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Mental imagery in education: What impact on the relationships with visuospatial processing and school performance in junior high school students?

Elena Commodari [a], Jasmine Sole [a], Maria Guarnera [b], Valentina Lucia La Rosa [a,*]

[a] Department of Educational Sciences, University of Catania, Via Biblioteca 4, 95124 Catania, Italy
[b] Faculty of Human and Social Sciences, Kore University of Enna, 94100 Enna, Italy

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ABSTRACT

This study examined the relationship between mental imagery, visuospatial processing, and academic performance among junior high school students. The influence of these variables on learning outcomes in Italian, mathematics, art, and music was also investigated. Third-year students were tested using the Mental Imagery Test and Raven's Progressive Matrices. Gender differences were explored, revealing no significant differences in mental imagery and visuospatial processing. Higher mental imagery correlated with better academic performance, particularly in Italian and mathematics. Visuospatial processing mediated the relationship between mental imagery and academic performance in Italian and mathematics, suggesting its significant role in these subjects. However, this mediation was not significant for music and art, suggesting the involvement of alternative cognitive mechanisms. These findings highlight the importance of mental imagery and visuospatial processing in academic success, particularly in abstract subjects, and advocate for educational strategies targeting these cognitive domains to enhance not only student performance but also creativity and thinking skills.

1. Introduction

1.1. The role of mental imagery in cognitive functions

The role of mental imagery in cognitive processes has been a subject of interest for many years, and its impact on various aspects of human cognition and behavior has been widely recognized (Pearson, 2019; Pearson et al., 2015). Mental images are internal representations that reflect sensory, perceptual, emotional, or other types of experiential states that a person is aware of and that exist without external stimuli that typically produce perceptual or emotional equivalents (Guarnera et al., 2017; Jaencke et al., 2017; Spagna, 2022). These images are central to many cognitive functions, such as perception and memory (Wimmer et al., 2015). *Mental imagery* is a cognitive function that creates multisensory mental images or representations of perceived or remembered objects (Guarnera et al., 2019; Kosslyn, 1994; Richardson, 1969). This function is crucial in enhancing visual perception and memory performance processes. In particular, it involves the ability to manipulate mental images to accomplish a specific task (Guarnera et al., 2017, 2019).

* Corresponding author.
E-mail address: valarosa@unict.it (V.L. La Rosa).

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Kosslyn (1980) described four main mental imagery processes: generation, inspection, maintenance, and transformation. Later, Pearson et al. (Pearson et al., 2013) provided a detailed explanation of these processes. *Generation* involves the formation of mental representations that do not rely on external stimuli. Specifically, an image can be formed from immediate sensory data (such as looking at a photograph, creating a mental image, and retaining it after looking away or closing one's eyes) or from information previously stored in long-term memory (Guarnera et al., 2019). *Maintenance* refers to the ability to hold images in short-term memory. In particular, once formed, a mental image fades quickly, typically lasting only approximately 250 ms, the time it takes to move the eyes (Guarnera et al., 2017, 2019; Kosslyn, 1980, 1994). This short lifespan suggests the need for active maintenance to enable further imaging tasks such as inspection or transformation. *Inspection* involves examining a created image to understand specific features or spatial attributes. For example, to describe the shape of a fox's ear, one would first visualize the fox and then inspect the shape of the ear within this mental image to form an answer (Kosslyn et al., 2001). Finally, *transformation* is the process of changing the mental image. Two well-studied types of image change are mental rotation, which involves rotating the mental representations of two- and three-dimensional objects, and image restructuring, which involves changing or modifying the interpretation of a mental image (Guarnera et al., 2017; Kosslyn, 1994). The type of mental imagery process used will change the amount of cognitive effort required to complete a task (Castellano et al., 2015).

1.2. Visuospatial processing and mental imagery

The literature suggests that mental imagery is essential in visuospatial processing by influencing processes such as memory and perception (Spagna, 2022). Specifically, *visuospatial processing* can be defined as the ability of working memory to generate and transform visual and spatial information presented in static and dynamic displays (Castro-Alonso & Atit, 2019; McGrew, 2009). It involves the perception, analysis, and manipulation of visual and spatial relationships, including tasks such as understanding spatial relationships, navigating environments, and visualizing objects in space (Ness et al., 2017). This process is closely linked to specialized working memory systems, particularly the visuospatial sketchpad, which operates independently of verbal processing and allows individuals to effectively manage and interpret visual data (Baddeley, 2003). Visuospatial processing is essential for tasks that involve real-time manipulation of objects and spatial reasoning, such as navigating, interpreting diagrams, or solving geometric problems (Hegarty & Waller, 2004).

The ability to generate and maintain mental images is closely linked to visuospatial tasks and development, highlighting the complex relationship between these cognitive processes (Wimmer et al., 2015). However, although visuospatial processing and mental imagery are closely related, they serve different purposes and involve distinct mechanisms. Whereas visuospatial processing involves the real-time manipulation of spatial relationships based on immediate sensory input, mental imagery focuses on the internal generation of images that may not correspond to real-time visual stimuli, allowing for the manipulation of mental images independent of present sensory information (Kosslyn, 1994). Regarding cognitive mechanisms, visuospatial processing involves specialized systems distinct from verbal processing, including the visuospatial sketchpad in Baddeley's working memory model, which allows individuals to maintain and manipulate spatial information in real-time (Baddeley, 2003). In contrast, mental imagery involves neural mechanisms that overlap with both perception and memory, as brain areas activated during visual perception can also be engaged during mental imagery, highlighting their close relationship but distinct functional roles (Pearson et al., 2015; Spagna et al., 2024). Functionally, visuospatial processing is critical for tasks that require immediate spatial reasoning, such as navigation, understanding diagrams, or solving problems involving the spatial arrangement of objects (Hegarty & Waller, 2004). Meanwhile, mental imagery plays a critical role in tasks such as creative thinking, problem-solving, and planning, allowing individuals to simulate outcomes, rehearse actions, or visualize future scenarios without external visual input, essential for academic and cognitive tasks that require abstract thinking (Pearson et al., 2015; Sima et al., 2013).

Research underlines that spatial mental images are processed in the spatial property processing subsystem, which is explicitly linked to the dorsal processing stream responsible for spatial information during visual perception (Sima et al., 2013). In addition, mental imagery is directly related to true and false memory processes, and the accuracy with which images are created and maintained improves with age, particularly between ages four and eight, indicating a developmental aspect of this cognitive process (Wimmer et al., 2015). Studies have also shown that mental imagery may share processing systems with perception, suggesting its influence on visuospatial processing (Aleman et al., 2005; D'Angiulli et al., 2024).

1.3. Mental imagery and visuospatial processing: implications for creativity and academic performance

Mental imagery and visuospatial processing are important in enhancing creativity and thinking. Creativity involves generating novel ideas and solutions, often requiring students to visualize and mentally manipulate abstract concepts, processes inherently linked to mental imagery (Aziz-Zadeh et al., 2013). Mental imagery serves as a representational medium that provides access to cognitive processes such as symbolization and combination of elements, potentially facilitating the emergence of new and creative ideas (Palmiero et al., 2016). Mental imagery allows students to engage with abstract ideas in subjects such as math, science, and art and promotes creative problem-solving and divergent thinking. Visuospatial processing is also crucial to creative thinking, especially in design, experimentation, and spatial reasoning tasks integral to STEM education. Research shows that visuospatial working memory plays a central role in creative thinking, particularly in tasks requiring mental manipulation of images and spatial reasoning. Lu et al. (2021) state that high visuospatial working memory capacity allows individuals to store and manipulate more complex visual and spatial information, enhancing verbal and figural creativity. This finding is particularly relevant for junior high school students, who are often required to engage in activities that involve visualizing and transforming spatial data, such as geometry or creative arts projects. These cognitive abilities contribute significantly to students' ability to generate new ideas and think flexibly, both critical components of creativity.

As a result, mental imagery and visuospatial processing significantly impact also academic performance, especially in subjects that require abstract thinking, such as art, music, literacy, and mathematics. Concerning art education, research has shown that the duration of visual art training is positively associated with visual imagery skills, with students in art-related fields demonstrating stronger mental imagery skills (Morrison & Wallace, 2001). In addition, students with high visuospatial skills can accurately represent three-dimensional objects on a two-dimensional surface, resulting in more realistic and expressive artwork (McGraw, 2004). These skills enable them to translate mental images into visual representations effectively. In addition, understanding the principles of balance, symmetry, and proportion relies on this cognitive skill. In addition to supporting creativity, mental imagery and visuospatial processing support problem-solving in art, enabling students to find innovative solutions to artistic challenges and overcome obstacles in their creative process (Colombo & Antonietti, 2013).

Research on school performance in musical subjects has shown that mental imagery is important in music composition. Composers can use it to imagine sounds, predict how a composition will sound, and compare their mental ideas with notated music (Jaencke et al., 2017). Mental imagery also comes into play when composers use symbols and representations in their mind's eye to experiment with musical elements. In this respect, mental imagery is not limited to a single sensory mode but can be multisensory, incorporating both auditory and visual information. Examples include composers who visualize scenes and images alongside auditory experience (Küssner et al., 2022). Therefore, mental imagery, particularly a combination of visual and auditory elements, can enhance compositional creativity by facilitating generating, exploring, and manipulating musical ideas (Cotter, 2019; Jaencke et al., 2017).

Additionally, intensive music training has been shown to improve students' visuospatial, cognitive, and memory skills. A longitudinal study on Italian preadolescent students found that music training was associated with improved non-verbal reasoning, language, reading, memory, and numerical and visual-spatial skills (Carioti et al., 2019). In addition, it has been demonstrated that playing a musical instrument in junior high school has been linked to having better audiovisual working memory and fluid intelligence, which are crucial for succeeding in subjects that demand abstract thinking (Commodari & Sole, 2019; Lippolis et al., 2022).

Many studies have highlighted the importance of visuospatial skills in mathematics education. These skills are not only crucial in the early stages of learning mathematics (Hegarty & Kozhevnikov, 1999; McKenzie et al., 2003; Rasmussen & Bisanz, 2005) but also play a significant role in later developmental stages of mathematical tasks (Fastame, 2021; Guarnera et al., 2019) and specifically involve the mental representation of space, enabling the processing of spatial relationships between objects and facilitating the manipulation and transformation of mental images (Guarnera et al., 2017).

Mental imagery is also crucial in literacy, improving comprehension, text visualization, and overall language processing. When individuals engage in mental imagery while reading, they create 'mind movies' that help clarify information, enhance comprehension, and can involve any of the five senses (Commodari et al., 2019; Suggate & Lenhard, 2022). In this regard, reading comprehension was more strongly associated with mental imagery than reading speed (Suggate & Lenhard, 2022). In addition, the ability to discriminate between different shapes and characteristics, such as those that make up letters, involves basic mental imagery skills, which are critical to developing reading skills (Yousef Atoum & M. Reziq, 2018).

1.4. Gender differences in mental imagery, visuospatial processing and academic performance

Gender differences in the relationship between mental imagery, visuospatial processing, and academic performance are an important area of research. Generally, males and females tend to differ in cognitive tasks involving mental imagery and visuospatial processing, which may affect their academic performance in various subjects. Research has consistently shown that males may have an advantage in spatial visualization skills, particularly in tasks that require mental rotation, a key component of visuospatial processing and critical in fields such as mathematics and other STEM disciplines (Halpern et al., 2016; Wei et al., 2016). Meta-analyses have reported moderate to large effect sizes favoring males in mental rotation tasks, especially under time conditions, suggesting that males may use more efficient mental rotation strategies (Maeda & Yoon, 2012; Voyer et al., 1995). Lauer et al. (2019) also showed gender differences in mental rotation early in childhood, with a slight male advantage and an increase with age, reaching a moderate effect size by adolescence. The developmental trajectory of this advantage is influenced by various procedural factors, such as stimulus dimensionality and mirror discrimination tasks, which contribute to more significant gender differences (Linn & Petersen, 1985; Voyer et al., 1995). However, spatial skills are plastic and can be improved with targeted training, suggesting that these gender differences are shaped by both biological and environmental factors (Lane & Sorby, 2021).

In contrast, females often excel at tasks requiring verbal and memory skills, so they report better performance in subjects such as literacy and arts (Halpern et al., 2016). Despite these cognitive differences, research consistently shows that females outperform males in overall school performance and are more engaged in academics, likely due to socialization processes and different parental expectations (Musso et al., 2022; Ogden et al., 2021). These findings underscore the importance of gender differences in academic achievement, which are determined by cognitive abilities, individual variations, educational strategies, and environmental influences. Therefore, a thorough assessment of gender differences in mental imagery and visuospatial processing is essential to understand their impact on academic achievement and address potential educational inequalities.

1.5. The importance of mental imagery and visuospatial processing in middle school

This topic is undoubtedly complex and has been studied primarily in preschool and school-age children. However, it remains understudied in later school years, particularly in middle school, although it is a critical developmental period during which significant cognitive, emotional, and social changes occur. During this time, students experience remarkable advances in cognitive functions such as working memory, abstract reasoning, and problem-solving, which are crucial to mastering increasingly complex academic tasks (Best & Miller, 2010). These cognitive changes are directly related to the growing importance of mental imagery and visuospatial processing, as these skills are critical to the performance in subjects that require abstract thinking. Emotionally, adolescents face increased challenges in emotional regulation and heightened sensitivity to peer influence, both of which can affect their engagement in learning and their use of cognitive resources such as mental imagery (Steinberg, 2005). Socially, students at this stage move toward greater independence and prioritize peer relationships, influencing their attitudes toward school and shaping the learning environment (Brown & Braun, 2013). These interconnected developments underscore the importance of investigating mental imagery and visuospatial processing during this critical period, as they play a pivotal role in supporting cognitive growth, emotional management, and social adaptation in learning contexts.

In light of these considerations, this study aims to contribute to the literature on this topic by providing empirical evidence on the role of these cognitive functions in middle school students' academic performance, thereby offering valuable insights that could inform educational strategies and interventions. Specifically, by focusing on this age group, the study addresses a critical gap in the literature and seeks to improve our understanding of the cognitive mechanisms that support academic success during a crucial developmental period.

1.6. Aims and research hypotheses

This study aimed to explore the role of mental imagery in the academic performance of a sample of junior high school students. Specifically, we investigated the impact of mental imagery on academic performance in subjects requiring abstract thinking, such as Italian language and literature (abbreviated later as Italian), mathematics, art, and music, through its effects on visuospatial processing.

Our main hypothesis and additional exploratory hypotheses are formulated as follows:

Main Hypothesis (H1) Visuospatial processing abilities mediate the relationship between mental imagery and academic performance in Italian, mathematics, art, and music, controlling for gender to account for potential differences in cognitive abilities.

H2. Higher proficiency in mental imagery is associated with better academic performance across subjects (Italian, mathematics, art, and music). This hypothesis also explores the positive correlation between mental imagery and visuospatial processing abilities, emphasizing their impact on academic outcomes.

H3. Specific components of mental imagery, such as the ability to manipulate and maintain visual information, differentially contribute to visuospatial processing skills. This hypothesis seeks to identify which aspects of mental imagery are most strongly linked to enhanced visuospatial abilities.

The hypothesized model is presented in Fig. 1.

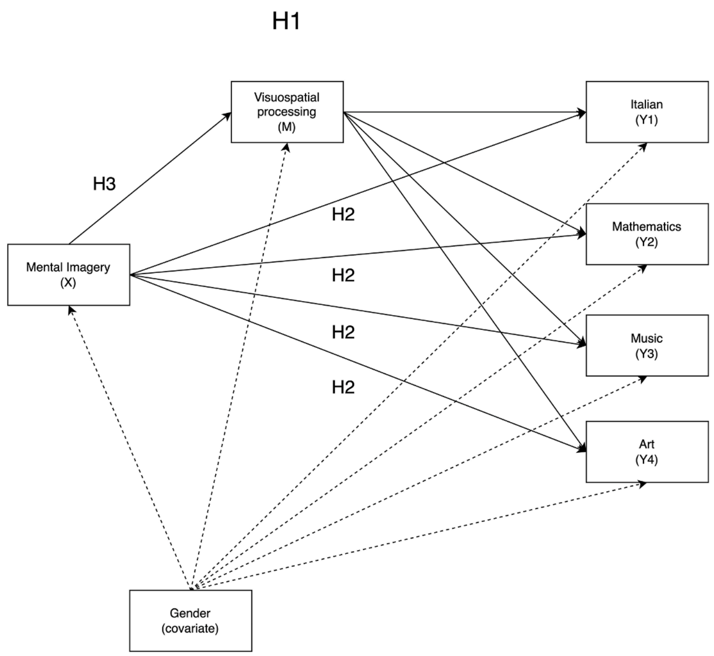

Fig. 1. Conceptual Diagram of the Hypothesis Model.

2. Material and methods

2.1. Procedures

The study's participants were third-year students from a public junior high school in a provincial capital city in Sicily (Italy). The Italian school system is structured in a series of stages, beginning with kindergarten, progressing through primary school, and then moving on to lower and upper secondary school. In particular, after primary school, students enter junior high school, also known as middle school or lower secondary school, which lasts for three years and accommodates students between the ages of 11 and 14. Junior high school is a transitional stage between primary and secondary education. It offers a curriculum designed to deepen students' academic knowledge while preparing them for the choices in upper secondary school. In junior high school, the curriculum becomes more subject-oriented, with students receiving instruction in Italian language and literature, mathematics, science, history, geography, technical education (which includes computer science and technology), art and music, physical education, and a second language, usually English, which continues from elementary school.

The research included nine third-year classes, with an average of 14 students per class, equally distributed in terms of gender and aged between 12 and 13 years.

In conducting the study, the authors adhered to the Ethical Code for Italian Psychologists (Law of February 18, 1989, no. 56), the Legislative Decree concerning data privacy (DLGS 196/2003), and the Ethical Code for Psychological Research set forth on March 27, 2015, by the Italian Psychologists Association. The study was designed to avoid collecting any sensitive information that could reveal the identity of the participants. Before the study, the parents of the students from the participating school were informed and consented to their children's involvement. The Internal Ethics Review Board (IERB) of the Department of Educational Sciences of the University of Catania approved the study.

2.2. Measures

During the initial session, each participant underwent the Mental Imagery Test in a strictly individual setting. Later, in a small group setting, Raven's Progressive Matrices were administered in a subsequent session. Expert researchers conducted all assessments in a designated classroom during school hours.

2.2.1. Mental imagery test

The Mental Imagery Test (MIT), developed by Di Nuovo et al. (2014), is a set of tasks designed to assess mental imagery abilities. These tasks focus on generating, maintaining, and manipulating various types of images. Typically, this test is administered individually and takes about 30 to 60 min to complete.

The test consists of a *Core Battery* that includes a set of tests that precisely assess mental imagery and an optional set of cognitive comparison tests that evaluate the efficiency of cognitive functions (attentional, verbal and visuospatial memory, spatial reproduction) that do not involve active transformation of memorized images. Only the tests that make up the *Core Battery* will be considered for the study objectives.

The tests of the Core Battery are as follows:

- *Visualizing letters*: The subject is asked to imagine, while being named in sequence, 12 capital letters of the alphabet and, for each letter named, to say whether or not it contains curved parts (e.g., A, P, G, or R, not L, M, V or N).
- *Brooks' F' Test:* The subjects are instructed to visualize walking along the outline of a large capital letter F printed on a card they observed for 30 s. They must determine and vocalize whether the borders they encounter while moving counter-clockwise from the lower left corner are on the outside or inside of the letter.
- *Clock*: The task requires the participant to visualize an analog clock with the hands pointing to 10 min past 10. They are then asked to imagine the same clock reflected in a mirror and to say what time it appears to show. Finally, they are asked to predict what time it will occur to be in the mirror after another ten minutes.
- *Cube*: The task involves showing for 30 s a drawing of a cube composed of 9 smaller cubes on each face (arranged in a 3×3 grid), with the outer faces colored. After the image is removed, the participant is instructed to mentally visualize the cube and report the number of smaller cubes with three colored faces, two colored faces, one colored face, and no colored faces.
- *Subtraction of parts:* An image of a digital clock with all its LEDs lit is followed by another image showing four LEDs in different positions. The task for the subject viewing these images is to determine which parts of the original figure remain visible by subtracting the four displayed LEDs from the total number of initially lit LEDs.
- *Mental exploration of a map:* The subject is shown a map of an island with a house, a church, a lake, and a forest. The instructions emphasize the importance of carefully observing the map and memorizing the distances between these elements. When the map is removed, the participant is asked to answer four questions about the relative distances between pairs of the previously viewed elements.
- *Imagined paths:* The subject is instructed to visualize a ball moving in different directions. They are told the direction the ball is rolling and have to track this movement mentally. Ultimately, the participant has to determine and report whether the ball will end up above, below, or at the same level as its starting point.
- *Mental representation of shapes of objects:* The subject is given a list of 20 everyday objects (e.g., bottle, pizza, candle, tower, bed) and is instructed to mentally picture these objects and then determine w if the object has a taller or larger shape.

The total mental imagery score is obtained by summing the results of the individual subtests. The Cronbach's α for this total score is 0.78 in our sample.

2.2.2. Raven standard progressive matrices

The Raven's Standard Progressive Matrices (RSPM) (Raven, 1936) is widely recognized as an effective tool for assessing visuospatial processing abilities. It is the first in three tests, along with the Raven Colored Progressive Matrices (RCPM) and the Raven Advanced Progressive Matrices (RAPM). The RSPM assesses an individual's ability to make perceptual associations and reason analogically through non-verbal, visual geometric patterns with a missing piece, requiring the participant to identify the correct missing segment. This non-verbal format minimizes the influence of language and verbal reasoning, allowing for a more direct assessment of visuospatial abilities in diverse populations, including those with language barriers. The test consists of five sets of 12 items each, with progressively more complex items requiring increasingly higher cognitive ability levels to encode and process the visual information. Each item engages visuospatial processing skills as participants analyze geometric designs, infer relationships, and manipulate visual data (Soulieres et al., 2009). The RSPM's gradual increase in task complexity also allows for a comprehensive assessment of visuospatial abilities across a range of difficulties, facilitating the identification of different levels of cognitive processing in individuals (Soulieres et al., 2009). The test typically takes <30 min, although no strict time limit exists. Scores are determined by the number of correct responses, which are then converted to IQ scores (Raven, 2000; Raven et al., 1988). Overall, the RSPM's nonverbal format, focus on visual pattern recognition, correlation with other cognitive measures, and structured difficulty make it a robust tool for assessing visuospatial processing that effectively captures the essential components of this cognitive domain while minimizing extraneous influences of verbal ability.

The reliability of RSPM in adolescent populations is well established, with previous research (Kramer & Huizenga, 2023) showing strong internal consistency (Cronbach's α = 0.86). Similarly, RSPM showed strong internal consistency in our sample, with a Cronbach's α of 0.82.

2.2.3. Academic achievement

The grades reported by students in the first quarter report card in Italian, mathematics, art, and music were used to assess academic performance in these subjects, according to previous studies on similar topics (Escolano-Pérez & Bestué, 2021; Sánchez et al., 2020). Italian middle schools' grading system typically uses a scale from 1 to 10, with 10 being the highest grade and 1 being the lowest. The distribution of these grades generally follows a bell-shaped curve, with few students receiving the lowest (1–3) and highest (9–10) grades. Most scores cluster around the median score of 7. Students must achieve a minimum grade of 6 to pass and move on to the next grade level. This grading system is used in various subjects, and student performance is assessed through tests, oral examinations, and assignments.

2.3. Statistical analyses

The Statistical Package for the Social Sciences (SPSS) version 29.0 (IBM Corporation, Armonk, NY) was used for statistical analyses. A priori sample size was calculated using the software G*Power 3.1.9.3 (Faul et al., 2007). The mediation model includes four dependent variables (Italian, Mathematics, Music, Art) and three predictors (Mental Imagery, Visuospatial Processing, and Gender as a covariate). Assuming a medium size of $f^2 = 0.15$ for each path (Faul et al., 2009), a power of 0.90, an alpha level of 0.05, a sample size of $n = 99$ is required to achieve adequate power for each path analysis involving three predictors. Considering that the dependent variables in the model are not analyzed independently but connected through a common mediator, a total sample size of 99 can be regarded as adequate for our study.

Continuous variables were presented as Mean (M) ± Standard Deviation (SD), while categorical variables were shown using frequencies and percentages. A series of independent samples *t*-tests were conducted to compare academic achievement in Italian, mathematics, art, and music between males and females and between students with high and low mental imagery scores. Despite the non-normal distribution of some variables, the *t*-test was chosen because of its robustness to violations of normality, as supported by previous literature (Posten, 1984; Rasch et al., 2007), which showed that the *t*-test is very robust in practical applications, especially when sample sizes are sufficient or nearly equal. The magnitude of the differences between the means was assessed by calculating the effect size through Hedge's formula (Hedges, 2016). Values of 0.20 indicated a small effect, 0.50 a medium effect, and 0.80 a large effect (Cohen, 1988). Pearson's correlation coefficients were calculated to examine the strength and direction of the relationship between visuospatial processing skills and academic achievement across all subjects.

Furthermore, a multiple regression analysis was conducted to assess the differential contributions of different mental imagery skills to visuospatial processing skills. Finally, to test the main hypothesis, a mediation model with multiple outcomes was conducted using JASP software (JASP Team, 2024) to explore the indirect effects of mental imagery on academic performance in Italian, mathematics, art, and music simultaneously through the mediator, visuospatial processing. In light of the literature on the influence of gender on the variables of interest, the analysis was controlled for gender.

3. Results

Participants were 130 junior high school students (males = 63; females = 67; age range: 12–13; $M = 12.62$, $SD = 0.49$), thus exceeding the required sample size of 99. Table 1 reports the mean scores of the questionnaires and the mean grades of the students in Italian, mathematics, art, and music.

Independent-sample *t*-tests were conducted to investigate differences between males and females in their performance on the MIT and Raven matrices. As shown in Table 2, the results reported no significant differences between males and females in mental imagery skills and visual-spatial processing ($p > .05$). However, a significant difference was found in the scores at the test 'Imagined paths' with males reporting better scores than females ($M = 9.62$, $SD = 1.90$ vs $M = 8.33$, $SD = 2.30$); the effect size was 0.61, indicating a medium to large effect.

To test Hypothesis 2 (H2), MIT's total score has been divided into high and low, assuming the median as a cut-off to verify if students with higher scores in mental imagery reported better academic performance in Italian, mathematics, art, and music compared to students with lower mental imagery. As noted in Table 3, students with high MIT scores ($M = 7.37$, $SD = 1.22$) outperformed those with low MIT scores ($M = 6.62$, $SD = 1.16$); the effect size was 0.63, indicating a medium to large effect. A significant difference was also found in mathematics, with high MIT scorers achieving higher mean grades ($M = 7.04$, $SD = 1.37$) than low scorers ($M = 6.33$, $SD = 1.28$); the effect size was 0.53, suggesting a medium effect. In music, students with high scores in mental imagery again had higher mean grades ($M = 7.64$, $SD = 1.16$) compared to students with low scores ($M = 7.19$, $SD = 1.12$); the effect size was 0.39, which is close to a medium effect. Finally, art grades were higher for the high MIT score group ($M = 7.40$, $SD = 1.30$) versus the low score group ($M = 6.97$, $SD = 1.23$); the effect size for art was 0.34, indicating a small to medium effect.

Pearson's correlation confirmed a significant positive correlation between mental imagery, visuospatial processing abilities, and academic performance in all subjects. Specifically, as reported in Table 4, a strong positive correlation exists between MIT and Raven's IQ scores ($r = 0.614$, $p < .001$) that underscores the potential interrelatedness of mental imagery and visuospatial processing. Furthermore, the MIT and Raven's IQ scores show positive correlations with academic performance in Italian, mathematics, music, and art, with the strongest associations observed in Italian and mathematics.

To verify Hypothesis 3 (H3), a multiple regression analysis was conducted to investigate the relative contribution of each component of mental imagery to visuospatial processing abilities. RSPM scores were used as the dependent variable, while the scores on the different MIT subtests served as independent variables. Preliminary analyses were conducted to ensure the assumptions of normality, linearity, multicollinearity, and homoscedasticity were not violated. The Durbin-Watson statistic was 1.761, indicating no significant issues with autocorrelation. Collinearity diagnostics showed acceptable levels of tolerance and VIF, suggesting that multicollinearity was not a concern in this model.

As reported in Table 5, the regression model was statistically significant [$F(8, 121) = 18.254$, $p < .001$] and explained 54.7 % of the variance in RSPM scores ($R^2 = 0.547$). The most significant predictors of Raven's scores were the scores in the subtests' Subtraction parts' ($\beta = 0.525$, $p < .001$) and 'Visualizing letters' ($\beta = 0.267$, $p < .001$), both demonstrating strong positive associations. The score in the subtest' Mental representation of shapes of objects' also showed a significant positive association ($\beta = 0.150$, $p = .020$). Although included in the model, other variables did not significantly predict RSPM scores.

Finally, to test the main hypothesis (H1), we performed a mediation analysis to simultaneously examine the association between mental imagery (X) and academic performance across all subjects of interest (Y), with visuospatial processing as a mediator (M) and gender included as a covariate. The detailed results of the mediation models, with and without gender as a control variable, are shown in Table 6.

The mediation models provided interesting results regarding the effect of mental imagery on the academic domains considered in this study, with particular attention to the effects of mediation through visuospatial processing. Mental imagery showed a significant direct effect on performance in Italian when gender was included as a control variable ($B = 0.04$, $p = .01$). In contrast, the effects on Math, Music, and Art did not reach statistical significance ($p > .05$). None of the direct effects were significant without controlling for gender ($p > .05$), suggesting that gender may directly influence the strength of these relationships.

Regarding indirect effects, visuospatial processing was observed to significantly mediate the association between mental imagery and performance in Italian ($B = 0.03$, $p = .008$) and Mathematics ($B = 0.04$, $p = .001$) when gender is controlled for. These mediation effects were also present without controlling for gender ($B = 0.04$, $p = .001$ for Italian, and $B = 0.05$, $p < .001$ for Mathematics), confirming the hypothesis that visuospatial processing is a critical mediator in these domains. Indirect effects on Music and Art were

Table 1
Means and standard deviations of scores on study variables.

	M	SD	Range
MIT total score	63.02	6.81	46–79
MIT - Visualizing letters	11.37	1.31	0–12
MIT- Brooks' F' Test	8.34	2.18	2–10
MIT - Clock	0.22	0.67	0–4
MIT - Cube	1.35	2.04	0–6
MIT - Subtraction of parts	9.07	2.55	0–12
MIT - Mental exploration of a map	5.02	1.17	1–6
MIT - Imagined paths	8.95	2.21	2–11
MIT - Mental representation of shapes of objects	18.88	1.26	14–20
IQ Raven	110.00	12.28	76–127
Mean grades in Italian	7.01	1.24	4–10
Mean grades in Mathematics	6.70	1.37	4–9
Mean grades in Music	7.42	1.16	4–10
Mean grades in Art	7.19	1.28	4–10

Notes. MIT = Mental Imagery Test; IQ = Intelligence Quotient.

Table 2
Gender differences in mental imagery and visuospatial processing scores.

	Males (n = 63)		Females (n = 67)		t	p	g
	M	***SD***	***M***	***SD***			
MIT total score	63.46	5.99	62.61	7.52	0.71	0.24	0.12
MIT - Visualizing letters	11.27	0.79	11.46	1.65	−0.84	0.20	0.15
MIT- Brooks' F' Test	8.38	2.25	8.30	2.13	0.21	0.41	0.04
MIT - Clock	0.16	0.65	0.27	0.69	−0.93	0.18	0.16
MIT - Cube	1.49	1.99	1.22	2.09	0.75	0.23	0.13
MIT - Subtraction of parts	9.19	2.45	8.96	2.65	0.52	0.30	0.09
MIT - Mental exploration of a map	4.84	1.26	5.18	1.06	−1.66	0.05	0.29
MIT - Imagined paths	9.62	1.90	8.33	2.30	3.47	**< 0.001**	0.61
MIT - Mental representation of shapes of objects	18.87	1.29	18.90	1.24	−0.10	0.46	0.02
IQ Raven	108.81	11.14	111.12	13.25	−1.07	0.14	0.19

Notes. MIT = Mental Imagery Test; IQ = Intelligence Quotient.

Table 3
Differences in school grades in students with low and high mental imagery scores.

	Low MIT score (n = 63)		High MIT score (n = 67)		t	p	g
	M	***SD***	***M***	***SD***			
Mean grades in Italian	6.62	1.16	7.37	1.22	−3.62	**< 0.001**	0.63
Mean grades in Mathematics	6.33	1.28	7.04	1.37	−3.04	**.001**	0.53
Mean grades in Music	7.19	1.12	7.64	1.16	−2.25	**.013**	0.39
Mean grades in Art	6.97	1.23	7.40	1.30	−1.96	**.026**	0.34

Notes. MIT = Mental Imagery Test.

Table 4
Correlations for study variables.

	1.	2.	3.	4.	5.	6.
1. MIT total score	–					
2. IQ Raven	.614**	–				
3. Mean grades Italian	.361**	.426**	–			
4. Mean grades Mathematics	.288**	.419**	.679**	–		
5. Mean grades Music	.208*	.242**	.600**	.406**	–	
6. Mean grades Art	.206*	.246**	.654**	.635**	.567**	–

Notes. MIT = Mental Imagery Test; IQ = Intelligence Quotient.
* $p < .05$; ** $p < .001$.

Table 5
Multiple regression analysis on the predictors of Raven's IQ scores.

	β	t	p	F	R^2
				18.25	.547
(Intercept)		2.084	.039		
MIT - Visualizing letters	.267	4.104	**< 0.001**		
MIT- Brooks' F' Test	.106	1.638	.104		
MIT - Clock	.068	1.077	.284		
MIT - Cube	.086	1.310	.193		
MIT - Subtraction of parts	.525	7.292	**< 0.001**		
MIT - Mental exploration of a map	−0.084	−1.351	.179		
MIT - Imagined paths	.021	.304	.761		
MIT - Mental representation of shapes of objects	.150	2.351	**.020**		

Notes. MIT = Mental Imagery Test; IQ = Intelligence Quotient.

not significant in any of the models tested ($p > .05$), suggesting that mediation through visuospatial processing may not be relevant for these domains.

Finally, the total effects of mental imagery were significant in all domains, both with and without controlling for gender ($p < .001$ for Italian and Mathematics; $p < .01$ for Music and Art), supporting the hypothesis that mental imagery influences academic performance overall.

Fig. 2 summarizes the full mediation model, showing the relationships between mental imagery, visuospatial processing, and the

Table 6
Direct, indirect, and total effects from the mediation model.

		Controlled for Gender			Not Controlled for Gender		
Effect Type	**Path**	**B**	**β**	**p-value**	B	**β**	**p-value**
Direct Effects	Mental imagery → Italian	.04	.22	**.01**	.03	.02	.10
	Mental imagery → Mathematics	.02	.11	.24	.01	.01	.62
	Mental Imagery → Music	.03	.17	.09	.02	.01	.37
	Mental Imagery → Art	.03	.18	.06	.02	.01	.40
Indirect Effects	Mental imagery → Visuospatial processing → Italian	.03	.16	**.008**	.04	.03	**.001**
	Mental imagery → Visuospatial processing → Mathematics	.04	.20	**.001**	.05	.03	**< 0.001**
	Mental imagery → Visuospatial processing → Music	.01	.06	.32	.02	.02	.09
	Mental imagery → Visuospatial processing → Art	.01	.06	.34	.02	.02	.08
Total Effects	Mental imagery → Italian	.07	.38	**< 0.001**	.07	.05	**< 0.001**
	Mental imagery → Mathematics	.06	.31	**< 0.001**	.06	.04	**< 0.001**
	Mental imagery → Music	.04	.23	**.003**	.03	.03	**.01**
	Mental imagery → Art	.04	.24	**.001**	.04	.03	**.01**

academic domains considered. For simplicity, gender effects are not shown in the graphical representation of the mediation model.

4. Discussion

The present study aimed to explore the impact of mental imagery on academic performance in junior high school students, with a specific focus on how this cognitive function influences visuospatial processing skills and, consequently, performance in Italian, mathematics, art, and music. The results of this study support the notion that mental imagery plays a significant role in academic achievement also in junior high school, particularly in subjects that require strong visuospatial processing skills (Bizzaro et al., 2018; Fastame, 2021; Guarnera et al., 2019).

Contrary to reports in the literature (Halpern et al., 2016; Wei et al., 2016), no significant differences were found between males and females in mental imagery and visuospatial processing scores. However, males reported better scores on the *Imagined Paths* subtest, primarily involving spatial skills. This finding warrants further investigation, as it suggests that, while overall mental imagery and visuospatial processing skills may not differ significantly between the sexes, specific components of these cognitive processes may be more susceptible to gender differences. The finding that males performed better on the *Imagined Paths* test may indicate underlying differences in specific spatial abilities or preferences in mental visualization strategies between males and females. In this regard, research has shown that gender differences in spatial skills, such as those required for the *Imagined Paths* tasks considered in this study, can be influenced by a variety of factors, including educational experiences and age-related development (Levine et al., 2005; Voyer et al., 1995). These differences often emerge during early development and may be exacerbated or diminished by educational practices and socialization patterns that boys and girls experience differently (Newcombe, 2007). Therefore, future studies might benefit from exploring these cognitive tasks in younger subjects, where the influence of educational and socialization differences may be less

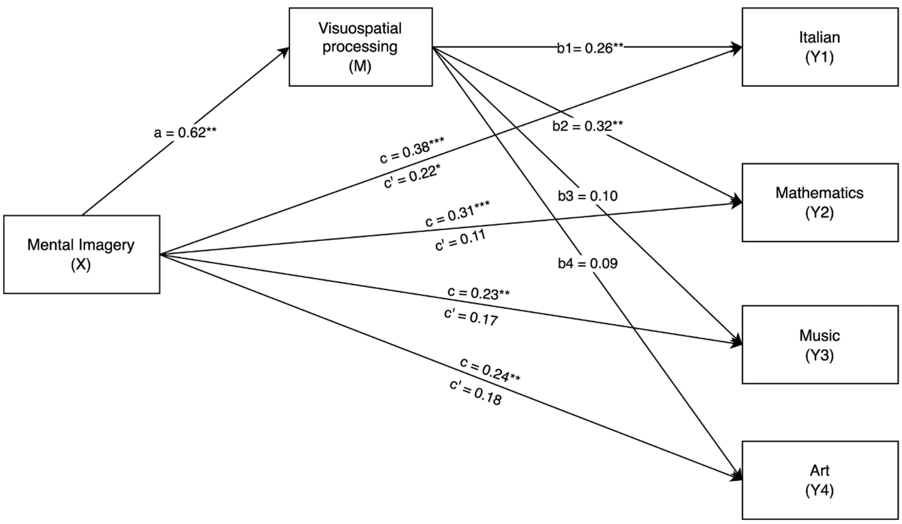

Fig. 2. Mediation Model for Mental Imagery (X) on Academic Performance in Italian (Y_1), Mathematics (Y_2), Music (Y_3), and Art (Y_4) Through Visuospatial Processing (M) Controlled for Gender. a, b, c and c are path coefficients representing standardized regression coefficients. The c path coefficient represents the total effect of X on Y. The c' path coefficient refers to the direct effect of X on Y. * $p < .05$, ** $p < .01$, *** $p < .001$.

pronounced, to minimize the impact of this variable on the results.

The results of test H2 indicated that junior high school students with higher mental imagery skills demonstrated better academic performance in all subjects, with particularly pronounced effects in Italian and mathematics. This finding is consistent with the literature, which emphasizes the importance of mental imagery in cognitive processes such as memory, perception, and especially visuospatial processing (Pearson, 2019; Pearson et al., 2015). The significant differences in performance between students with high and low mental imagery scores underscore the central role that mental imagery plays in academic achievement, possibly through its influence on cognitive functions critical to learning and understanding complex concepts. These significant differences could be explained by the involvement of several cognitive functions, such as working memory, spatial reasoning, and mental rotation, that likely mediate this relationship. Working memory, which allows individuals to hold and manipulate mental representations, is essential for tasks requiring sustained mental imagery, particularly in subjects such as math and language, where students must manage and process complex information over time (Cowan, 2016).

Similarly, spatial reasoning contributes to academic success by allowing students to understand and manipulate spatial relationships between objects, which is critical to problem-solving in subjects such as geometry and other STEM disciplines (Mix & Cheng, 2012). In addition, mental rotation, a specific aspect of spatial reasoning, helps students mentally manipulate objects in space. This skill is valuable for tasks that require visual-spatial analysis, such as those found in mathematics (Città et al., 2019). Furthermore, the more significant effect of mental imagery skills on academic performance in Italian and mathematics confirmed even in preadolescents the literature data on children, which emphasizes the central role of the ability to construct and manipulate mental imagery in learning and performance in these subjects (Commodari et al., 2019; Fastame, 2021; Guarnera et al., 2019; Hegarty & Kozhevnikov, 1999; Suggate & Lenhard, 2022).

H2 was also supported by a significant positive correlation between mental imagery, visuospatial processing skills, and academic performance across all subjects. This finding is consistent with previous literature suggesting that the ability to generate, maintain, and manipulate mental imagery is closely related to visuospatial tasks and cognitive development (Kosslyn et al., 2001; Pearson, 2019). The strong correlation between mental imagery and visuospatial processing skills thus highlights the interrelated nature of these cognitive functions and their collective impact on academic performance. These cognitive processes (e.g., working memory, spatial reasoning, and mental rotation), which are integral to both mental imagery and visuospatial processing, may explain why the mediation analysis identified visuospatial processing as a significant mediator between mental imagery and academic achievement in subjects such as Italian and mathematics. It is plausible that mental imagery enhances students' ability to engage in these cognitive processes, thereby improving academic outcomes. However, while the data suggest that visuospatial processing mediates the relationship between mental imagery and performance in these subjects, it is important to interpret these findings with caution, as they may vary depending on the specific cognitive demands of each subject. Future studies should further explore these hypotheses to understand better the cognitive mechanisms underlying the observed relationships and investigate the potential for targeted cognitive training to improve academic performance.

The results regarding H3 indicate that specific components of mental imagery, particularly the abilities involved in the *Subtraction of Parts* and *Visualization of Letters* subtests, are significant predictors of visuospatial processing abilities. Specifically, the first task falls within Pearson's classification of the ability to restructure and reinterpret images (Pearson et al., 2013). The second task, on the other hand, is primarily concerned with the "generative" aspect of visual imagery, without requiring the strong involvement of essential skills such as perception and memory, and mainly involves shapes that are already automated during early reading processes and are thus easily recalled (Commodari et al., 2019; Guarnera et al., 2017). These findings suggest that certain types of mental imagery tasks, particularly those that require the generation of mental images and the active transformation of memorized images, are more strongly associated with visuospatial processing skills. Therefore, developing and improving these particular mental imagery skills may be critical in strengthening middle school students' visuospatial processing skills.

The mediation analysis to test the main hypothesis provided insights into the relationship between mental imagery, visuospatial processing, and academic achievement in junior high school students. For Italian, visuospatial processing partially mediates the relationship between mental imagery and academic performance, suggesting that the ability to generate and manipulate mental images contributes to better reading comprehension and language processing (Commodari et al., 2019; Suggate & Lenhard, 2022) in part through its influence on visuospatial processing skills. In mathematics, visuospatial processing fully mediated the relationship, suggesting that the impact of mental imagery on mathematical ability is primarily through its influence on visuospatial skills. Therefore, these findings confirm the critical role of spatial reasoning and mental images manipulation in understanding and solving mathematical problems (Fastame, 2021; Hegarty & Kozhevnikov, 1999),

Interestingly, the mediation models for music and art did not show visuospatial processing as a significant mediator. In exploring these unexpected differences, it is essential to consider the involvement of alternative cognitive mechanisms specific to these disciplines. Music, for example, involves a complex set of cognitive processes that go beyond visuospatial reasoning. First, auditory processing plays a central role, with musicians relying heavily on their ability to mentally represent and manipulate sound rather than visual-spatial information (Schellenberg, 2016). Furthermore, engagement with music requires the coordination of multiple skills, including auditory perception, kinesthetic control, pattern recognition and memory. These processes activate brain regions associated with executive functions, such as attentional control and goal setting, and improve behavioural regulation (Barrett et al., 2013). Long-term music training has been shown to lead to structural changes in the brain, such as increased grey matter in areas related to auditory processing and motor control, and enlargement of the corpus callosum, which improves interhemispheric communication (James et al., 2013; Toader et al., 2023). Furthermore, music's strong association with emotional processing through activation of regions such as the basal ganglia, which are involved in pleasure and reward (Toader et al., 2023; Zaatar et al., 2024), suggests that emotional engagement, rather than visuospatial skills, may play a more important role in musical performance and creativity.

Similarly, alternative cognitive mechanisms come into play in the case of art. Indeed, the visual arts require considerable cognitive resources, particularly executive functions such as working memory and attentional control. Artists must constantly switch between broad concepts and finer details, which increases their ability to effectively manage and store visual information (Perdreau & Cavanagh, 2015; Weaver et al., 2024). Neuroimaging studies show that artists have higher visual processing abilities than non-artists, as well as more efficient activation of brain regions associated with executive functions, particularly during tasks such as drawing from memory or observation (Chamberlain & Wagemans, 2015; Weaver et al., 2024). These findings suggest that visual recognition and memory, rather than visuospatial processing alone, may be the main cognitive skills leading to success in the visual arts. In addition, both music and art involve motor processes. For example, rhythm perception in music is closely linked to motor function, enhancing anticipation skills and rhythmic timing, further demonstrating the integration of cognitive processes and physical movement (Toader et al., 2023; Zaatar et al., 2024). In the visual arts, the physical act of creation, whether through drawing, painting or sculpture, requires the control and coordination of fine motor skills (Weaver et al., 2024). These cognitive and motor mechanisms, which are unique to music and art, may explain why visuospatial processing did not mediate the relationship between mental imagery and academic performance in these creative disciplines. Future research should explore the interplay of these alternative cognitive and motor mechanisms and their role in influencing performance in these subjects. In addition, educational approaches to music and art may differ significantly from those used in more traditional subjects, including a greater emphasis on exploratory and student-centered learning, which may affect how student performance is assessed and interpreted in academic settings (Hetland et al., 2007). Individual differences in students' creative inclinations and personal engagement with music and art may also contribute to differences in academic performance. In this regard, studies have shown that personal interest and intrinsic motivation significantly influence students' success in these areas (Ryan & Deci, 2000) Therefore, these variables require further investigation in future studies to fully explain the performance differences observed in this study.

4.1. Strengths and limitations

One of the major strengths of this study is its multidimensional approach, which examines a variety of cognitive functions and their impact on different academic subjects. This comprehensive perspective on the role of mental imagery in educational settings is a significant contribution to the field. Another notable strength of this study is its focus on preadolescents attending junior high school. Indeed, as mentioned, this age group is significant because it represents a critical developmental period during which cognitive, emotional, and social changes are significant. The study's methodology, characterized by a broad range of tests and the use of a representative sample, increases the reliability of the results and makes them applicable to a wider population of students. Applying statistical rigor, including using mediation models and evaluating effect sizes, strengthens the study findings' statistical significance and practical relevance.

However, the study is not without limitations. Although the sample size is statistically adequate, its limitation to a specific geographic and cultural context may limit the applicability of the findings to broader populations from different cultural contexts. In addition, the study's cross-sectional design prevents the establishment of causal relationships with certainty. Another limitation of the present study is its focus on a specific age group, which may not fully capture the developmental origins of gender differences in spatial tasks such as *Imagined Paths*. It is also important to note that our sample size did not allow for a more nuanced assessment of the dimensionality of the mental imagery construct, and this limitation should be addressed in future research. Finally, using teacher-assigned grades as a proxy for academic achievement, while practical, may introduce subjectivity and variability not accounted for in the analysis.

4.2. Practical implications of the findings

The results of this study have important practical implications for educators, curriculum designers, and educational policymakers. The study highlights the critical role of mental imagery and visuospatial processing in the academic performance of middle school students, particularly in subjects that require abstract thinking, such as mathematics, literacy, arts, and music. Understanding the importance of these cognitive functions suggests that educational strategies should be targeted to enhance students' mental imagery and visuospatial skills during this critical developmental period.

A first practical implication is the integration of targeted cognitive exercises into the curriculum that specifically focus on improving mental imagery and visuospatial processing. For example, incorporating activities that require students to visualize and manipulate spatial information, such as mental rotation tasks or geometry-based problem-solving exercises, could strengthen these cognitive skills and, in turn, improve academic outcomes. In addition, educators could adopt teaching methods that use mental imagery to aid memory retention and comprehension, such as encouraging students to create mental "mind maps" of information or to visualize scenarios described in texts. Moreover, professional development programs for teachers could include training on the importance of mental imagery and visuospatial processing and provide them with tools and techniques to effectively promote these skills in the classroom. By understanding the link between these cognitive processes and academic success, teachers can better support students' learning and help them develop the cognitive skills needed to succeed in challenging academic tasks.

The results also have important implications for teaching and learning, particularly for promoting creativity and thinking skills in middle school students. Mental imagery and visuospatial processing are essential cognitive tools that allow students to engage in mental simulation, explore multiple perspectives, and generate innovative ideas. Educators working with middle school students can use these cognitive processes to enhance creativity by incorporating more visual and spatial tasks into their lessons. For example, encouraging students to use mental imagery when solving problems in subjects such as math, science, and art can help them explore new ideas and approach problems creatively. In addition, targeted interventions to strengthen visuospatial processing skills at this developmental stage can improve academic performance and enhance students' ability to think creatively. In this regard, several programs have been validated in different age groups, such as preschool children or university students, and can be successfully adapted to the adolescent population to promote these skills, offering promising directions for educational interventions. For example, Sorby's Improving Spatial Visualization Skills program, originally developed for engineering students (Sorby, 2015), can be successfully adapted for younger students, promoting improvements in their ability to mentally manipulate objects and improving performance in STEM subjects. Similarly, programs such as Spatial Thinking in the Middle Grades (STMG) have been specifically designed for preschool children and can be adapted for adolescents, using interactive and hands-on activities to promote spatial reasoning and visualization, which in turn enhance critical thinking and problem-solving skills in a range of academic areas (Newcombe, 2010). Integrating these already validated programs, and others specifically designed to promote these skills, into the middle school curriculum could provide students with the necessary tools to tackle increasingly complex academic tasks, while promoting creative and flexible thinking.

Finally, the study's findings could inform the development of educational policies prioritizing cognitive skills training as part of an integrated approach to education. Policymakers might consider advocating for the inclusion of cognitive development programs within the standard curriculum to ensure that all students can develop the mental imagery and visuospatial processing skills critical for academic achievement and overall cognitive growth. Therefore, educational strategies should not only focus on academic success, but also on the broader development of soft skills that will serve students in their academic and personal growth.

5. Conclusions

In conclusion, this study highlights the central role of mental imagery and visuospatial processing in the academic achievement of middle school students, particularly in subjects that require high levels of abstract thinking. The research highlights the importance of integrating cognitive skills training into the curriculum by examining the relationship between these cognitive processes and educational outcomes. The findings suggest that enhancing students' mental imagery and visuospatial skills can improve academic achievement and creative thinking. Because middle school is a critical developmental period, understanding and supporting these cognitive functions is essential to promoting students' overall cognitive and academic growth. Future research should continue to examine these relationships across age groups and educational contexts and provide further insights into how best to support cognitive development and academic success through targeted educational interventions.

Educational relevance and implications statement

This study explores the relationship between mental imagery, visuospatial processing, and academic performance among junior high school students, focusing on subjects requiring abstract thinking, such as Italian, mathematics, art, and music. Our results underline that better mental imagery skills are associated with higher academic performance in Italian and mathematics, with visuospatial processing playing a crucial mediating role. These findings have particular implications for educational strategies aimed at junior high school students, suggesting that programs designed to enhance mental imagery and spatial reasoning could significantly improve academic outcomes in critical thinking and problem-solving subjects. This targeted approach could lead to more effective educational interventions to promote creativity and thinking skills in this crucial developmental stage.

CRediT authorship contribution statement

Elena Commodari: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Conceptualization. **Jasmine Sole:** Writing – review & editing, Investigation, Data curation. **Maria Guarnera:** Writing – review & editing. **Valentina Lucia La Rosa:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation.

Declaration of competing interest

All authors declare no conflicts of interest concerning the authorship or the publication of this article.

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Data availability

Data will be made available on request.

References

Aleman, A., de Haan, E. H., & Kahn, R. S. (2005). Object versus spatial visual mental imagery in patients with schizophrenia. *Journal of Psychiatry & Neuroscience, 30*(1), 53–56.

Aziz-Zadeh, L., Liew, S. L., & Dandekar, F. (2013). Exploring the neural correlates of visual creativity. *Social Cognitive and Affective Neuroscience, 8*(4), 475–480. https://doi.org/10.1093/scan/nss021

Baddeley, A. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36*(3), 189–208. https://doi.org/10.1016/s0021-9924(03)00019-4

Barrett, K. C., Ashley, R., Strait, D. L., & Kraus, N. (2013). Art and science: How musical training shapes the brain. *Frontiers in Psychology, 4*(713). https://doi.org/10.3389/fpsyg.2013.00713

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development, 81*(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Bizzaro, M., Giofrè, D., Girelli, L., & Cornoldi, C. (2018). Arithmetic, working memory, and visuospatial imagery abilities in children with poor geometric learning. *Learning and Individual Differences, 62*, 79–88. https://doi.org/10.1016/j.lindif.2018.01.013

Brown, B. B., & Braun, M. T (2013). Peer relations. In C. Proctor, & P. A. Linley (Eds.), *Research, applications, and interventions for children and adolescents: A positive psychology perspective* (Eds., pp. 149–164). Springer Science + Business Media.

Carioti, D., Danelli, L., Guasti, M. T., Gallucci, M., Perugini, M., Steca, P., Stucchi, N. A., Maffezzoli, A., Majno, M., Berlingeri, M., & Paulesu, E. (2019). Music Education at School: Too Little and Too Late? Evidence From a Longitudinal Study on Music Training in Preadolescents. *Frontiers in Psychology, 10*, 2704. https://doi.org/10.3389/fpsyg.2019.02704

Castellano, S., Guarnera, M., & Di Nuovo, S. (2015). Imagery in Healthy and in Cognitively Impaired Aging. *Clinical Gerontologist, 38*(2), 103–113. https://doi.org/10.1080/07317115.2014.990599

Castro-Alonso, J. C., & Atit, K. (2019). Different Abilities Controlled by Visuospatial Processing. In J. C. Castro-Alonso (Ed.), *Visuospatial processing for education in health and natural sciences* (Ed., pp. 23–51). Springer International Publishing. https://doi.org/10.1007/978-3-030-20969-8_2.

Chamberlain, R., & Wagemans, J. (2015). Visual arts training is linked to flexible attention to local and global levels of visual stimuli. *Acta Psychologica, 161*, 185–197. https://doi.org/10.1016/j.actpsy.2015.08.012

Città, G., Gentile, M., Allegra, M., Arrigo, M., Conti, D., Ottaviano, S., Reale, F., & Sciortino, M. (2019). The effects of mental rotation on computational thinking. *Computers & Education, 141*, Article 103613. https://doi.org/10.1016/j.compedu.2019.103613. Article.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge.

Colombo, B., & Antonietti, A. (2013). Imagery and Creativity. *Encyclopedia of creativity, invention, innovation and entrepreneurship* (pp. 895–899). Springer New York.

Commodari, E., Guarnera, M., Di Stefano, A., & Di Nuovo, S. (2019). Children Learn to Read: How Visual Analysis and Mental Imagery Contribute to the Reading Performances at Different Stages of Reading Acquisition. *Journal of Psycholinguistic Research, 49*(1), 59–72. https://doi.org/10.1007/s10936-019-09671-w

Commodari, E., & Sole, J. (2019). Music education in junior high school: Perception of emotions conveyed by music and mental imagery in students who attend the standard or musical curriculum. *Psychology of Music, 48*(6), 824–835. https://doi.org/10.1177/0305735619832962

Cotter, K. N. (2019). Mental Control in Musical Imagery: A Dual Component Model. *Frontiers in Psychology, 10*, 1904. https://doi.org/10.3389/fpsyg.2019.01904

Cowan, N. (2016). The many faces of working memory and short-term storage. *Psychonomic Bulletin & Review, 24*(4), 1158–1170. https://doi.org/10.3758/s13423-016-1191-6

D'Angiulli, A., Laarakker, C., & Buchanan, D. M. (2024). An ART Tour de Force on Mental Imagery: Vividness, Individual Bias Differences, and Complementary Visual Processing Streams. *Information, 15*(1), 59. https://doi.org/10.3390/info15010059

Di Nuovo, S., Castellano, S., & Guarnera, M. (2014). *MIT - Mental Imagery test*. Hogrefe.

Escolano-Pérez, E., & Bestué, M. (2021). Academic Achievement in Spanish Secondary School Students: The Inter-Related Role of Executive Functions, Physical Activity and Gender. *International Journal of Environmental Research and Public Health, 18*(4), 1816. https://doi.org/10.3390/ijerph18041816

Fastame, M. C. (2021). Visuo-spatial mental imagery and geometry skills in school-aged children. *School Psychology International, 42*(3), 324–337. https://doi.org/10.1177/0143034321992458

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. https://doi.org/10.3758/brm.41.4.1149

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/bf03193146

Guarnera, M., Faraci, P., Commodari, E., & Buccheri, S. L. (2017). Mental Imagery and School Readiness. *Psychological Reports, 120*(6), 1058–1077. https://doi.org/10.1177/0033294117717262

Guarnera, M., Pellerone, M., Commodari, E., Valenti, G. D., & Buccheri, S. L. (2019). Mental Images and School Learning: A Longitudinal Study on Children. *Frontiers in Psychology, 10*, 2034. https://doi.org/10.3389/fpsyg.2019.02034

Halpern, D. F., Benbow, C. P., Geary, D. C., Gur, R. C., Hyde, J. S., & Gernsbacher, M. A. (2016). The Science of Sex Differences in Science and Mathematics. *Psychological Science in the Public Interest, 8*(1), 1–51. https://doi.org/10.1111/j.1529-1006.2007.00032.x

Hedges, L. V. (2016). Distribution Theory for Glass's Estimator of Effect size and Related Estimators. *Journal of Educational Statistics, 6*(2), 107–128. https://doi.org/10.3102/10769986006002107

Hegarty, M., & Kozhevnikov, M. (1999). Types of visual–spatial representations and mathematical problem solving. *Journal of Educational Psychology, 91*(4), 684–689. https://doi.org/10.1037/0022-0663.91.4.684

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence, 32*(2), 175–191. https://doi.org/10.1016/j.intell.2003.12.001

Hetland, L., Winner, E., Veenema, S., & Sheridan, K. (2007). *Studio thinking: The real benefits of arts education*. Teachers College Press.

Jaencke, L., Wong, S. S. H., & Lim, S. W. H. (2017). Mental imagery boosts music compositional creativity. *PLoS One, 12*(3), Article e0174009. https://doi.org/10.1371/journal.pone.0174009

James, C. E., Oechslin, M. S., Van De Ville, D., Hauert, C.-A., Descloux, C., & Lazeyras, F. (2013). Musical training intensity yields opposite effects on grey matter density in cognitive versus sensorimotor networks. *Brain Structure and Function, 219*(1), 353–366. https://doi.org/10.1007/s00429-013-0504-z

JASP Team. (2024). *JASP (Version 0.19)*. University of Amsterdam.

Kosslyn, S. M. (1980). *Image and mind*. Harvard University Press.

Kosslyn, S. M. (1994). *Image and brain: The resolution of the imagery debate*. MIT Press.

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural foundations of imagery. *Nature Reviews Neuroscience, 2*(9), 635–642. https://doi.org/10.1038/35090055

Kramer, A. W., & Huizenga, H. M. (2023). Raven's Standard Progressive Matrices for Adolescents: A Case for a Shortened Version. *Journal of Intelligence, 11*(4). https://doi.org/10.3390/jintelligence11040072

Küssner, M. B., Taruffi, L., & Floridou, G. A. (2022). Music and Mental Imagery. *Routledge*. https://doi.org/10.4324/9780429330070

Lane, D., & Sorby, S. (2021). Bridging the gap: Blending spatial skills instruction into a technology teacher preparation programme. *International Journal of Technology and Design Education, 32*(4), 2195–2215. https://doi.org/10.1007/s10798-021-09691-5

Lauer, J. E., Yhang, E., & Lourenco, S. F. (2019). The development of gender differences in spatial reasoning: A meta-analytic review. *Psychological Bulletin, 145*(6), 537–565. https://doi.org/10.1037/bul0000191

Levine, S. C., Vasilyeva, M., Lourenco, S. F., Newcombe, N. S., & Huttenlocher, J. (2005). Socioeconomic status modifies the sex difference in spatial skill. *Psychological Science, 16*(11), 841–845. https://doi.org/10.1111/j.1467-9280.2005.01623.x

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*(6), 1479–1498.

Lippolis, M., Müllensiefen, D., Frieler, K., Matarrelli, B., Vuust, P., Cassibba, R., & Brattico, E. (2022). Learning to play a musical instrument in the middle school is associated with superior audiovisual working memory and fluid intelligence: A cross-sectional behavioral study. *Frontiers in Psychology, 13*, Article 982704. https://doi.org/10.3389/fpsyg.2022.982704

Lu, R., Zhang, Y., Bao, N., Su, M., Zhang, X., & Shi, J. (2021). Visuospatial, rather than verbal working memory capacity plays a key role in verbal and figural creativity. *Thinking & Reasoning, 28*(1), 29–60. https://doi.org/10.1080/13546783.2021.1911848

Maeda, Y., & Yoon, S. Y. (2012). A Meta-Analysis on Gender Differences in Mental Rotation Ability Measured by the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R). *Educational Psychology Review, 25*(1), 69–94. https://doi.org/10.1007/s10648-012-9215-x

McGraw, T. M. (2004). The effects of two-dimensional stimuli and three-dimensional stereoptic stimuli on spatial representation in drawings. *Studies in Art Education, 45*(2), 153–169. https://doi.org/10.1080/00393541.2004.11651763

McGrew, K. S. (2009). CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research. *Intelligence, 37*(1), 1–10. https://doi.org/10.1016/j.intell.2008.08.004

McKenzie, B., Bull, R., & Gray, C. (2003). The effects of phonological and visual-spatial interference on children's arithmetical performance. *Educational and Child Psychology, 20*(3), 93–108. https://doi.org/10.53841/bpsecp.2003.20.3.93

Mix, K. S., & Cheng, Y. L. (2012). The relation between space and math: Developmental and educational implications. *Advances in Child Development and Behavior, 42*, 197–243. https://doi.org/10.1016/b978-0-12-394388-0.00006-x

Morrison, R. G., & Wallace, B. (2001). Imagery vividness, creativity and the visual arts. *Journal of Mental Imagery, 25*(3–4), 135–152.

Musso, P., Ligorio, M. B., Ibe, E., Annese, S., Semeraro, C., & Cassibba, R. (2022). STEM-gender stereotypes: Associations with school empowerment and school engagement among Italian and Nigerian adolescents. *Frontiers in Psychology, 13*, Article 879178. https://doi.org/10.3389/fpsyg.2022.879178

Ness, D., Farenga, S. J., & Garofalo, S. G. (2017). *Spatial intelligence. why it matters from birth through the lifespan*. Routledge. https://doi.org/10.4324/9781315724515

Newcombe, N. S (2007). Taking science seriously: Straight thinking about spatial sex differences. In S. J. Ceci, & W. M. Williams (Eds.), *Why aren't more women in science?: Top researchers debate the evidence* (Eds., pp. 69–77). American Psychological Association. https://doi.org/10.1037/11546-006.

Newcombe, N. S. (2010). *Picture this: Increasing math and science learning by improving spatial thinking, 34* pp. 29–43). American Educator.

Ogden, T., Olseth, A., Sørlie, M.-A., & Hukkelberg, S. (2021). Teacher's assessment of gender differences in school performance, social skills, and externalizing behavior from fourth through seventh grade. *Journal of Education, 203*(1), 211–221. https://doi.org/10.1177/00220574211025071

Palmiero, M., Piccardi, L., Nori, R., Palermo, L., Salvi, C., & Guariglia, C. (2016). Editorial: Creativity and mental imagery. *Frontiers in Psychology, 7*, 1280. https://doi.org/10.3389/fpsyg.2016.01280

Pearson, D. G., Deeprose, C., Wallace-Hadrill, S. M., Burnett Heyes, S., & Holmes, E. A. (2013). Assessing mental imagery in clinical psychology: A review of imagery measures and a guiding framework. *Clinical Psychology Review, 33*(1), 1–23. https://doi.org/10.1016/j.cpr.2012.09.001

Pearson, J. (2019). The human imagination: The cognitive neuroscience of visual mental imagery. *Nature Reviews Neuroscience, 20*(10), 624–634. https://doi.org/10.1038/s41583-019-0202-9

Pearson, J., Naselaris, T., Holmes, E. A., & Kosslyn, S. M. (2015). Mental imagery: Functional mechanisms and clinical applications. *Trends in Cognitive Sciences, 19*(10), 590–602. https://doi.org/10.1016/j.tics.2015.08.003

Perdreau, F., & Cavanagh, P. (2015). Drawing experts have better visual memory while drawing. *Journal of Vision, 15*(5), 5. https://doi.org/10.1167/15.5.5

Posten, H. O. (1984). *Robustness of statistical methods and nonparametric statistics. theory and decision library*. In D. Rasch, & M. L. Tiku (Eds.). *1* pp. 92–99). Springer.

Rasch, D., Teuscher, F., & Guiard, V. (2007). How robust are tests for two independent samples? *Journal of Statistical Planning and Inference, 137*(8), 2706–2720. https://doi.org/10.1016/j.jspi.2006.04.011

Rasmussen, C., & Bisanz, J. (2005). Representation and working memory in early arithmetic. *Journal of Experimental Child Psychology, 91*(2), 137–157. https://doi.org/10.1016/j.jecp.2005.01.004

Raven, J. (2000). The Raven's progressive matrices: Change and stability over culture and time. *Cognitive Psychology, 41*(1), 1–48. https://doi.org/10.1006/cogp.1999.0735

Raven, J. C. (1936). *Raven standard progressive matrices (RSPM)*. APA PsycTests. https://doi.org/10.1037/t07027-000

Raven, J. C., Court, J. H., & Raven, J. (1988). *Manual for raven's progressive matrices and vocabulary scales*. Lewis.

Richardson, A. (1969). *Mental imagery*. Springer. https://doi.org/10.1007/978-3-662-37817-5

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*(1), 54–67. https://doi.org/10.1006/ceps.1999.1020

Sánchez, T., Gilar-Corbi, R., Castejón, J.-L., Vidal, J., & León, J. (2020). Students' evaluation of teaching and their academic achievement in a higher education institution of Ecuador. *Frontiers in Psychology, 11*, 233. https://doi.org/10.3389/fpsyg.2020.00233

Schellenberg, E. G. (2016). Music and cognitive abilities. *Current Directions in Psychological Science, 14*(6), 317–320. https://doi.org/10.1111/j.0963-7214.2005.00389.x

Sima, J. F., Schultheis, H., & Barkowsky, T. (2013). Differences between spatial and visual mental representations. *Frontiers in Psychology, 4*, 240. https://doi.org/10.3389/fpsyg.2013.00240

Sorby, S. A. (2015). Developing 3D spatial skills for engineering students. *Australasian Journal of Engineering Education, 13*(1), 1–11. https://doi.org/10.1080/22054952.2007.11463998

Soulieres, I., Dawson, M., Samson, F., Barbeau, E. B., Sahyoun, C. P., Strangman, G. E., Zeffiro, T. A., & Mottron, L. (2009). Enhanced visual processing contributes to matrix reasoning in autism. *Human Brain Mapping, 30*(12), 4082–4107. https://doi.org/10.1002/hbm.20831

Spagna, A. (2022). Visual mental imagery: Inside the mind's eyes. *Handbook of Clinical Neurology, 187*, 145–160. https://doi.org/10.1016/B978-0-12-823493-8.00010-9

Spagna, A., Heidenry, Z., Miselevich, M., Lambert, C., Eisenstadt, B. E., Tremblay, L., Liu, Z., Liu, J., & Bartolomeo, P. (2024). Visual mental imagery: Evidence for a heterarchical neural architecture. *Physics of Life Reviews, 48*, 113–131. https://doi.org/10.1016/j.plrev.2023.12.012

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in Cognitive Sciences, 9*(2), 69–74. https://doi.org/10.1016/j.tics.2004.12.005

Suggate, S., & Lenhard, W. (2022). Mental imagery skill predicts adults' reading performance. *Learning and Instruction, 80*, 1–10. https://doi.org/10.1016/j.learninstruc.2022.101633

Toader, C., Tataru, C. P., Florian, I. A., Covache-Busuioc, R. A., Bratu, B. G., Glavan, L. A., Bordeianu, A., Dumitrascu, D. I., & Ciurea, A. V. (2023). Cognitive Crescendo: How Music Shapes the Brain's Structure and Function. *Brain Sciences, 13*(10), 1390. https://doi.org/10.3390/brainsci13101390

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*(2), 250–270. https://doi.org/10.1037/0033-2909.117.2.250

Weaver, A. N., Vodyanyk, M., & Jaeggi, S. M. (2024). How music and art tune and sculpt your brain's architecture. *Frontiers for Young Minds, 11*, Article 1151914. https://doi.org/10.3389/frym.2023.1151914

Wei, W., Chen, C., & Zhou, X. (2016). Spatial ability explains the male advantage in approximate arithmetic. *Frontiers in Psychology, 7*, 306. https://doi.org/10.3389/fpsyg.2016.00306

Wimmer, M. C., Maras, K. L., Robinson, E. J., Doherty, M. J., & Pugeault, N. (2015). How visuo-spatial mental imagery develops: image generation and maintenance. *PLoS One, 10*(11), Article e0142566. https://doi.org/10.1371/journal.pone.0142566

Yousef Atoum, A., & Reziq, M. (2018). Can mental imagery predicts reading comprehension? *Current Research Journal of Social Sciences and Humanities, 1*(1), 13–20. https://doi.org/10.12944/crjssh.1.1.02

Zaatar, M. T., Alhakim, K., Enayeh, M., & Tamer, R. (2024). The transformative power of music: Insights into neuroplasticity, health, and disease. *Brain, Behavior, & Immunity - Health, 35*, Article 100716. https://doi.org/10.1016/j.bbih.2023.100716