structured motor activity, is recognized as one of the main promoters of cognitive health and psychophysical well-being in children and adolescents (Ceruso et al., 2024; Tomporowski et al., 2008). Numerous studies in the fields of neuroscience and educational psychology support the hypothesis that active bodily participation contributes to the enhancement of higher cognitive functions, such as working memory, cognitive flexibility, behavioral inhibition, and selective attention (Ahmed et al., 2021; Casella et al., 2022).

These functions, collectively referred to as executive functions, are considered key predictors of academic success (Diamond, 2013), emotional self-regulation and the capacity to adapt in complex environments (Stoet, 2016; Invernizzi et al., 2022). Neurophysiological evidence suggests that coordinative exercises and motor tasks requiring attention and adaptive control can stimulate neuroplasticity, involving key brain structures such as the prefrontal cortex, cerebellum, and basal ganglia (Madonna et al., 2020; Leisman et al., 2016), all regions implicated in the regulation of complex cognitive processes (Richter et al., 2024).

In light of this evidence, the present study aims to investigate, within a sample of secondary school students, whether an integrated activity – in which motor education lessons are supplemented with short digital interventions based on cognitive tests (administered through the digital platform Cognition.run) – can produce significant improvements compared to traditional motor activities in two specific areas: executive cognitive skills, assessed through standardized tests (Go/No-Go, Flanker, and Stroop), and basic motor skills, measured using Witty SEM digital timing tools (reaction times and visuomotor accuracy). The limitations of the present study include both the duration of the protocol (12 weeks), which, while sufficient to observe improvements, does not allow for the evaluation of the long-term persistence of the effects and the assessment of intra-class variability due to environmental factors or uncontrolled individual differences (ex. motivation, familiarity with digital tools).

Methodology

The sample analyzed in this study was selected from an Italian lower secondary school, involving a total of six classes from two sections, distributed among first, second, and third grades. All students were regularly enrolled and attending classes. Figure 1 shows the PRISMA flowchart regarding the number of students involved and the eligibility criteria.

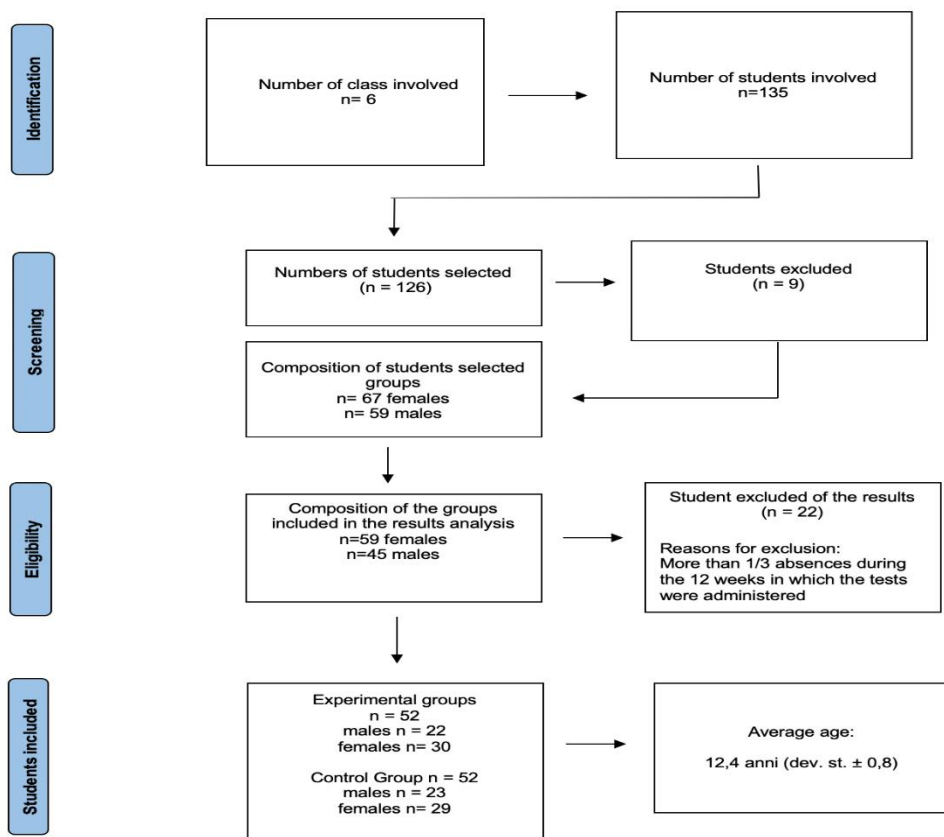


Figure 1. PRISMA flowchart (adapted from Page et al., 2021) regarding the selection of students

The disparity between male and female students reflects the actual composition of the school classes and was not artificially modified for methodological reasons. The collected data were subjected to statistical analysis (ANOVA) and mean classification using Tukey's test. Students were assigned to the experimental and control groups through stratified randomization by class. The experimental group participated in both physical activity and digital cognitive tests, while the control group engaged in traditional physical activities and psychomotor games. All participants were in good general physical health and did not present with disabling neuropsychiatric diagnoses. Students with general learning difficulties or normal to slightly below-normal motor coordination were also included, in line with the inclusive spirit of the educational project. Recruitment involved the active collaboration of the teaching staff, and written informed consent was obtained from parents. Participation in the study was voluntary, with no rewards or

penalties, and data were processed anonymously in accordance with privacy regulations (GDPR – EU Regulation 2016/679). The project was entirely conducted during school hours under the supervision of school teachers. The experimental intervention lasted for 12 weeks, corresponding to approximately three school months, and was fully integrated within the curricular timetable, during hours regularly dedicated to physical education. This duration aligns with previous studies suggesting that a period of 8–12 weeks is sufficient to produce measurable changes at both cognitive and motor levels (Wollesen et al., 2020). Each week, both groups (experimental and control) participated in two 60-minute sessions of physical activity, totaling 24 sessions across the intervention period. Activities took place in the gymnasium or suitable school spaces, supervised by physical education teachers and operators experienced with the protocol. In the experimental group, an additional 10 minutes of each session were devoted to the execution of cognitive tests via the Cognition.run platform (www.cognition.run), using digital devices (tablets or laptops) provided by the school. Each participant in the experimental group completed a total of 20 cognitive sessions, corresponding to 200 minutes of distributed and consistent digital training. The cognitive tests administered during each session alternated among the following:

- Go/No-Go Task → response inhibition, decision speed. The Go/No-Go task is a widely used paradigm to effectively assess response inhibition capability (Barry et al., 2022).
- Flanker Task → selective attention, resistance to distractors. The Flanker task measures the average reaction time between incongruent and congruent trials (Shih et al., 2025).
- Stroop Online Task → interference control, cognitive flexibility. The Stroop task measures the average reaction time between incongruent and congruent trials and mainly evaluates executive functions, such as attentional processes, speed of processing, and inhibition (Westfal et al., 2025).

The order of the tests was systematically alternated to reduce learning or boredom effects and to stimulate different cognitive areas over time. In the control group, the two weekly hours were entirely dedicated to physical exercises. Physical activities included exercises inspired by psychomotor games, characterized by the alternation of visual, auditory, and spatiotemporal stimuli. This methodological choice aligns with literature emphasizing that psychomotricity – the coordination between perception, action, and thought – supports both motor and cognitive learning in educational contexts (Pesce et al., 2015; Erickson et al., 2019). The

games proposed stimulated the ability to inhibit automatic responses, adapt to new conditions, and make quick decisions – all central elements of executive functions – while maintaining the same general activity content as the experimental group, except for the digital component. In both conditions, the motor protocol included:

- Coordinative exercises (jumping, bounding, obstacle courses),
- Psychomotor games (integrated auditory/visual stimuli),
- Timed or variable rhythm drills.

The content of the physical activities was designed to isolate the effect of the independent variable, namely exposure to digital cognitive training. The program was organized to:

- Avoid interference with other school subjects,
- Be logistically manageable by the teachers,
- Ensure systematic, progressive, and distributed student engagement over time.

The teachers received introductory training on the use of the Cognition.run platform and the rationale behind the intervention. Any session missed by students due to exceptional circumstances was rescheduled in the following weeks. The assessment of motor skills measured the students coordination and reaction abilities, with particular attention to response times and accuracy, using the Witty SEM® system (Microgate, Bolzano, Italy) following Horváth et al. (2022). Two specific tests were employed:

Go Light Reaction Time (simple reaction time test)

- Description: The student stands approximately 60 cm away from the SEM module. When the module lights up, they must react as quickly as possible by touching it with one hand
- Measure: Simple reaction time (in milliseconds), calculated as the interval between the onset of the visual stimulus and the hand touch.
- Objective: To assess the speed of stimulus processing and neuromotor readiness.
- Repetitions: Each student performed 3 consecutive attempts. The best recorded time was used for analysis.

Reactive Light Tapping (visuomotor precision test)

- Description: Five SEM modules are positioned on a vertical wall. The modules light up randomly, one at a time, and the student must quickly touch only the illuminated ones, avoiding errors.

- Test duration: 30 seconds.
- Measures collected:
 - Number of valid hits
 - Number of errors
 - Accuracy percentage (valid hits / total stimuli × 100)
 - Average time per correct hit

Each student was tested individually in a familiar school environment after a standard warm-up (5 minutes) before execution. Each student performed three 30-second trials. Data analysis was conducted by selecting the best overall score as representative of the individual's maximum performance (Baumgartner et al., 1995; Morrow et al., 2011). The three trials for each test were performed consecutively, with a one-minute recovery period between attempts. The motor skill assessment procedure included two evaluation points: t0 (during the first week of the protocol) and t12 (at the twelfth and final week of the protocol).

Results

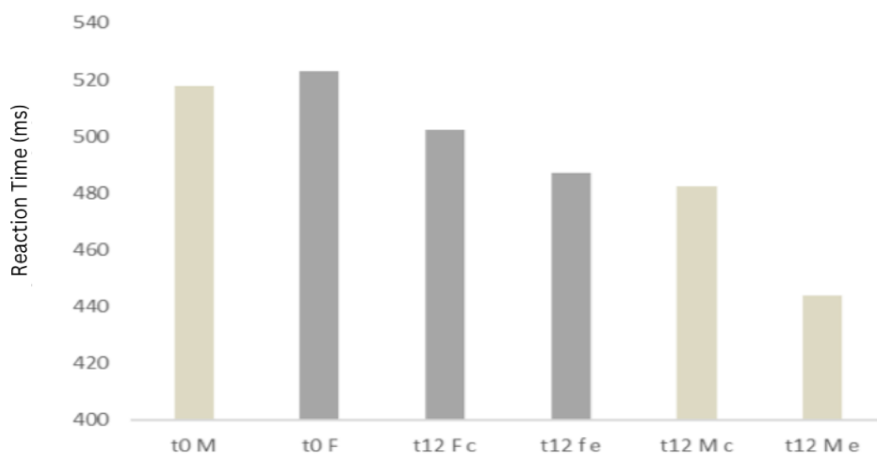


Figure 2. Mean reaction times in the Go Light Reaction Time test expressed in milliseconds.

F = females; M = males; c = control group; e = experimental group; t0 = week 0; t12 = week 12. Means marked with the same letters are not significantly different from each other ($p < 0.01$).

Figure 2 shows the results of the Go Light Reaction Time test. The average reaction times at t0 (beginning of the assessment) and at t12 (12 weeks after the beginning) showed no significant differences between males and females at t0. At t12, a slight difference is observed between the female control group and the female experimental group, while no significant difference is found between the control group males and the experimental group females. The best performance is recorded by the experimental group males at t12, with a mean value of 444 ms, which is 38 ms lower than the control group males at t12 and 43 ms lower than the experimental group females at t12. The gender-related differences revealed by the data analysis pertain only to the experimental group, which showed slightly better reaction times in males compared to females. This finding is consistent with the results reported by Thomas et al. (1985) and Puciato et al. (2011), who highlighted a slight neuromotor advantage in school-age males.

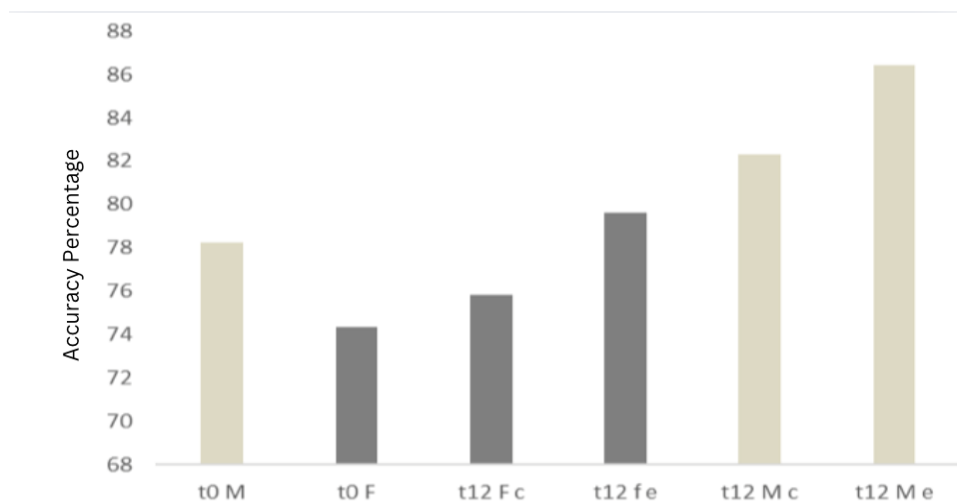


Figure 3. Response accuracy percentage in the Reactive Light Tapping test

F = females; M = males; c = control group; e = experimental group; t0 = week 0; t12 = week 12. Means marked with the same letters are not significantly different from one another ($p < 0.01$).

Figure 3 shows the accuracy percentage in the Reactive Light Tapping test. In this test, the male group reacted significantly more effectively than the female group. In fact, males at t0 showed an average response percentage comparable to that of females in the experimental group at t12. The average accuracy of the experimental group males at t12 was 86%. This result was significantly higher—by 4.66%—than

that of the control group males at t12, and by 6.98% compared to the experimental group females at t12. These differences, consistent with a non-competitive educational context, were statistically significant ($p < 0.01$) and support the hypothesis that digital cognitive training can enhance neuromotor performance by activating the same neural networks involved in movement planning and attentional control (Ružbarská et al., 2023). This observation suggests a possible “developmental window” for optimal simultaneous motor-cognitive learning, likely between the ages of 11 and 13, when the brain exhibits high plasticity and greater responsiveness to multisensory stimuli (Best & Miller, 2010).

Discussion

The observed improvement in specific motor skills, such as reaction time to selective visual cues (Go Light discrimination test), can be interpreted as a direct consequence of the enhancement of executive functions stimulated by the cognitive tasks integrated into the educational program (Lopez et al., 2020). The selected digital exercises (Go/No-Go, Flanker, Stroop) are characterized by their demand for fast and accurate responses under conditions of interference or stimulus-response conflict, thereby stimulating inhibitory control, selective attention, and working memory—mechanisms also involved in the organization and execution of goal-directed movement.

The results may also be interpreted through the lens of sensorimotor integration and multisystem learning, which posit that cognitive function development is not separate from motor experience but is built through a continuous dialogue between body and mind (Leisman et al., 2016). The cognitive digital tests proposed through the Cognition.run platform stimulated functions such as selective attention, inhibitory control, and working memory—all of which are also implicated in performing fast and coordinated motor tasks (Faubert et al., 2012; Voodla et al., 2024). In particular, the Reactive Light Tapping test, which required students to respond selectively only to target stimuli, proved highly effective in transferring skills acquired through cognitive testing to the motor domain.

Conclusions

This study investigated the effectiveness of an educational intervention based on the integration of physical activity and cognitive stimulation in a school setting, with the aim of enhancing executive functions and motor coordination in a sample of

lower secondary school students. The implementation of an experimental protocol, which included the use of the digital platform Cognition.run to administer standardized cognitive tests (combined with targeted motor exercises and objective chronometric assessments via the Witty SEM system), allowed for a systematic exploration of the relationship between cognitive functions and motor skills. The results obtained from the experimental group were compared with those of a control group. Findings showed that students in the experimental group demonstrated significant improvements compared to their peers who participated solely in traditional physical education. Although moderate in absolute value, the differences were statistically significant in both reaction time and visual accuracy, indicating greater efficiency of the integrated protocol in enhancing the neuro-cognitive components involved in movement control and selective attention. These results are particularly meaningful considering the intervention was carried out in an ordinary school context, with no performance pressure or competitive goals, demonstrating that even within standard educational environments it is possible to foster the development of key transversal competencies through conscious and evidence-based didactic strategies.

The connection between cognitive and motor domains, extensively documented in the neuroscientific literature (Shi et al., 2022; Limone et al., 2023), is further confirmed by this study, where the synergy between cognitive tasks and physical activity yielded better results than physical activity alone.

It is important to highlight that the use of objective, digital systems for data collection helped avoid evaluation bias and ensured reliable measurement of progress. The Witty and Witty SEM systems provided accurate data on reaction speed and the accuracy of motor responses to visual stimuli, allowing for dependable comparisons between groups, classes, and test phases (pre/post). This methodological approach is a strength of the study, as it supports a clearer attribution of observed improvements to the experimental protocol rather than to external or subjective variables.

Another important aspect concerns the organizational structure of the intervention, which required only limited time commitment. The experimental group dedicated just 10 minutes twice a week to cognitive activity, fully integrated into existing lab-based educational sessions. Despite its brevity, the intervention produced meaningful results, suggesting that effectiveness depends not on the quantity of time but rather on the quality and consistency of the proposed stimuli. In other words, appreciable improvements in both cognitive and motor functions can be achieved in ordinary school contexts, provided that tools and teaching strategies are aligned with current scientific evidence (Fedewa et al., 2011). The

collected data also enabled exploration of class- and gender-based differences. An additional strength of the study lies in the high replicability of the protocol: the use of a free, accessible online platform such as Cognition.run makes the intervention easily implementable in other school contexts, requiring only minimal technical and organizational resources. At the same time, the integration with digital motor measurement devices allows for the creation of a comprehensive educational pathway that values the unity of body and mind and provides teachers with objective tools for monitoring student progress (Formenti et al., 2019; Hu et al., 2025). Based on the data collected, it can be stated that the introduction of cognitive-motor programs in schools represents a promising educational practice capable of generating positive outcomes both at the individual and institutional levels. The integration of digital cognitive exercises with physical activity produced measurable benefits in the development of executive and motor skills, without requiring structural changes to the school curriculum. These results open up new perspectives for didactic innovation and the promotion of student well-being.

Author contributions

The contribution of which is to be referred to as follows:

- Pedagogical Approaches to Body–Mind Integration is to be attributed to Pompilio Cusano e Stefania Maddalena
- Methods, Results and Discussion are to be attributed to Pompilio Cusano
- Conclusion is to be attributed to Stefania Maddalena

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