Canadian Journal of Experimental Psychology
2007, Vol. 61, No. 1, 13-20

DOI: 10.1037/cjep2007002

Memory for Object Location: A Span Study in Children

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Abstract The aim of the present study was to analyze the developmental changes in three spatial processes, namely, in positional reconstruction involving the retention of spatial locations per se (Positional encoding task), in the assignment of objects to positions (Object-to-position assignment task), and in the integration of these two (Combined task). A span procedure was used to assess the development of spatial memory in children aged 6, 8, and 10 years tested in these three tasks. The findings of the present study provide developmental spans for each relocation task. Results show an age-dependent improvement in all tasks, suggesting that spatial position is not automatically encoded. The results also show different developmental patterns for the relocation tasks considered, suggesting that spatial memory comprises a number of different component processes.

Résumé L'objet de la présente étude était d'analyser les changements dans le développement de trois processus spatiaux, nommément en reconstruction positionnelle supposant la rétention des emplacements spatiaux proprement dits (tâche de codage positionnel), dans l'assignation d'objet à des positions (tâche d'assignation objet-position) et dans l'intégration de ces deux tâches (une tâche combinée). Une procédure de portée a été utilisée pour évaluer le développement de la mémoire spatiale chez des enfants de 6, 8 et 10 ans testés dans ces trois tâches. Les résultats de la présente étude révèlent des portées de développement pour chaque tâche de relocalisation. Ils témoignent aussi d'une amélioration en fonction de l'âge de toutes les tâches, ce qui suggère que la position spatiale n'est pas codée automatiquement. Les résultats montrent aussi des modèles de développement différents pour les tâches de relocalisation examinées, ce qui suggère que la mémoire spatiale est constituée de processus impliquant différentes composantes.

Spatial memory enables us to find our way in the environment but also to find objects such as keys or glasses that we have recently used and placed somewhere in our surroundings. Regarding this ability, it has been suggested that it might depend upon a variety of component processes, specifically, memory for the locations of individual items and memory for occupied locations, that may be affected differently by variations in stimulus characteristics or task demands (Puglisi, Park, Smith, & Hill, 1985). More recent studies (Postma & De Haan, 1996; Schumann-Hengsteler, 1992; Shoqeirat & Mayes, 1991) also suggest that three separate spatial processes may be involved in short-term object location memory. First, one needs to remember the precise position occupied in a given space (positional encoding per se), then one has to decide which object was at which position (object-to-position assignment), and finally one has to integrate both types of processes. Evidence from studies in adults shows that disrupting the phonological loop, with a concurrent verbal task (articulatory suppression), interferes with the object-to-position assignment process, suggesting that it relies to some extent upon verbal coding (Postma & de Haan, 1996). On the other hand, interfering with the visuo-spatial sketchpad with a simultaneous activity, such as repeated tapping of a spatial pattern, disrupts the positional encoding process (Pickering, Gathercole, Hall, & Lloyd, 2001).

With regards to object-to-position assignment, there is agreement in the literature that a developmental improvement in the number of associations remembered is found. Schumann-Hengsteler (1992) reported that children improved with age in remembering the positions of specific objects. In this study, a picture reconstruction task with simultaneous presentation of scene-like visual spatial arrangements was used. Subjects had to recognize objects and reconstruct the initial spatial arrangement. In the first experiment, an age-dependent improvement in remembering the locations of specific objects was shown in 4- and 11-year-olds. The second study with 3- and 7-year-olds revealed similar results. In line with these findings, Walker, Hitch, Doyle, and Porter (1994) reported a study in which a probed memory task was used to investigate children's short-term visual memory for an object's spatial location or colour. The results of their second experiment indicate that there was a developmental improvement in memory for spatial positions in children of 5 and 7 years of age. Other studies have also found this developmental improvement for tasks in which different objects have to be linked to different positions (Rossi-Arnaud, Alfano, & Longoni, 1999; Siemens, Guttentag, & McIntyre, 1989).

On the other hand, with regards to spatial location, Hasher and Zacks (1979) suggested that it is encoded and retained automatically and that as a consequence of being automatic, memory for spatial location should not show any developmental enhancement. Although a number of studies have investigated the development of spatial memory (Hamilton, Coates, & Heffernan, 2003; Logie & Pearson, 1997; Orsini et al., 1987), few have specifically addressed the issue of the development of positional encoding per se. Schumann-Hengsteler (1992), in the experiments mentioned previously, observed that whereas children improved with age in remembering the locations of specific objects, there was no age effect on memory for the critical loci themselves. Other results are in contrast with the latter study and report a developmental improvement in positional encoding (Conte, Cornoldi, Pazzaglia, & Sanavio, 1995; Siemens, Guttentag, & McIntyre, 1989). Siemens et al. (1989) presented children aged 4 to 8 and college students with 3-7 items in different cells of a 4 × 4 matrix and required the children to remember the identity, the locations, or both identity and locations. In both experiments, there were much larger age differences in retention of location than of identity information. Recent work by Postma, Wijnalda, and Kessels (2001) and by Rossi-Arnaud et al. (1999) used Postma and de Haan's experimental paradigm and compared the performance of children in three different relocation conditions. In the first condition, named the positional encoding task, all objects are the same and hence only precise locations have to be remembered. In the object-to-position assignment task, the positions where objects should be replaced are marked; hence only the association between object identity and location needs to be remembered whereas in the combined task both positions and object-position associations have to be coded. Both studies suggest that there might be age differences in memory for positions per se. However, both studies use a fixed length procedure (i.e., children are shown a fixed number of stimuli simultaneously), which does not really address the question of how many stimuli children can actually encode and remember at each age considered. The latter is better examined using a span procedure.

Spatial span has generally been determined using the Corsi's block test (e.g., Isaacs & Vargha-Khadem, 1989; Logie & Pearson, 1997; Orsini et al., 1987), which entails a sequential presentation of the items to be remembered. One of the aims of the present study was to determine the span in children of different age groups for visuo-spatial information presented simultaneously. Different from studies that have measured span using the recall of occupied cells in a matrix (e.g., Miles, Morgan, Milne, & Morris, 1996; Wilson, Scott, & Power, 1987), in the present study span will be measured in parallel for each of the relocation conditions previously described, namely, the positional encoding task, the object-to-position assignment, and the integration of these two. This allows one to examine if performance in the three conditions shows different developmental trends. This pattern of results would, on the one hand, lend some support to the idea that these conditions tap different memory processes and, on the other hand, allow us to understand whether some processes develop before others, in particular whether nonassociative processes (e.g., positional encoding) develop before associative processes (object-to-position assignment). Further, results will also answer the question of whether there is a developmental improvement for each of the three spatial memory processes described above, including positional encoding per se. In the experiment described below, children aged 6, 8, and 10 years were randomly assigned to one of three groups and a span procedure was used in each of the experimental conditions mentioned above (Positional encoding, Object-to-position assignment, Combined).

Method

Participants

A total of 167 children from a junior high school in middle-class areas in Rome, Italy, participated in the study. Not all data were taken into account either because children did not complete the task or because they were outliers (data were eliminated that exceeded three standard deviations from the mean) or because teachers informed the experimenters of children's specific deficits. Data taken into account for the analyses came from a total of 155 subjects. The youngest group of participants comprised 52 children (33 males, 19 females) with a mean age of 6 years 2 months (standard deviation = 4.2 months). The middle age group comprised 54 children (28 males, 26 females) with a mean age of 8 years 3 months (standard deviation = 4.3 months). The oldest group consisted of 49 children (21 males, 28 females) with a mean age of 10 years 4 months (standard deviation = 3.0 months). In each age group, children were randomly assigned to one of three groups according to the type of task considered: Positional encoding, object-to-position assignment, and the combined task.

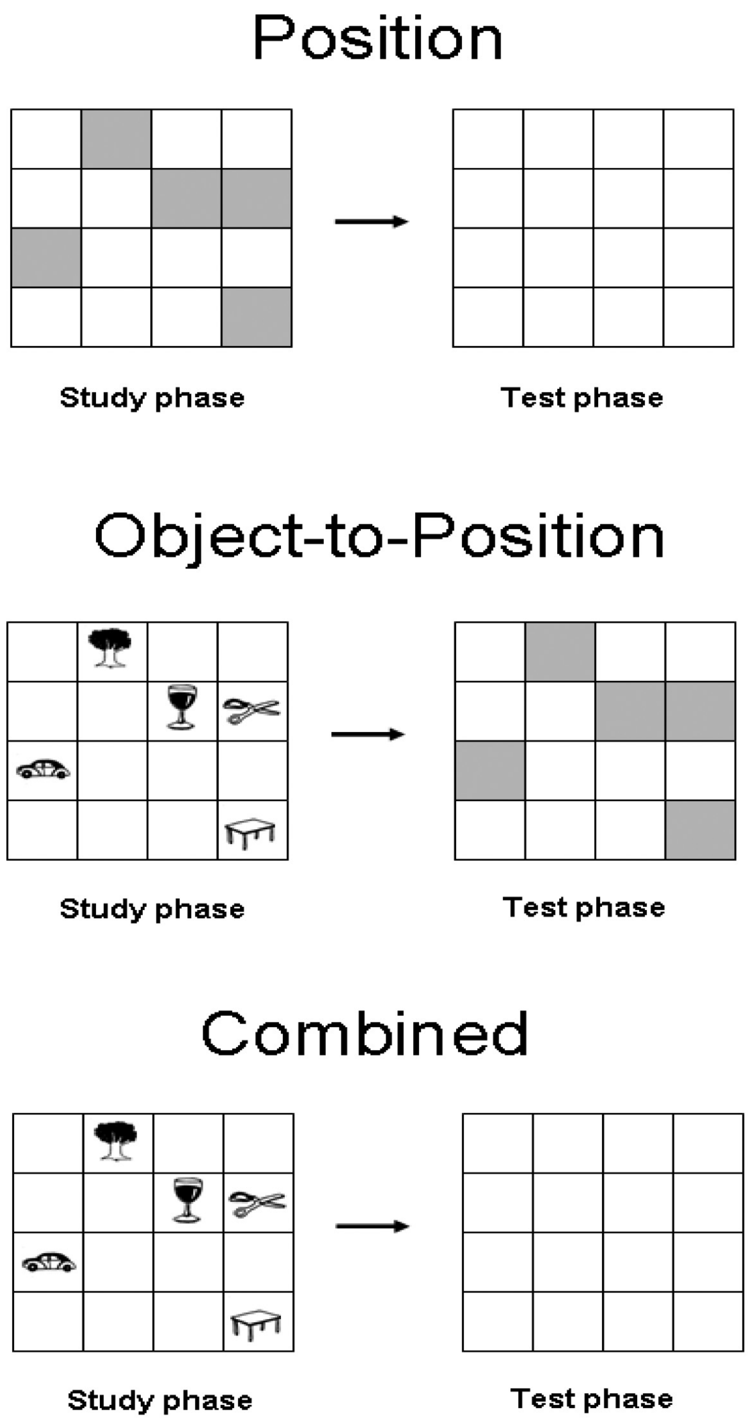

Figure 1. Example of the stimulus display in the study and in the test phase for each of the tasks considered: a) positional encoding (Position); b) Object-to-position assignment; and c) the Combined task.

Materials

The stimuli used were 10 × 10 cm paper cards arranged in a 4 × 4 paper matrix on a table, with each cell measuring 10 × 10 cm. In the position condition, the stimuli were black paper cards. In the object-to-position and combined condition, the stimuli were line drawings of familiar objects selected from a larger group of items tested (Longoni & Scalisi, 1994; Nisi, Longoni, & Snodgrass, 2000) because of their high frequency in children's language (Marconi, Ott, Pesenti, Ratti, & Tavella, 1993) and according to the number of syllables of the object name. The final 12 black and white pictures comprised 12 pictures of objects with two-syllable names (scala - *stairs*, stella - *star*, osso - *bone*, scarpa - *shoes*), three-syllable names (bicchiere - *glass*, albero - *tree*, tavolo - *table*, forbici - *scissors*), and four-syllable names (pantaloni - *trousers*, coccodrillo - *crocodile*, orologio - *clock*, semaforo - *traffic-light*). Pilot work had established that the objects were uniquely named by 70 children aged between 6 and 10. Examples of the stimulus displays are shown in Figure 1.

Procedure

Each child was tested individually in a quiet testing room in the school. Cards were randomly arranged over a paper matrix while children had their backs turned. When the array was ready, children studied the pictures placed on the matrix for a 30 s observation period. An interval of approximately 4 s followed during which children had again their backs turned and the experimenter gathered cards in a pile, mixed them, and then displayed them randomly ordered in a column on a side of the matrix. Children were asked to relocate as accurately as possible the cards on the matrix. They were told there was no time restriction and the cards could be shifted to a new position as many times as necessary.

On any given trial, the examiner displayed a particular sequence of cards, randomly sampled from the set of items, using a classical span procedure, as reported in Gathercole, Adams, and Hitch (1994). Sequences of increasing length, starting from length two, were presented if the subject correctly recalled two strings for each length. If the child failed to repeat both of the two lists at one length, no further lists were given. When the child correctly recalled only one of the first two lists at a particular length, a third list of the same length was given. If the third list was correctly repeated, trials at the next length were given. If the child incorrectly repeated the third list, testing stopped. Span was scored as the maximum length at which the child correctly recalled at least two lists. According to Postma and de Haan's paradigm, one relocation task was the object-to-position assignment, in which the position where objects were to be relocated was marked on the matrix, and the children were required to remember which object had previously been at each marked location; the other condition is the "combined" condition in which subjects had to relocate the cards on the matrix, without any marking of the original positions. In the positional encoding task, children had to remember only the exact place occupied on the matrix by the black paper cards.

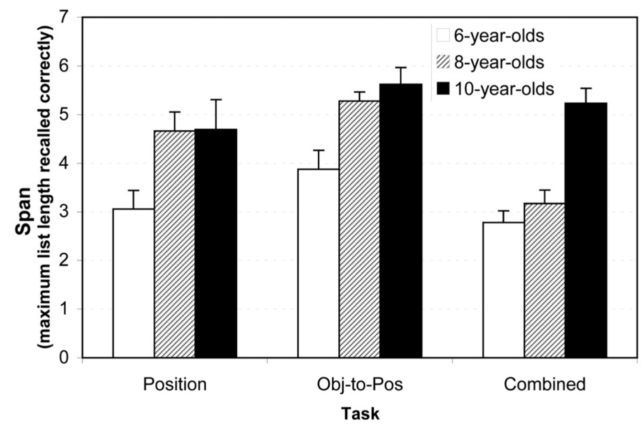

Figure 2. Mean span and standard error for correctly relocated items in the three different age groups for the three different relocation tasks: a) positional encoding (Position); b) Object-to-position assignment (Obj-to. Pos); and c) the Combined task.

Data analysis

A single two-way analysis of variance (ANOVA) with two between-group factors, age group (3 levels: 6, 8, and 10 years of age), and task (3 levels: Positional encoding, Object-to-position assignment, Combined) was performed on the span measured for each child. The Newman-Keuls post-hoc test was carried out where necessary. To better illustrate the developmental trend in span performance, correlation analyses were carried out between subjects' performance and their ages expressed in months.

Results

The mean span and standard deviation for correctly relocated items in the three different age groups in the three different relocation tasks are shown in Figure 2.

When the span for correctly remembered positions and correctly relocated objects in children aged 6, 8, and 10 years were analyzed, statistical analysis indicated a significant main effect of Age, $F(2, 146) = 23.11$, $p < .001$, and a significant main effect of Task, $F(2, 146) = 9.31$, $p < .001$. Post-hoc comparisons indicated that performance in the object-to-position task was significantly higher than in the positional encoding task ($p < .01$) and than in the combined task ($p < .001$); the levels of performance in the latter two tasks did not differ significantly. With respect to the main effect of Age, post hoc comparisons indicated that all age groups differ from each other ($p < .001$ when comparing 6-year-olds to 8- and 10-year-olds and $p < .01$ when comparing 8- and 10-year-olds). Further, the analysis also revealed a significant Age × Task interaction, $F(4, 146) = 2.56$, $p < .05$. Post-hoc comparisons indicated that the performance of 8-year-olds grouped with the performance of 10-year-olds for the positional encoding and object-to-position tasks, whereas it grouped with the performance of 6-year-olds for the combined task. Specifically, in the positional encoding task, the span for correctly remembered positions is significantly lower in 6-year-olds than in older children ($p < .01$ when comparing 6- and 8-year-olds and 6- and 10-year-olds). Children of 8 years of age did not differ from 10-year-olds in the span for positions remembered ($p = .95$). In the object-to-position task, the span for correctly relocated objects is significantly lower in 6-year-olds than in older children ($p < .05$ when comparing 6- and 8-year-olds; $p < .01$ when comparing 6- and 10-year-olds). Children of 8 years of age did not differ from 10-year-olds in the span for objects relocated ($p = .46$). In the combined task, the span for correctly relocated objects is significantly higher in 10-year-olds than in younger children ($p < .001$ when comparing 6- and 10-year-olds and when comparing 8- and 10-year-olds). Children of 8 years of age did not differ from 6-year-olds in the span for objects relocated ($p = .69$).

Across task (within age) comparisons confirmed the above interpretation. Performance for the 6-year-olds and 10-year-olds is comparable across all tasks, whereas performance for the 8-year-olds is significantly lower in the combined task than in both the positional encoding task ($p < .01$) and the object-to-position task ($p < .001$).

A correlation analysis of subjects' performance and their ages (expressed in months) was also performed for each type of task considered. The Pearson correlation (r) was 0.356 ($p < 0.05$) in the Position task ($n = 48$), 0.481 ($p < 0.01$) in the Object-to-position task ($n = 52$), and 0.613 ($p < 0.01$) in the Combined task ($n = 55$).

Discussion

In the present study, developmental changes in three spatial processes were examined. We used the positional encoding task to measure the retention of spatial positions per se, the object-to-position task to measure the association of objects to locations, and the combined task to measure the integration of these two processes.

A first aim of the present study was to measure the span for spatial positions, the span for the association between objects and their positions, and the span in a spatial memory task requiring the ability to combine these two processes. A second goal was to test the hypothesis that there is a developmental trend in these spatial processes and, finally, a third objective was to assess whether there are selective developmental patterns for these distinct components of positional memory, specifically, whether the two basic processes, such as remembering the positions per se or assigning objects to positions, develop earlier than the ability to combine them.

Regarding spatial span, whereas a number of studies have analyzed spatial span in children either with a Corsi's block test (e.g., Isaacs & Vargha-Khadem, 1989; Logie & Pearson, 1997; Orsini et al., 1987) or with the recall of occupied cells in a matrix (e.g., Miles et al., 1996; Wilson, Scott, & Power, 1987), none have to date analyzed, in parallel, the development of span for the three spatial processes previously mentioned. The studies that have examined such a distinction between processes have used a fixed length procedure. The use of a span procedure allows us to obtain a measure of the maximum level of performance that can be achieved by the subject, and that level of performance is commonly assumed to be a consequence of the cognitive resources available (Duff & Logie, 2001). Our data make an important contribution to this field of study because they provide spans for children of three different age groups that we propose are specific to three spatial processes, tested in parallel in three separate spatial relocation tasks. These results clarify resource availability at each age level and for each of the spatial memory tasks considered, and can thus be useful for further studies in children or for a neuropsychological use of the paradigm presented.

Regarding span in the positional encoding task, the level of performance appears to fall below that observed in previous span studies using tasks that might, at first sight, look similar (Hamilton et al., 2003; Logie & Pearson, 1997). In the latter studies, children aged 6 show a span of three or four like ours, but in those studies span goes up to six in children aged 8 to 10. In our positional encoding task, mean span at 10 years of age is 4.69. However, a comparison with these studies might not be entirely appropriate since a number of major differences can be found between these earlier studies and the present research. First, it is important to note that both the Logie and Pearson (1997) and the Hamilton et al. (2003) studies display patterns for 2 s before removing them. Since in Postma and de Haan's paradigm, and therefore in ours, patterns are presented for 30 s, it is unclear whether the tasks considered actually tap the same processes. Data by Hamilton et al. (2003) are also difficult to compare because in the latter study a recognition procedure is used to measure the visual span while in our study children have to recall the patterns observed. If the recall version of the Logie and Pearson visual pattern task (VPT) is considered, a further difference is that in their study children are tested on matrices that are rather small compared to the one used in the present research. In their experiments, the dimension of the matrix is set by the number of coloured squares on which the child is tested. Testing started with two coloured (and two blank squares) and the matrix was thus a 2 × 2 pattern. If the child was successful, the number of squares in the pattern was increased to show three coloured and three blank squares in a 2 × 3 matrix. Children in the Logie and Pearson (1997) study were thus shown the 16-square pattern used in our study only if they had been successful with seven coloured squares. The latter only rarely happens, especially in children aged from 5 to 9. Lastly, span was calculated differently in the Logie and Pearson (1997) study, using the sequence length at which testing was stopped because the child was successful on only one trial out of three. If this method of identifying span were used in our study, it would certainly increase the span values obtained.

With regards to the hypothesis that there is a developmental trend for all the processes considered, the significant main effect of age indicates that there is an age-dependent improvement in all tasks. Further, the significant correlations found in each task between subjects' age and performance provide clear evidence of a developmental trend. Age effects in the object-position assignment process are in agreement with the literature, which suggests an improvement with age in memory for object-position associations (Postma et al., 2001; Schumann-Hengsteler, 1992; Siemens et al., 1989). On the other hand, as previously mentioned, there are a number of contradictory results with regards to a developmental enhancement in memory for spatial positions per se. The significant age effect found in the present study in the positional encoding task is in agreement with previous data showing that the positional reconstruction process is consistently affected by age (Puglisi et al., 1985; Siemens et al., 1989). If we consider span studies (Logie & Pearson, 1997), we find that in recall the VPT span is about three at age 5 to 6 and goes up to eight in 11-year-old children. If we consider earlier studies using Postma and de Haan's paradigm (Postma et al., 2001; Rossi-Arnaud et al., 1999) but with a fixed-length procedure, we also find that older children perform better than younger ones. It must be noted, however, that there might be a fundamental difference between the current study and earlier ones using the same paradigm which lies in the nature of the spatial processes demanded by the task. In the original research (Postma & de Haan, 1996; Postma, Izendoorn, & de Haan, 1998), location accuracy was measured in mm displacement and positional reconstruction thus entailed fine coordinate spatial relations processing. The current study does not address the fine metric considerations of the earlier research and, in the present experiment, positional reconstruction could depend upon a categorical encoding of the locations. Taken together, results thus suggest that there is an improvement of performance with age both when recall of metric information is required and when only the location in a matrix needs to be remembered. Overall, the findings argue against the view that occupied-position information is encoded automatically (Hasher & Zacks, 1979).

When looking at performance across tasks, it is interesting to note that performance in the positional encoding task overall appears slightly lower than that in the object-to-position assignment. This might be related to the way children encode the information in each condition. For instance, it has been reported that a concurrent verbal task strongly interferes with the object-to-position assignment task (Postma & de Haan, 1996), suggesting that this process depends on verbal encoding. It is therefore possible that when having to assign objects to premarked positions, children use a "mixed" verbal and visual code while in the positional encoding task they can rely only on visual codes. Further, it is interesting to note that in the 6- and 10-year-old children, there is a relatively small reduction in performance when the positional encoding and the assignment of objects to positions are performed together in the combined task. The fact that performance in the two tasks does not drop significantly when these are performed together is consistent with the idea that each task relies on separate resources, thus providing an additional source of evidence for distinct processes in spatial memory performance.

When looking at the developmental patterns, it is interesting to note that children first improve their ability in remembering the spatial positions per se and in associating the objects to the positions. Our results show that there is a significant improvement both in positional encoding and in object-position assignment at 8 years of age. However, increases in the efficiency of both positional encoding and object-to-position assignment tasks are not accompanied by an increase in the combined task between ages 6 and 8. It is only later that children improve in the ability to perform positional encoding and object-position assignment together. Our data show a significant improvement in the combined condition at age 10. This selective developmental pattern for the three tasks considered is consistent with the view that these tasks tap distinct components of object-position memory, and our results might thus provide an example of developmental fractionation (Logie & Pearson, 1997). The patterns observed are what was expected although, using the same experimental paradigm, Postma et al. (2001) had not found this pattern of results in children. However, in their study, as suggested by the authors, there was probably a practice effect that masked the higher complexity effect in that, in their procedure, the combined condition was always performed at the end of the experiment.

Our pattern of results suggests that the combined condition is indeed the most complex relocation condition and that the ability in this distinct component of object-position memory depends upon the development and integration of the two other more elementary processes. A possible explanation for the developmental patterns observed for the three spatial abilities considered in the present study might, as mentioned above, be related to the way children encode the information in each condition. If the object-to-position assignment task depends, at least partly, on verbal encoding (Postma & de Haan, 1996), it has to be considered that in children verbal encoding might not be effectively applied until the age of 8 years (Hitch, Halliday, Schaafstal, & Schraagen, 1988). An alternative account for our data, which does not invalidate the previous one, considers that the combined task requires concurrent position and object-to-position processing. Since one of the latter processes is spatial in nature and the other has been shown to be, at least partly, verbally mediated, relocation in the combined condition might require a cross-modal integration process that may make demands upon executive resources. Thus a significant improvement in performance in the combined task might depend on executive functioning and particularly on the developing availability of executive resources. Earlier research has produced direct and indirect evidence for a relationship between visuo-spatial span performance and executive function (Chuah & Mayberry, 2000; Hamilton, Coates, & Heffernan, 2003). What remains unclear is whether executive involvement in this type of task is related to strategic maintenance processes and/or simple refresh maintenance.

The use of Postma and de Haan's paradigm, which has been successfully applied in various contexts, might help unravel how spatial memory develops in children particularly because it allows us to test spatial memory when different spatial attributes are made available. The three relocation tasks might allow us to understand exactly how children solve each task and analyze whether the strategies used in each relocation task vary in children of different ages.

The authors would like to thank Dr. Pietro Spataro for providing statistical help and advice. We are also grateful to Dr. Bruce Milliken and two anonymous reviewers for comments on an earlier draft of this paper.

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