Developmental changes in directing attention within visual short-term memory:

The role of long-term representations

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Abstract

Visual Short-term memory (VSTM) is one of the most crucial processes involved in many cognitive tasks. It is well-established that VSTM in adults can support a limited amount of information. However, this amount can be increased with the help of visuo-spatial attentional cues. In an earlier study, Shimi et al (2014) found that not only adults' but also children's VSTM benefited from attentional cues, however, children benefited from these cues to a smaller degree compared to adults, indicating children's difficulties in orienting attention during the maintenance of information in VSTM. In addition, research showed that adults' VSTM is higher when participants need to retain familiar items than unfamiliar (Cowan et al., 2015; Ricker & Cowan, 2010). Shimi and Scerif (2015) also found that the familiarity of the item can enhance VSTM in adults and showed further that familiarity can also enhance VSTM in children, yet to a smaller degree, suggesting possible developmental differences in how long-term memory (LTM) may facilitate VSTM. Importantly, they demonstrated that VSTM maintenance is better for cued familiar items for both children and adults, yet children benefitted less from attention cues compared with older individuals, indicating that attentional benefits interact with memoranda familiarity differently across development. Put together, these previous findings suggested that both attentional control and LTM may constrain children's VSTM compared with older individuals. Therefore, our goal here was to examine further the developmental changes in directing attention within VSTM and the exact role long-term representations may play in these developmental improvements. To investigate this further, we trained 7-year-olds, 11-year-olds, and young adults to associate unfamiliar items (i.e., meaningless shapes) with familiar items (i.e., animals) in order to learn and store new mental representations in LTM. Then, we examined the impact of these newly-formed LTM representations on attentional orienting in service of VSTM performance across different age groups and in comparison with control groups. Results showed that all participants' VSTM benefitted from attentional cues, however, benefits were smaller for children than for adults. In addition, item familiarity facilitated participants' performance and cue benefits were larger for familiar than unfamiliar items. Performance was also affected by age, as adults performed better than children. Finally, while adults in the training group performed better than adults in the control group, children's performance in the two experimental groups did not differ. These age group differences may indicate potential differences in how children use LTM representations to facilitate VSTM. Overall, data from the current thesis are in agreement with previous research in the field that suggests that memoranda characteristics, top-down biases, and storage capacity contribute to developmental differences in VSTM.

Keywords: familiarity, attentional orienting, visual short-term memory, development, long-term memory

Developmental changes in directing attention within visual short-term memory: The role of long-term representations

Visual short-term memory [VSTM; also referred to as visual working memory in the literature (VWM)], which refers to the temporary storage of visual information, is one of the most crucial components in many cognitive tasks as many mental activities require STM (Alvarez & Cavanagh, 2004; Jarrold & Towse, 2006). Furthermore, STM performance correlates with intelligence (Oberauer et al., 2005; Kane et al., 2005; Alloway & Alloway, 2013; Colom, Flores-Mendoza, Quiroga, & Privado, 2005; Colom, Rebollo, Abad, & Shih, 2006), while deficits in STM are correlated with learning difficulties, attention deficit hyperactivity disorder (Siegel & Linder, 1984; Maehler & Schuchardt, 2016), and poor academic achievement (Alloway et al., 2009).

It is well-established that VSTM can support a limited amount of information (Luck & Vogel, 1997; Vogel et al., 2001). The amount of simultaneously-encoded information in VSTM is around four items for adults (Cowan, 2001). Regarding this, Phillips (1974) found that when individuals were presented with more than four items, using the change-detection paradigm, their VSTM performance was not as good as it was with four items (Phillips, 1974). Nevertheless, VSTM capacity increases dramatically from early ages to young adulthood and therefore VSTM storage is not fixed from birth (Cowan et al., 2005; Ross-sheehy et al., 2003). More specifically Gathercole (1999) showed that STM is developing until the eighth year and then it shows a robust increase until the 11th or 12th year.

Cowan et al. (2010) examined developmental changes in VWM capacity in a group of 7-year-olds, 12-year-olds, and adults in order to understand what explains improvements in VWM performance during development. Participants completed a change-detention task, during which they were presented with different set size arrays of coloured shapes and were instructed to remember the color and location of each shape. Subsequently, they had to decide if the final probe item was the same or different to the array item previously presented at that location. Results showed no differences across the age groups with a small set size array (e.g., 2 shapes) whereas, with a larger set size array (e.g., 3 shapes), 7-years-olds remembered fewer items than 12-year-olds and adults. Based on these results, Cowan and colleagues suggested that developmental changes in storage capacity, that is how many items one can remember, explain improvements in VWM performance. In a follow-up study with groups of 6-8-years-olds, 11-13-years-olds, and college students, Cowan et al. (2011) used the same task, however this time with a slower presentation of the array items, to limit the potential influence of inefficient encoding in younger children. Age-related differences in how many items participants could report remained, suggesting that encoding abilities do not contribute to better VWM/VSTM performance.

In addition to overall age group differences in VWM/VSTM performance, individual differences are important to consider when examining VSTM/VWM processes. Early in the literature, Daneman and Carpenter (1980) emphasized that individual differences in WM capacity should be taken into account when examining how WM influences other processes and showed that individual differences in WM affect reading abilities. Similarly, many other researchers in the field have shown that variation in WM relates to other cognitive abilities (Conway, Jarrold, Kane, Miyake, Towse, 2007).

Beyond VSTM/VWM storage capacity, other studies with adults have suggested that attentional functions may influence the capacity of VSTM and that individual differences in attentional abilities can explain variation in VSTM/VWM capacity within the same age group (Hasher, Zacks, & May, 1999; Engle, Tuholski, Laughlin, & Conway, 1999). Indeed, in another line of developmental studies, it has been shown that individual differences in attentional orienting relate to an individual's VSTM performance (Shimi et al., 2014; Shimi & Scerif, 2015). In the perceptual domain, Posner's cueing paradigm (1980) was vital in demonstrating that attentional cues, which orient participants' attention to a location, can facilitate adults' processing of the upcoming perceptual stimulus (Posner, 1980). To date, many adult studies using a modified version of the Posner's cueing paradigm have systematically shown that attentional orienting enhances VSTM performance by directing attention to a stimulus maintained in VSTM (e.g., Griffin & Nobre, 2003; Kuo et al., 2012; Chun et al., 2011).

In previous research, Shimi et al (2014) found that not only adults' VSTM but also children's VSTM benefited from attentional cues although to a smaller degree, suggesting that developmental differences in VSTM can be explained by developmental differences in attentional orienting during maintenance of information, not only by capacity limits. Specifically, the authors carried out two experiments with 6–7 year-olds, 10–12 year-olds, and young adults to examine in depth the influence of attention on children's VSTM performance. The goal of the first experiment was to investigate whether children use attention cues prior to encoding information in VSTM and during maintenance of information to facilitate their limited VSTM capacity similar to adults. The experiment involved the Attentional Orienting task (similar to the Posner cueing paradigm) and contained three types of trials: firstly, in *pre-cue* trials, participants' attention was guided before encoding information with the help of an attention cue, an arrow, pointing to one out of four upcoming items; secondly, in *retro-cue* trials, the arrow was presented during the maintenance of information and guided participants' attention to one of the four items already encoded in VSTM, and lastly, in *neutral* trials, participants had to remember all four items and there was no attention cue presented either before encoding or during maintenance. The results showed that benefits from pre-cues were similar for all age groups but benefits from retro-cues were smaller for 7-year-olds compared to older children and young adults. These findings indicated a developmental difference in directing attention during the maintenance period and more specifically, they revealed 7-year-olds’ weakness in using visuospatial attentional control to maintain selected information in VSTM. The goal of the second experiment was to examine whether this developmental difference in using attentional control to select information during maintenance was characterized by voluntary or automatic processes.

In order to investigate this further, Shimi et al (2014) reduced the predictive validity of the attentional cues during maintenance to 50%, in contrast with the first experiment when the cues were 100% valid, and asked all participants to ignore the cues. The results indicated that attentional benefits were reduced for all age groups and therefore that all participants were able to ignore the attentional cues voluntarily (Shimi et al., 2014). These findings confirmed that the developmental differences in VSTM, which were observed in the first experiment, were driven by the 7-year-olds’ less efficient ability to orient attention during maintenance to facilitate VSTM. To sum up, the study by Shimi et al. (2014) was the first to examine the relation between attentional orienting and VSTM in children, demonstrating a developmental change in how attentional orienting can facilitate VSTM performance, as younger children’s attention benefits during maintenance were smaller than older individuals and depended on voluntary visuospatial orienting. Importantly, as said earlier, individual differences are important to consider when examining VSTM/VWM processes, and the authors examined how the impact of individual differences in visuospatial attention correlates with VSTM capacity, using measures of VSTM/VWM span (Dot Matrix and Spatial Recall). Results showed that individual differences in orienting attention were correlated with the variability in VSTM and visuospatial working memory tasks in children (Shimi et al., 2014). Similarly, the results of Astle et al (2012) supported that individual differences in visuospatial attention affect VSTM capacity.

Nevertheless, further research has shown that there are additional factors that must be taken into consideration to understand developmental differences in VSTM capacity limits. One such factor concerns the characteristics of the items such as their familiarity. As explained in more detail below, findings have shown that familiar items are easier to hold in VSTM and therefore result in better later recall than unfamiliar items.

Specifically, Shimi and Scerif (2015) demonstrated that attention cue benefits were larger for both children and adults when the items encoded and retained in VSTM were highly familiar (e.g., animals) than meaningless (e.g., abstract shapes). In this study, the items were nameable objects and all participants appeared to recall the familiar and nameable items directed by a retro-cue more accurately than the more difficult-to-name and unfamiliar shapes. Importantly, the authors ensured that participants did not rely on phonological codes or subvocal rehearsal for the familiar items by using 3-syllable items and items that had similar perceptual complexity. Therefore, these results indicated that item familiarity can trigger representations in VSTM that are already stored in long-term memory (LTM). However, item familiarity appeared to benefit 7-year-olds less than the 11-year-olds and young adults, indicating a developmental difference in the ability for dual coding, that is in the ability to retain familiar items using both visual and non-visual (semantic) codes (Paivio, 1971). Furthermore, similar to previous findings (Shimi et al., 2014), cueing benefits during maintenance were significantly smaller for 7-year-olds than for 11-year-olds and young adults demonstrating that both attentional orienting during maintenance and the nature of the memoranda constrain VSTM performance in childhood.

Based on these results, Shimi and Scerif (2017) proposed a new integrative VSTM/VWM model that explained how memoranda characteristics and the familiarity of the item contributes to VSTM maintenance. According to this model, visual sensory input is first stored in a high-capacity iconic memory (IM) system. Then, some information is transferred to the durable but more limited VSTM system through an attentional mechanism that is responsible for scanning and reactivating the mental representations. Mental representations that are not reactivated enough, will decay before reaching VSTM. Importantly, this process can be affected by additional factors such as the memory load and the memoranda characteristics. That is, the familiarity of the items can constrain or enhance the attentional reactivation of these items, influencing further later VSTM performance. More specifically, meaningful items activate more mental codes, i.e., a visual and a long-term semantic code (Shimi & Scerif, 2015), facilitating their retention in VSTM. Therefore, the more meaningful the item is (i.e., familiar item), the more efficient its reactivation from long term memory (LTM) is. On the other hand, unfamiliar (meaningless) items will make this reactivation process more difficult and slower because participants rely on fewer mental codes (only visual), and so fewer unfamiliar items will be re-called from VSTM in comparison with familiar items (Shimi & Sherif, 2017).

Other studies in the literature have also shown that VSTM capacity is higher when participants retain familiar than unfamiliar items (Cowan et al., 2015; Ricker & Cowan, 2010). In Cowan et al.’s research (2015), participants from 4 age groups (grades 1-2, 3-4, 5-6, and college students) completed a change-detection task that included English letters (i.e., familiar items) or unfamiliar characters to examine the patterns of developmental improvement in memory and the impact of letter knowledge on VSTM. In this task, the memory array was followed by a single probe item at the location of one of the previously-presented items and participants had to indicate whether the probe was the same as the item at that location or not. Results showed that while letter knowledge contributed to VSTM performance, VSTM capacity with unfamiliar characters was higher for older individuals than for young children, prompting the authors to suggest that developmental improvements in familiarity are not enough to account for increases in VSTM.

Additional recent findings indicated that familiarity will help the individual to connect the item presented to them to their existing knowledge and therefore benefit their VSTM capacity (Asp, Störmer & Brady, 2019). Specifically, Xie and Zhang (2017) found that familiarity can increase the storage capacity of VSTM. Their experiment contained two groups: the high-familiarity group in which participants (young adults) had high knowledge of first-generation Pokémon and the low-familiarity group in which participants had less or no knowledge of first-generation Pokémon. They found that Pokémon familiarity boosted VSTM. In another study, recognition of items was more accurate when young adults (aged 18-34 years old) had to remember familiar items such as faces than unfamiliar shapes (Asp et al., 2019). Similarly, Reder et al. (2013) showed that participants are more likely to store an item in VSTM when the context is related to preexisting representations (e.g., famous faces) (Reder et al., 2013).

Altogether, these findings provide clear evidence that VSTM can benefit from the familiarity of a stimulus. Importantly though, Shimi and colleagues showed that young children benefit less from familiar items compared with older individuals, suggesting differential influences of LTM representations on VSTM over development. Therefore, our goal here was to examine in depth the exact role long-term representations may play in VSTM performance across age groups. Critically, considering previous findings on developmental differences in attentional orienting during maintenance, we aimed to investigate further how LTM representations contribute to age-related changes in orienting attention within VSTM. To do so, we trained 7-year-olds, 11-year-olds, and young adults to associate unfamiliar items (i.e., meaningless shapes) with familiar items (i.e., animals) in order to construct and store new mental representations in LTM. We then examined the impact of these newly-formed LTM representations on attentional orienting and on VSTM performance by contrasting their performance to the performance of participants who did not undergo such training.

We hypothesized that if dual coding facilitates participants' LTM representations, all participants of the "training" group will demonstrate better VSTM performance for these newly-formed long-term representations compared with control participants, who encountered the same items for the first time. Importantly, we hypothesized that, within the "training" group, younger children will perform more poorly than older children and adults because of their less efficient dual coding ability and their less developed ability to orient attention during maintenance.

Method

Participants

The study involved 91 participants that fell within three age groups: 32 typically-developing children (16 males and 16 females) aged 6 and 7 years old (M = 6.78, sd = .61), 18 typically-developing children (10 males and 8 females) aged 10 and 11 years old (M = 10.56, sd = .51), and 41 healthy young adults (14 males and 27 females) between 20 and 30 years old (M = 22.71, sd = 2.35). Furthermore, participants were divided into two experimental groups: the training group consisted of 46 participants (16 6-7-year-olds, 9 10-11-year-olds, 21 young adults) and the control group consisted of 45 participants (16 6-7-year-olds, 9 10-11-year-olds, 20 young adults). Children in the training group were tested in fulfilment of the current thesis whereas adult data in the training group were taken from the experimental database of the Memory and Attention Development lab. Participant data of the control group were obtained with permission from the first author of a published study (Shimi & Scerif, 2015) for comparison with our training group for the purpose of the current dissertation.

Participants in the training group were recruited via advertisements in the community and from the student population of the University of Cyprus. Children diagnosed with mental health/neurodevelopmental disorders, children that received special education, and/or had sensory difficulties (based on parent reports) were excluded from the study. Adult participants did not report any mental health difficulties. All participants had normal vision or vision corrected with glasses. Before testing, ethical approval was obtained by the Cyprus National Bioethics Committee. Parents of child participants and adult participants signed informed consent forms before participating. Children also verbally assented to participate in the study.

Apparatus

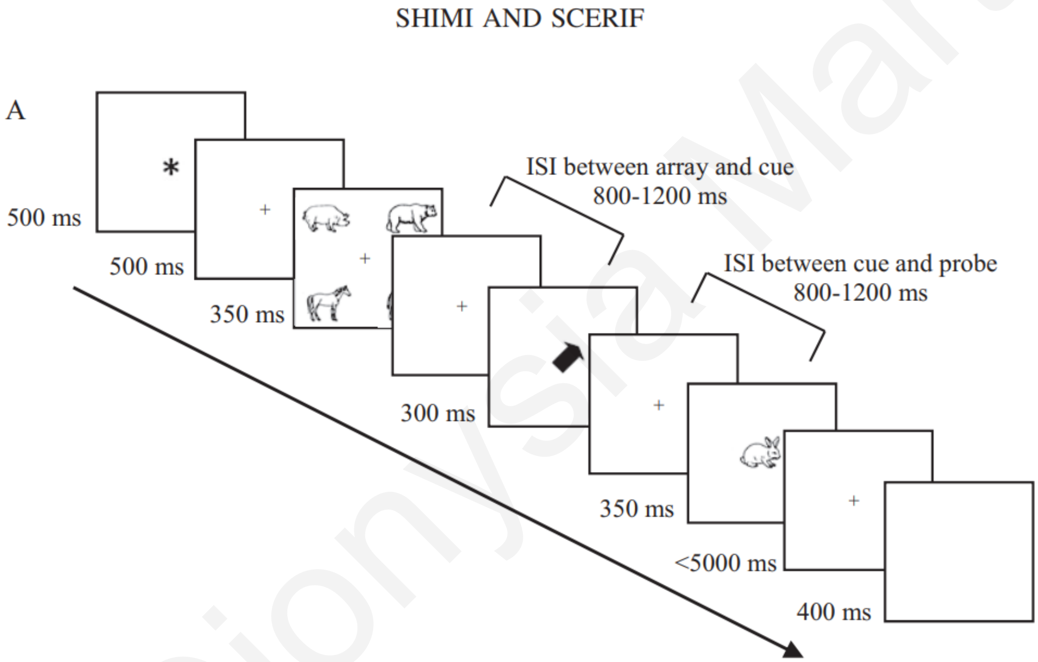
Association Training Task:

The participants who comprised the training group carried out the training task, which consisted of two phases. In the first phase, participants saw pairs of images on the computer screen, that is, they saw a familiar item (an animal) along with an unfamiliar abstract shape and they were instructed to associate the two pictures of the pair together. In total, there were 8 pairs of images, i.e., there were 8 unfamiliar abstract shapes, each one paired with one of 8 familiar animals, and the pairs were presented consecutively. In the second phase, to ensure that participants had successfully associated the two images in each pair together, we tested their associative memory in two ways. Firstly, they were presented with an animal along with the 8 possible shapes and they were asked to choose the relevant shape that matched the animal. Participants gained feedback for correct and incorrect pairing. Secondly, participants underwent the same testing procedure but this time they were presented with an abstract shape and they had to choose the relevant animal from the 8 possible animals. Again, they received feedback about correct and incorrect pairing and the procedure was repeated for about 30 trials until participants reached 100% correct matching for all pairs.

Attentional Orienting Task (AOT):

This task was identical to the task used in the study by Shimi and Scerif (2015). On every trial, participants saw briefly 4 items, familiar (animals) or abstract shapes depending on the condition type (familiar or unfamiliar). Subsequently, they saw another item (familiar or abstract shape depending on the condition type) and had to respond if this final item was one of the previously presented 4 items (see Figure 1 A). The 4 items were always followed by an attentional cue, which was either spatially informative (retro-cue) or uninformative (neutral cue) to the location of the item to be probed (see Figure 1 B). In retro-cue trials, a black arrow directed participants' attention to the location of one of the previously presented items. In neutral cue trials, a black filled square was presented centrally and provided no spatial information about the location of the item to be probed. To ensure that participants relied on visual and/or semantic codes to retain the items in VSTM, all animal names were three-syllabus Greek words so that participants were not able to subvocally rehearse them in the time available. The task contained two practice blocks of six trials each, so that participants were familiarised with the task, and four test blocks of 48 trials each, totalling 192 test trials. There were 128 probe-present trials and

64 probe-absent trials. Of the probe-present trials, 64 were retro-cue and 64 were neutral trials. Of the probe-absent trials, 32 were retro-cue and 32 were neutral. Retro-cue and neutral cue trials occurred randomly within each test block. Finally, two of the test blocks contained familiar items and the other two contained abstract shapes. These blocks were counterbalanced across participants.



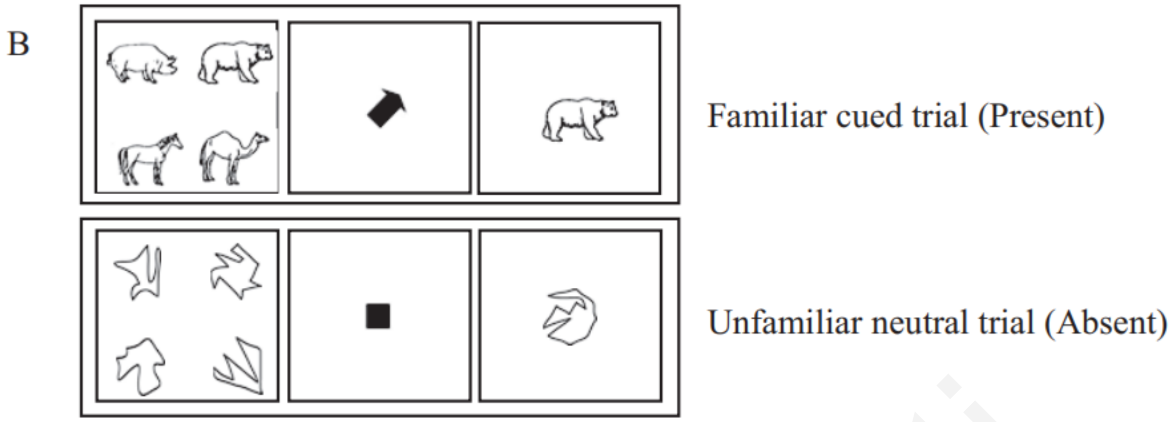


Figure 1 (taken from Shimi and Scerif, 2015)

Figure 1: Panel A illustrates the sequence of a trial whereas panel B shows the two memoranda familiarity conditions (familiar, unfamiliar) and the two types of trials (cued, neutral) for present and absent trials.

Procedure

Participants in the training group were tested at the Memory and Attention Development Lab at the University of Cyprus. Participants in the training group completed the training task, followed by a 5-minute break, and then carried out the AOT task. Participants in the control group completed only the AOT task. Children in the control group were tested at their school whereas adults in the control group were tested at the lab.

For the purpose of the testing for the current dissertation, child participants in the training group came to the lab outside school hours, either on weekdays early in the afternoon or on weekends. Upon arrival, the parents read the information sheet and signed the consent form, and once we ensured that the child felt comfortable with the procedure of the study the examiner began the testing session. Both tasks were completed in a bright room without noise and distractions and participants sat at a comfortable distance from the computer screen. First, the examiner explained the Association Training task using cards depicting the animals and shapes. The task was carried out on a touched computer that allowed children to learn and associate the pairs easily by touching the screen. The examiner provided occasional feedback, encouragement, and frequent breaks based on the child's needs. When children completed the first task, they had a 5-minute break where they watched a short (unrelated to the task) video and were offered a beverage. Subsequently, the examiner explained the AOT using cards. The task was completed on a laptop and children were advised to place the index finger of each hand on each mouse button to give fast responses. Also, the examiner explained to children that they should pay attention to the arrow when it was presented, as it would help them remember the items. The task began with practice trials to ensure that children understood the task well, during which the examiner provided feedback. Following the practice, children completed the task that contained frequent breaks.

Statistical design and Analyses

Two mixed-design ANOVAs were performed to test the effects of the experimental group (training vs. control), memoranda familiarity (familiar vs. unfamiliar), cue-condition (retro-cue vs. neutral), and age group (7-year-olds, 11-year-olds, adults) on the depended measures of accuracy (d-prime) and median response times (RTs). Also, a one-way ANOVA was performed to compare the cue benefits on d-prime across the three age groups as well as a paired-samples t-test to compare the cue benefits between the two memoranda familiarity conditions.

Results

D-prime

There were significant main effects of familiarity, *F*(1,85) = 63.53, *p*<.001, η_p^2 =0.43, cue-condition, *F*(1,85) = 133.52, p<.001, η_p^2 =0.61, and age group, *F*(2,85) = 68.77, p<.001, η_p^2 =0.62. Analyses of simple main effects for the familiarity revealed significantly higher d-prime scores in the familiar block than in the unfamiliar block (M=0.96 and M=0.54 respectively, p<.001). Analyses for the cue-condition indicated significantly higher d-prime scores in the retro-cue condition than in the neutral condition (M=1.06 and M=0.44 respectively p<.001). Furthermore, analyses for the age group showed significantly different d-prime scores across the three age groups. Adults had significantly higher d-prime scores (M=1.27) than both 10-11-year-olds (M=0.73, p<.001) and 6-7-year-olds (M=0.26, p<.001), and 10-11-year-olds had significantly higher d-prime scores than 6-7-year-olds (p<.001).

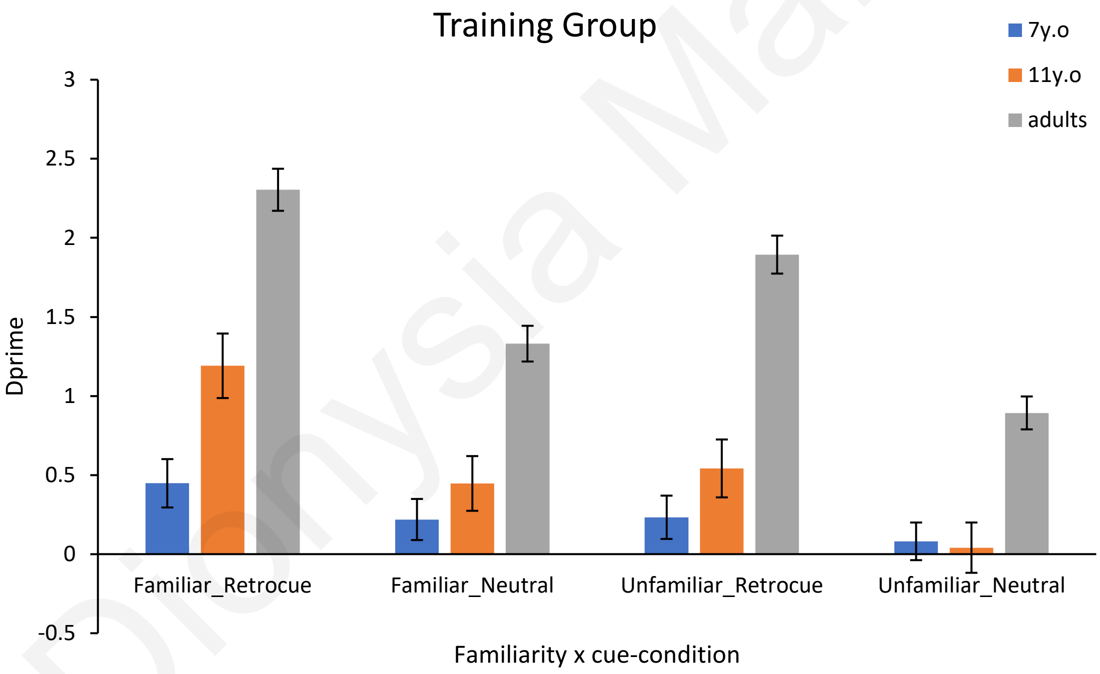
In addition, there were significant interactions for familiarity x age group, *F*(2,85) = 5.37, p=.006, η_p^2 =0.11, cue-condition x age group, *F*(2,85) = 16.50, p<.001, η_p^2 =0.28, familiarity x cue-condition, *F*(1,85)= 4.83, p=.03, η_p^2 =0.05, and experimental group x age group, *F*(2,85)=8.20, p<.001, η_p^2=.27. Simple main effects analyses for the familiarity x age group interaction demonstrated higher d-prime scores in familiar blocks than in the unfamiliar blocks for all age groups (6-7-year-olds: M=0.36 and M=0.16 respectively, p=.02; 10-11-year-olds: M=1.05 and M=.40 respectively, p<.001; adults: M=1.47 and M=1.06 respectively, p<.001). Additionally, in the familiar blocks, adults had significantly higher d-prime scores than both 6-7-year-olds (p<.001) and 10-11-year-olds (p=.007), and 10-11-year-olds higher d-prime scores than 6-7-year-olds (p<.001). In the unfamiliar blocks, adults had higher d-prime scores than both child groups (p<.001 for both child groups) whereas there was no significant difference between 6-7-year-olds and 10-11-year-olds (p=.12).

Simple main effects for the cue-condition x age group interaction demonstrated significantly higher d-prime scores in retro-cue trials than in neutral trials for all age groups (6-7-year-olds: M=0.41 and M=0.11 respectively, p<.001; 10-11-year-olds: M=1.03 and 0.431 respectively, p<.001; adults: M=1.74 and M=0.79 respectively, p<.001). Additionally, adults had higher d-prime scores than 6-7-year-olds and 10-11 year-olds, who in turn had higher d-prime scores than 6-7-year-olds in both retro-cue (all ps<.001) and neutral trials (all ps≤.01). Results from the follow-up one-way ANOVA [*F(*2,90)=16.73, p<.001], comparing the cue benefits across age groups, showed larger cue benefits for adults (M=.95) than for 10-11-year-olds (M=.60, p=.03) and 6-7-year-olds (M=.30, p<.001). Cue benefits did not differ significantly between the two child groups (p=.12).

Also, simple main effects for the familiarity x cue-condition interaction showed significantly higher d-prime scores in retro-cue trials than in neutral trials, both in familiar (M= 1.32 and M= 0.60 respectively, p<.001) and unfamiliar blocks (M=0.80 and M=0.29 respectively, p<.001), as well as higher d-prime scores in familiar than in unfamiliar blocks both in retro-cue (p<.001) and neutral trials (p<.001). A follow-up t-test comparing the cue benefit between the two familiarity conditions showed that participants benefitted from retro-cues more in familiar (M=.75) than in unfamiliar blocks (M=.56), *t*(90)=2.09, *p*=.04.

Finally, simple main effects for the experimental group x age group interaction showed that in the training group, adults had higher d-prime scores than both 6-7-year-olds and 10-11-year-olds (p<.001 for both), whereas the two child groups did not differ significantly between them (p=.13). In contrast, in the control group, adults and 10-11-year-olds had higher d-prime scores than 6-7-year-olds (p<.001) whereas adults and 10-11-year-olds did not differ between them (p=1.00). Finally, adults in the training group (M=1.60) had significantly higher d-prime scores than adults in the control group (M=.93, p<.001), 10-11-year-olds in the training group (M=.56) had smaller d-prime scores than 10-11-year-olds in the control group (M=.90, p=.05), whereas 6-7-year-olds in the training group (M=.25) did not differ from the 6-7-year-olds in the control group (M=.27, p=.83).

None of the other effects reached statistical significance.



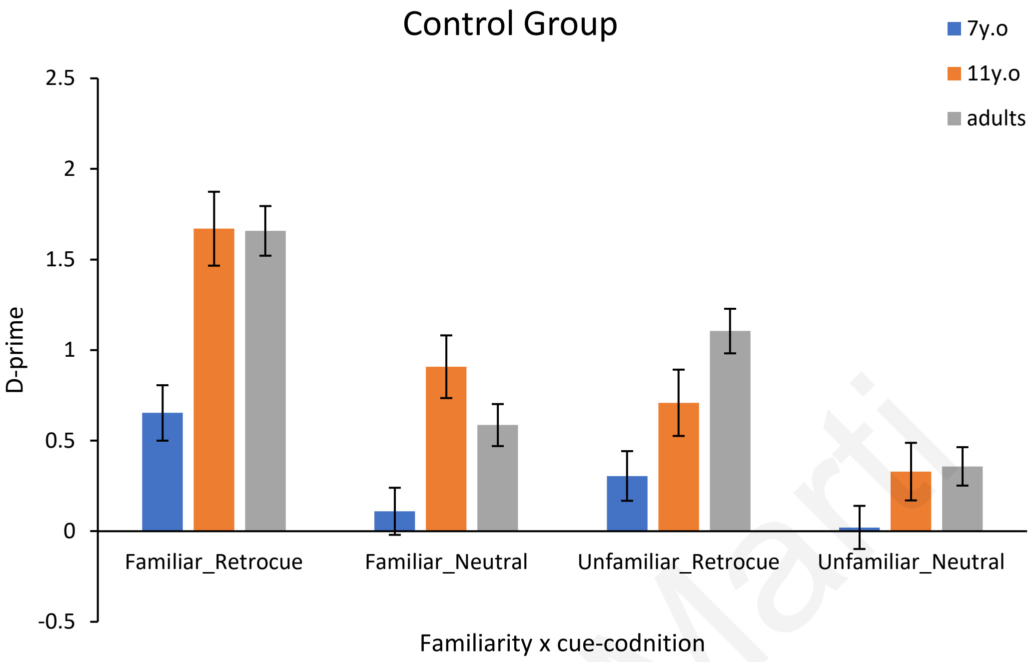


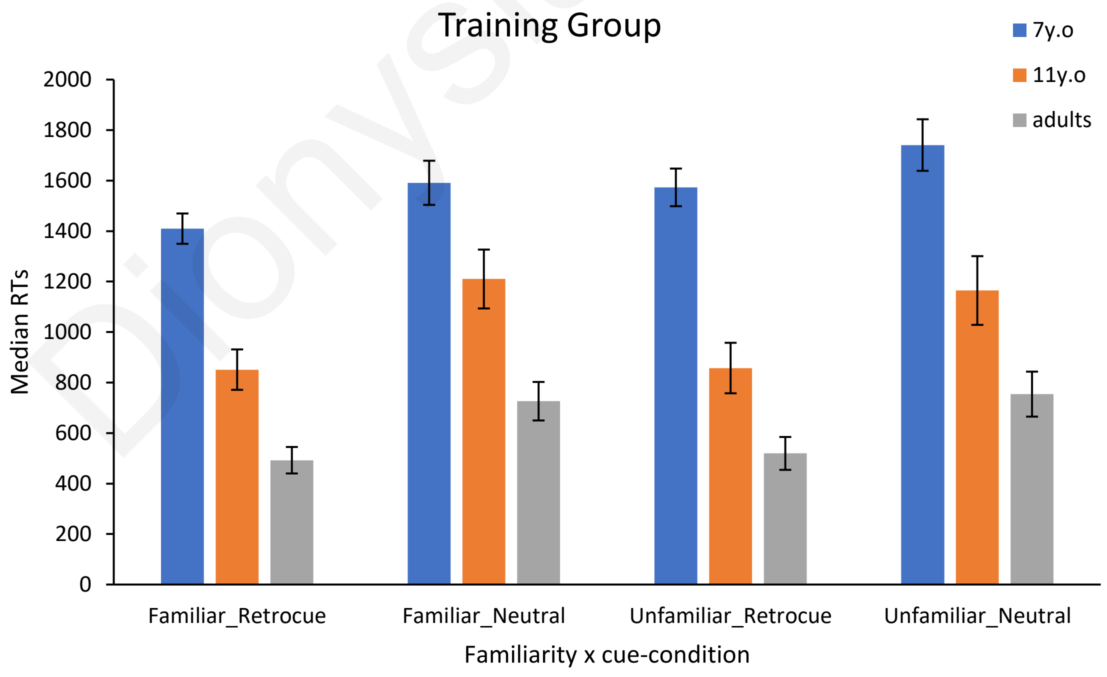
Figure 2: D-prime scores on retro-cue and neutral trials, comparing familiar and unfamiliar blocks, for all age groups, for the training group (top panel) and the control group (bottom panel). Error bars represent standard error of the mean.

Median RTs

There were significant main effects of familiarity, *F*(1,85)=8.09, p=.006, η_p^2 =0.09, indicating faster responses in the familiar block than in the unfamiliar block (M=1010.59 and M=1082.63 respectively), of cue-condition, *F*(1,85)=103.73, p<.001, η_p^2 =0.55, caused by faster responses in retro-cue trials than in neutral trials (M=912.304 and M=1180.917 respectively), and of age group, *F*(2,85)=80.48, p<.001, η_p^2 =0.65, with adults (M= 699.26) responding faster than 6-7-year-olds (M=1506.47, p<.001) and 10-11-year-olds (M=934.10, p=.000), who in turn responded faster than 6-7-year-olds (p<.001).

Finally, there was a significant experimental group x age group interaction, *F*(2,85)=3.60, p=.03, η_p^2 =0.08). Simple main effects showed significant differences in RT across all age groups of the training group. More specifically, in the training group, adults responded faster than both 6-7-year-olds (M=632.07, p<.001) and 10-11-year-olds (M=1020.92, p<.001), who in turn responded faster than 6-7-year-olds (M=1578.45, p<.001). In contrast, in the control group, adults (M=775.44) did not differ significantly in RT from 10-11-year-olds (M=847.29, p=1.00), whereas both age groups responded faster than 6-7-year-olds (M=1434.50, ps<.001). There were no statistically significant differences in RT between the two experimental groups (training vs control) in any of the age groups (p=.14 for 6-7-year-olds and p=.18 for 10-11-year-olds, except for a trend for significance in adults p=.08).

None of the other effects reached statistical significance.



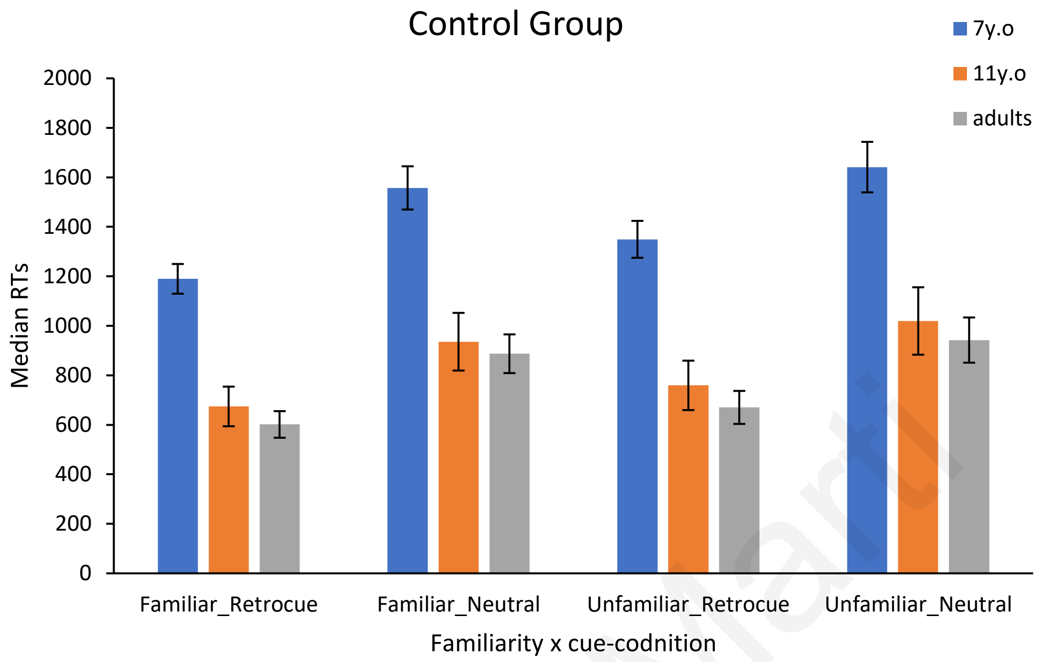


Figure 3: Median reaction time (RT) scores on retro-cue and neutral trials, comparing familiar and unfamiliar blocks, for all age groups, for the training group (top panel) and the control group (bottom panel). Error bars represent standard error of the mean.

Discussion

The goal of the current study was to investigate further age group differences in directing attention within VSTM and the exact role LTM representations may play in these developmental improvements. The study involved training 6-7-year-olds, 10-11-year-olds, and young adults to associate unfamiliar items (i.e., meaningless shapes) with familiar items (i.e., animals) so they would learn and store new mental representations in LTM. Subsequently, we examined the impact of LTM representations on VSTM performance across the three (training) age groups and compared their performance to the performance of control groups that did not undergo training.

In summary, there were significant main effects of familiarity, cue-condition, and age group on accuracy (d-prime) as well as significant interactions between familiarity and age group, familiarity and cue-condition, age group and cue-condition, and experimental group and age group. These findings are explained in more detail below. Importantly, follow-up examinations of cue benefits indicated that all age groups benefitted from retro-cues, however, these benefits were larger in adults than in both 10-11-year-olds and 6-7-year-olds. Additionally, participants benefitted from retro-cues more in the familiar than in the unfamiliar blocks. Furthermore, we found significant main effects of familiarity, cue-condition, and age group on reaction times (RTs) as well as a significant interaction between experimental group and age group. Findings for the most important main effects and interactions are presented in sequence.

Firstly, results showed that VSTM performance in all age groups was clearly affected by the characteristics of the memoranda, as all participants scored higher with familiar and nameable items than with unfamiliar and difficult to label shapes. In addition, overall, participants had faster responses in the familiar than in the unfamiliar blocks showing that familiarity facilitates retrieval of information from VSTM as well. These results are in agreement with previous studies that showed that VSTM performance is better when participants retain familiar than unfamiliar items (Shimi and Scerif, 2015; Cowan et al., 2015; Ricker & Cowan, 2010)

Furthermore, there were clear age group differences in overall VSTM performance. Overall, adults performed significantly better than older and younger children and older children performed better than younger children confirming developmental improvements in VSTM as in earlier studies (Cowan et al., 2010; Shimi & Scerif, 2015; Shimi & Scerif, 2017). It is well established that VSTM is characterized by developmental changes (Cowan et al., 2005;

Gathercole, 1999), and this change has been attributed to an increase in storage capacity (e.g., Cowan et al., 2010, 2011).

In addition, findings regarding cue-condition (visuospatial retro-cues vs. neutral cues) revealed that visuospatial attentional cues during maintenance benefited all participants, as VSTM performance was more accurate and faster when participants were presented with attentional cues during maintenance than in neutral trials. A number of adult studies using the same paradigm pointed out that visuospatial attention benefits VSTM performance (Griffin & Nobre, 2003; Kuo et al., 2012; Chun et al., 2011), but the exact function of retro-cues during the maintenance of items in VSTM remains unclear (as discussed in Shimi and Scerif, 2017).

Importantly, age group differences in cue benefits were also evident in the current study. While adults had significantly larger cue benefits than both older and younger children, the comparison of the two child groups showed no significant differences in cue benefits. This finding is in agreement with the previous finding of Shimi and colleagues (Shimi et al., 2014; Shimi & Scerif, 2015) that showed that not only adults' but also children's VSTM benefited from attentional cues, however to a smaller degree compared to adults.

The results regarding the interaction between familiarity and age group showed that all participants performed better in familiar than in unfamiliar conditions. In the familiar condition, adults performed significantly better than both 10-11-year-old and 6-7-year-old children, whilst 10-11-years-olds performed significantly better than 6-7-years-olds. In the unfamiliar condition, adults performed significantly better than both 10-11-year-old and 6-7-year-old children, whereas no significant difference was found between 6-7-years-olds and 10-11-years-olds. These results are in agreement with previous findings indicating that highly meaningful items facilitate reactivation of representations from LTM, due to familiar items reactivating both visual and non-visual (semantic) codes (Paivio, 1971), while meaningless items make reactivation and maintenance harder and slower (Shimi & Sherif, 2017). Also, the literature suggests that 7-year-olds benefit from familiarity less than 11-year-olds and young adults due to a developmental difference in the ability for dual coding (Shimi & Scerif, 2015) and current results seem to support this earlier developmental finding.

Furthermore, the current results regarding the interaction between familiarity and cue-condition showed better VSTM performance in familiar than in unfamiliar conditions in both retro-cue and neutral trials as well as better VSTM performance in retro-cue than in neutral trials in both familiar and unfamiliar conditions. Importantly, there was a larger cue benefit in familiar than in unfamiliar conditions for all participants. These results confirm previous findings that revealed that the memoranda characteristics interact with attentional control by permitting or constraining participants to attentionally bias and maintain representations in VSTM accurately (Shimi & Scerif, 2015).

Finally, the main goal of the study was to examine the impact of LTM representations on VSTM performance across the different age groups. The interaction between the experimental group and age group suggested that the association training impacted the age groups differently. Comparing the two adult groups, there were significant differences in overall performance between the adults who completed the training task and those who did not, with the training group having better VSTM performance. This finding indicated that, while carrying out the second Attentional Orienting Task (AOT), adults in the training group possibly maintained the unfamiliar/newly-associated items with multiple mental codes, visual and semantic (Paivio, 1971) which helped them to retain these items better in VSTM than in the control adult group. However, the fact that adults in the training group still performed better with familiar than unfamiliar items may suggest that it takes longer to create robust long-term representations than with the one training session of the current study. In contrast, 10-11-year-olds and 6-7-year-olds in the training group did not have better VSTM performance than the two chld groups in the control group. Although all children in the training group reached 100% accuracy in the Association Training Task and therefore associated the unfamiliar with other familiar items, it may be that children are not as good at using LTM representations to retain items in VSTM, at least with a single training session. A future extension of this study with multiple association training sessions may provide further insight into the exact role LTM representations may play in developmental improvements in VSTM performance.

In conclusion, this study provided further evidence that familiarity, attentional abilities during maintenance, as well as age, affect VSTM performance. In the context of school psychology, this thesis offers important knowledge as it demonstrates that multiple factors constrain the maintenance of information and in turn influence VSTM performance. For example, as children grow older they can retain more items in VSTM and therefore teachers should be careful not to overload students' VSTM beyond their capacity limits during teaching, which would, in turn, impact negatively their learning in the classroom. Learning is a key area that falls within the expertise of school psychologists and school psychologists' duties include identifying limitations in learning as well as strategies that benefit learning across the developmental stages. Furthermore, VSTM/WM has been robustly associated with intelligence and academic performance in kindergarten and elementary school (Alloway and Alloway, 2010, Cowan et al., 2005, Cowan et al., 2006) and the role of school psychologists is to explore strategies that will benefit learning and in turn academic performance. Therefore, given that memory and attention are characterized by developmental improvements, research on VSTM and its interaction with attention, provides important information about the mechanisms that underpin memory function and therefore ways that can enhance it. Finally, developmental studies in this area allow us to identify new methods to study and evaluate limitations and changes in VSTM performance, which in the future can be used in psychological evaluations that school psychologists carry out.

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