Chapter #19

VISUOSPATIAL PROCESSING IN THE RESOLUTION OF THE CORSI BLOCK-TAPPING IN BILINGUAL AND MONOLINGUAL CHILDREN

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ABSTRACT
Several studies (Grosjean, 2019) have shown that bilingualism provides an advantage in executive functions. Visuospatial Working Memory (vs WM) is a component of "working memory" responsible for the temporary storage and manipulation of visual and spatial information. The aim of this study is to identify and compare vs WM information processing strategies and to highlight different cognitive profiles between monolingual and bilingual children. The methodology of this research is situated within an experimental framework using the Corsi Block-Tapping Test (Corsi, 1972), which specifically assesses Visuospatial Working Memory. The test comprises two conditions: direct spatial memory and indirect spatial memory. In these tasks, the participant needs to tap the blocks shown by the experimenter in direct or indirect order. To gain a better understanding of the characteristics of the presumed cognitive functioning in Corsi Block-Tapping Test success, this study focused on analysing the nature of errors in the "direct" and "indirect" conditions of the Corsi Block-Tapping Test. This comprehensive error analysis allowed for a deeper exploration of how individuals approached Visuospatial Working Memory tasks and provided insights into their cognitive decision-making processes during the test.

Keywords: bilingualism, visuospatial working memory, cognitive profiles, executive functions.

1. INTRODUCTION

1.1. Bilingualism

The constant mobility of individuals has given rise to a cultural and cosmopolitan diversity that has peaked the interest of cognitive science studies in bilingual individuals. Bilingualism, as a complex linguistic phenomenon, can be conceptualized as an individual's competence or ability to communicate proficiently in two languages. This competence can result from early immersion in a bilingual environment or systematic learning of two distinct languages. Historically, bilingualism was often considered as a dichotomy between complete mastery of two languages. However, research (Grosjean, 2010) has highlighted the variability in levels of linguistic competence in each language and the flexibility of bilingualism, ranging from the coexistence of two distinct languages to a fluid continuum of language skills. Researchers have shown that bilingualism seems to facilitate cross-cultural communication and it also has positive effects on sensory and cognitive abilities. To explain this effect, a hypothesis (Bialystok & Martin, 2004) proposes that mutual interference between the bilingual child's two languages forces the child to develop ability to inhibit one language while using another and, in some ways, accelerate sensory and cognitive development (such as attention, memory, imagination, inhibition, cognitive flexibility, programming, planning, and language skills). Another study has shown that bilinguals performed better than monolinguals on category tests (Bialystok, Craik, & Luk, 2008). Bilingual individuals are frequently exposed to two linguistic systems and must switch between languages based on the context. Bilinguals often develop superior inhibitory control, which refers to the ability to suppress irrelevant information or responses. As we delve deeper into bilingualism and its impact on cognitive functions, it becomes clear that bilingual competence goes beyond linguistic boundaries. After discussing its influence on language skills and inhibitory control, it's crucial to explore its broader effects on executive functions, especially in young children.

1.2. Bilingualism Advantages on Cognitive Functions

Previous studies have shown that in young children aged 6 years old, learning multiple languages simultaneously promotes the development of executive functions (Barac; Bialystok; Castro & Sanchez, 2014). Executive functions refer to a complex set of highly integrated and interdependent cognitive processes responsible for planning, regulating, managing, and adapting behaviours in response to environmental demands (Miyake & Friedman, 2012; Diamond, 2013). This advantage is reflected in bilingual children through enhanced cognitive processing speed, mental flexibility, and better resistance to interference (Bialystok, Craik, Klein, & Viswanatha, 2004; Bialystok, 2006; Bialystok & Feng, 2009) compared to monolingual children. It is suggested that the alternation between two systems of mental representation of languages (linguistic and cultural codes), in bilinguals could explain the different information processing strategies compared to monolinguals.

The cognitive benefits of bilingualism in children, it is important to connect this with our understanding of how individuals process information, especially in complex problem-solving scenarios. The Information Processing Model, developed by Newell and Simon (1972), provides a useful framework for examining cognitive mechanisms in such situations.

1.3. The information Processing Model in Cognitive Research

The Information Processing Model (Problem Solving Model) developed by Newell and Simon (1972) provides a solid conceptual framework for understanding how individuals process information when faced with complex problem-solving tasks. This model emphasizes the importance of cognitive mechanisms such as perception, memory, attention, and decision-making. It also considers problem-solving as an iterative process involving multiple distinct stages, such as problem understanding, strategy generation, action planning, and result evaluation.

2. OBJECTIVES, METHODS

The aim of the present study is to explore the effect of a language learning context on information processing and retrieval strategies in Visuospatial Working Memory (vs WM). The purpose is also to identify distinct cognitive profiles between bilingual and monolingual children aged 6 to 10 year-olds. To accomplish these objectives, participants took part in the Corsi Block-Tapping Test, specifically designed to assess Visuospatial Working Memory abilities. The choice of this test is motivated by its adaptability to a bilingual population as it does not require verbalization, enabling a more precise evaluation of executive skills in a multilingual context. To assess whether these differences vary by age, participants were divided into two age groups: a first group of participants aged 6 to 7 years and 11 months, and a second group aged 8 to 10 years and 11 months. The selection of this age range is based on the theory of Pascual-Leone (Pascual-Leone, Goodman, Ammon, & Subelman, 1978), which claims that individuals transition from one stage of development to another by transcending their previous cognitive schemes. In this context, this age selection reflects critical periods where children are likely to develop new cognitive schemes allowing for a more sophisticated understanding and efficient management of executive functions. This choice is also driven by the desire to identify how this cognitive transcendence differs between bilingual and monolingual children, thereby shedding light on the potential advantages of bilingualism in the development of executive functions. Emphasis is placed on the analysis of participants' errors during the Corsi Block-Tapping Test resolution. The general hypothesis underlying this study predicts that, on one hand, bilingual children will make fewer errors than their monolingual counterparts during the test execution. On the other hand, it predicts that the nature of errors observed will be distinct between bilingual and monolingual groups, suggesting the adoption of different information retrieval strategies in visuospatial working memory.

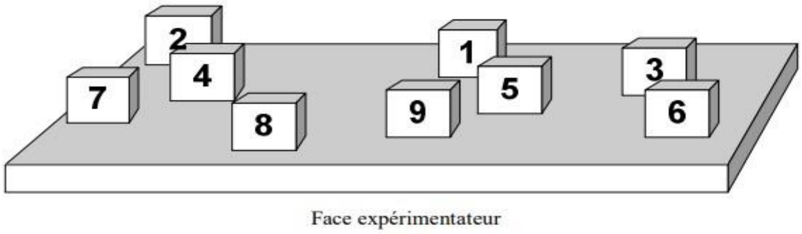
2.1. Participants

This study involved 66 children aged 6 to 7 years and 11 months (M = 7.5; SD = 0.86), including 33 bilingual subjects and 33 monolingual subjects. Additionally, 58 children aged 8 to 10 years and 11 months were recruited (M = 10.02; SD = 0.59), among whom there were 29 bilingual subjects and 29 monolingual subjects. The choice of the age range from 6 to 10 years is based on elements from the multidimensional model of Pascual-Leone (Pascual-Leone et al., 1978), a neo Piagetian model considers this age range as a developmental period characterized by increased neuroplasticity. During this developmental period, children's brains are particularly receptive to environmental stimuli and learning processes. According to this model, children aged 6 to 10 years are in the phase of concrete operations, during which their visual memory abilities gradually develop. These abilities stabilize around the age of 14 and reach full maturity around 19-20 years of age. During this developmental period, individuals demonstrate improved logical reasoning and problem-solving abilities in concrete contexts. Within the framework of Pascual-Leone's theory, cognitive development is divided into multiple dimensions, each corresponding to distinct age groups and stages of cognitive growth. Among these dimensions, Dimension 3 (with an average age range of 6-8 years-old) focuses on the use of mental strategies to solve more complex problems. The following dimension, Dimension 4 (approximately 8 to 10 years-old) concentrates on the integration of advanced mental operations and the increase in working memory resources to support the construction of complex knowledge and enhance problem-solving abilities (Pascual-Leone et al., 1978; Pascual-Leone, 1987; Pascual-Leone & Johnson, 2005). These dimensions progress in two-year increments from the age of 3 to a maximum of 7 years at the end of adolescence. To explore these developmental changes, an inter-age comparison of vs WM abilities was conducted within the present study.

2.2. Materials

The Corsi Block-Tapping Test was administered to the participants. This test was primarily designed to assess visuospatial working memory abilities, which refer to the capacity to recall and retain a specific amount of information over a given period (Corsi, 1972; Jones, Ferrand, Stuart, & Morris, 1995). The choice of the Corsi Block-Tapping Test is justified by its ability to measure Visuospatial Working Memory while being suitable for a bilingual population. This standardized test is also appropriate for different age groups. The Corsi Block-Tapping Test has been used in studies involving children of various ages, demonstrating its validity in assessing Visuospatial Working Memory performance during development (Isaacs & Vargha-Khadem, 1989). The test apparatus consists of a white board on which 9 identical blue cubes (28x28x28 mm) are placed, following the original version (Corsi, 1972). The blocks are numbered from 1 to 9 and are visible only to the experimenter (cf. Figure 1). This task, referred to as spatial memory, comprises two conditions: direct visuospatial memory and indirect or reverse visuospatial memory. The experimental procedure in the current study is the same for both conditions (direct and indirect orders).

Figure 1.
Illustration of the original Corsi Tapping-Block task (Corsi, 1972).



2.3. Experimental Procedure

In this study, the subject sits facing the experimenter, separated by a table on which the test apparatus is placed. The experimenter sequentially taps out visuospatial pointing sequences using their index finger, starting with two blocks. For each sequence, two trials of the same length are presented. Subsequent trials are only offered if at least one of the first two trials is correctly reproduced. The pointing sequence is executed at a pace of one block per second. To prevent the subject from memorizing the block order as a visual pattern, the experimenter lifts their hand approximately thirty centimeters between each pointing sequence and never repeats the same gesture. After the experimenter has completed the pointing sequences, the subjects are immediately asked to replicate the same action.

The experimenter provides the following instruction for the direct order: "I am going to tap out a sequence of blocks on this board. When I finish tapping the blocks, I want you to tap the same blocks in the same order as me. After that, I will tap out more sequences. The length of the sequences will gradually increase." If the subject begins to execute the instruction before the experimenter finishes reading it, the following instruction will be read as follows: "Please wait until I have finished." The instruction for the indirect order is as follows: "I am going to tap out a sequence of blocks on this board. When I finish tapping the blocks, I want you to tap the same blocks, but in the reverse order of mine. After that, I will tap out more sequences. The length of the sequences will gradually increase" (instructions inspired by those proposed by Kessels, Van Zandvoort, Postma, Kappelle, & De Haan, 2000). The subject can self-correct in case of errors. The procedure used is adapted from the Wechsler Memory Scale (Wechsler, & Naglieri, 2009).

Three criteria for successfully completing the test (direct and reverse orders) are used to measure the scope of Visuospatial Working Memory in relation to:

(i) Precise Block Location: The designated block is correctly identified based on its position on the board. (ii) Direction of Path or Sequence: The direction of movement from one block to another is correct and matches the pattern presented by the experimenter.

(iii) Exact Number of Tapped Blocks: The exact number of blocks in the given sequence is correctly noted.

During the assessment, errors are recorded in three categories: (i) direction, (ii) location, and (iii) number errors, made by the participants. The experimenter counts the number of errors as follows:

(i). Direction: A direction or path error means that the subject recalls the correct blocks pointed out by the experimenter but not in the correct cube-to-cube direction. (ii). Location: A location error means that the subject does not remember the correct block (number visible to the experimenter). (iii). Number: A number error means that the subject does not remember the same number of blocks pointed out per level.

If two attempts of an item fail, the experimenter terminates the test.

Exploring the information processing and retrieval strategies employed by participants to solve spatial problems can be achieved through error analysis. According to Clément (2006), the discovery of solutions and the implementation of procedures depend on three elements: the situation, memory knowledge, and representation. "The situation" refers to the context in which the spatial problem is solved. In the context of the Corsi Block-Tapping Test, the situation encompasses elements such as the arrangement of cubes in space, specific task related constraints, as well as cues or information available in the environment. This dimension of situational analysis allows for the assessment of how participants interact with their environment in an attempt to solve the problem, including identifying errors related to the perception and understanding of the spatial configuration of the cubes. "Memory knowledge" is a fundamental element in error analysis. It involves considering how individuals mobilize their pre-existing knowledge, memory skills, and ability to access stored information in memory to solve the task. This dimension of analysis helps understand how errors can result from shortcomings in retrieving, manipulating, or properly using memorized information. "Representation" is a dynamic and transient construct that emerges from the interaction between the situation and the knowledge available in memory. It plays a crucial role in solving spatial problems such as the Corsi Block-Tapping Test. Representation can be considered a kind of mental model or cognitive structure used by participants to organize, interpret, and manipulate spatial information. Through an examination of the construction and utilization of mental representations by participants in solving spatial problems, the investigation aims to elucidate the specific methodologies employed in problem-solving approaches. Thus, by exploring information processing and retrieval strategies during the resolution of spatial problems, taking into account the elements mentioned by Clément (2006) such as the situation, memory knowledge, and representation, we can better understand the cognitive processes involved in these tasks and identify factors that influence individuals' performance.

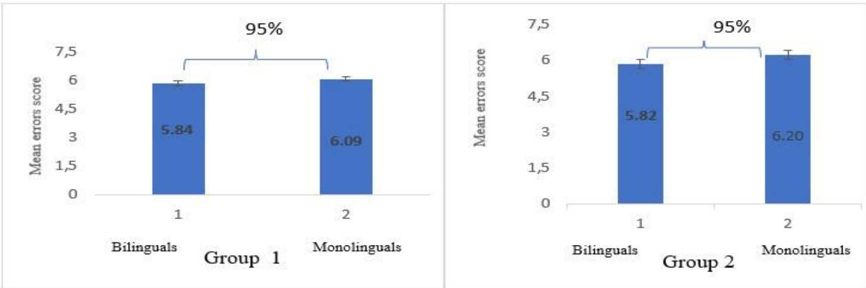
2.4. Analysis and Results

A comparative analysis of errors made in vs WM between bilingual and monolingual participants in the first group, has shown, a lower average error score for bilingual participants ($M=5.84$; $SD=1.60$) compared to monolingual participants ($M=6.09$; $SD=1.42$, Cf. Graph 1). The independent T. Test analysis reveals a significant difference ($p=0.02$) between the groups. These results suggest a positive influence of bilingualism on Visuospatial Working Memory performance at this young age.

In the second group, a comparative analysis of errors made in Visuospatial Working Memory (WM) between bilingual and monolingual participants also reveals a significant difference ($p = 0.01$). Bilingual participants exhibit an average error score of $M = 5.82$;

SD = 1.66, while monolingual participants have an average error score of M = 6.20; SD = 1.32 (cf. graph 1). These results suggest a positive influence of bilingualism on Visuospatial Working Memory performance at this later age.

Graph 1.
Mean Errors Score (error bars) in Corsi block-tapping test (Bilinguals Vs. Monolinguals aged 6-8 years-old (Group 1) and 8-10 years-old (Group 2)).



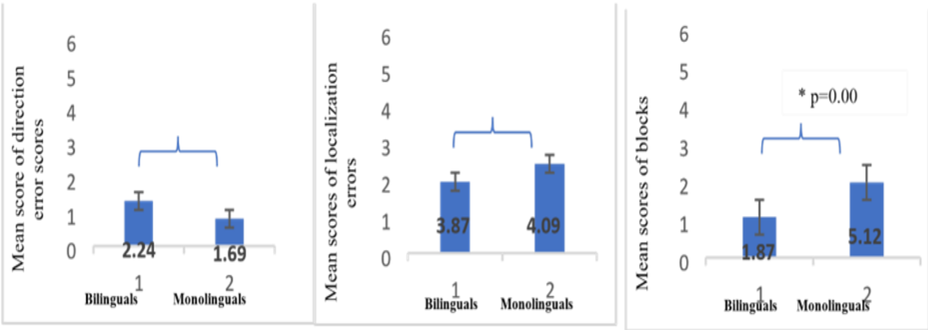
A second analysis focused on the errors made by the participants: errors in direction, errors in location, and errors in the number of pointed blocks in the sequences for each group of participants.

2.4.1. Group 1: Ages 6 to 7.11 years-old

Direction Errors analysis: The analysis of direction errors reveals interesting results. Bilingual participants have a higher average score for direction errors (M = 2.24; SD = 1.47) compared to monolingual participants (M = 1.69; SD = 1.44) (cf. Graph 2). The T-test indicates that the observed difference is not statistically significant ($p = 0.13$). However, it is important to note that the descriptive analysis of directional errors does not lead to a significant conclusion about the observed difference. Nonetheless, it may suggest that bilingual participants encounter more difficulties when it comes to mentally manipulating spatial information, such as the relative position of objects in space, distances, and orientations.

Location Errors Analyses: The analysis of location errors reveals no significant difference (T-test, $p = 0.45$). However, it's important to note that the analysis shows a slightly higher average of location errors in monolingual participants (M = 4.09; SD = 1.28) compared to bilingual participants (M = 3.87; SD = 0.99) (cf. Graph 2). Despite the lack of statistical significance, these results suggest an interesting trend. Monolingual participants appear to exhibit a tendency to make more errors when it comes to memorizing and reproducing spatial information compared to bilingual participants. This disparity could potentially be explained by considering the challenges monolingual participants may face in coordinating visual attention. In a localization task, monolingual participants must temporarily hold pertinent visuospatial information, such as the positions of objects to be located, in their working memory. However, due to the higher cognitive load on visuo-spatial working memory, monolingual participants may encounter difficulties maintaining this information in memory while effectively coordinating their visual attention. This challenge could be a contributing factor to the observed higher number of location errors.

Graph 2.
Mean Directional, localization and number error Scores in Corsi block-tapping test (Group 1 (Bilinguals Vs. Monolinguals aged 6- 8 years old).



2.4.2. Number Errors Analysis

The results of the analysis of block-counting errors are significant and show a marked difference in favour of bilingual participants, with a lower average score of block-counting errors (M = 1.87, SD = 1.38) compared to monolingual participants (M = 5.12, SD = 1.65), as indicated by the T-test ($p < 0.001$). These results suggest a positive influence of bilingualism on the manipulation of spatial information. The significant difference in block

counting errors strongly supports this conclusion, with bilingual participants displaying a notably superior performance compared to their monolingual counterparts. This implies that bilingual individuals may have a cognitive advantage when it comes to tasks involving spatial information manipulation.

2.4.3. Group 2: Ages 8 to 10.11 years-old

Direction Errors Analysis:

The analysis of direction errors reveals that bilingual participants have a higher average score for direction errors (M = 2.62; SD = 0.99) compared to monolingual participants (M = 1.24; SD = 1.13) (cf. Graph 3). These results indicate that bilingual participants encounter additional issues when it comes to following non-verbal directional instructions compared to monolingual participants, likely due to a higher cognitive load. Significant differences ($p < 0.01$) between the two groups were found in the T-test, underscoring the cognitive challenges faced by bilingual individuals in tasks involving non-verbal spatial information.

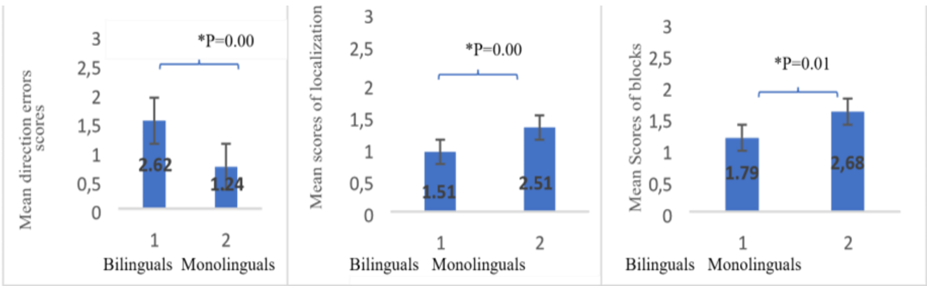
Location Errors Analysis:

The analysis of location errors reveals that monolingual participants have a higher average score of location errors (M = 2.51; SD = 0.89) compared to bilingual participants (M = 1.51; SD = 0.77) (cf. Figure 2). These results indicate significant differences ($p < 0.01$) between monolingual and bilingual participants. This suggests that monolingual participants face greater challenges when it comes to accurate spatial location tasks compared to their bilingual counterparts.

Number Errors Analysis:

The analysis of block-counting errors reveals that bilingual participants have a lower average score of errors in the number of pointed blocks (M = 1.79; SD = 1.15) compared to monolingual participants (M = 2.68; SD = 1.36) (cf. Graph 3). These results indicate significant differences (p = 0.01) between bilingual and monolingual participants. This suggests that bilingual participants exhibit a more accurate performance in counting pointed blocks compared to their monolingual counterparts.

Graph 3.
Mean Directional, localization and number error Scores in Corsi block-tapping test (Bilinguals Vs. Monolinguals aged 8-10 years old).



The data reveals that monolingual children exhibit a higher frequency of errors in terms of location and the number of pointed blocks, while bilingual children demonstrate an increased prevalence of direction errors, as shown in graph 3. These observed trends are likely influenced by various factors, including frequent language switching, which could play a determining role in the observed disparities. Language switching can influence the overall cognitive load of bilinguals. Indeed, frequent switching between two languages requires a degree of cognitive flexibility, which may potentially increase the cognitive load when performing tasks involving spatial information. The coordination of visual attention and the manipulation of spatial information require efficient use of working memory. Bilinguals may face an additional challenge due to the need to manage two languages and transition between them, potentially increasing the demand for cognitive resources associated with these visuo-spatial tasks.

3. FUTURE RESEARCH DIRECTIONS

The results of our research provide promising data, but a better understanding can be achieved by comparing them with subsequent studies conducted on a larger sample of children. The integration of new approaches, such as the complex tasks we have described, would also be desirable to enrich our understanding. Furthermore, a longitudinal study conducted over time could provide meaningful, and potentially definitive, insights into the subject. A comparison of linguistic characteristics between different languages could have been relevant and should be considered. To assess inhibition and verbal flexibility, the use of tests such as the Stroop test and Verbal Fluency Tasks could also be considered to gain a more comprehensive view of the cognitive processes involved. By considering these perspectives, we can deepen our knowledge and make a significant contribution to this field of research.

4. CONCLUSION/DISCUSSION

The current study extensively examined the results of comparative analyses of performance in Visuospatial Working Memory (vs WM) between groups of bilingual and monolingual individuals, divided into two distinct age groups. In the first group, consisting of children aged 6 to 7.11 years-old, significant differences were found in terms of errors made in vs WM between bilingual and monolingual subjects. Bilinguals exhibited a lower average error score, suggesting higher visuospatial ability in bilingual children at this early age. The significant difference was observed in the number of pointed block errors, with clear statistical significance. Bilingual subjects displayed a markedly lower number of cube-pointing errors compared to monolingual subjects. These results underscore the positive impact of bilingualism on spatial information manipulation in children of this early age cohort.

According to Pascual-Leone's theory, children in this age group are likely in a cognitive development phase where they are progressively acquiring more complex visuospatial skills. The benefits of bilingualism in reducing pointed block errors may reflect an enhancement in their ability to mentally manage spatial information, which is consistent with Pascual-Leone's developmental model.

In the second group, consisting of children aged 8 to 10.11 years-old, the analyses continued to reveal significant differences between bilingual and monolingual subjects in terms of directional, location, and number-pointing errors. Bilinguals showed a significantly higher average number of directional errors compared to monolinguals, suggesting that bilinguals may face additional challenges in following non-verbal management instructions, likely due to increased cognitive load. The analysis of location errors revealed a significant difference in favour of bilinguals, with a lower average number of location errors compared to monolinguals. This finding reinforces the idea that monolingual subjects may have specific challenges related to the coordination of visual attention, resulting in a higher frequency of location errors. Regarding the number of pointed block errors, the results showed a significant difference in favour of bilinguals, confirming the positive impact of bilingualism on spatial information manipulation in children of this older age cohort.

According to Pascual-Leone's theory, older children in this age range have generally reached a more advanced stage of cognitive development, meaning they can mentally manipulate more complex spatial information. However, bilinguals exhibited more directional errors, which could indicate increased complexity in their coordination of visual attention and their ability to follow non-verbal management instructions, suggesting a higher cognitive load.

The comparative analysis of Visuospatial Working Memory (vs WM) between bilingual and monolingual participants in two age groups yielded significant insights. In the younger age group (6 to 7.11 years-old), bilingual children demonstrated superior vs WM performance, as evidenced by a lower average error score. This difference was particularly pronounced in the number of pointed block errors. These results align with the theoretical framework proposed by Pascual-Leone, suggesting that bilingualism positively influences spatial information manipulation in early childhood.

In the older age group (8 to 10.11 years-old), bilingual participants exhibited distinct error patterns. Although they displayed a higher frequency of directional errors, bilingual participants surpassed their monolingual counterparts in both location and number-pointing accuracy. These findings indicate that bilingualism may introduce additional cognitive challenges, possibly related to language switching and the coordination of visual attention. However, they still excel in manipulating spatial information.

The research sheds light on the nuanced relationship between bilingualism and cognitive processes, particularly Visuospatial Working Memory. Understanding these differences can inform educational strategies and interventions. Educators may consider the advantages of bilingualism in enhancing specific cognitive skills when designing curriculum and activities.

Moreover, these findings have potential implications for cognitive development theories and bilingualism studies. They underscore the importance of considering age-related cognitive changes and the role of language switching in bilinguals. Future research could delve deeper into these aspects, potentially enriching our understanding of cognitive development.

This research opens avenues for further investigations, including longitudinal studies with larger cohorts and cross-linguistic comparisons. Additionally, the study highlights the relevance of assessing inhibition and verbal flexibility in bilingual children using tests like the Stroop task and Verbal Fluency task.

These results validate our hypothesis and demonstrate that language acquisition modifies the strategies used in a Visuospatial Working Memory task. Information retrieval strategies in Visuospatial Working Memory differ between bilingual and monolingual subjects, illustrating distinct visuospatial behavioural processing patterns between the two populations. It is important to note that this study does not conclude that bilingual children have better abilities compared to monolingual children in all tasks. Rather, the differences between the two groups are noticeable in specific tasks that involve information processing and resolution strategies in Visuospatial Working Memory. To conclude, this study contributes valuable insights into the cognitive effects of bilingualism, emphasizing the multifaceted nature of Visuospatial Working Memory and its relation to language skills. The results prompt us to explore the intricate dynamics of cognitive processes in bilingual individuals, with potential implications for educational and cognitive research.

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KEY TERMS & DEFINITIONS

Executive functions: are cognitive skills that allow us to act in an organized way to reach goals (there are three main ones: working memory update (MdT), mental flexibility and cognitive inhibition). These functions are closely linked and thus enable cognitive and behavioural control (Friedman & Miyake, 2012). These executive functions also play a main role in many cognitive activities, such as solving mathematical problems and understanding scientific concepts (Gathercole et al., 2019).

The Visuospatial Working Memory (vs WM): is a component of working memory, plays a crucial role in many cognitive activities. Visuospatial Working Memory (vs WM) allows visual information, such as objects, shapes, colours and patterns, to be temporarily stored in memory for processing and mental manipulation. It also allows the mental manipulation of spatial information, such as the relative position of objects in space, distances and orientations, which is essential for navigation and spatial orientation. The Visuospatial Working Memory (vs WM) plays a role in coordinating visual attention by keeping information about objects or locations we need to pay attention to in temporary memory, while filtering out visual distractions. It helps to solve spatial problems, such as searching for a hidden object in a complex environment, constructing a mental route or carrying out tasks that involve spatial relationships. Visuospatial Working Memory (vs WM) facilitates the integration of visual information with other sensory modalities, such as hearing and touch, to form a coherent representation of the world.

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