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Is Refreshing in Working Memory Impaired in Older Age? Evidence from the Retro-Cue Paradigm

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The data and analysis scripts for the experiment are available at the Open Science Framework at: https://osf.io/bqv7t/

Abstract

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Impairments in refreshing have been suggested as one source of working memory (WM) deficits in older age. Retro-cues provide an important method of investigating this question: a retro-cue guides attention to one WM item, thereby arguably refreshing it and increasing its accessibility compared to a no-cue baseline. In contrast to the refreshing deficit hypothesis, intact retro-cue benefits have been found in older adults. Refreshing, however, is assumed to boost not one but several WM representations when sequentially applied to them. Hence, intact refreshing requires the flexible switching of attention among WM items. So far, it remains an open question whether older adults show this flexibility. Here we investigated whether older adults can use multiple cues to sequentially refresh WM representations. Younger and older adults completed a continuous color delayed estimation task, in which the number of retro-cues (0, 1, or 2) presented during the retention interval was manipulated. The results showed a similar retro-cue benefit for younger and older adults, even in the two-cue condition in which participants had to switch attention between items to refresh representations in WM. These findings suggest that the capacity to use cues to refresh information in visual working memory may be preserved with age.

A fundamental function of human cognition is to manipulate and update information flexibly as required by one's current task. Working memory (WM) is widely acknowledged as the capacity-limited system supporting such abilities, with only a few representations held in mind at a time. Strikingly, this severe capacity limit becomes increasingly constrained in healthy older age.[1] Much research has investigated the locus of this age deficit to uncover the factors that limit WM capacity and reveal the basic machinery underlying WM functioning.

One account suggests that, relative to younger adults, older adults are impaired in their ability to use attention to maintain information in WM, especially through refreshing.[2,3] Refreshing is considered a domain-general mechanism that functions to bring a representation into the focus of attention in WM, thereby augmenting its later accessibility.[4–6] In particular, refreshing can be conceived as strengthening the binding between a verbal or visuospatial WM representation and its retrieval cue (e.g., its relative spatial position in an array), thereby improving its likelihood to be recalled from WM.[5–9] One way to investigate refreshing is the retro-cue paradigm. Retro-cues are presented during the retention interval (RI) of a WM task to direct attention to one of the items, yielding better recall from WM compared to no-cue or neutral-cue baselines.[10–12, for review, see 13] Thus, the retro-cue benefit is consistent with a role of refreshing in assisting maintenance of information in WM, and as such, an age-related deficit in the retro-cue benefit may indicate impairments in refreshing. The limited evidence regarding this question is, so far, mixed. Some studies using the paradigm have found that only younger adults benefit from retro-cues,[14–16] but subsequent work has shown similar retro-cue benefits between younger and older adults.[17–19] Further research is thus needed to firmly establish whether older adults can use cues to focus their attention on one WM item for refreshing.

Age-invariant retro-cue benefits, however, may not indicate that refreshing is fully functional in old age. The traditional retro-cue paradigm only requires focusing on a single representation, which is just one component of refreshing. Most theoretical accounts assume that refreshing operates sequentially on multiple representations,[20–27] yielding cumulative boosts according to how often items are refreshed. Congruent with this assumption, in studies manipulating refreshing by presenting sequences of retro-cues and instructing participants to think of each cued item, recall varied linearly with refreshing frequency (0, 1, or 2 times) in younger adults.[5,6] This task taxes all components involved in refreshing: focusing attention on one representation, switching flexibly among representations, and preserving the refreshing boost after the focus moves away. To date, it is unclear whether older adults show impairments in any of these components of refreshing, thereby partially explaining age-related deficits in WM. This would support the assumption that refreshing is an essential process for keeping information available in WM.

The goals of the present study were two-fold. First, we tested whether a single retro-cue confers similar benefits for younger and older adults. Given the currently mixed evidence on this matter, replication is essential for establishing the conditions in which age deficits in WM focusing are observed. Second, as a substantial novel contribution, we assessed whether older adults can use a second retro-cue to flexibly switch attention among representations in WM to refresh them. To the best of our knowledge, no other study has examined whether older adults can flexibly refresh items in WM when guided by multiple retro-cues. These goals correspond to the overall aim to understand whether the source of age-related deficits in WM is a relative inability to focus and/or switch attention to refresh information in WM.

In order to address these two goals, we modified the single retro-cue task:[18] Participants saw five to-be-remembered colors, and after a brief RI, one item was tested by reproducing its color using a continuous color ring (see Figure 1). The dependent variable in this task was the distance in the color ring (in degrees) between the tested item color and the color reported by the participant (hereafter, recall error). Participants performed this task in two blocks: No-

Cue and Retro-cue. In the No-Cue block, the screen remained blank during the RI. In the Retro-cue Block, one or two successive retro-cues appeared pointing to the positions of the previously presented items. Participants were informed that the retro-cue indicated which item would be tested, and that in the case of two retro-cues, only the last retro-cue indicated the to-be-tested item, rendering the first cue invalid. Single and double-cue trials were randomly intermixed. Therefore, upon seeing the first retro-cue, participants could not anticipate whether this cued item would be tested or not (i.e., the first retro-cue was only valid in 50% of the trials, being in essence a probabilistic cue). Furthermore, presentation of the second-retro cue requires participants to switch their attention to the next cued item in order to refresh it.

We predicted that younger and older adults should show a similar standard retro-cue benefit: recall error is reduced in trials with a single retro-cue relative to the no-cue baseline, replicating prior work with a similar task.[18,19] This would support the notion that older adults are relatively unimpaired in directing attention to one WM item in order to refresh it. Furthermore, it would also indicate that both age groups can use attentional cues even when these cues are not completely valid and the outcomes of prioritizing one representation over others in WM are uncertain. Double-cue trials that require switching attention to another WM item prior to refreshing should replicate a retro-cue benefit in younger adults.[4] If older adults have a specific deficit in refreshing when switching attention among different representations, then they should exhibit a smaller or null retro-cue benefit during the double retro-cue condition relative to younger adults.

Method

Participants and Design

Twenty-five younger adults (18 female; M_{age} = 18.92, *SD* = 0.70, range = 18 – 21) and 24 older adults (18 female; M_{age} = 70.38, *SD* = 4.49, range = 64 – 78) participated in the experiment. One younger adult was excluded due to a computer malfunction. Younger adults were students from the University of Essex who participated in exchange for partial course credit, and older adults were recruited from the local Essex community and received an honorarium of £6. All of the older adults self-reported no medical history of memory or cognitive impairment (mini-mental status exam [MMSE]: $M = 29.38$, $SD = 0.82$, range = 27 – 30), and all of the participants passed a brief test for color blindness.

The experiment followed a mixed nested design, such that age group was a between-subjects factor, and the within-subjects factors of the length of the RI and number of cues were nested. The logic of this design is as follows: to keep the time available to use each retro-cue constant (namely 1.25 s; see Figure 1), increasing the number of presented cues (1 vs. 2) necessarily involved increasing the RI. Accordingly, we created two no-cue conditions (one with a short RI and one with a long RI) such that the duration of the RIs matched the time until presentation of the valid retro-cue (i.e., the point after which the cued/tested item is in the focus of attention, and hence protected from forgetting; see Figure 1). Hence, the short no-cue condition served as a baseline to the single retro-cue trials, whereas the long no-cue condition served as baseline to the double retro-cue trials. The dependent variable of interest was recall error, ranging from 0° to 180°, with 0° reflecting perfect performance.

Materials and Procedure

Participants were tested individually in quiet booths; an experimenter was present in the booth during the instructions and practice trials, and monitored several participants from outside their booths thereafter. After providing informed consent, all participants completed a web-based color vision test, and in addition older participants completed the MMSE. The experiment was programmed in Matlab using the Psychtoolbox[28,29] and adapted from the task described by Souza.[18] Participants first completed a perceptual color matching task wherein a target-color disk and a grey-probe disk were presented to the left and right of the center of the screen, respectively. A continuous color wheel (consisting of 360 colors sampled from a circle in the CIELAB color space, with L = 70, a = 20, b = 38, and radius = 60) was presented around the two disks, and participants were instructed to match the color of the probe to the one of the target using the color wheel. The probe disk changed colors as the participant moved the mouse along the color wheel. When participants were satisfied with the color of the probe, they were instructed to press the left-mouse button. Colors were randomly sampled from the color wheel in each trial. After five practice trials, participants completed a block of 25 self-paced test trials. At the end of the block, participants received feedback about their average accuracy, which was expressed as a percentage based on their mean response error (i.e., 100 - 100*mean error/180). Participants later completed another block of 25 perceptual match trials before concluding the experiment.

Participants then completed two blocks each comprising 100 trials of the visual WM task (see Figure 1). One block comprised only no-cue trials and one block comprised only retro-cue trials, and block order was counterbalanced across participants. Within the No-Cue block, the RI conditions (i.e., short and long no-cue trials) were equally frequent and randomly intermixed. Within the Retro-Cue block, single and double retro-cue trials were also randomly intermixed and equally likely. Participants received four practice trials before beginning the test trials for each block. Each trial began with a fixation cross for 0.5 s, followed by the presentation of 5 colored disks for 1 s. The disks were shown at equal distances from the center of the screen and equidistant from each other along an imaginary circle. The colors of the disks were randomly sampled (without replacement) from the color wheel in each trial. Participants were instructed to try to remember the colors and their locations on the screen as precisely as possible. During the no-cue block, a blank screen followed for either 1 s (short RI) or 2.25 s (long RI), and ended with presentation of the test display. During the retro-cue block, the offset of the colored disks was followed by a 1 s blank screen and then a retro-cue in the form of an arrow pointing to one of the color locations for 0.25 s, followed by a blank screen for another 1 s. For single retro-cue trials, the test display was shown next. In the case of trials with two retro-cues, another arrow appeared after the blank screen and pointed to a different location for 0.25 s, followed by another blank screen for 1 s, and only then the test display appeared. Participants were informed that the last presented retro-cue indicated which color would be tested with 100% certainty. Given that single and double retro-cue trials were randomly intermixed, participants were unaware of whether they would be tested immediately after the first cue or after a potential second cue. This was important to ensure that participants were motivated to focus their attention to the first cued location and then switch to the second cued location if required by a second retro-cue. At test, participants were shown a dark gray circle at the location of the dot they had to report using the continuous color wheel. As in the perceptual matching task, participants used the mouse to move along the color wheel to select the color they thought best matched the test item’s color. An inter-trial interval of 2 s preceded the onset of the next trial. Similar to the perceptual matching task, participants received a break that displayed feedback regarding their performance for the previous 25 trials. The entire experiment lasted about 1 hr.

Data Analysis

We analyzed the raw data using two methods: (1) Bayesian inferential statistics available in the BayesFactor package[30] (Bayesian t-tests and Bayesian Analysis of Variance [BANOVA]) and (2) Bayesian estimation of the size of the retro-cue effects using Bayesian Estimation Software (BEST)[31], both implemented in R.[32] Regarding the first method, Bayesian statistics compare the likelihood of the data under different models that include or omit main effects and interactions between fixed predictors (hereafter Alternative models, M_1) against a Null model (M_0) which assumes only between-subject variability (i.e., subject as a random effect). The ratio of the likelihood of these two models is the Bayes Factor (BF).

The BF quantifies the evidence in the data for accepting one model over the other (e.g., the ratio of the Alternative model over the Null, BF_{10}, or the ratio of the Null model over the Alternative, BF_{01}). In the BANOVA analyses, we tested several models including and omitting the predictors of interest, and we selected from this analysis the model with the largest BF_{10} (hereafter, the best model). We then proceeded to quantify the evidence against including further predictors in the best model, and the evidence against removing the predictors that are listed in the best model (see Table 1).

Regarding the second method, BEST assesses the size of differences between conditions (e.g., age group, retro-cue condition) in terms of raw scores and effect sizes by providing a mean and range of credible values (i.e., a 95% highest-density interval [HDI]) for each. The presence or absence of the effects can be quantified according to the proportion of credible values that fall in a region of practical equivalence (ROPE), that is, small effect sizes in the range of -0.1 to 0.1. For example, we can assess whether the evidence favors a null age difference in the retro-cue effects. BFs from one-sided Bayesian *t* tests are also reported alongside the effects for comparison (see Table 2).

Finally, the distribution of responses in this task can be modelled as a mixture of two components:[33] (a) a circular normal distribution (i.e., a von Mises distribution) centered on the true color of the tested item, reflecting the successful retrieval of the tested object, with the standard deviation (SD) of this distribution indicating the precision with which objects are stored in visual WM; and (b) a uniform distribution reflecting random guessing.[a] We fitted to the data a hierarchical Bayesian version using code in R developed by Hardman and

[a] Mixture modelling could also include a further third parameter reflecting the probability of confusing memory items with each other (binding error).[34] The hierarchical implementation reported here only included the two-parameter model version. We also fitted our data using the hierarchical three-parameter model implemented by Oberauer and colleagues.[35] Evaluation of the posterior of the estimated parameters indicated that aging mainly affected the guessing parameter (the results are available on the OSF). Given that BFs for the effects of interest are not available to be computed in the implementation of Oberauer and colleagues, we preferred to report the results as estimated with the two-parameter model.

colleagues.[36] Hierarchical modeling is well suited for the case of the present study in which a relatively small number of trials was collected per design cell (50 trials). Simulation work has shown that non-hierarchical modeling requires, at least, double this amount of trials to recover unbiased model estimates.[37] Recent modeling work, however, indicated that hierarchical models do accurately recover parameters with low a number of trials as used here.[35]

Results

Perceptual Matching Task

To assess age differences in color perception and motor response noise, we first tested whether younger and older adults differed in their performance on the perceptual color matching task using a Bayesian *t*-test. Two older adults' mean response error during the task was more than three standard deviations from the group mean, and thus their data were excluded from this analysis.[b] Younger adults (*M* = 2.91°, *SD* = 0.81) tended to have a lower error in matching the color of the target compared to older adults (*M* = 3.95°, *SD* = 1.88), BF_{10} = 3.10. Next, we contrasted age groups in terms of their performance in the perceptual matching task and the WM task with a BANOVA. The model including the effects of age, task, and their interaction had the largest likelihood over the Null ($BF_{10} = 3.20 \times 10^{39}$), followed by the main effects only model ($BF_{10} = 7.81 \times 10^{36}$). The ratio of the evidence for these two models (BF = 409.26) indicates that there was overwhelming support for the age by task interaction in the data. In other words, the age difference observed in the perceptual matching task was much smaller than that observed in the WM task. Thus, the relatively small age difference on color perception and motor noise uncovered in the perceptual color matching task may have contributed but cannot fully account for the age differences in the

[b] The outlying performance for these participants occurred during the second block of the perceptual matching task, and thus there may have been some fatigue or confusion at the end of the experiment. Excluding these participants for the analysis of WM performance did not change the pattern of results.

WM task. Moreover, plotting response hue as a function of studied hue for both tasks (see Figures 2 and 3) showed that responses varied as a direct function of the studied hue (diagonal line) in both the perception and WM tasks across the whole range of color values on the wheel. Thus, there were no obvious biases toward or disadvantages for certain colors depending on age group.

The principal analysis concerned recall error during the WM task. We tested models including age group, RI, and number of cues as well as two-way interactions between age group and RI and age group and number of cues as fixed predictors. Figure 4 shows the data across each of these variables, and Table 1 presents the BF_{10} of the tested models. The best model included only main effects of Age, RI, and Cue. This indicates that younger adults outperformed older adults, retro-cues improved performance relative to their respective no-cue baseline (i.e., a retro-cue effect; see Figure 4), and performance tended to be better in conditions with a short RI/single-cue relative to a long RI/double-cue (but note that the evidence was rather ambiguous for this effect, see Table 1). Thus, despite an overall age-related deficit in WM performance, a retro-cue benefit was observed in both younger and older adults. Most importantly, there was at least substantial evidence against including an Age x Cue or Age x RI interaction, indicating that older adults benefited similarly from the retro-cues irrespective of the number of cues (which was nested in the RI factor). The assessment of the size of these effects using BEST mirrored this pattern of results (see Table 2): there was consistent evidence for a moderate to large retro-cue effect in younger and older adults, and younger adults outperformed older adults across conditions. However, the evidence favored a null impact of age on the retro-cue effect, with 19-26% of the credible effect sizes falling within the region of practical equivalence (ROPE; i.e., an effect size between -0.1 and 0.1).

Specific analysis of the double-cue condition. Since our principal hypothesis concerned the retro-cue effect in double-cue trials, we further conducted a 2 (age group: younger, older) x 2 (cueing: no-cue vs. double retro-cue) mixed BANOVA to examine whether the retro-cue effect differs between age groups. The best model included only main effects of age group and cueing ($BF_{10} = 4.45 \times 10^{11}$), and, importantly, this model was preferred (BF = 3.90) to the model including an interaction of age and cueing ($BF_{10} = 1.14 \times 10^{11}$). As reported previously, the Bayesian estimation of the retro-cue effect in double-cue trials also favored a null impact of age (see Table 2), although the evidence as estimated by using BEST was more ambiguous (the ratio of the evidence was 2:1 in favor of the Null).

Mixture Model Parameters

Figure 5 shows the group-level parameter estimates obtained from the mixture model reflecting the probability of recalling the tested item (panel A) and the imprecision with which this information was retrieved from memory (panel B). Figure 6 shows the posterior of the retro-cue effect in each parameter for the two age groups. The vertical, red line at zero indicates the Null hypotheses of no effect, and the horizontal bar underneath the posterior indicates the range of credible values of the parameter (wherein 95% of the values fall).

Young adults showed a higher probability of retrieving the tested item ($BF_{10} = 15.32$) than older adults (see Figure 5). Young adults also tended to show lower memory imprecision than older adults, but the evidence for this effect was ambiguous ($BF_{10} = 1.44$). Retro-cues improved the probability of recall ($BF_{10} = 2.30 \times 10^8$), but their impact on memory imprecision was ambiguous ($BF_{10} = 1.11$; note that the credible intervals include 0 in Figure 6). With regard to the probability of recall, there was strong evidence against the inclusion of an interaction between age and cue ($BF_{01} = 176.10$). This was the case even when the double retro-cue effect was considered ($BF_{01} = 461.48$). The evidence also tended to favor the Null for the interaction of age and cue when considering memory imprecision ($BF_{01} = 4.55$) across all conditions. When considering only the double-cue effect, however, there was ambiguous evidence for an interaction between age and cue, with retro-cues tending to reduce memory imprecision for young adults, but not for older adults ($BF_{10} = 1.98$). This is further evident in the overlap of the posterior distributions shown in Figure 6d.

Discussion

The current study investigated the role of two components of refreshing (focusing and switching attention between representations) as an underlying source of age-related impairments in WM maintenance. Here we tested whether age impairs the ability to focus attention on one WM item when a retro-cue indicates that it is potentially relevant, thereby indexing focusing efficiency. We further tested whether attention can be disengaged from the focused item when its relevance changes (i.e., when a second retro-cue renders it invalid), in order for attention to be re-directed to another WM item, thereby measuring switching efficiency. By modifying a retro-cue task to present 0, 1, or 2 cues, we observed that despite the overall lower WM performance of the older adults compared to the younger adults,[1] they tended to benefit to a similar degree from retro-cues. This occurred irrespective of whether the effective use of the cues required only focusing (single retro-cue), or whether it also required switching attention between WM items (double retro-cue). These findings replicate prior work indicating that older adults do not suffer from a relative inability to focus their attention on representations in WM,[18,19] even when the retro-cue is technically invalid in 50% of the trials. Furthermore, our study provides the first evidence that older adults can withdraw attention from one focused item and redirect it to another item, indicating flexible switching of attention in WM similarly to what has been previously demonstrated for younger adults.[4,38]

Mixture Modeling and Error Patterns

Mixture modeling of our data indicated that retro-cues consistently improved the probability of recalling information from memory for both age groups, and irrespective of the number of cues presented. Memory imprecision, on the other hand, was only tentatively improved by retro-cues in both age groups, and for older adults the requirement to switch attention between representations (in double-cue trials) abolished the hint of a retro-cue benefit in this parameter (leading to some ambiguous evidence for an interaction of cue and age group). The observation of consistent retro-cue benefits in probability of recall, with more ambiguous evidence for an effect in precision, replicates previous research with the retro-cue effect.[18,39–41] Also, the results of the modeling allowed us to unravel one potential way in which older adults may be impaired in switching attention between representations in WM: compared to younger adults, they do not show a reduction in memory imprecision. However, we note that this effect was small, and the evidence for its presence was weak. Hence, further replication is needed to establish the reliability of this finding.

Refreshing and the Retro-Cue Benefit

Prevalent explanations of retro-cue effects include the notions that retro-cues (1) strengthen the cued, relevant information in WM and/or (2) facilitate removal of the uncued, irrelevant information in WM, or (3) protect representations from time-based decay (see Ref. 13 for a review). Hence, demonstrations of a benefit for a single retro-cue condition cannot be unambiguously linked to refreshing because participants may refresh the cued item, remove non-cued items, or the cued item is protected from decay, or perhaps some combination of these processes. In paradigms using multiple cues such as the one employed here, however, removal of non-cued items is sub-optimal because one of the non-cued items will become relevant again in a large proportion of trials. Previous studies have shown that when a retro-cue is not highly predictive of the to-be tested item, validly testing the cued item yields benefits, whereas testing an item other than the cued one (invalid cue condition) does not lead to performance costs.[38,42] This pattern is expected under the assumption that participants simply refreshed an item without removing non-cued items. Hence, the use of the double-cue paradigm employed here renders removal a less likely explanation of the retro-cue benefits than refreshing.[4]

Furthermore, the design of the current study also controlled for time-based forgetting a representation may have suffered during the RI up to the point of test or cueing. That is, the RI was matched between no-cue and retro-cue trials, such that the presentation of the test and the retro-cue, respectively, occurred after the same amount of time had elapsed. Performance during the no-cue trials was still worse than the retro-cue trials despite the matched timing, and the evidence for an effect of RI was not substantial. Accordingly, the design allows us to rule out protection from decay as an explanation of the retro-cue effects observed in the current study, and further suggests that these effects likely reflect the strengthening that occurs as a function of refreshing the items in the focus of attention.

Is Refreshing Impaired in Old Age?

The cueing manipulation used here measures whether participants can refresh items in WM and the size of the refreshing boost achieved. More specifically, by varying the number of cues as we did here, we could further measure two important components of refreshing, namely, the ability to focus and switch attention between WM representations. These tests did not reveal signs of aging deficits that could explain the reduced WM capacity of older adults. Regarding the focusing component of refreshing, the results are congruent with other recent research suggesting preserved attentional focusing in older age,[17–19] but they conflict with studies suggesting an age-related deficit in the retro-cue effect.[14–16] It is still unclear what exact leads to this mixed pattern, but one possible candidate could be speed-accuracy tradeoffs. Older adults consistently show a slowing of processing speed compared to younger adults.[43–45] Studies failing to observe retro-cues benefits in older age used either short post-cue intervals[15] or required speeded responses to the memory test[14,16], whereas studies observing retro-cue benefits in older adults used either very long post-cue intervals[17] or relatively long post-cue intervals combined with unspeeded responses to the memory test.[18,19] When speeded processing is required, the measure of age-related deficits in attentional control may be conflated with deficits due to age-related slowing. Hence, studies on attentional control in older adults should be mindful about the time provided for focusing attention and for responding to the memory test, in order not to force older adults to tradeoff accuracy for speed. In the present studies, we allowed participants to use the cue for a long period (1.25 s) before the memory test, which was also unspeeded. Research with the retro-cue with young adults has shown that benefits emerge with 300 ms, and remain stable thereafter.[39,46–48] Hence, the time of the post-cue events provided more than sufficient time to compensate for age-related slowing, and the unspeeded test reduced any incentive for speed accuracy trade-offs.

Regarding the switching component of refreshing, the results suggested that older adults are similarly able as younger adults to switch their attention and refresh another item in WM. This was particularly evident in the null interaction between age and the retro-cue effect in the double-cue trials that required participants to switch their attention between representations in WM. Although the evidence for the null interaction was not overwhelming for the raw data, the evidence was much more convincing for the target recall parameter as estimated with the two-parameter mixture model. To our knowledge, this is the first demonstration that older adults can flexibly switch their attention using retro-cues, but it is not the first study to examine whether switching attention is deficient in older age. Indeed, there are a number of studies by Verhaeghen, Basak, and colleagues that have demonstrated an age-related deficit in focus switching.[49–53] Their studies have used a modified *n*-back task wherein younger and older participants indicate whether the current item (e.g., a digit) matches the item presented *n* positions back, and update the item in memory with the newly presented item. Memory load in this task is varied by presenting items in several columns (e.g., two columns for two series of digits to update and compare). Importantly, some trials require participants to switch their attention between the different columns. The results of these focus switching studies have shown preserved item accessibility (i.e., response latency) between age groups, but a greater decrease in item availability (i.e., reduced accuracy) in older adults than younger adults when the item has left the focus of attention.

At first glance these results seem at odds with the current study given that they indicate an age-related deficit in switching attention. However, there are a number of substantial differences between the paradigms that may explain the inconsistency. First, probes are presented for a recognition decision during the *n*-back task, whereas participants reconstructed the studied items in the current study. Given the well-known age-related deficit to reject lures,[54,55] a recognition decision could be a more difficult method of retrieval than reconstruction and thereby exacerbate any otherwise intact switching capacity in older age. For example, a 4 may be presented in one column to be compared to the last-presented item in that column, but a 4 could also appear in a different column later on, and thus may in effect become a lure and cause a reduction in accuracy. Furthermore, the modified *n*-back task potentially has many more components involved in executing the task than the retro-cue task used in the current study. For example, our study only required participants to focus and switch their attention once per trial between a constant number of presented items that did not have to be updated. The modified *n*-back task in Verhaeghen, Basak, and colleagues' studies is much more involved: participants must similarly encode stimuli (e.g., digits), but thereafter the focusing and switching steps are implemented multiple times within the same trial, and participants are required to update the content of their WM on an ongoing basis. The requirement to constantly update the memoranda requires a tight balance between stability and flexibility in which refreshing of an item may make it more difficult to update it later. These extra aspects may make the task of switching attention more challenging than was the case in the current study, thereby leading to an inconsistent effect of age on its efficiency between the studies. Indeed, preserved focused switching has been observed before in older adults in the modified Sternberg task in a design that, similarly to the present study, only required switching once.[56] Finally, the number of presented items (i.e., set size) is often manipulated in the studies with the modified *n*-back task, whereas this study did not manipulate set size. In fact, this is the principal finding from the focus switching studies: accuracy decreases with increasing set size to a greater extent for older compared to younger adults. So, it may be the case that the relatively preserved switching ability in the older adults of the current results could become deficient as set size increases.

Although the current study provided evidence against age-related deficits in focusing and switching attention, other possibilities remain. We have not tested, for example, whether the benefit conferred by focusing attention on one item remains after the focus moves away to refresh another item. When we presented a second retro-cue, the first cued item was rendered invalid, and thus keeping it strengthened was not required nor measured. This was necessary in the present study to give participants the highest incentive to switch attention to the second cued item to the best of their abilities, thereby assuring that we would not fail to observe a double-cue benefit due to a lack of motivation. When refreshing is to be applied to several representations in WM, however, the refreshing boost has to be persistent. Although, the resilience of the retro-cue effect has been extensively demonstrated for young adults with different types of distraction manipulations,[57–60] to the best of our knowledge no study so far has tested it in older age. It could be the case, for example, that older adults' lower WM performance is attributable to an inability to preserve the refreshing boost after attention has been distracted. Thus, future research could focus on whether this third component of sustaining the beneficial effect of refreshing is deficient in older age. Alternatively, other studies have used sequences of up to four cues to guide refreshing in WM in order to demonstrate that refreshing yields a cumulative boost to WM performance.[5,6] This may also be a fruitful avenue to investigate whether the refreshing boost remains after the focus moves away from one item. Finally, findings that participants can refresh under instructed-refreshing conditions does not necessarily mean that they do so spontaneously whenever attention is free to be directed to WM contents. Hence, it remains a possibility that older adults can refresh when guided to do so, but fail to do so spontaneously.[2,3] This is consistent with research in other domains of memory suggesting that older adults can be instructed to employ effective, elaborative strategies to remember information, but may be still less likely to do so spontaneously relative to younger adults.[61,62, but see 63,64] Thus, although the current study suggests that focusing and switching attention may be more similar between younger and older adults, further research is warranted in order to determine whether other components of refreshing, such as those described previously, are deficient in older age.

Conclusion

Our results suggest that older adults are as able as younger adults to focus and to switch attention between representations in WM when guided by retro-cues, thereby refreshing these representations and increasing their accessibility in WM. These findings indicate that, although WM capacity is reduced in old age, these two components of refreshing are preserved.

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Figure 1. Example of the conditions implemented in the experiment trials: cue condition (no-cue versus retro-cue; blocked) nested within retention interval (RI; short versus long, varied randomly within block). The inset in the top-right corner shows the timing of the implemented conditions: From top to bottom row, no-cue short, no-cue long, single retro-cue, and double retro-cue. Note that the valid retro-cue is indicated by a blue-frame and the invalid retro-cue is indicated by a red-frame. See the online article for a color version of this figure.

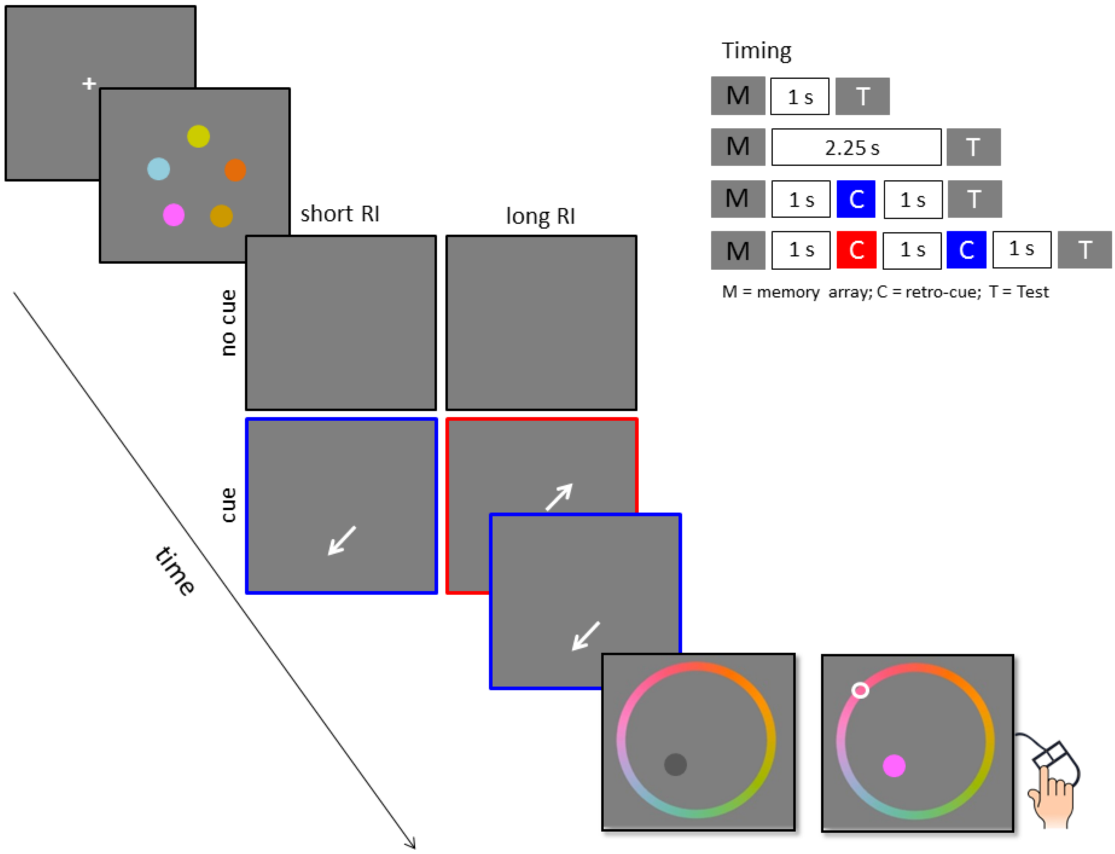

Figure 2. Response hue as a function of studied hue during the perceptual matching task for younger and older adults both before and after the working memory (WM) task. See the online article for a color version of this figure.

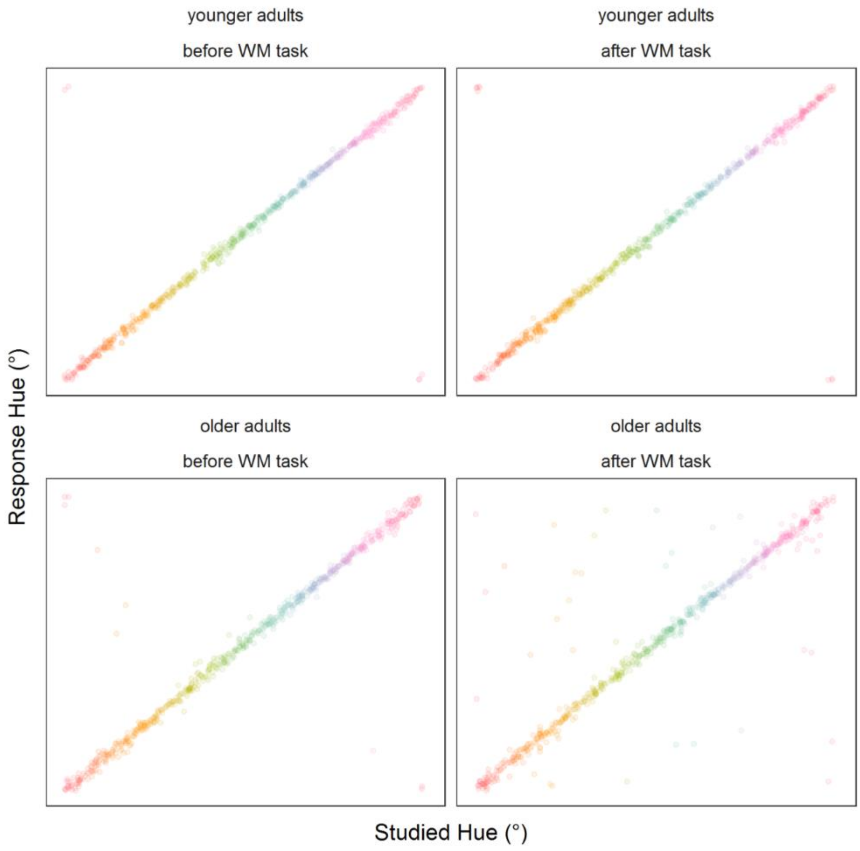

Figure 3. Response hue as a function of studied hue during the no-cue and retro-cue trials of the working memory (WM) task for younger and older adults. See the online article for a color version of this figure.

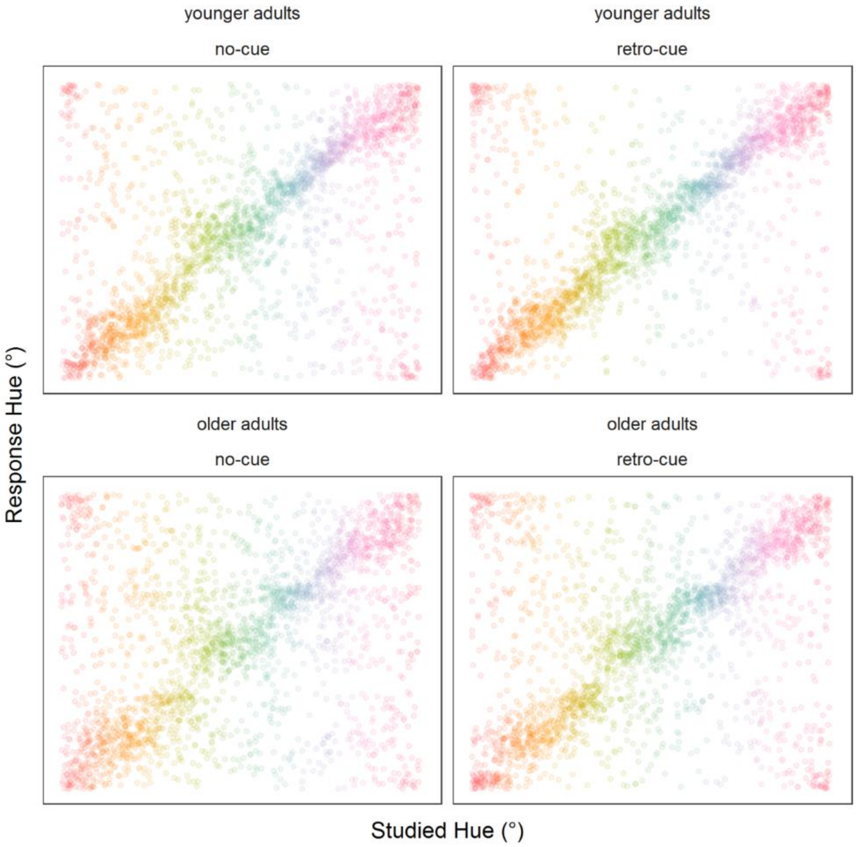

Figure 4. Mean recall error as a function of retention interval and number of cues for younger and older adults. Error bars reflect 95% within-subjects confidence intervals.

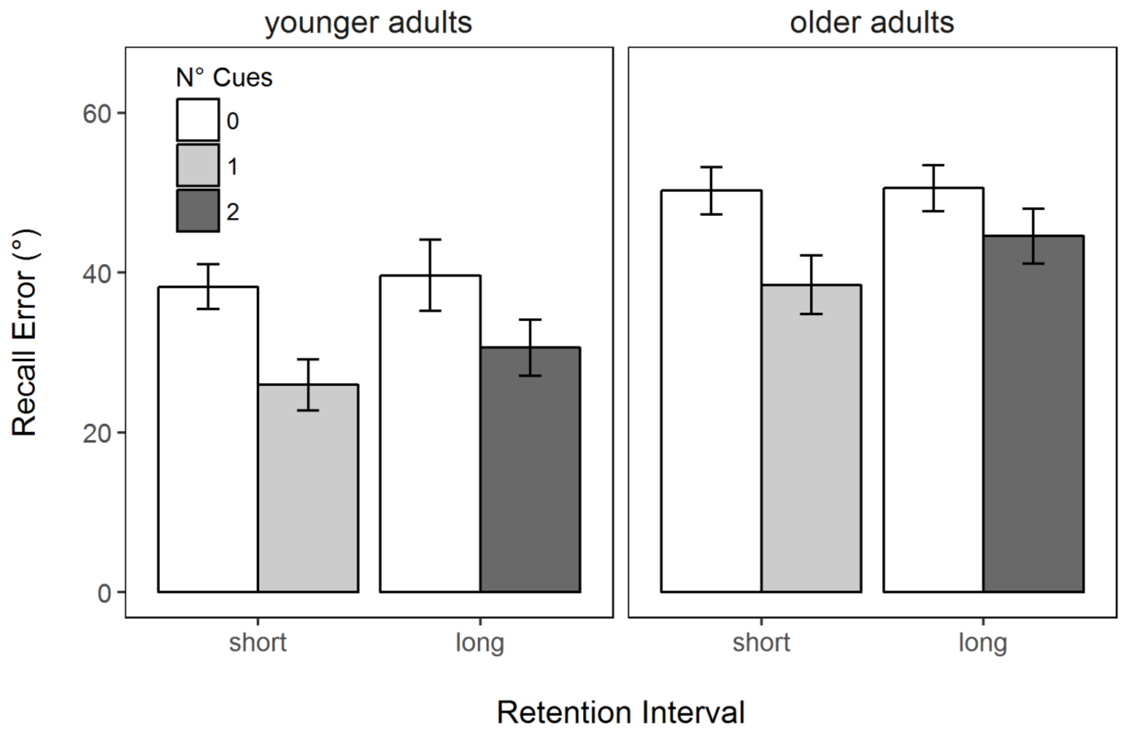

Figure 5. Mean estimate for group-level parameters of the two-parameter hierarchical Bayesian mixture model fitted to the data of each age group and experimental condition. Error bars represent the 95% HDI. Panel a. Probability that a target item is in memory. Panel b. Precision with which features (both target and nontarget) were recalled from memory, with larger values indicating greater precision.

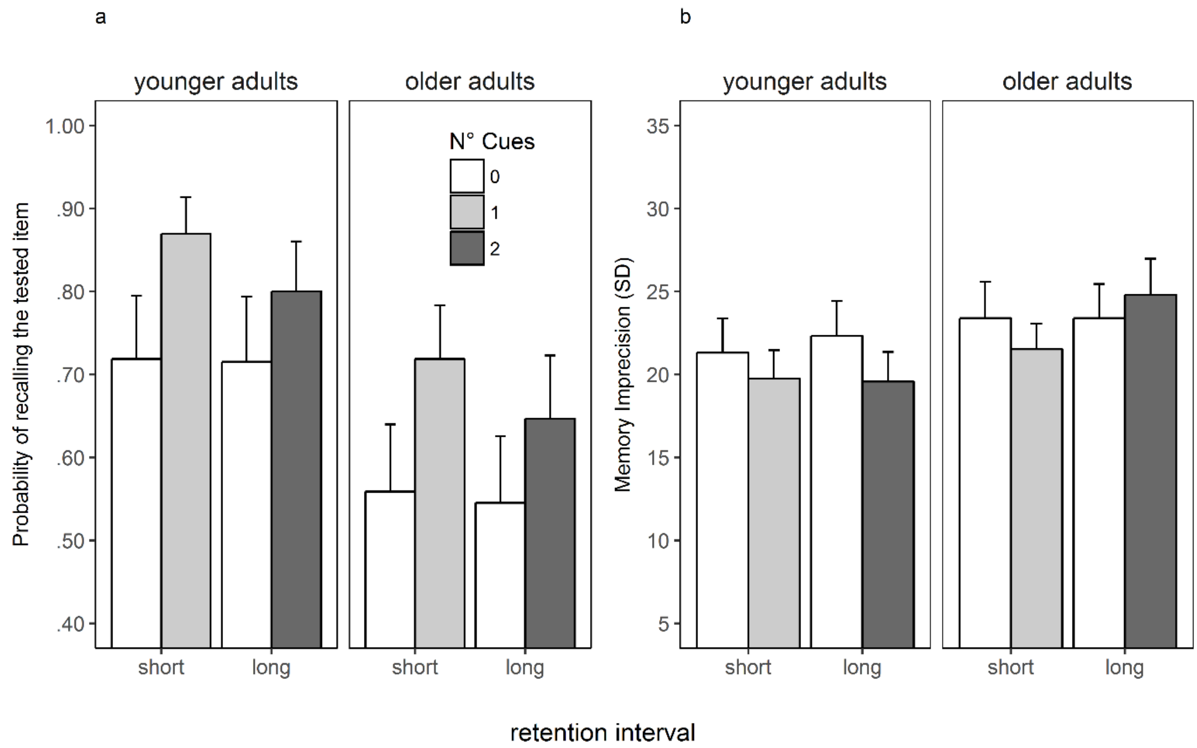

Figure 6. Posterior distribution of the retro-cue effect (Retro-Cue – No-Cue) for younger and older adults in each mixture model parameter, and across the two types of cue conditions (single and double retro-cue effect). Panel a. Increase in probability of recall in single retro-cue trials compared to the short no-cue condition. Panel b. Increase in probability of recall in double retro-cue trials compared to the long no-cue condition. Panel c. Decrease in memory imprecision in single retro-cue trials compared to the short no-cue condition. Panel d. Decrease in memory imprecision in double retro-cue trials compared to the long no-cue condition. The two lines indicate represent the two age groups. Each panel shows the percentage of the curve that is above and below 0 (null effect), and 95% highest density interval, HDI, of the parameter (bar underneath each curve). See the online article for a color version of this figure.

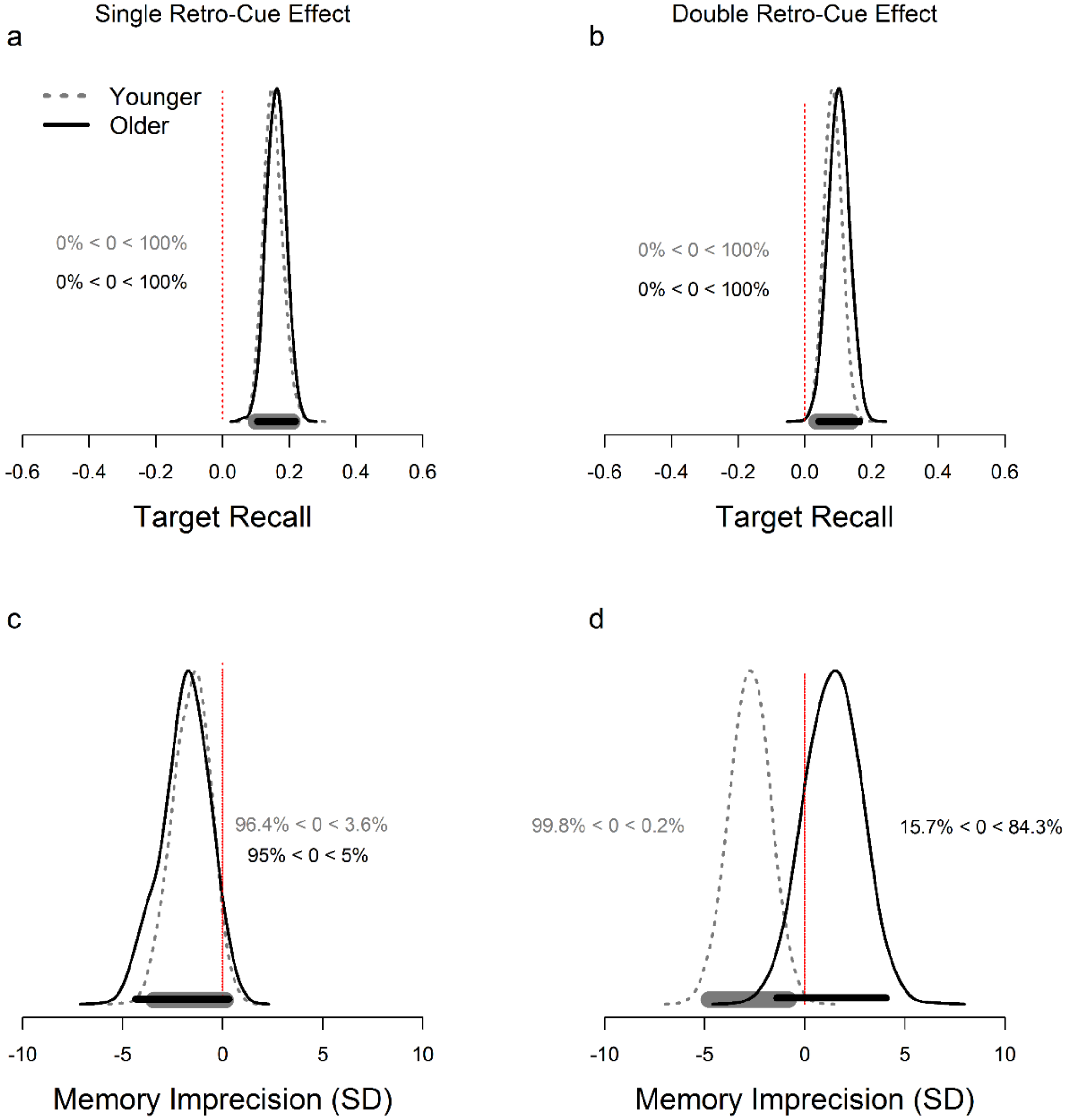

Table 1.

Relative Likelihood of Models with Different Fixed Effects over the Null Model (BF_{10}), and relative likelihood of the Best Model (Higher Likelihood over the Null) Over the Alternative Model Specified in Each Row ($BF_{Best/Current}$).

Model	Model name	Included fixed effects					BF_{10}	$BF_{Best/Current}$
		Age	RI	Cue	Age x RI	Age x Cue		
1	Includes all interactions	✓	✓	✓	✓	✓	9.77×10^{21}	$BF_4/BF_1 = 17.30$
2	Includes Age x Cue	✓	✓	✓		✓	4.44×10^{22}	$BF_4/BF_2 = 3.81$
3	Includes Age x RI	✓	✓	✓	✓		3.76×10^{22}	$BF_4/BF_3 = 4.50$
4	**Best Model (Main effects only)**	✓	✓	✓			$\mathbf{1.69 \times 10^{23}}$	**---**
5	Remove RI	✓		✓			7.22×10^{22}	$BF_4/BF_5 = 2.34$
6	Remove Cue	✓	✓				4.05×10^{13}	$BF_4/BF_6 = 4.17 \times 10^9$
7	Remove Age		✓	✓			7.49×10^{20}	$BF_4/BF_7 = 225.76$

Note. RI = Retention interval.

Table 2.
Mean recall error, and 95% highest density interval (HDI), estimated from Bayesian *t* tests assessing (a) the age effect in each condition, (b) the cueing benefit in each age group and condition, and (c) the age effect on the cueing effect for each condition.

	Age group				Age effect					
	Younger		Older		Raw score		Effect size			
Condition	Mean	95% HDI	Mean	95% HDI	Mean	95% HDI	Mean	95% HDI	*p* (ROPE)	BF_{10}
no-cue, short RI	37.91	[32.03, 43.70]	50.38	[45.41, 55.21]	-12.47	[-20.10, -4.96]	-1.00	[-1.65, -0.35]	0	46.27
retro-cue, short RI	25.96	[21.87, 30.05]	37.98	[33.42, 42.66]	-12.02	[-18.63, -6.26]	-1.19	[-1.84, -0.55]	0	515.55
single retro-cue benefit										
Raw score	11.56	[7.05, 16.18]	11.77	[6.18, 17.46]	-0.07	[-7.12, 6.97]	-0.01	[-0.59, 0.62]	0.26	0.32
Effect size	1.18	[0.54, 1.84]	0.93	[0.38, 1.48]						
p (ROPE)	< 0.0001		< 0.001							
BF_{10}	2338.43		265.31							
no-cue, long RI	38.31	[31.75, 45.79]	50.92	[45.81, 56.23]	-12.60	[-21.45, -3.84]	-0.93	[-1.71, -0.19]	0.01	7.46
retro-cue, long RI	30.47	[24.96, 36.09]	43.86	[38.96, 49.29]	-13.39	[-21.10, -5.89]	-1.07	[-1.72, -0.43]	0	124.02
double retro-cue benefit										
Raw score	7.01	[2.06, 11.98]	5.54	[0.90, 10.45]	1.81	[-4.64, 8.04]	0.22	[-0.48, 0.93]	0.19	0.53
Effect size	0.75	[0.10, 1.45]	0.56	[0.05, 1.07]						
p (ROPE)	0.01		0.03							
BF_{10}	7.86		4.50							

Note . RI = Retention Interval. For each effect, the evidence (BF) for the alternative hypothesis over the null is presented (BF_{10}) for a one-sided test. *p* (ROPE) = probability of values within a region of practical equivalence (effect size between -0.1 and 0.1).