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Developmental trajectories of motor imagery in relation to physical fitness in children aged 7 to 14 years: A 1-year follow-up study

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ABSTRACT

Motor imagery (MI) is fundamentally linked to the motor system. It improves motor learning and optimizes motor actions without physical execution, highlighting its unique role in rehabilitation programs and motor performance. Understanding the developmental trajectories of MI and the factors influencing its variability across ages could enable more effective, age-specific strategies for pediatric rehabilitation. This study assessed 65 children aged 7 to 14 years at two time points 1 year apart. MI ability was assessed using the Movement Imagery Questionnaire for Children, and physical fitness was evaluated using the SLOfit testing battery. Among the three perspectives assessed; internal visual imagery (IVI), external visual imagery (EVI), and kinesthetic imagery (KI), KI was unique in not correlating with age at both time points. The development of MI perspectives varied between athletes and non-athletes, with non-athletes showing a decline in IVI compared with athletes. This differential was further evidenced by significant differences in KI between the groups at the second assessment, with a similar trend observed at the first assessment. Of the physical fitness tests, only the 600-m run correlated consistently with KI at both assessments. Our findings suggest that regular participation in sports significantly affects KI performance, highlighting the importance of sports participation for the development of MI abilities in children. Future research should examine additional assessment points in different age groups and sport experience to better

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understand the development of MI and its potential implications for pediatric rehabilitation.

Introduction

Motor imagery (MI) is a cognitive phenomenon in the domain of cognitive function that involves creating a mental stimulation of a motor action without any visible body movement (Decety, 1996). This form of cognitive skills has been shown to elicit similar brain activity patterns to actual task execution (Marusic & Grosprêtre, 2018), particularly in the motor and premotor cortex areas (Porro et al., 1996). This similarity allows MI to improve motor performance (Zhang et al., 2011) and facilitate motor learning (Simonsmeier et al., 2021) in healthy young and older adults (Ruffino et al., 2017) as well as in patients recovering from neurological conditions (Braun et al., 2013) and injuries (Marusic et al., 2018).

Recent meta-analyses involving both healthy and symptomatic children and adolescents underscore the potential of MI for enhancing motor performance and facilitating the rehabilitation of motor functions (Behrendt et al., 2021; Frank et al., 2023). Specifically, studies on healthy children have demonstrated a medium positive effect of MI training on motor performance (Frank et al., 2023). Despite these positive findings, the authors noted the poor quality of the included studies, with few randomized controlled trials and a lack of detailed knowledge about the developmental trajectories of MI in children and the key factors influencing its progression.

Specifically, it remains unclear at what age children can fully develop MI skills. Current literature suggests that only a few children aged 5 to 7 years are capable of MI, and these skills do not stabilize until 10 to 12 years (Caeyenberghs, Wilson, et al., 2009; Smits-Engelsman & Wilson, 2013). Although evidence indicates that MI can improve motor performance (Doussoulin & Rehbein, 2011), the effect of regular participation in a sport training program and physical fitness on MI ability remains largely unexplored (Behrendt et al., 2021). In addition, there is limited understanding of the developmental trajectories of various MI categories and the extent to which they are influenced by these factors.

MI can be broadly classified into two categories: kinesthetic imagery (KI), where one imagines the sensations of bodily movements, and visual imagery, which is further divided into internal and external categories based on perspective. Internal visual imagery (IVI) entails creating mental images from a first-person viewpoint, whereas external visual imagery (EVI) involves creating images from a third-person perspective.

Understanding the factors that influence different categories of MI can significantly enhance and accelerate the rehabilitation of motor functions in children with impairments. For instance, research has shown that KI tends to be more effective in motor learning (Fontani et al., 2014), gaining muscle strength (Yao et al., 2013), and maintaining muscle strength (Paravlic et al., 2018). KI is also more successful in activating sensorimotor representations (Meugnot et al., 2015; Oldrati et al., 2021). Neurologically, KI produces brain activation patterns that more closely resemble those of actual motor execution compared with visual imagery methods (Yang et al., 2021). Gaining a deeper understanding of MI developmental trajectories and the factors that primarily influence the ability to recreate various categories of MI across different ages could lead to more effective and tailored strategies for pediatric rehabilitation.

In our previous study (Šlosar et al., 2023), we assessed MI ability in 100 elementary school children and found that those who regularly engaged in training programs achieved higher scores in KI. This finding is consistent with research by Robin et al. (2021), which indicated that adult athletes have greater proficiency in KI compared with non-athletes. To further investigate the effect of regular engagement in a training process on MI ability and its various categories across developmental stages, our current study aimed to (1) explore the development of MI in children aged 7 to 14 years and (2) assess how MI relates to physical fitness, using tests administered twice a year. This study aimed to deepen our understanding of MI developmental trajectories and their interaction with consistent engagement in training programs.

Method

Participants

The enrollment process was conducted twice within a year, comprising two main phases. In May 2022, a cohort of 100 children (50 girls and 50 boys; mean age = 10.3 ± 1.3 years, range = 7–13) was recruited from a local elementary school (Piran, Slovenia) to participate in the Šlosar et al. (2023) study. Eligibility was restricted to children aged 7 to 13 years in accordance with the age range criteria established by Martini et al. (2016) for the Movement Imagery Questionnaire for Children (MIQ-C) assessment. Participants with injuries, chronic physical impairments, or cognitive disorders were excluded. A year later, in May 2023, a subset of 65 children (31 girls and 34 boys; mean age = 11.4 ± 1.6 years, range = 8–14) from the same group, available for re-enrollment, underwent a subsequent evaluation for the study. Table 1 provides a demographic breakdown of the 65 participants tested at both time points categorized by age, sex, and athletic status. The analysis in this research focused exclusively on this subset for both the initial and subsequent measurements. Parents provided children's personal details, including their current athletic status classified as either "athlete" or "non-athlete." An "athlete" designation indicated consistent engagement for a minimum of 6 months in structured activities that featured guided instructional or coaching sessions aimed at skill development or specific objectives. During the second assessment, this period was extended to 1 year. This adjustment aimed to enhance the distinction between athletes and non-athletes and to clarify the implications of regular sports participation. The study was approved by the Science and Research Centre Koper ethics committee.

Measures

Motor imagery ability

The study used the validated Slovene translation of the MIQ-C (Šlosar et al., 2023) to assess the MI ability in children. Mean scores were calculated for each evaluated imagery perspective (IVI, EVI, and KI), with higher scores denoted as superior mental imagery abilities.

Physical fitness

The assessment of physical fitness was conducted using the SLOfit system (Jurak et al., 2020), a Slovenian national surveillance system for monitoring children's motor development. The test battery comprised six specific tests:

—*Backward obstacle course:* This test assesses participants' coordination while maneuvering through a 10-m obstacle course. Participants are required to overcome a 50-cm-high box and slide inside a frame measuring 23 cm in diameter by walking backward on all fours (ensuring that hands do not slide), aiming to complete the course as quickly as possible.
—*20-s arm plate tapping:* This assessment measures the repetitive speed of alternate tapping using the dominant arm on two round plates, each 20 mm in diameter, positioned 61 cm apart at their

Table 1
Demographic breakdown of 65 participants by age, sex, and athletic status

Age (years)	Day 1		Day 365	
	Boys/Girls	Athletes/Non-athletes	Boys/Girls	Athletes/Non-athletes
7	2/2	2/2		
8	1/1	1/1	2/2	3/1
9	3/8	6/5	1/1	1/1
10	7/8	8/7	3/8	7/4
11	10/7	12/5	7/8	8/7
12	8/2	6/4	10/7	13/4
13	3/3	4/2	8/2	6/4
14			3/3	4/2

nearest edges. Participants are tasked with tapping between the two plates as many times as possible within a 20-s interval.

—*Bent arm hang:* This evaluation assesses arm and shoulder girdle strength by timing how long individuals can maintain a position with their arms bent, keeping their chin above the high bar.

—*Standing long jump:* This test measures explosive strength by evaluating the distance achieved in a standing long jump performed on a specialized mat designed to measure the jump's length.

—*60-m run:* Speed is assessed using a 60-m sprint test conducted from a standing start.

—*600-m run:* General aerobic endurance is assessed with a 600-m run test conducted along a circular path.

Procedure

Both the MIQ-C and SLOfit assessments were carried out twice in a year: first in May 2022 (hereinafter referred to as Day 1) and then in May 2023 (referred to as Day 365). Cognitive interviews using the MIQ-C were carried out by two researchers on both Day 1 and Day 365 (within a range of ±2 days). Adhering to a consistent protocol, both researchers ensured that all participants were situated in identical conditions—a calm and silent room maintained at an optimal temperature. On Day 365, the participants were interviewed by the same researcher who had conducted their interviews on Day 1. Detailed information regarding the visual imagery scores from both the IVI and EVI perspectives, as well as KI, has been extensively elaborated elsewhere (Šlosar et al., 2023).

The assessment of physical fitness was part of the annual national surveillance monitoring consistently conducted during the same period each year. The procedure for each test was meticulously supervised by the same physical education professor.

Statistical analysis

All data are presented with an average and standard deviation. All statistical tests were performed with SPSS 25.0 (IBM, Armonk, NY, USA). To compare results between Day 1 and Day 365, the Wilcoxon signed-rank test was employed. Sex (boy/girl) and athletic status (athlete/non-athlete) differences were evaluated using the Mann–Whitney test. Spearman's p correlations were used to examine the relationship between MIQ-C scores and age on both Day 1 and Day 365, with values $\geq .10$ indicating a weak correlation, scores $\geq .40$ indicating a moderate correlation, and scores $\geq .70$ indicating a strong correlation, as interpreted according to Schober et al. (2018). The progression of IVI, EVI, and KI among athletes, non-athletes, and semi-athletes (those who became athletes by the second assessment) is illustrated using spaghetti plots, with further detailed analysis of progression in athletes and non-athletes conducted using the Wilcoxon signed-rank test. Nonparametric partial correlations, controlling for age, were computed to explore the associations between SLOfit and MIQ-C scores in all participants and within subgroups based on athletic status. A significance level of $p < .05$ was applied for all statistical analyses. Scatter plots were used to visually inspect correlations, with consideration for potential outliers.

Results

The Wilcoxon signed-rank test (Table 2) showed no significant differences between Day 1 and Day 365 ($ps > .05$) across all assessed MI perspectives. No differences in mean IVI, EVI, and KI values were

Table 2
Differences between Day 1 and Day 365 of all assessed motor imagery perspectives

Day 1			Day 365		
	M	*SD*	*M*	*SD*	*p*
KI	4.76	1.02	4.91	1.32	.232
IVI	5.48	1.06	5.23	1.29	.297
EVI	5.22	1.41	5.48	1.27	.082

Note. KI, kinesthetic imagery; IVI, internal visual imagery; EVI, external visual imagery.

found between sex categorization or between athletes and non-athletes except for KI at Day 365 (p = .039), as shown in Table 3.

Correlation testing between age and MI perspectives revealed significant associations with IVI and EVI at both Day 1 (IVI: r_s = .264, p = .032; EVI: r_s = .392, p = .001) and Day 365 (IVI: r_s = .308, p = .013; EVI: r_s = .361, p = .003). Notably, KI showed no correlation with age across both assessment periods (Day 1: r_s = .222, p = .073; Day 365: r_s = .083, p = .509) (Fig. 1).

The spaghetti plot (Fig. 2) illustrates the progression in IVI, EVI, and KI among athletes, non-athletes, and semi-athletes (those who became athletes by the second assessment).

Due to the limited sample size of only 3 cases, detailed progression analysis was confined to athletes and non-athletes. This analysis found no significant differences between the two assessments except for a notable decline in IVI (p = .038) over time in non-athletes (Table 4).

After controlling for age, the analysis was conducted to examine the relationship between various physical fitness tests and MI perspectives across all participants, with a specific focus on athletes and non-athletes. In the entire cohort, a weak correlation was observed solely between KI and the 600-m test at both Day 1 (r_s = −.283, p = .046) and Day 365 (r_s = −.300, p = .038). The analysis of subgroups based on athletic status revealed no additional significant pairwise comparisons (ps > .05) (Table 5).

Table 3
Sex categorization (girls = 31; boys = 34) and athletic status differences at Day 1 (athletes = 39; non-athletes = 26) and Day 365 (athletes = 42; non-athletes = 23)

Dimension		Category	*M* ± *SD*	*p*
KI	Day 1	*Sex*		
		Girls	4.70 ± 0.95	
		Boys	4.82 ± 1.09	.718
		Athletes vs. non-athletes		
		Athlete	4.92 ± 1.03	
		Non-athlete	4.54 ± 0.96	.082
	Day 365	*Sex*		
		Girls	4.65 ± 1.16	
		Boys	5.13 ± 1.43	.075
		Athletes vs. non-athletes		
		Athletes	5.12 ± 1.32	
		Non-athletes	4.52 ± 1.25	.039*
IVI	Day 1	*Sex*		
		Girls	5.58 ± 0.94	
		Boys	5.39 ± 1.17	.584
		Athletes vs. non-athletes		
		Athletes	5.35 ± 1.08	
		Non-athletes	5.70 ± 1.02	.130
	Day 365	*Sex*		
		Girls	5.04 ± 1.35	
		Boys	5.39 ± 1.24	.262
		Athletes vs. non-athletes		
		Athletes	5.28 ± 1.44	
		Non-athletes	5.13 ± 0.98	.228
EVI	Day 1	*Sex*		
		Girls	5.01 ± 1.43	
		Boys	5.40 ± 1.38	.293
		Athletes vs non-athletes		
		Athletes	5.17 ± 1.60	
		Non-athletes	5.30 ± 1.04	.810
	Day 365	*Sex*		
		Girls	5.27 ± 1.30	
		Boys	5.66 ± 1.23	.164
		Athletes vs non-athletes		
		Athletes	5.51 ± 1.37	
		Non-athletes	5.43 ± 1.09	.456

Note. KI, kinesthetic imagery; IVI, internal visual imagery; EVI, external visual imagery.
* p < .05.

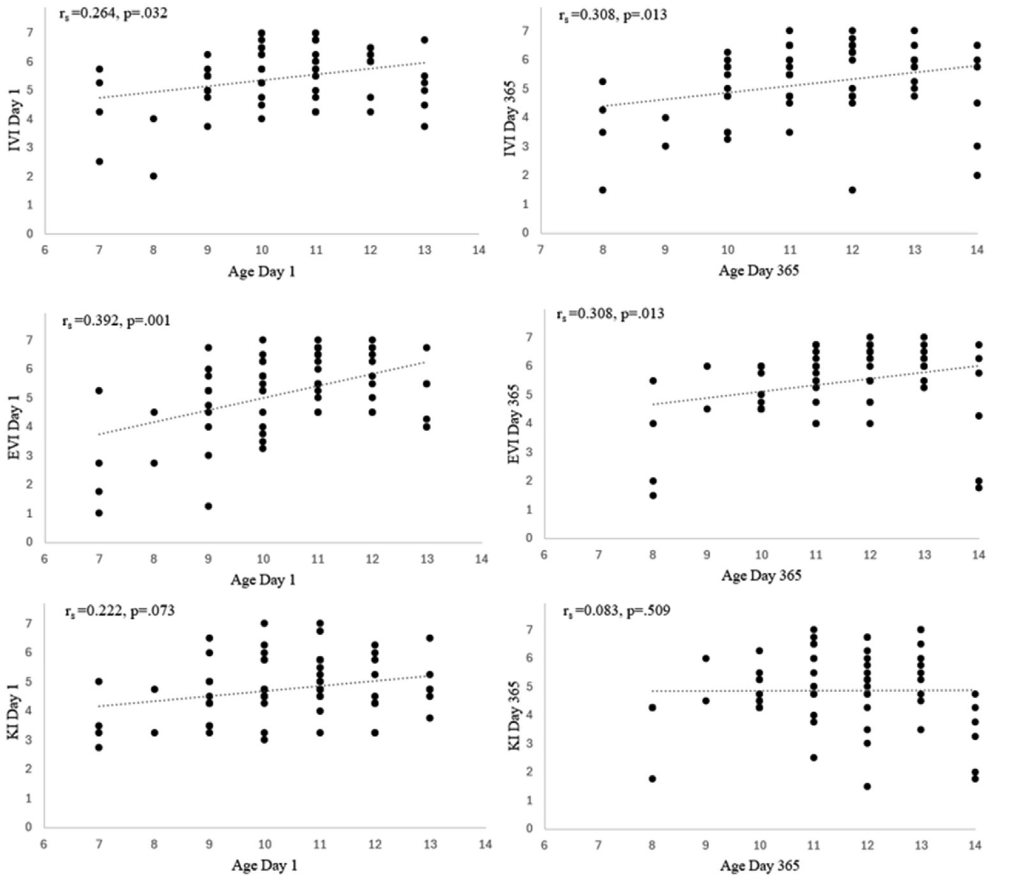

Fig. 1. Correlation analysis between age and motor imagery perspectives (internal visual imagery [IVI], external visual imagery [EVI], and kinesthetic imagery [KI]) on Day 1 and Day 365.

Discussion

Our study involving elementary school-aged children revealed distinct developmental trajectories of MI perspectives over a 1-year follow-up period. Specifically, the measures of EVI, IVI, and KI did not show improvement over the year. Among the three perspectives assessed, KI was unique in not correlating with age at both time points. In addition, the progression of MI perspectives varied between athletes and non-athletes, with non-athletes exhibiting a decline in IVI compared with athletes. This differential progression was further reflected in the significant differences observed in KI scores between the two groups at Day 365, with a similar trend observed at Day 1. When investigating the relationship between physical fitness tests and MI perspectives, the 600-m run was the sole test consistently correlating with KI in both assessments.

MI has been extensively investigated in rehabilitation practices (Marusic & Grosprêtre, 2018; Paravlic, 2022) and sport performance (Ladda et al., 2021). However, a few studies explored the course of MI development in elementary school-age children and the key factors influencing their ability to vividly engage in it. Research indicates that MI ability develops alongside motor skills throughout childhood, with the relationship between the two strengthening with age (Caeyenberghs, Tsoupas, et al., 2009). Compared with Caeyenberghs, Tsoupas, et al.'s (2009) and Caeyenberghs, Wilson, et al.'s (2009) evaluation of MI in terms of performance, including errors and movement time, our study focused on assessing the vividness of imaging movements in all three existing perspectives.

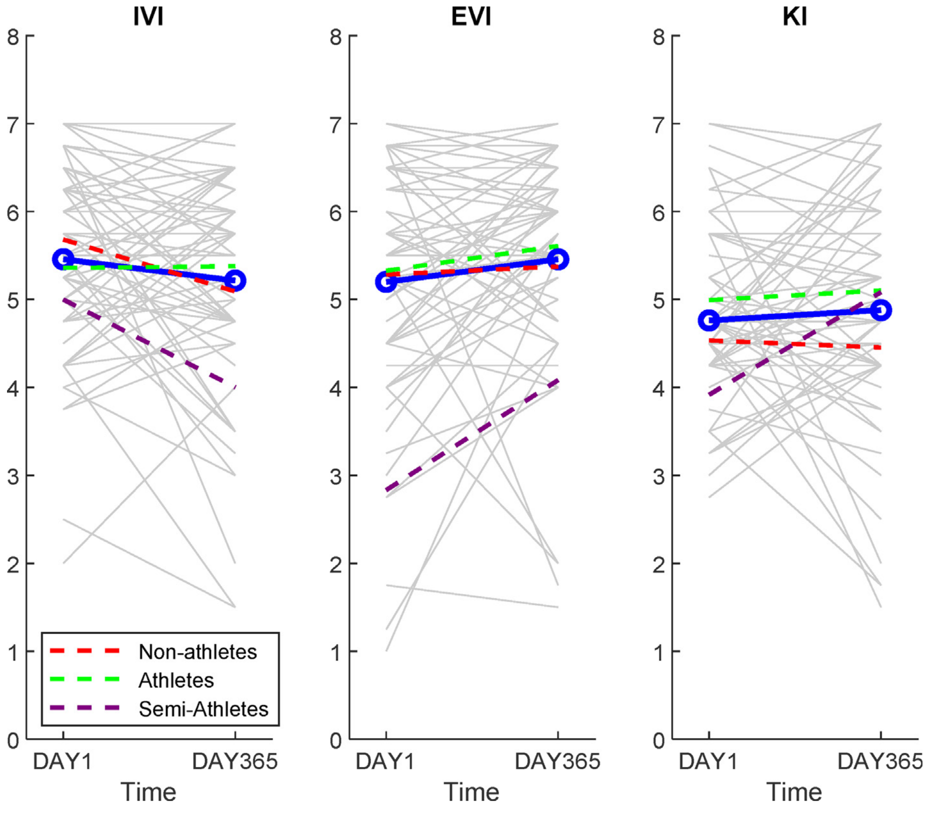

Fig. 2. Progression of athletes (n = 39), non-athletes (n = 23), and semi-athletes (n = 3) in internal visual imagery (IVI), external visual imagery (EVI), and kinesthetic imagery (KI) from Day 1 to Day 365. In this figure, the solid blue line with circles indicates the average progress of all participants irrespective of their athlete status.

Table 4
Wilcoxon test analysis of motor imagery perspective differences between Day 1 and Day 365 in athletes and non-athletes

	Athletes			Non-athletes		
Dimension	Day 1 *M* ± *SD*	Day 365 *M* ± *SD*	*p*	Day 1 *M* ± *SD*	Day 365 *M* ± *SD*	*p*
IVI	5.36 ± 0.98	5.37 ± 1.30	.450	5.68 ± 1.05	5.09 ± 0.99	.038*
EVI	5.32 ± 1.39	5.61 ± 1.23	.132	5.28 ± 1.06	5.37 ± 1.08	.701
KI	4.99 ± 1.01	5.11 ± 1.30	.328	4.53 ± 0.98	4.25 ± 1.56	.486

Note. KI, kinesthetic imagery; IVI, internal visual imagery; EVI, external visual imagery.
* $p < .05$.

When investigating children's MI ability and its potential correlation with physical fitness, it is crucial to measure the clarity with which children can imagine movements using appropriate assessment tools (Martini et al., 2016). Our findings illustrate distinct developmental trajectories for the different MI perspectives. Specifically, whereas IVI and EVI were found to be associated with age, KI appeared to be more influenced by participants' involvement in structured sport activities, reflecting the evolving capability to generate and monitor internal models of action (Robin et al., 2021). Over the 1-year period, non-athletes exhibited a significant decrease in IVI, with a similar but nonsignificant decline observed in KI. Conversely, athletes showed slight improvements across all assessed perspectives at

Table 5

Controlling for age, nonparametric partial correlation analysis (r_s and p values reported) between different physical fitness tests and motor imagery perspectives

	Day 1						
		Backward obstacle course	20-s arm plate tapping	Bent arm hang	Standing long jump	60-m run	600-m run
All	KI	.176 (.233)	.019 (.898)	.220 (.125)	.217 (.131)	−.159 (.270)	−.283 (.046) *
	IVI	−.050 (.731)	.053 (.713)	.077 (.597)	.066 (.650)	−.113 (.435)	−.021 (.885)
	EVI	−.006 (.967)	.157 (.277)	.230 (.108)	.261 (.067)	−.160 (.266)	−.235 (.100)
Athletes	KI	.243 (.180)	.078 (.672)	.183 (.315)	.148 (.419)	−.102 (.579)	−.172 (.348)
	IVI	−.081 (.659)	−.013 (.945)	−.032 (.863)	.064 (.855)	−.095 (.607)	.082 (.654)
	EVI	−.082 (.654)	.173 (.344)	.105 (.569)	.251 (.165)	−.208 (.254)	−.110 (.549)
Non-athletes	KI	−.042 (.892)	−.043 (.890)	.301 (.318)	.122 (.690)	−.324 (.280)	−.263 (.385)
	IVI	.037 (.904)	.437 (.135)	.274 (.134)	.130 (.672)	−.288 (.340)	−.310 (.303)
	EVI	.004 (.989)	.444 (.129)	.155 (.221)	.214 (.482)	−.044 (.887)	−.186 (.543)
	Day 365						
		Backward obstacle course	20-s arm plate tapping	Bent arm hang	Standing long jump	60-m run	600-m run
All	KI	−.124 (.402)	.025 (.865)	−.150 (.310)	.172 (.242)	−.124 (.399)	−.300 (.038) *
	IVI	−.153 (.301)	.075 (.613)	−.022 (.880)	.025 (.864)	.120 (.418)	−.093 (.529)
	EVI	−.107 (.470)	.195 (.185)	.061 (.682)	.158 (.283)	.121 (.413)	-.073 (.620)
Athletes	KI	.124 (.296)	−.182 (.311)	−.248 (.165)	−.088 (.625)	.029 (.874)	−.113 (.530)
	IVI	−.031 (.866)	.019 (.918)	−.092 (.612)	.030 (.870)	.113 (.532)	−.068 (.707)
	EVI	−.064 (.723)	.192 (.284)	.053 (.768)	.071 (.693)	.126 (.485)	.014 (.940)
Non-athletes	KI	−.272 (.419)	.245 (.468)	−.057 (.867)	.440 (.175)	−.310 (.353)	−.336 (.312)
	IVI	.170 (.616)	−.198 (.560)	.139 (.684)	−.503 (.115)	.469 (.146)	.466 (.149)
	EVI	.257 (.445)	−.025 (.942)	−.180 (.597)	.135 (.692)	.150 (.659)	.002 (.996)

Note. The *p* values are in parentheses. KI, kinesthetic imagery; IVI, internal visual imagery; EVI, external visual imagery.

* Correlation is significant at the .05 level.

the second assessment. These results support the concept that active individuals generally exhibit more advanced and rapid development of MI capabilities compared with sedentary individuals. Furthermore, this is consistent with the theory that physical fitness enhances the perception, integration, and processing of somatosensory information, thereby improving MI skills (Mandolesi et al., 2024).

When exploring the relationship between MI and selected tests assessing physical fitness, results demonstrate a trend toward a moderate correlation between KI and the 600-m run test. These results reinforce our previous findings, supporting the hypothesis that KI is closely associated with movement skills. It can be argued that the development of KI in children is significantly influenced by their participation in sports. Through structured guidance from coaches and repetitive practice of specific skills, children are required to visualize and execute complex movements, which provides more KI practice compared with non-athletes. In contrast, conflicting findings arise from Zapała et al. 's (2021) study, suggesting that visual MI rather than kinesthetic MI is associated with nonspecific motor skills. It is crucial to note, however, that all the children involved in their study were football players, and the evaluated motor skills were limited to tasks such as the reaction time task and the eye–hand coordination task.

Among the physical tests assessed in our study, endurance appears to be the most effective discriminator between children who consistently participate in a training process and those who do not. Although further statistical investigation is constrained by the age heterogeneity of participants, our assumption gains support from the observation that, at this young age, certain physical abilities may naturally excel without accumulated sport training, such as explosive power (related to the standing long jump), velocity (60-m run test), coordination (backward obstacle course), and strength (bent arm hang). Conversely, endurance, if not regularly trained, appears challenging to elevate to a higher level. Although we did not find direct scientific evidence supporting our hypothesis, existing studies indicate that youth athletes outperformed non-athletes on cardiorespiratory fitness tests (Armstrong et al., 2011; Silva et al., 2013).

Compared with the commonly used mental chronometry paradigm, which compares the duration of actual and imagined performance (Souto et al., 2020; Spruijt et al., 2015), our study explored the distinct categories of MI development. By assessing the vividness of IVI, EVI, and KI, we provided a deeper understanding of the underlying processes in motor–cognitive development during childhood. Our findings offer valuable insights into determining the most practical method for optimizing pediatric rehabilitation with children of varying ages and experiences; given that children's MI abilities can vary greatly, understanding which forms of MI are most effective for developing or relearning physical abilities can enhance effectiveness of rehabilitation programs.

Although the association found between participation in structured training programs and MI is noteworthy, it is crucial to consider the limitations of the measures employed in interpreting these findings. Although widely accepted for testing the physical fitness of Slovene children, alternative measures, such as the Test of Gross Motor Development–Third Edition (Ulrich, 2019), are more established in the literature. Similarly, enhancing the assessment of MI could be achieved by incorporating additional tasks into the questionnaire, such as mental chronometry (Greiner et al., 2014). Our results suggest that EVI and IVI may be related to children's developmental stages, whereas KI performance appears to be linked to their accumulated sports experience. However, these interpretations should be viewed with caution due to their speculative nature. The consistent correlation between the 600-m run and KI in both assessments warrants further investigation through experimental studies to explore these relationships more deeply.

Conclusions

In our investigation, we found that consistent engagement in a well-structured training program can effectively shape the development trajectory of MI abilities. Of particular note is the finding that only KI exhibits a unique absence of correlation with age, emphasizing a robust link with accumulated sports expertise. This understanding implies that the refinement of KI skills in young individuals is not merely a function of time but also is intricately tied to the depth and quality of sports involvement. Although MI has received considerable attention in rehabilitation and sports, our study contributes novel perspectives on MI development in children. The outcomes offer valuable insights that may aid in identifying optimal methods for enhancing pediatric rehabilitation across diverse age groups and varying levels of sports expertise.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Chat GPT 3.5 to refine the text and make it more fluid. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Luka Šlosar: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Katarina Pus:** Writing – review & editing, Investigation, Data curation. **Uros Marusic:** Writing – review & editing, Resources, Methodology, Conceptualization.

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Data availability

Data will be made available on request.

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