Development of attentional orienting to visual memories

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ABSTRACT

Working memory capacity is strikingly limited, but the nature of these limits remains controversial. A largely unexplored field is the development of visual working memory. We know that WM capacity critically increases during childhood. However, it is still unclear which aspects of WM explain this development. Investigating these aspects could contribute not only to our understanding of visual WM development, but also could shed a light on the mechanisms that underlie WM capacity in adults by uncovering differences in developmental trajectories of processes within WM. This study aimed to test the influence of content cues in WM capacity, and more specifically, the development of attentional control with content information. We explored multiple hypotheses using the single-probed recognition version of the change detection paradigm. All of our inferences are based on Bayesian analysis of variance. We found overwhelming evidence of the content pre-cue in accuracy for all groups. The evidence for the content retro-cue across all groups was inconclusive. We did not find decisive evidence for the development of content retro-cue benefit. However, when we analysed the data from the adults only, we have a robust yet small effect of content retro-cue.

ACKNOWLEDGMENTS

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INTRODUCTION

Working memory (WM) is a cognitive system with limited capacity that holds information available for processing (Miyake & Shah, 1999). It is related to reading comprehension (Daneman and Carpenter, 1980), fluid intelligence (Heitz, Redick, Hambrick & Kane, 2006), problem solving (Kyllonen and Christal, 1990), reasoning ability (Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002), and scholastic achievement (Alloway & Alloway, 2010). WM has also been shown to predict academic success more accurately than IQ during the early years of formal education, particularly in reading, spelling, (Alloway & Alloway, 2010), arithmetical abilities and mathematical skills (Alloway & Passolunghi, 2011).

We know that working memory capacity is limited (Baddeley, 1986, 1996: Just & Carpenter, 1992), but how and why it is limited remains controversial. In this study, we focused on two frameworks of WM, because they are helpful in discussing hypotheses about WM limits further. Both frameworks emphasize the role of attentional control in WM and regard long-term memory as a part of WM. However, they have important differences.

Working memory frameworks

The Embedded-Processes framework, proposed by Cowan (1995; 1999) describes three components embedded within each other: (1) the memory system, including both long-term knowledge and recently-observed stimuli; (2) information within the memory system in a heightened state of activation; and (3) within that, a portion of the activated memory currently in the focus of attention. The focus of attention reflects the items currently in conscious awareness, and it is limited to four coherent, integrated items or chunks (Cowan, 2011). Oberauer (Oberauer, 2002, 2009) modified this framework and proposed the Three-embedded-components model of working memory. It is comprised by: (1) the activated part of (LTM) which contains relevant information for a current task, such as digits for arithmetic operations; (2) the broad focus of attention, which holds around four of the representations in the activated LTM; and (3) the focus of attention. In this model, the focus of attention can only hold one item (Oberauer & Hein, 2012), or two if they are chunked (Oberauer & Bialkova, 2009). The notable difference between both models – how many items can be held at once in the focus of attention – has been the centre of a debate in WM.

The focus of attention

Evidence for the single-item focus of attention and the multiple-item focus of attention hypotheses that follow these models is mixed. Oberauer (2002) found evidence for for a single-item focus of attention. The author asked participants to encode two lists of digits with varying set size. A cue identified each list as active or passive. The results showed that latencies were shorter when an arithmetic operation was carried out on the same digit as the preceding step, than when another digit of the same set was accessed. The author reasoned that this time difference, called "object-switch cost", was the product of the rapid changes in the focus of attention among items within the broad focus. The item in the focus of attention was said to be updated by changing its content only, in a way that updating the same object would incur in shorter object-switch costs than updating another object from the set. Moreover, the object-switch costs increased with the length of the relevant list only (Oberauer, 2003). These findings were interpreted as evidence for a single-item focus of attention.

Other evidence, however, does not seem to support this view. Gilchrist and Cowan (2011) modified the procedure used by Oberauer and Bialkova, (2009) and found that the focus of attention could still hold two separate items. Moreover, another study (Heuer & Schubö, 2016) also found evidence for a focus of attention that can hold two items without chunking, by presenting items in contiguous or non-contiguous locations. These findings together indicate that the focus of attention can hold more than one item at once. Another possibility could be that the focus of attention is flexible, and can zoom in and out to hold multiple items at once (Cowan et al., 2005), when a task is practiced beforehand. However, Oberauer (2002), stated that this flexible focus of attention could only account for the broad focus or for the narrow focus of attention in his model. Hence, more research is needed to estimate how many items can be held in the focus of attention.

This estimation of items in the focus of attention, however, can be problematic. Visual WM has been extensively studied with the change detection paradigm (Luck & Vogel, 1997). In this paradigm, participants are presented with memory display of a set of items, followed by a test display. There are two versions of this paradigm: in the single-probed recognition, the test display contains one item and the participant must indicate whether the item in the probe display was in the previous array. In the whole-display recognition, the test display contains a full set of items, and the participant indicates if any of the items in the probe display are different from the previous array. Rouder, Morey, Morey, and Cowan, (2011) reported inconsistencies in the literature when measuring capacity via recognition tasks that result from the use of the incorrect formula to estimate capacity in each one of the versions of this recognition task. Moreover, the conditions that must be followed to estimate WM capacity, are not always considered in all studies (Cowan, 2011). For instance, Saults & Cowan (2007) posited that the array to be remembered must be followed by a mask and then by the item to be tested, and that further grouping (Miller, 1956), rehearsal (Baddeley, 1986) or refreshing processes (Raye, Johnson, Mitchell, Greene, & Johnson, 2007) should be prevented. These inconsistencies in visual WM research could be in part, responsible for the mixed results in WM capacity.

Retrocues and hypotheses about forgetting

Both the Cowan (1995; 1999) and Oberauer (2002; 2009) models of working memory claim that WM capacity and attention are fundamentally integrated concepts. To investigate this relationship between attention and WM capacity, researchers have created different strategies to bias participant's attention, such as manipulating the proportion of trials that test specific shapes, so that attention can be isolated as the critical factor in WM capacity estimation. Among these strategies, the Posner paradigm (1980) is the most popular method. The typical trial in this paradigm consists in a spatial cue presented prior to encoding (pre-cue) that guides attention toward certain item on the array to be encoded. Studies using perceptual tasks have found a pre-stimulus enhancement in visual cortices with pre-cues that orient attention to locations (Kastner, Pinsk, De Weerd, Desimone & Ungerleider, 1999) and object features (Chawla, Rees & Friston, 1999) such as colour (Liu, Slotnick, Serences & Yantis, 2003) and shape (Stokes, Thompson, Nobre & Duncan, 2009). Thus, precues facilitate encoding of stimuli, leading to increased WM performance (Botta, Santangelo, Raffone, Lupiáñez & Belardinelli, 2010; Griffin & Nobre, 2003; Murray, Nobre & Stokes, 2011) and shorter reaction times (Posner, 1980). These findings leave no doubt about the importance of attention during encoding for WM capacity.

Compared to the study of attention during encoding in WM, the interest for attention during maintenance is relatively new and less well developed. The following two studies first explored whether a cue presented during this period could also improve WM capacity. Landman, Spekreijse and Lamme (2003) studied a phenomenon called same blindness, in which subjects show difficulty spotting a constant between two otherwise different scenes separated by an interval. During this interval, they presented a retro-cue to measure its effect on the ability to detect changes. They found that cueing after the stimulus presentation, dramatically improved performance, and noted that this cue was operating in the participants' internal representations. Griffin & Nobre (2003) presented participants with an array of four coloured crosses, followed by a probe display with a single coloured cross in the centre. Participants indicated whether this probe was present in the memory array. They used spatial cues either before the memory array (pre-cues) or after the array was presented (retro-cue), or were given no cue. All cues were valid (i.e., indicated the correct location of the probe in the array) on 80% of the trials. The study found that both pre-cues and retro-cues improved accuracy and reaction times, and this pattern persisted when they asked participants to indicate whether a peripheral probe stimulus matched the colour of the item presented at the same position in the array.

Retro-cues pose a unique opportunity for visual WM research. They allow us to explore the selection-of-information process, the nature of the selected information, and the consequences of attentional orienting on visual information. Interestingly, the retro-cue benefit implies that individuals can extract more information from memory than when no cue is provided. Thus, the previously assumed limit of WM could be accounted by how the information is accessed, and not only due to a rigid structure of WM (Oberauer, 2016). Importantly, the retro-cue paradigm could shed light on the mechanisms of forgetting in visual WM.

Different assumptions about the mechanisms by which memories are lost from visual WM can explain the retro-cue benefit. One of these is the time-based decay hypothesis (Brown, 1958). This hypothesis assumes that representations decay with time, and that attention to representations counteracts forgetting (Pertzov et al., 2013). Some studies have found that performance decreases as the duration of the retention interval increases (e.g. Morey & Bieler, 2013; Ricker & Cowan, 2014), which can be seen as evidence of time-based decay. However, these findings could be also explained by temporal distinctiveness, which suggests that rather than being forgotten, visual representations are damaged by the interference of other information, or instead, erroneous representations are retrieved from previous sources with similar features (Souza & Oberauer, 2015).

Another hypothesis suggests that retro-cues reduce memory load by removing irrelevant items from visual WM (Oberauer, 2001; 2014), freeing capacity to process the high-value, retro-cued information and/or encode new relevant information. According to this assumption, the set-size effects (i.e., WM performance decreases as the set-size increases) decreases as irrelevant items are removed. Whereas some authors provided evidence for this hypothesis (e.g., Griffin & Nobre, 2003), others failed to support it (e.g. Matsukura et al., 2007). Another assumption is that attention strengthens cued items in memory, increasing its accessibility for later use (Rerko & Oberauer, 2013), without discarding irrelevant items. Heuer and Schubö (2013) found that unattended items could be refocused and retrieved. This could be interpreted as evidence for this hypothesis as it suggests that unattended items remain unchanged in visual WM. Finally, another hypothesis suggests that memories are lost because visual input after encoding can distort or replace memory representations. In this hypothesis, the retro-cue insulates relevant items from interference (Matsukura et al., 2007; Makovski & Jiang, 2007). It is likely that the retro-cue effect can be explained by many of these hypotheses, because they are not mutually exclusive. It could also be that different features of visual representations are lost in different ways. More research is needed to find further support to any of these hypotheses.

Format and organisation of visual memories

Retro-cues guide attention to features of the representations (e.g., shapes or locations). Researchers are still investigating whether visual representations integrate these features in one item or not. Two hypotheses have been suggested. The feature-based storage hypothesis suggests that visual representations are stored as independent features, and attention is needed to maintain the correct associations between them (Wheeler & Treisman, 2002). The other hypothesis, called the object-based storage hypothesis, holds that visual WM holds single objects that integrate multiple features without cost (Luck & Vogel 1997; Vogel, Woodman, & Luck, 2001). In this view, objects in memory remain integrated or are completely lost if attention is removed. Whether visual information is stored as a single object or as different features, still needs clarification.

Broadly, retro-cues used to explore visual WM can be divided into spatial-based and content-based retro-cues. Most studies on attentional orienting during maintenance have used spatial retro-cues (e.g., Astle et al., 2012; Matsukura, Luck, & Vecera, 2007; Nobre et al., 2004). In real life situations, however, we might need to search memory based on object features other than their location. For instance, if we want to know if a skin rash is hastily worsening, we need to compare the size and colour of the mental representation we have from the last time we saw it, with the same features on the actual rash. Despite the importance of non-spatial attention during visual WM maintenance, studies about content retro-cues are scarce (Pertzov, Bays, Joseph, & Husain, 2013). Studying attention oriented by content features can contribute to further understand the organisation and features that integrate visual memories.

Finally, another largely unexplored field is the development of visual WM. We know that WM capacity critically increases during childhood (Cowan et al., 2010; Gathercole, 1999; Gathercole, Pickering, Ambridge, & Wearing, 2004; Riggs, McTaggart, Simpson, & Freeman, 2006; Shimi et al., 2014). However, it is still unclear which aspects of WM explain this development. Investigating these aspects could contribute not only to our understanding of visual WM development, but also could shed a light on the mechanisms that underlie WM capacity in adults by uncovering differences in developmental trajectories of processes within WM. Some studies explored whether the differences between adults and children's WM capacity can be explained by changes in storage capacity, or by the improvement in attentional control. For instance, Cowan and colleagues (2010) found that 12-year-olds and adults were better than 7-year-olds at attending to changes in pre-cued items, but only when with larger set sizes. With small set sizes, this difference in attentional control disappeared. This suggests an integration of storage and attentional control; attention sometimes must be shared between maintenance and selection of items in WM, in a way that when there is too much information to store, there are not enough resources for attentional control. Reasoning that those differences could have resulted from inadequate encoding due to the short time in which the memory array was displayed, Cowan, AuBuchon, Gilchrist, Ricker, & Saults (2011) replicated the procedure but with a much slower presentation of the items to ensure adequate encoding, and also found age differences in performance, confirming that storage capacity increased with development. These findings together suggest that storage capacity increases during childhood, and that attentional control decreases when this capacity is overloaded.

Researchers have also explored the development of attentional control during maintenance. Astle, Nobre and Scerif (2012) used spatial pre and retro-cues to explore short-term memory and WM differences among 7-year-olds, 10-year-olds, and adults. They found that adults benefited more from retro-cues than children did, and that retro-cue benefit in children predicted visual short-term memory and visual WM spans. Another recent study (Shimi, Nobre, Astle, & Scerif, 2014) also found that 7-year-olds benefited less from spatial retro-cues in comparison with 11-year-olds and adults. These findings suggest that the development of attentional orienting guided spatially during maintenance could account for the increase of WM capacity across the lifespan. What we still need to know is whether non-spatial cues contribute to WM in the same way.

The influence of content cues in visual working memory capacity.

This study aimed to test the influence of content cues in WM capacity, and more specifically, the development of attentional control with content information. We explored multiple hypotheses using the single-probed recognition version of the change detection paradigm (Luck and Vogel, 1997). We tested the effectiveness of content cues via accuracy. First, we looked for differences in performance between 5-7-year-olds, 10-12-year-olds, and adults in the no cue condition; this would allow us to know if visual WM capacity changes across the lifespan.

Second, we evaluated whether content cues can boost memory as Shimi et al. (2014) observed for spatial cues; if individuals benefit from content cues as from spatial cues, it would mean that visual information is organised by at least two feature dimensions, (space and shape). It also would imply that content information can be used as an effective retrieval cue for visual memories to the same degree as spatial information. Shimi et al. (2014) also reported smaller spatial retro-cue benefits for younger children. We explored whether the ability to search visual memories by content also develops with age.

We also manipulated the number of cued items by varying the combinations of the two available shapes, to investigate whether the cue benefit can only be found when cuing one item (e.g., Makovski & Jiang, 2007), or also when cuing multiple items (e.g., Heuer & Schubö, 2016). Under the single-item focus of attention hypothesis, we would expect higher boosts in accuracy when one cued item is tested, whereas under the multiple-item focus of attention hypothesis, we would expect equivalent boosts for two or even three cued items.

Finally, we aimed to examine a possible interaction between age and the number of cued items. If storage overload limits attentional control in children as found by Cowan et al. (2010), it could be that cues are more effective in 6-year-olds when limited to one item, especially considering the findings of an fMRI study (Kharitonova, Winter, & Sheridan, 2015) which suggested that adults can store four items, whereas children aged 5-8 can store approximately 1.4 items.

METHOD

Participants

Target sample size (n=75) was based on other studies using a similar task (e.g. Mall, Morey, Wolff, & Lehnert, 2014; Riggs, McTaggart, Simpson, & Freeman, 2006). Some participants were excluded from the analyses and replaced, giving a total of 81 participants recruited. Participants were excluded due to equipment failure (1 child), eye-tracking calibration failure (2 adults, 2 children), inability to manipulate the controller (1 child), and consent withdrawal (1 child). After completing the task, three children were excluded due to colour-blindness (2 children) and excessively high rate (37%) of unanswered trials (1 child). The final sample analysed comprised twenty-two children between 5 and 7 years (*M* = 6.53, *SD* = 1.02, 13 female, "6-year-olds" henceforth); twenty-four children between 10 and 12 years (*M* = 10.98, *SD* = 0.84, 15 female, "11-year-olds"); and twenty-five adults from 18 to 40 years (*M* = 27.63, *SD* = 3.90, 15 female, "adults"). All participants had normal or corrected-to-normal vision. Adults were recruited from the University of Edinburgh Careers Service portal (https://mycareerhub.ed.ac.uk/). Children were recruited through the Wee Science laboratory (http://www.weescience.ppls.ed.ac.uk/) database. Adult participants were compensated with £7, and child participants with £10, which was given to the parent to cover transportation expenses and a reward for the child participant. This study was approved by the research ethics committee of the School of Philosophy, Psychology, and Language Sciences with number of application 204-1617/4. Adult participants and parents of children participants gave written informed consent. Children signed assent sheets.

Materials and Apparatus

The experimental task was programmed in E-Prime v.2.0 (Psychological Software Tools, Pittsburgh, PA) and presented on a computer screen. The stimuli were pictures of candies, which could be either square or circle. The memory and probe shapes were filled with one of seven colours with the following RGB values: orange (254, 164, 144), yellow (202, 206, 20), teal (10, 235,193), green (20, 233, 10), blue (132, 191, 254), purple (194, 10, 254) and pink (254, 122, 229) on a grey background (150, 150, 150). For the retention phase and the cue, the stimuli were grey (153, 153, 153). The background was always grey (150, 150, 150). During the session, participants sat at approximately 60 cm from the computer screen. The shapes were presented within an invisible circle that subtended 8.5°. The location of stimuli were 1.9° either directly above, below, left or right of the centre of the screen. Items fitted within invisible rectangles that subtended 2.3°.

Procedure

Participants were tested in the EyeLink room of the Developmental Lab in the Psychology department of The University of Edinburgh. Each session lasted approximately 30 minutes for children and 50 minutes for adults. The chair and screen position were adjusted depending on the height of the participant. Each session began with an Ishihara Colour Vision Test (Ishihara, 1966). Participants who responded incorrectly to two of the six items were excluded from the analysis.

Before starting the task, an image of a fairy with a dialog box containing the instructions was presented to all participants, and a story was told to children, so as to engage them in the task. The cover story was that a fairy named Hanna mixed her candies with the candies of a friend and she needed help to distinguish hers. The task was to indicate whether a specific candy (i.e., the probe) was present in a previous array. The fairy would help by sometimes showing the shape of the to-be-tested candy. This shape cue could be presented before or after the to-be-memorised array. The examiner explained the task by presenting examples on a tablet until the instructions were fully understood, emphasising the importance of trying to use the helpful cues to make remembering easier. Next, six practice trials with accuracy feedback but without cues were presented.

When cues were presented, they were always valid (i.e., they always predicted the probe shape). There were three different types of trials depending on the type of cue. Neutral trials contained a fixation point (which provided no information about the probe) instead of a cue. In pre-cue trials, cues were shown before presentation, and in retro-cue trials the cue was presented at the centre of the retention array. The cues were single grey shapes. Figure 1 depicts the sequence of cued trials. To prevent confusion, trials were presented in two blocks. In one block, trials were either pre-cued or neutral, whereas in the other block trials were either retro-cued or neutral. The order of the blocks was randomised. To prevent exhaustion, children completed two blocks of 48 trials, with only set size three (i.e., 3 items on the display). The number of shapes on the presentation and retention arrays that matched the cue shape determined the number of cued items. For children, thus, the number of cued items could be one or two. To further explore the set size effect and the effect of the number or cued items, adults completed 144 trials, each one with either three or four shapes. Therefore, the number of cued items could be 0, 1, 2 or 3.

The trials consisted of an initial display with an array of coloured items ("presentation"). This was followed by a screen with the same shapes in grey ("retention") which was, in turn, followed by a display with a single coloured item ("probe"). Participants responded to the probe by pressing the right button on a controller when the probe was on the presentation array and the left one when it was not. After the probe response, a screen containing a brief reminder of the instructions was shown, along with the instruction to press the "A" button on the controller to continue to the next trial.

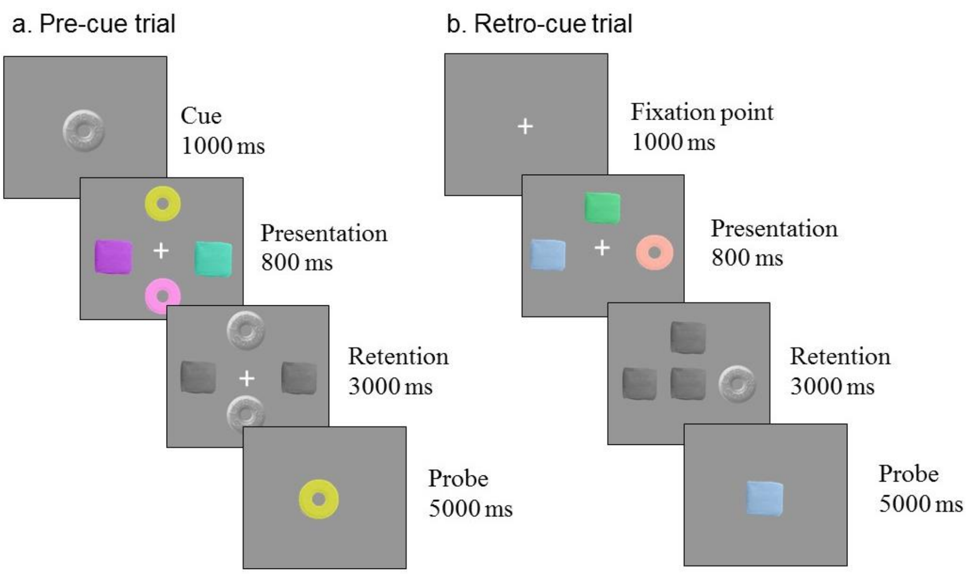

Figure 1. Schematic illustration of the trials sequence, showing the seven colours and the duration of each display. In pre-cue trials (a), the cue was shown before the presentation. In retro-cue trials (b), the cue was presented in the centre of the retention screen. The probe screen lasted for 5,000-ms or until the participant responded.

RESULTS

All of our inferences are based on Bayesian analysis of variance (ANOVA; Rouder, Morey, Speckman, & Province, 2012), calculated using the R package BayesFactor (version 0.9.12-2; R. D. Morey & Rouder, 2013). An advantage of Bayesian inference is that it allows for meaningful interpretation of null effects. Bayes factors are the relative evidence for one model compared to another, and they are interpreted in comparison with the prior expectations of the reader. In this technique, the models are built including all possible combinations among factors and their possible interactions, against a baseline with only the between-participants variance. This corresponds to the null expectation that none of the manipulated factors influenced performance, but that performance varies only by participant. The model with the largest Bayes factor is the best fitting model. This value tells us how many times more that model can account for the data than the null model that only assumes that participants differ from each other.

We first present analyses of proportions of correct responses. Figure 2 provides means for each condition (no cue, pre-cue and retro-cue) in each age group, and Figure 3 shows means for proportion of correct responses in the different age groups.

Developmental analysis

For the developmental analysis, we excluded the trials with set size 4. We first analysed the data of the trials with arrays of three items, for a fair comparison between age groups. In this dataset, we subjected the proportion of correct responses to the arcsine square root transformation to prevent the violation of assumptions of homogeneity. The ANOVA compared the proportions of correct responses by the number of cued items (0, 1, or 2), the condition (no cue, pre-cue, and retro-cue), and the group (6-year-olds, 11-year-olds, and adults), with participant as a random factor. The model with the highest Bayes factor included only main effects of condition and age ($BF = 3.6 \times 10^{16}$).

First, we investigated whether content cues improved accuracy as seen with spatial cues. The analysis yielded in a Bayes factor of 8213926117 compared to the model without condition, showing that there is a content cue benefit, and that content information can be used as a retrieval cue for visual representations in the same way as spatial cues. The means for cue condition can be seen in Figure 2.

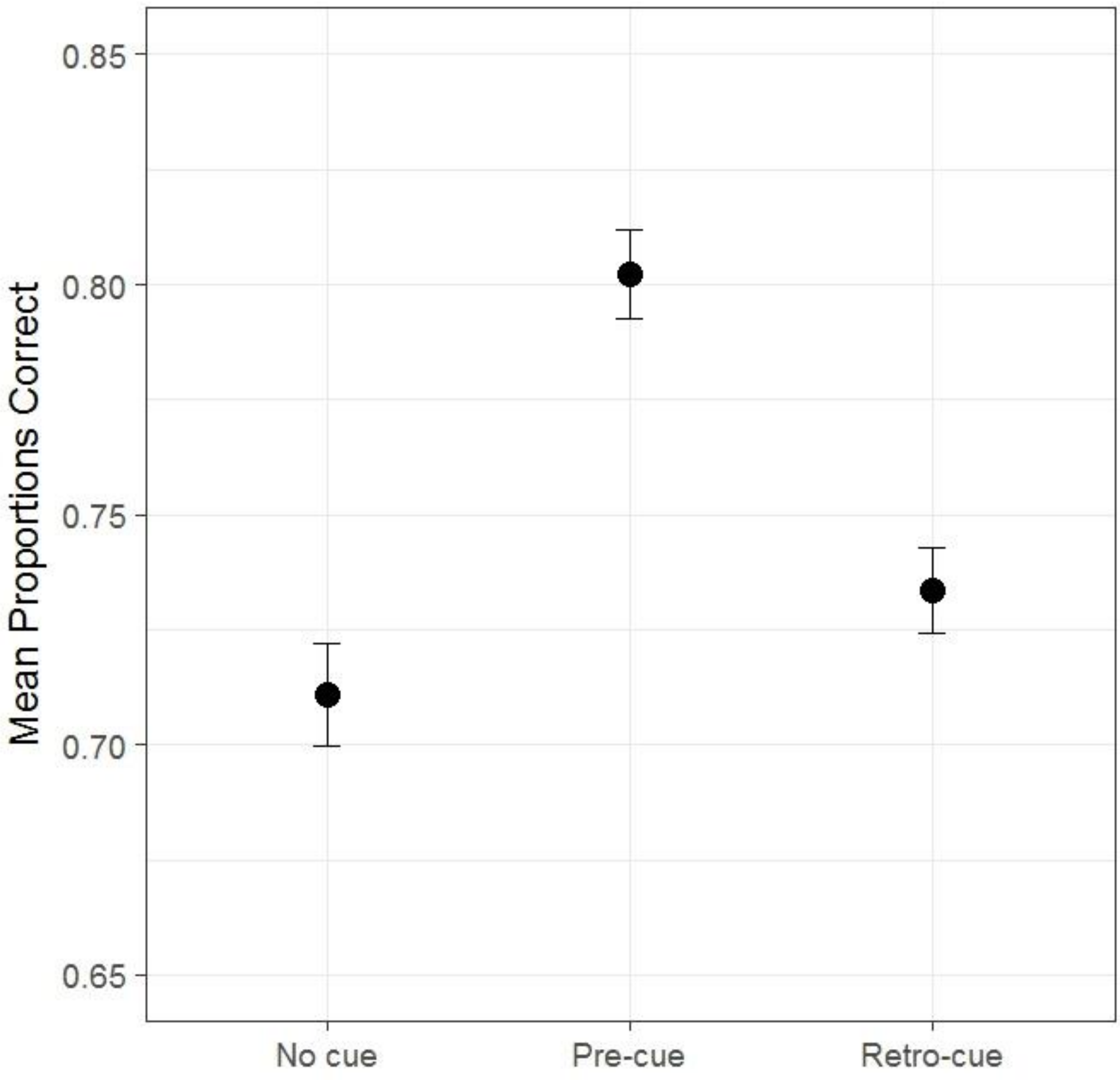

Figure 2: Mean proportions correct in different cue conditions

Second, we tested whether visual WM capacity changes across the lifespan. We evaluated the strength of the age effect by comparing the best model against the one excluding age. The comparison yielded a Bayes factor of 4050037, which is very strong evidence in favour of the hypothesis that visual WM changes across the lifespan. According to the accuracies we observed, visual WM improves as children develop. Means for each group in the no cue condition are shown in Figure 3.

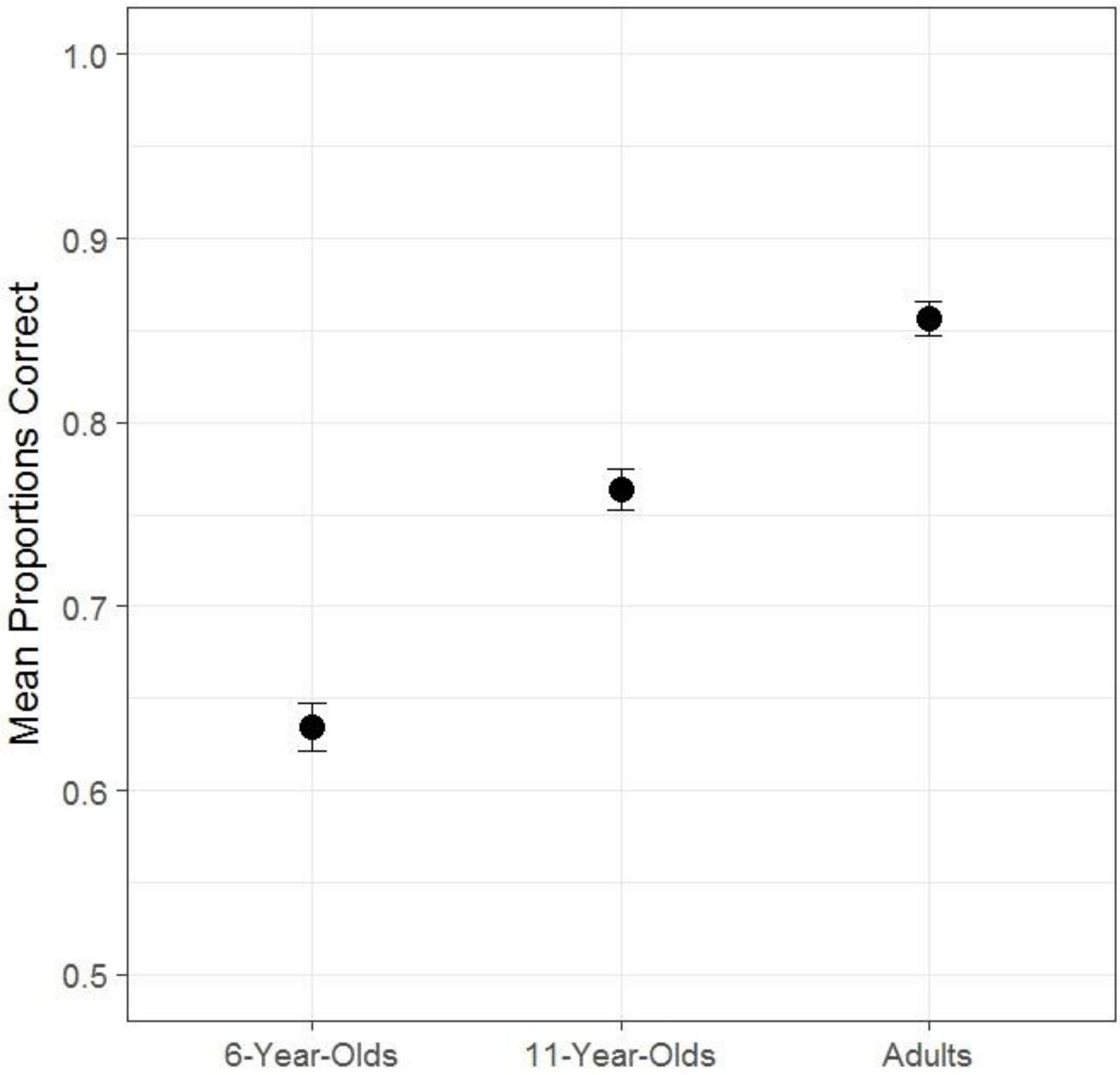

Figure 1: Mean proportions correct in different age groups

Our main hypothesis was whether children differed from adults in visual WM performance, when their attention was guided by content features. The respective Bayesian analysis showed a ratio of 17-to-1 in favour of the model without an interaction between type of cue and age. This ratio of likelihood, serves as an index of how many times one model will accurately predict the data compared to another. Therefore, we found evidence against the influence of age and type of content cue, in visual WM capacity.

This study concerns the role of content retro-cues in visual WM performance. Shimi et al. (2014) found that children benefited less from the spatial retro-cues than from spatial pre-cues. To further distinguish between the pre-cue and retro-cue effect, we created a dataframe omitting pre-cue trials. The best model contained group and condition (BF = 297159). However, when we evaluated the effect of condition, we obtained a Bayes factor of 1.89, which is only tentative evidence favouring a retro-cue benefit. More data is needed to find evidence for or against the content retro-cue effect. Finally, the model including the interaction between age and condition was less likely to predict the data (*BF* = 8.39) than the model excluding the interaction.

We also investigated the effect of the number of cued items, which was in the second best model. The comparison between these models resulted in a Bayes factor of 4.86 against including the effect of the number of cued items in the model. A Bayes factor so small indicates that more data are needed to find evidence in favour or against the models. Thus, the evidence against the inclusion of this factor in the model is only tentative.

Considering the hypotheses about the limits of the focus of attention, we investigated whether younger children would have better performance when only one item was cued. The best model did not include the number of cued items effect. Therefore, we compared the second best model with the model including the interaction between age and number of cued items. The comparison resulted in a ratio of 18-to-1 in favour of the model with main factors only. This implies that performance is not accurately predicted by the interaction between the number of attended items and age. When excluding the pre-cue effect from the analysis, the comparison between the model with the main effect of the number of cued items and the model without the effect, resulted in a Bayes factor of 7 favouring the model without the effect of cued items. To investigate the interaction between age and the number of cued items, we compared the model including this interaction against the best model with the main effect of number of cued items. It yielded in a Bayes factor of 8, which is only tentative evidence against the interaction.

Analysis of set sizes and number of cued items.

To analyse the set-size effect, we created a third dataframe with adults only. Thus, the between subjects factors were set size (3 or 4), number of cued items (0, 1, 2, or 3) and condition, always assuming variance between participants. Analysis of proportion of correct responses by condition is depicted in Figure 3, and for set size in Figure 5.

The best model ($BF = 4.67 \times 10^{21}$) contained only main effects of condition and set size. We first evaluated the effect of condition ($BF = 2.82 \times 10^{16}$), which indicated very strong evidence for cue effect. The best model showed a BF of 6.11 when compared to the model including the effect of number of cued items, which indicated only tentative evidence against the effect of number of cued items to predict the data. The evaluation of the set size effect, produced a Bayes factor of 228254275. Therefore, the number of items contained in the memory array is a good predictor of accuracy.

The model excluding the interaction between condition and set size showed a Bayes factor of only 3 compared to the model including the interaction. Therefore, more data is needed to determine whether the interactions can predict performance.

To distinguish the retro-cue effect, we carried out another ANOVA, excluding the pre-cue trials. The best model (BF = 317614137) included only main effects of condition and set size. The Bayes factor of the condition effect was 34.89, which is evidence in favour of the retro-cue effect (Figure 4). On the other hand, the Bayes factor of the set size was 120138645, which is strong evidence of the inclusion of set size in the model. The ratio of the best model compared to the one with the interaction between condition and set size, showed a Bayes Factor of 2.6, which is provides only tentative evidence against this interaction. Next, we compared the model including the interaction between the number of cued items and the set size against the one excluding this interaction. The Bayes factor was 5, which is tentative evidence against the inclusion of the interaction in the model. To further explore the hypothesis about the number of items in the focus of attention, we compared the model including the interaction between condition and number of cued items, against the model excluding this interaction. We found tentative evidence (BF = 2.2) against the interaction between condition and the number of cued items.

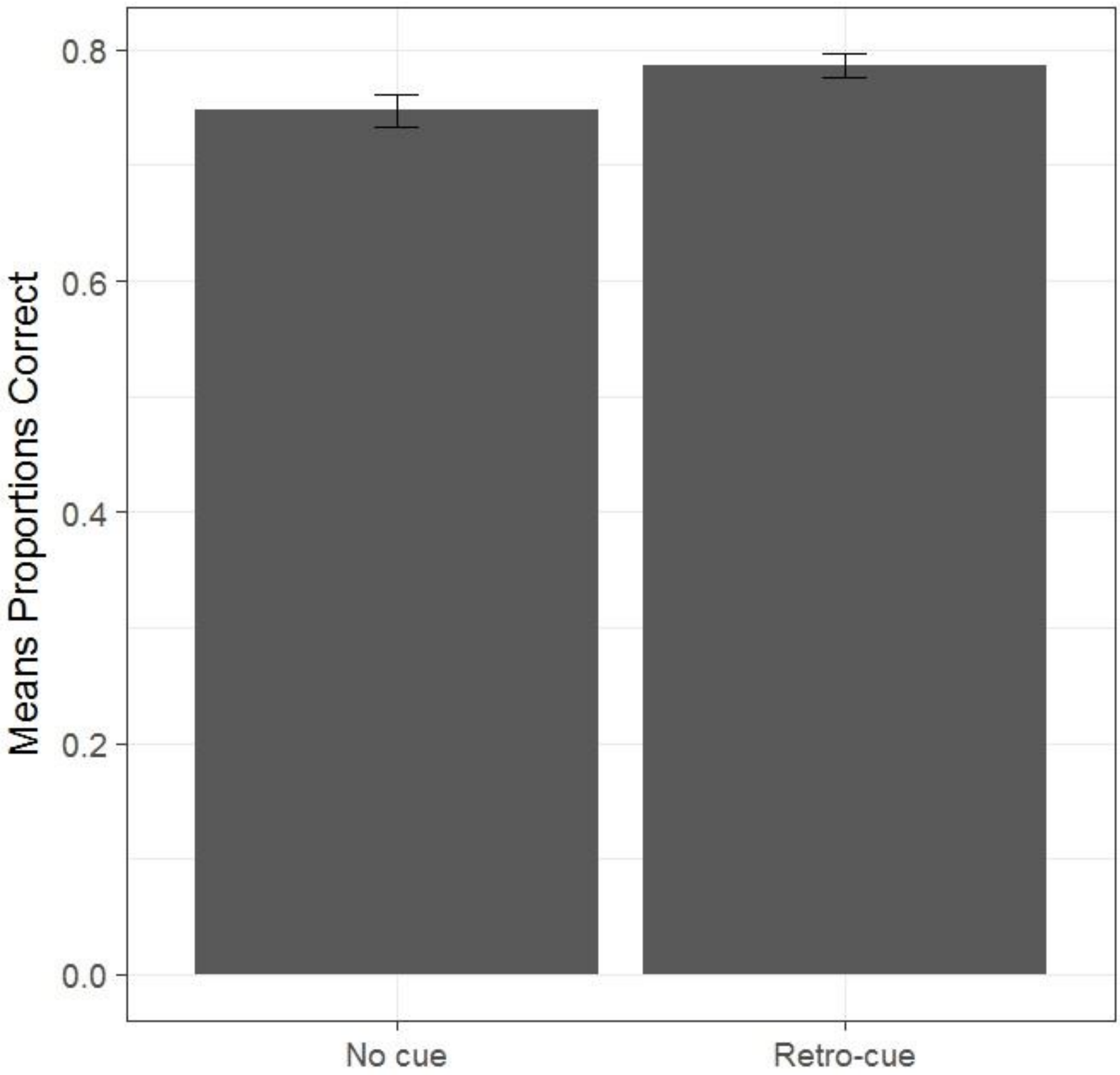

Figure 4: Retro-cue effect in the adult age group

DISCUSSION

The main questions this study aimed to answer were whether content-based cues improve visual working memory capacity, and whether general attentional orienting towards visual memories develops across the lifespan, as observed with location-based cues. To our knowledge, this is the first study to explore the development of the content retro-cue benefit.

We confirmed that content cues boost memory as reported for spatial cues. We also provided evidence that attentional orienting guided by content information increases visual WM capacity compared to the no cue condition across age groups. As expected, we also found a large effect of the memory load (Sternberg, 1975), resulting in higher accuracy with set size of three compared to set size of four. Finally, we found tentative evidence against the number of attended items during both encoding and maintenance.

One of our main hypotheses concerned the control of attention directed to memories. Hence, for a clean demonstration of the retro-cue effect, we carried out analyses with all cue conditions, and with retro-cues and no cue trials only. The processes of attentional orienting during encoding and retrieval pose different cognitive demands. Whereas external attention in the perceptual domain requires sustained attention after the orienting cue in anticipation of the stimulus array, internal attention in the memory domain requires maintenance and selective retrieval of encoded items (Lepsien & Nobre, 2006). Furthermore, one of the main questions that motivated this study was whether the ability to search memories via content cues develops as we age. With this in mind, we carried out analyses without pre-cue trials, and we obtained only tentative evidence for the retro-cue effect when analysing data across all groups. Intriguingly, we found strong evidence for the retro-cue effect when analysing only the adults' data. One possible explanation is that the retro-cue effect increases with age. We could only confirm or rule out the possibility that the retro-cue benefit increases with age, if we have found strong evidence for or against this interaction. However, we observed no decisive evidence to make further interpretations.

An important consideration to understand tentative evidence is the behaviour of Bayes factors with small effects. If the effect in children were present but small, it could be the case that our sample size was insufficient to differentiate invariances, yielding to inconclusive results (Rouder, Speckman, Sun, Morey, & Iverson, 2009) when analysing the data from all groups, as opposed to the finding of an effect for the adults only.

It is beyond the scope of this study to contribute to the clarification of some of the conflicting hypotheses in visual WM research described in the introduction, insofar as we did not manipulate the appropriate variables. However, as some of the underlying assumptions of these hypotheses can aid the understanding of our results, we briefly discuss them in the following sections.

The focus of attention

The question about how many items in memory the focus of attention can select at once has not found an answer that fits in the two WM frameworks we presented in the introduction. To this day, despite the attempts to find a common explanation for the mixed evidence for both a single-item and a multiple-item focus of attention (e.g. Oberauer & Hein, 2012; Cowan, 2010; Gilchrist & Cowan, 2011) the issue is still under debate. Although our study was not designed to further test these hypotheses, we would have expected that if there were a single-item focus of attention, retro-cueing one item should have been more effective than retro-cueing two or more. We found evidence, nonetheless, against the inclusion of the main effect of the number of cued items in the best model. In other words, individuals' accuracy was independent of the number of items in memory they attended. Additionally, we reported only tentative evidence for the interaction between the retro-cue and the number of cued items. Even if there were an effect of the number of cued items and an interaction with cue condition it would only have accounted, partially, for the small improvement (4%) in accuracy reported in retro-cue trials, namely, the range of the effect of the number of cued items would have been from zero to .04.

Content-based retro-cues

Contrary to some studies that found large retro-cue benefit with content retro-cues (e.g., Heuber, Pertzov, Bays, Joseph, & Husain, 2013; Li & Saiki; 2014) we reported only a negligible benefit in the retro-cue trials compared to the neutral trials. One striking difference between those studies and the present study was the interval between the retro-cue and the probe item. Whereas studies that reported evidence for retro-cue benefits delayed the probe presentation by more than 400 ms (e.g. Heuber & Schubö, 2016; Astle, Nobre, & Scerif, 2012; Pertzov, Bays, Joseph, & Husain, 2013) or used variable delays (e.g. Li & Saiki; 2014), in our task the probe item was presented immediately after the cue offset. The retrieval head start hypothesis (Souza, Rerko, & Oberauer, 2016) about the retro-cue effect could explain, at least partially, the small retro-cue benefit we reported. The assumption underlying this hypothesis is that the retro-cue improves retrieval, conceptualised as the gradual gathering of evidence for an item in memory before the subject makes a decision about the probe item. It is possible, thus, that our participants did not have time to accumulate evidence to make a correct decision about the probe test was on the memory array. Furthermore, some studies reported that strong retro-cue benefits emerged after a 500 ms delay between the retro-cue and the test display (Souza, Rerko, & Oberauer, 2014) or remained stable after 400 ms (Tanoue and Berryhill, 2012). It is possible, therefore, that individuals could have obtained larger benefits from searching representations by content if they have had more time to gather information before deciding whether the probe item was in the memory array. This highlights the importance of the inter-stimulus intervals in visual WM tasks.

Another possible explanation for the retro-cue benefit is the removal hypothesis (Oberauer, 2001) in which the retro-cue tags cued items as relevant for the task, and in consequence, tags uncued items as irrelevant for its removal (Oberauer, 2001; 2014). The effect of removal, thus, should be found in decreased size effects as the removal of uncued items frees capacity to process cued items. Under this hypothesis, it could possibly be that the small retro-cue effect we obtained explains, at least partially, the higher accuracy reported for set size three than for set size four. Though our data reproduced the pattern described by Sternberg (1966) for the set size effect, we did not find evidence for or against the interaction between this effect and the type of cue. Hence, we cannot rule out nor confirm the possibility that the small retro-cue benefit we found accounts for the differences between both set sizes. Because irrelevant items are supposed to be permanently discarded according to this view, invalid retro-cue trials could provide evidence for this hypothesis. Further research testing invalid retro-cued items could contribute to elucidate whether content retro-cues promote the removal of uncued items, freeing capacity to process incoming visual stimuli.

Format and organisation of visual memories

Attention to memories can be retrieved by content information, as indicated by the robust retro-cue effect we reported for adults. The effect size we found, however, was relatively small, and this finding appears to stand in contrast to studies that have shown a large benefit of non-spatial retro-cues (e.g., Gilchrist, Duarte & Verhaeghen; 2015; Heuer & Schubö, 2016; Pertzov, Bays, Joseph, and Husain, 2013, Li & Saiki; 2014; Ku, 2015). We suggest that the different effect size we found is due to the aforementioned lack of delay between the retro-cue and the probe test. Support for this suggestion comes from another study that reported no benefit for non-spatial retro-cues (Berryhill, Richmond, Shay, and Olson, 2012), in which the presentation of the probe test was delayed by only 400 ms. As mentioned before, retro-cue effects have been reported to stabilize after this period (Tanoue & Berryhill, 2012). Hence, the small retro-cue effect we found could be due to specificities of the task and not because the effect is small per se.

Research on content retro-cues has mostly used colours and shapes. While some studies found larger benefits for colour-based retro-cues (e.g. Pertzov et al., 2013; Li & Saiki, 2015) others found larger benefit for shape retro-cues (e.g. Gilchrist, Duarte, & Verhaeghen, 2012). Moreover, when comparing spatial versus content retro-cues, some have reported that visual memories can be retrieved more effectively with spatial information (e.g. Berryhill, Richmond, Shay, and Olson, 2012), whereas others reported greater benefit for colour based than location based (e.g., Heuer & Schubö, 2016). Furthermore, in contrast with our results, Gilchrist, Duarte and Verhaeghen (2012) reported no memory load effect for shape-based retro-cues. Taken together, these findings seem to indicate that whether spatial information appears to be a stronger retrieval cue than content information depends on specificities of the task.

A question that comes to mind when noting that visual memories can be retrieved by a variety of features, is what is the format and organisation of visual memories. Our results converged with other studies demonstrating that at least two feature dimensions can retrieve representations: colour and shape. In addition, spatial information has been demonstrated as an effective cue retrieval. Visual WM literature has been dominated by two possible explanations, namely the object-based (Luck & Vogel 1997; Vogel, Woodman, & Luck, 2001) and the feature-based (Wheeler & Treisman, 2002) hypotheses. According to the feature-based hypothesis, the function of attention oriented to memory, is to bind the independent features that comprise an item. Li and Saiki (2015) suggested that features in memory connect to each other with different intensity. For instance, colour-location conjunctions can only be bound via a colour-location connection when attention is biased by colour and location retro-cues, indicating that the degree in which colour and location bias each other has the same strength. On the other hand, a colour retro-cue is less effective than a spatial retro-cue when binding colour-shape-location conjunctions. Therefore, it is possible that all three feature dimensions are connected with the same strength. They found that color-shape connection was weaker than the other connection within a visual WM representation. Additionally, location-colour and location-shape have the strongest connections, which would account for a stronger effect of spatial retro-cues over colour and shape retro-cues. The correct response in our task, required participants to bind shape and colour. It could be argued that due to a weak connection between shape and colour within representations, the shape retro-cue in our study resulted in a smaller benefit than the observed with spatial cues in other studies (e.g. Shimi et al, 2014). There are at least two potential objections for this argument. First, previously mentioned studies noted stronger effects for content based retro-cues (e.g. Heuer & Schubö) and second, even when location was not tested, the shapes were at different locations on the array, i.e., had a spatial feature. Location is virtually inherent in shapes. To elucidate further the effects or non-spatial cues, it is necessary to control for unintended spatial cues that could influence attention.

Development of attentional orienting to visual memories

One of the main questions that motivated this study was whether internal attention toward visual memories changed from childhood to adulthood when guided by content features, as described by Shimi et al. (2014) for spatial cues. In a first analysis across age groups, our results converged with previous studies that provided evidence for the improvement of WM capacity across the lifespan, showing a striking improvement between the 7 and 12 years (Cowan et al., 2010; Gathercole, 1999; Gathercole, Pickering, Ambridge, & Wearing, 2004; Riggs, McTaggart, Simpson, & Freeman, 2006; Shimi et al., 2014). Unsurprisingly, we found overwhelming evidence for condition. The Posner paradigm (1980) has been used for orienting attention in the perception domain, accumulating evidence as an effective way of biasing attention during encoding, improving WM capacity. Because it is well known now that the pre-cue effect is strong, we carried out a second analysis excluding the pre-cue trials. In this second analysis, both the effect of condition and the interaction between this and age, were only tentative. These results do not allow us to confidentially interpret the influence of attentional orienting towards visual memories.

This study is exploratory in nature. In contrast with research on the content retro-cue effect in adults, children had been tested either with spatial pre-cues and retro-cues (e.g., Astle, Nobre & Scerif, 2012), or with spatial retro-cues (e.g. Cowan et al., 2010; 2011), but no with content retro-cues. Heuber and Schubö (2016) found evidence of a similarity in the mechanisms of pre-cues and retro-cues, especially with attentional orienting guided by content information. Therefore, it could be that the trajectory that the spatially orientation follows across the lifespan, resembles that of the attentional orienting guided by content information.

Limitations and future directions.

As mentioned in the discussion, we did not use a delay between the retro-cue and the probe test. Whether the Head Start hypothesis is correct or not, to make a fair comparison among studies, it is recommended to replicate the task as much as possible. Furthermore, the youngest children in Shimi et al. (2014)'s study were 7-year-olds, in comparison with the 5-year-olds of this study. This age difference could account for a lack of evidence of the retro-cue effect in the analysis across groups. Some of them struggled with the controller used in the task, possibly leading to incorrect responses. Finally, a larger sample size could contribute to find evidence for or against the hypotheses tested here.

Conclusion

We found that content cues can improve visual WM capacity across all age groups. Furthermore, we also reported evidence for a strong retro-cue effect in adults. However, we find only tentative evidence for an interaction between age and retro-cue, which implies that we cannot make conclusions regarding the development of the ability to orient attention to visual memories. We found that visual WM capacity increases. This study found evidence for a content pre-cue benefit across all age groups. This study opens a new field of visual working memory research, as it has been largely neglected.

REFERENCES

Astle, D. E., Summerfield, J., Griffin, I. C., & Nobre, A. C. (2012). Orienting attention to locations in mental representations. *Attention, Perception, & Psychophysics, 74,* 146–162. doi:10.3758/s13414-011-0218-3

Avons, S. E., Ward, G., & Russo, R. (2001). The dangers of taking capacity limits too literally. *Behavioral and Brain Sciences,* 24(1), 114-115. doi: 10.1017/S0140525X01223929

Baddeley, A., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *Recent Advances in Learning and Motivation.* (Vol. 8, pp. 47-90). New York: Academic Press.

Barrouillet, P., De Paepe, A., & Langerock, N. (2012). Time causes forgetting from working memory. *Psychonomic Bulletin & Review, 19,* 87–92. doi:10.3758/s13423-011-0192-8

Berryhill, M. E., Richmond, L. L., Shay, C. S., & Olson, I. R. (2012). Shifting attention among working memory representations: Testing cue type, awareness, and strategic control. *Quarterly Journal of Experimental Psychology, 65,* 426–438. doi:10.1080/17470218.2011.604786

Botta, F., Santangelo, V., Raffone, A., Lupiáñez, J., & Belardinelli, M. O. (2010). Exogenous and endogenous spatial attention effects on visuospatial working memory. *The Quarterly Journal of Experimental Psychology, 63*(8), 1590-1602. doi: 10.1080/17470210903443836

Brown, J. (1958). Some tests of the decay theory of immediate memory. *The Quarterly Journal of Experimental Psychology, 10*, 12–21. doi:10.1080/17470215808416249

Burnett Heyes, S. B., Zokaei, N., & Husain, M. (2016). Longitudinal development of visual working memory precision in childhood and early adolescence. *Cognitive development*, 39, 36-44. doi: 10.1016/j.cogdev.2016.03.004

Burnett Heyes, S., Zokaei, N., van der Staaij, I., Bays, P. M., & Husain, M. (2012). Development of visual working memory precision in childhood. *Developmental science*, 15(4), 528-539. doi: 10.1111/j.1467-7687.2012.01148.x

Chawla, D., Rees, G., & Friston, K. J. (1999). The physiological basis of attentional modulation in extrastriate visual areas. *Nature Neuroscience, 2*(7), 671-676. doi: 10.1038/10230

Colflesh, G. J. H., & Conway, A. R. A. (2007). Individual differences in working memory capacity and divided attention in dichotic listening. *Psychonomic Bulletin & Review, 14*, 699–703. doi: 10.3758/BF03196824

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science,* 19(1), 51-57. doi: 10.1177/0963721409359277

Cowan, N., Morey, C. C., AuBuchon, A. M., Zwilling, C. E., & Gilchrist, A. L. (2010). Seven-year-olds allocate attention like adults unless working memory is overloaded. *Developmental Science*, *13*(1), 120–33. doi: 10.1111/j.1467-7687.2009.00864.x

Cowan, N. (1995). *Attention and memory: An integrated framework.* New York, NY: Oxford University Press.

Cowan, N. (1999). An Embedded-Processes Model of Working Memory. In A. Miyake & P. Shah (Eds.) *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (pp. 62-101). Cambridge, UK: Cambridge University Press.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity, *Behavioral and Brain Sciences*, 24, 87-185. doi: 10.1017/S0140525X01003922

Cowan, N. (2005). *Working memory capacity.* Hove, UK: Psychology Press.

Cowan, N. (2011). The focus of attention as observed in visual working memory tasks: Making sense of competing claims. *Neuropsychologia*, *49*(6), 1401-1406. doi: 10.1016/j.neuropsychologia.2011.01.035

Cowan, N., Elliott, E. M., Saults, J. S., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*(1), 42-100. doi: 10.1016/j.cogpsych.2004.12.001

Gilchrist, A. L., & Cowan, N. (2011). Can the focus of attention accommodate multiple, separate items? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(6), 1484. doi: 10.1037/a0024352

Gilchrist, A. L., Duarte, A., & Verhaeghen, P. (2016). Retrospective cues based on object features improve visual working memory performance in older adults. *Aging, Neuropsychology, and Cognition*, 23(2), 184-195. doi: 10.1080/13825585.2015.1069253

Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *Journal of Cognitive Neuroscience, 15*(8), 1176-1194. doi:10.1162/089892903322598139

Heitz, R. P., Redick, T. S., Hambrick, D. Z., Kane, M. J., Conway, A. R., & Engle, R. W. (2006). Working memory, executive function, and general fluid intelligence are not the same. *Behavioral and Brain Sciences, 29*(2), 135-136. doi: 10.1017/S0140525X06319036

Kastner, S., Pinsk, M. A., De Weerd, P., Desimone, R., & Ungerleider, L. G. (1999). Increased activity in human visual cortex during directed attention in the absence of visual stimulation. *Neuron, 22*(4), 751-761. doi: 10.1016/S0896-6273(00)80734-5

Ku, Y. (2015). Feature-based and object-based attention orientation during short-term memory maintenance. Journal of neurophysiology, 114(6), 3036-3038. doi: 10.1152/jn.00342.2015

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?! *Intelligence, 14*(4), 389-433. doi: 10.1016/S0160-2896(05)80012-1

Landman, R., Spekreijse, H., & Lamme, V. A. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research, 43*, 149–164. doi: 10.1016/S0042-6989(02)00402-9

Leonard, J. A. (1953). Partial advance information in a choice reaction time task. *British Journal of Psychology, 49*(2), 89–96. doi: 10.1111/j.2044-8295.1958.tb00644.x

Li, Q., & Saiki, J. (2014). Different effects of color-based and location based selection on visual working memory. *Attention, Perception, & Psychophysics*, 77, 450–463. doi: 10.3758/s13414-014-0775-3

Liu, T., Slotnick, S. D., Serences, J. T., & Yantis, S. (2003). Cortical mechanisms of feature-based attentional control. *Cerebral Cortex, 13*(12), 1334-1343. doi: 10.1093/cercor/bhg080

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature, 390*(6657), 279-281. doi: 10.1038/36846

Makovski, T., & Jiang, Y. V. (2007). Distributing versus focusing attention in visual short-term memory. Psychonomic *Bulletin & Review, 14*, 1072–1078. doi: 10.3758/BF03193093

Makovski, Tal; Sussman, Rachel; Jiang, Yuhong V. (2008). Orienting attention in visual working memory reduces interference from memory probes. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, 34(2), 369-380. doi: 10.1037/0278-7393.34.2.369

Matsukura, M., Luck, S. J., & Vecera, S. P. (2007). Attention effects during visual short-term memory maintenance: Protection or prioritization? *Attention, Perception, & Psychophysics, 69*, 1422–1434. doi: 10.3758/PP.70.3.571

Maunsell, J. H., & Treue, S. (2006). Feature-based attention in visual cortex. *Trends in Neurosciences, 29*(6), 317–322. doi: 10.1016/j.tins.2006.04.001

McKeown, D., & Mercer, T. (2012). Short-term forgetting without interference. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*(4), 1057. doi: 10.1037/a0027749

Miyake, A. & Shah, P. (Eds.) (1999). *Models of working memory. Mechanisms of active maintenance and executive control.* Cambridge, UK: Cambridge University Press.

Morey, C. C., & Bieler, M. (2013). Visual short-term memory always requires general attention. *Psychonomic Bulletin & Review, 20*(1), 163-170. doi: 10.3758/s13423-012-0313-z

Morey, R. D., & Rouder, J. N. (2015). *BayesFactor Package (version 0.9.12–2).* Retrieved from http://bayesfactorpcl.r-forge.r-project.org/

Murray, A. M., Nobre, A. C., & Stokes, M. G. (2011). Markers of preparatory attention predict visual short-term memory performance. *Neuropsychologia, 49*(6), 1458-1465.

Nairne, J. S. (1990). A feature model of immediate memory. *Memory & Cognition, 18*, 251–269. doi: 10.3758/BF03213879

Nobre, A. C., Coull, J. T., Maquet, P., Frith, C. D., Vandenberghe, R., & Mesulam, M. M. (2004). Orienting attention to locations in perceptual versus mental representations. *Journal of Cognitive Neuroscience, 16*, 363–373. doi: 10.1162/089892904322926700

Lepsien, J., & Nobre, A. C. (2006). Cognitive control of attention in the human brain: Insights from orienting attention to mental representations. *Brain research*, 1105(1), 20-31. doi: 10.1016/j.brainres.2006.03.033

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 411–421. doi: 10.1037//0278-7393.28.3.411

Oberauer, K. (2005). Binding and inhibition in working memory: Individual and age differences in short-term recognition. *Journal of Experimental Psychology: General, 134*, 368–387. doi: 10.1037/0096-3445.134.3.368

Oberauer, K. (2009). Design for a working memory. In B. H. Ross (Ed.), *Psychology of learning and motivation: Advances in research and theory* (Vol. 51, pp. 45–100). San Diego, CA: Academic Press.

Oberauer, K., & Bialkova, S. (2009). Accessing information in working memory: Can the focus of attention grasp two elements at the same time? *Journal of Experimental Psychology: General*, *138*(1), 64-87. doi: 10.1037/a0014738

Oberauer, K., & Hein, L. (2012). Attention to information in working memory. *Current Directions in Psychological Science*, *21*(3), 164-169. doi: 10.1177/0963721412444727

Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language, 55,* 601–626. doi:10.1016/j.jml.2006.08.009

Öztekin, I., & McElree, B. (2010). Relationship between measures of working memory capacity and the time course of short-term memory retrieval and interference resolution. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(2), 383–397. doi: 10.1037/a0018029

Öztekin, I., Davachi, L., & McElree, B. (2010). Are representations in working memory distinct from representations in long-term memory? Neural evidence in support of a single store. *Psychological Science*, *21*(8), 1123-1133. doi: 10.1177/0956797610376651

Pertzov, Y., Bays, P. M., Joseph, S., & Husain, M. (2013). Rapid forgetting prevented by retrospective attention cues. *Journal of Experimental Psychology: Human Perception and Performance, 39*(5), 1224-1231. doi: 10.1037/a0030947.

Portrat, S., Barrouillet, P., & Camos, V. (2008). Timerelated decay or interference-based forgetting in working memory? Journal of Experimental Psychology: Learning, Memory, and Cognition, 34, 1561–1564. doi: 10.1037/a0013356

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, *32*(1), 3-25. doi: 10.1080/00335558008248231

Posner, M. I. (2016). Orienting of attention: Then and now. *The Quarterly Journal of Experimental Psychology, 69*(10), 1864-1875. doi: 10.1080/17470218.2014.937446

Prinzmetal, W., McCool, C., & Park, S. (2005). Attention: Reaction time and accuracy reveal different mechanisms. *Journal of Experimental Psychology: General, 134,* 73–92. doi: 10.1037/0096-3445.134.1.73

Ricker, T. J., & Cowan, N. (2010). Loss of visual working memory within seconds: The combined use of refreshable and non-refreshable features. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, 36(6), 1355–1368. doi:10.1037/a0020356

Ricker, T. J., & Cowan, N. (2014). Differences between presentation methods in working memory procedures: A matter of working memory consolidation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40(*2), 417. doi: 10.1037/a0034301

Riggs, K. J., McTaggart, J., Simpson, A., & Freeman, R. P. J. (2006). Changes in the capacity of visual working memory in 5- to 10-year-olds. *Journal of Experimental Child Psychology, 95*(1), 18–26. doi: 10.1016/j.jecp.2006.03.009

Rouder, J. N., Morey, R. D., Morey, C. C., & Cowan, N. (2011). How to measure working memory capacity in the change detection paradigm. *Psychonomic Bulletin & Review, 18*(2), 324-330. doi: 10.3758/s13423-011-0055-3

Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian t tests for accepting and rejecting the null hypothesis. *Psychonomic bulletin & review*, 16(2), 225-237. doi: 10.3758/PBR.16.2.225

Saults, J. S., & Cowan, N. (2007). A central capacity limit to the simultaneous storage of visual and auditory arrays in working memory. *Journal of Experimental Psychology: General, 136*(4), 663–684. doi: 10.1037/0096-3445.136.4.663

Schmidt B. K., Vogel E. K., Woodman G. F., Luck S. J. (2002). Voluntary and automatic attentional control of visual working memory. *Perception & Psychophysics, 64*(5), 754–763. doi: 10.3758/BF03194742

Shipstead, Z., & Engle, R. W. (2013). Interference within the focus of attention:Working memory tasks reflect more than temporary maintenance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*, 277–289. doi: 10.1037/a0028467

Sternberg, S. (1966). High-speed scanning in human memory. *Science*, *153*(3736), 652-654.

Stokes, M., Thompson, R., Nobre, A. C., & Duncan, J. (2009). Shape-specific preparatory activity mediates attention to targets in human visual cortex. *Proceedings of the National Academy of Sciences, 106*(46), 19569-19574. doi: 10.1073/pnas.0905306106

Süß, H. M., Oberauer, K., Wittmann, W. W., Wilhelm, O., & Schulze, R. (2002). Working-memory capacity explains reasoning ability—and a little bit more. *Intelligence, 30*(3), 261-288. doi: 10.1016/S0160-2896(01)00100-3

Sylvester, C. M., Shulman, G. L., Jack, A. I., & Corbetta, M. (2007). Asymmetry of anticipatory activity in visual cortex predicts the locus of attention and perception. *Journal of Neuroscience, 27*(52), 14424-14433. doi: 10.1523/JNEUROSCI.3759-07.2007

Vogel, E. K., McCollough, A. W., & Machizawa, M. G. (2005). Neural measures reveal individual differences in controlling access to working memory. *Nature*, *438*, 500–503. doi: 10.1038/nature04171

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2001). Storage of features, conjunctions, and objects in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(1), 92-114. doi: 10.1037//0096-1523.27.1.92

Wheeler, M. E., & Treisman, A. M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General*, *131*(1), 48-64. doi: 10.1037/0096-3445.131.1.48