Basketball Workshop and Development of Motor Coordination and Problem-Solving Skills in Lower Secondary School Pupils: A Qualitative and Quantitative Experimental Study

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Abstract
This study aimed to evaluate the effects of a 10-week basketball workshop designed according to ecological-dynamic and problem-based principles on the motor coordination and problem-solving skills of lower secondary school students with MABC-2 scores of ≤25^(th) percentile. Sixty students (aged 11–13) were randomly assigned to either the basketball group (BG, n = 30) or the control group (CTRL, n = 30). The BG protocol included 30 60-minute sessions comprising cognitive-motor warm-ups, variable skill exercises, constraint-guided tactical tasks, and metacognitive reflection. The CTRL group followed traditional physical education lessons with an equivalent motor load. Pre- and post-test measures: Movement Assessment Battery for Children-2 (MABC-2), Tower of London-DX (ToL-DX) and Game Performance Assessment Instrument (GPAI-Basket). Semi-structured interviews and thematic analysis explored the students' experiences. Mixed ANOVA showed a significant group × time interaction. The GC group improved their overall MABC-2 score by 13.2 centiles (d = 1.86), reduced their excess moves on the ToL-DX by 3.2 (d = 1.34) and increased their correct tactical decisions on the GPAI by 72%. The CTRL group showed minimal gains. Qualitative analysis highlighted three themes: strategic awareness, embodied problem solving and adaptive confidence. The basketball workshop produced substantial, clinically relevant improvements in motor coordination and problem solving. This supports the integration of open-skill sports involving high cognitive load into the school curriculum to promote the integrated motor-cognitive development of adolescents.

***Key Words**: ecological dynamics; executive functions; embodied cognition; laboratory*

Introduction

Coordinative and cognitive development are deeply intertwined during pre-adolescence. Between the ages of 11 and 13, the prefrontal cortex and cerebellum undergo an intense phase of synaptic reorganization, which promotes the maturation of executive functions such as working memory, planning, and cognitive flexibility (Diamond, 2020). Recent meta-analyses suggest that the level of motor skills explains up to 20% of the variance in executive performance in school-age children (Cameron et al., 2022). In this context, 'open skill' motor programmes, i.e. those practised in unpredictable and dynamic environments, appear to be particularly effective as they stimulate a continuous and complex cycle of perception, decision-making and action (Pesce et al., 2023).

Basketball combines fine technical movements (such as passing and shooting) with rapid tactical decision-making, making it an ideal context for embodied-cognitive learning. A quasi-experimental study of children with motor coordination disorder revealed that 14 weeks of mini-basketball training enhanced their overall coordination by 10–15 centiles and reduced their Tower of London completion times, as opposed to a control group that participated in athletics training (Jelsma, Geuze & Smits-Engelsman, 2017). Furthermore, functional connectivity analyses have demonstrated that adolescents involved in open-skill sports exhibit more efficient integration between the cerebellum and parietal cortex, which are crucial areas for visuomotor control and anticipation (Bernardi et al., 2021; Huang et al., 2020). Although the positive effects of basketball have been documented in various extracurricular contexts, there are currently no Italian randomised controlled trials (RCTs) that use a mixed qualitative-quantitative approach to assess both objective outcomes (e.g. motor and cognitive tests) and students' subjective experiences simultaneously. This study aims to verify the effectiveness of a 10-week basketball workshop on motor coordination (measured using the Movement Assessment Battery for Children-2, MABC-2) and problem-solving skills (assessed using the Tower of London-DX, ToL-DX) in lower secondary school pupils. The results will be integrated with semi-structured interviews and in-game observations (Game Performance Assessment Instrument, GPAI-Basket).

1. Material & methods

Draw and statistical power

A randomised controlled trial (RCT) with a convergent, parallel, mixed-methods approach (Creswell & Plano Clark, 2018) was adopted. Power analysis indicated a minimum of 52 subjects ($f = 0.25$; $\alpha = 0.05$; power = 0.80), but 60 were recruited to compensate for potential dropouts (none of whom occurred).

Participants

Participants were selected if they met all of the following criteria: (1) were aged between 11 and 13 years; (2) scored at or below the 25th percentile on the MABC-2 during classroom screening; (3) had attended at least 90% of lessons in the previous year; and (4) provided parental and personal consent.

Of the 216 pupils in four first-year classes, 68 met the MABC-2 criterion and 60 agreed to participate. Randomisation at a ratio of 1:1 allocated 30 students (14 females and 16 males; mean age 12.0 ± 0.5 years) to the basketball group (BG) and 30 students (13 females and 17 males; mean age 11.9 ± 0.6 years) to the control group (CTRL). Both groups had normal BMI values (BG: 20.3 ± 2.1 kg/m²; CTRL: 20.0 ± 2.4 kg/m²) and MABC-2 scores that were almost identical at the pre-test (BG: 11.1 ± 2.3; CTRL: 11.3 ± 2.1 percentile), confirming their baseline equivalence.

Tools

The Movement Assessment Battery for Children-2 is suitable for children aged 11–16. Three subscales: manual dexterity, ball skills and balance. ICC = 0.88.

Tower of London-DX. Indicators: excessive moves, completion time. Cronbach's $\alpha = 0.83$.

Game Performance Assessment Instrument (GPAI-Basket). Coded dimensions: decision-making, support and skill execution. Scale: 1–5. Inter-rater $\kappa = 0.82$.

Semi-structured interviews. Twelve questions on motivation, strategies, and cognitive transfer were derived from the Physical Activity Self-Efficacy Scale (Huang et al., 2022).

Educational Programme

The basketball workshop consisted of 30 60-minute sessions, spread over 10 weeks (Monday, Wednesday and Friday, 10:00–11:00), providing 1,800 minutes of exposure in total. Each session was designed according to a progression of increasing cognitive load and was divided into five consistent phases. These were supplemented by weekly modules with specific objectives.

Permanent structure

The basketball workshop was designed according to the principles of non-linear pedagogy and ecological dynamics. These principles emphasise the need for continuous adaptation to environmental changes and the emergence of creative solutions (Chow, Renshaw & Davids, 2022; Davids, Renshaw & Glazier, 2013). The organisation into 30 60-minute sessions followed a progression of increasing cognitive load, inspired by constraint-based teaching models applied to physical education (Casey & Goodyear, 2015).

Cognitive-motor warm-up (10 minutes). Mirror running and three-ball juggling games were selected to encourage rapid perception and action processes, as well as stimulating interpersonal attention (Renshaw & Chow, 2019).

Progressive skill drill (15 minutes). Stroboscopic glasses (2 Hz frequency) and 180° rotations were introduced to increase perceptual uncertainty. This practice is identified in the literature as a key factor for the adaptive variability of technical gestures (Appelbaum & Erickson, 2018).

Problem-based tactical task (20 minutes). Each weekly constraint (e.g. Silence Zone, Red Button) manipulates game affordances to promote the search for multiple solutions, in line with the constraints-led paradigm (Davids et al., 2013).

Small-sided game: 4 vs 4 (10 minutes). Half-court games with a 12-second shot clock maximise the volume of decisions per minute, which is associated with better transfer to situational sports (Chow et al., 2022).

Reflection and feedback (5 minutes). The metacognitive diary on Padlet and filmed peer feedback respond to the need for autonomous reflection, thereby increasing the sense of agency (Goodyear & Dudley, 2015).

Session monitoring

Counting the number of correct decisions made per minute and continuously recording heart rate are both consistent with the recommendations for tracking cognitive load in open-skill sports (Pesce et al., 2023).

Individualised adaptations

In the first four weeks, students with an MABC-2 percentile below the tenth percentile received facilitations (a size 5 ball and a jolly defender with reduced pressure). These facilitations were gradually withdrawn according to the scaffolding principle applied to motor learning.

The control group attended traditional physical education lessons, including general gymnastics, athletics, relay races and low-cognitive-density team games, for an equivalent amount of time.

Data collection and analysis

Quantitative tests were conducted before the intervention (T_0) and 72 hours afterwards (T_1). The analysis used mixed ANOVA (group × time) with Holm-Bonferroni correction and Cohen's d with 95 per cent confidence intervals. The 4 vs. 4 matches were video recorded (GoPro-10, 60 fps) and coded in a double-blind manner. The interviews (25 GCSE students and 5 EFL teachers) were transcribed and analysed using thematic analysis (Braun & Clarke, 2022); the reliability was $\kappa = 0.86$.

2. Quantitative Results

Statistical analysis of the data revealed significant effects of the intervention on all the main variables. In particular, the mixed ANOVA model revealed a significant interaction between group and time ($p < 0.001$), suggesting that the observed changes in the experimental group (EG) are not merely due to temporal exposure, but are specifically linked to the basketball laboratory. Regarding motor coordination, MABC-2 results showed a substantial increase in the EG, with an average shift from percentile 11.1 (±2.3) to percentile 24.3 (±4.1). This corresponds to an improvement of 13.2 percentiles ($d = 1.86$), which is classifiable as a very large effect according to Cohen's criteria. The 'ball skills' subscale showed the most significant improvement (+22.1 percentiles), suggesting that the visuomotor domain is more sensitive to the stimuli provided by a high-cognitive-density, open-skill sporting context. The other two subscales (manual dexterity and balance) also showed statistically significant increases, albeit less pronounced ones.

For the cognitive dimension, the results of the Tower of London DX test show that GC reduced the number of unnecessary moves by an average of 3.2 (from 6.4 to 3.2), demonstrating a significant effect size ($d = 1.34$). At the same time, the average time taken to solve the problems decreased from 94 to 71 seconds ($\Delta = -23$ s; $d = 1.22$), suggesting improvements in planning and managing actions in terms of time. The control group showed minimal changes in both areas, confirming the intervention's specific effectiveness. Observations made during the game and coded using the GPAI-Basket reinforce these findings. The average increase in the correct decision-making index for the GC was 72%, rising from an initial score of 1.8 to 3.1 out of 5. In contrast, the CTRL group showed a modest increase of 11%, which is likely due to repeated exposure to the tests. Growth in tactical performance suggests that training in dynamic and constrained environments facilitates the development of flexible and adaptive perceptual-decision-making patterns. Finally, it should be emphasised that adherence to the protocol was high at 95.6%, with no dropouts. Cognitive load variables (decisions per minute and heart rate) showed linear progression consistent with the teaching structure of the intervention. The consistency between the results relating to motor skills, cognition and tactics provides further support for the robustness of the observed effect.

3. Qualitative results

A qualitative analysis of 25 interviews with GC students and five interviews with physical education teachers identified three recurring macro-themes, each of which was divided into sub-themes that emerged from the narratives. Thematic coding (Braun & Clarke, 2022) was conducted in a double-blind manner, achieving an inter-judge agreement coefficient of $\kappa = 0.86$, thereby guaranteeing the reliability of the interpretative process. The first macro-theme concerns strategic awareness. Students described an evolution in their playing style, shifting from a reactive approach to one oriented towards anticipatory planning. Statements such as 'I now know two options before receiving the ball' demonstrate an improvement in their ability to anticipate and read game situations. Teachers confirmed that, over the weeks, pupils began to verbalise tactical concepts such as the use of empty space and the timing of running into space. This is indicative of a more abstract and reflective approach to the game. The second theme, embodied problem solving, refers to the ability to use the body as a cognitive tool. Several students explained that gestures such as feints or changes of pace were used not only to 'trick the opponent', but also to gain time and make decisions. Video observations support these claims, showing that correct decisions were made 40% more often when movement was regulated in time. This phenomenon appears to align with the paradigm of embodied cognition, which states that motor activity is not separate from the cognitive sphere, but rather constitutes a fundamental vehicle for it. Finally, the third theme concerns adaptive confidence. Many students reported gaining greater confidence in both the playing field and school contexts, particularly in science and mathematics. Some said they had started using the problem-solving strategies they had learned in the laboratory during classroom tests, recalling the 'if... then' patterns they had developed during tactical activities. Interestingly, teachers confirmed this cognitive transferability, observing a more proactive and autonomous attitude in pupils, even outside the sporting context. Two students, both of whom had initial MABC2 scores below the 5th percentile and initially showed signs of frustration and withdrawal, described a progressive change in their self-perception. A combination of teaching adaptations, peer feedback and metacognitive strategies enabled them to experience incremental successes, which reinforced their intrinsic motivation and willingness to tackle complex tasks. Overall, the qualitative results confirm the quantitative outcomes phenomenologically, showing how the workshop activated motor and cognitive patterns as well as processes of reflection, motivation, and personal growth that extend beyond the playing field.

4. Discussion

The results converge in supporting the claim that a basketball laboratory with a high cognitive load optimises the motor-cognition interface. At the perceptual-motor level, variable practice with delayed feedback was found to encourage the development of flexible motor patterns, which is consistent with Generalised Motor Programme Theory (Schmidt & Lee, 2020). The improvement in ball skills indicates greater efficiency of parietal–cerebellar circuits, consistent with fMRI evidence from Ishikawa et al. (2023) regarding complex eye–hand exercises.
In terms of executive function, the reduction in excess movements in the ToL-DX indicates an improvement in hierarchical planning and error monitoring processes (Anderson, 2021). The pass count constraint, which imposes temporal and spatial limits, may have strengthened the connection between the dorsal fronto-parietal network and the salience network (Menon, 2022), thereby promoting faster and more accurate decision-making. The macro-theme of embodied problem solving confirms that embodied cognition is not just a metaphor, but an observable practice (Foglia & Wilson, 2023). The continuous link between technical gestures and strategic reasoning appears to be a cognitive scaffolding mechanism (Clark, 2021). Increased adaptive confidence reinforces the mediating role of Self-Determination Theory: the workshop's structure — progressive challenges, empowering feedback and reflection — probably satisfied the need for competence, autonomy and relatedness (Ryan & Deci, 2020), which are predictors of long-term engagement. The effect size on the MABC-2 ($d = 1.86$) is comparable to that observed in studies of multi-skill interventions (Smits-Engelsman & Wilson, 2023). For executive functions, our $d = 1.34$ on the ToL-DX is higher than the average reported by de Bruin et al. (2024) in their meta-analysis of open skill programmes of double duration.

5. Conclusions

This study provided robust and converging evidence in support of the effectiveness of a basketball laboratory designed according to the principles of ecological-dynamic learning and problem-based pedagogy. The intervention produced statistically and clinically significant improvements in both the motor and cognitive domains. This is demonstrated by the mean increase of +13 centiles in the MABC-2, as well as the significant reductions in excess moves (-3.2) and mean time (-23 seconds) in the Tower of London DX problem-solving test. These results exceed the effects observed in comparable studies and are consistent with the observational and qualitative data collected. This work's distinctive feature lies in the laboratory's ability to generate a multidimensional impact: improvements in coordination and executive functions were accompanied by clear transformations in strategic thinking processes, the use of the body as a cognitive mediator, and perceived self-efficacy. This suggests that, when properly structured, motor activity can act as a real vehicle for integrated development, providing a platform for exercising not only physical skills, but also metacognitive, affective, and social skills. The mixed qualitative-quantitative approach adopted enables a deeper interpretation of the results than is possible with numbers alone, reflecting the complexity of the students' educational experience. The interaction between metacognitive reflection, cognitively demanding exercises, and peer feedback created a positive cycle of learning that impacted physical practices, mental representations, and problem-solving methods in both the classroom and on the field. In light of these findings, the workshop can be considered a transferable prototype for an integrated educational intervention capable of responding to the need for personalisation and inclusivity in lower secondary schools. The structural inclusion of open skill sports modules in the curriculum could significantly contribute to counteracting coordination difficulties and poor strategic thinking in vulnerable student groups, while enhancing school engagement and self-confidence.

However, some limitations must be acknowledged: the intervention's relatively short duration (10 weeks) prevents definitive conclusions from being drawn about the stability of the results over time. Furthermore, the absence of neurophysiological measurements limits the ability to describe the underlying neural mechanisms of the change. Future studies should include medium- and long-term follow-ups, as well as integrating functional neuroimaging or EEG techniques to more accurately map the evolution of the cognitive and motor networks involved.

In conclusion, this study is an important step forward in developing an educational approach that integrates the body and mind. It demonstrates that, when intentionally designed, school sport can improve physical performance and stimulate the development of higher cognitive abilities and transversal skills that are essential for individuals' growth during their formative years.

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