Investigating age differences in the influence of joint attention on working memory

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Abstract

Previous research has demonstrated that older adults make limited use of social cues as compared to younger adults. This has been investigated by testing the influence of gaze cues on attentional processes, with findings showing significantly smaller gaze cuing effects for older than younger adults. Here we aimed to investigate whether this would also result in age related differences in the influence of gaze cues on working memory. We therefore tested the effects of gaze cues from realistic human avatars on working memory across two experiments using dynamic head turns and more subtle eye gaze movements. We compared working memory for items looked at by the cue (congruent), looked away from by the cue (incongruent), and items shown when the cue looked down (neutral). Results demonstrated that for both older and younger adults, gaze cues influenced working memory processes, though there were some important differences related to the nature of the cue. When the cue made a dynamic head turn both younger and older adults showed an equivalent effect of gaze on attention. However, when only the eyes moved, while both the younger and older adults showed an effect of gaze on working memory, there appeared to be a difference in how the participants interpreted the neutral cue, with the older adults appearing to interpret the neutral cues in a similar way to the congruent cues. Overall, we provide important evidence that sharing attention benefits cognition across the lifespan.

Keywords: gaze; social; attention; gaze cuing, joint attention

Significance Statement

Previous research has suggested that older adults make limited use of social cues compared to younger adults. However, research to date has been limited, only investigating effects on attention, using simplistic social scenarios that lack ecological validity. Here we investigated for the first time the effect of dynamic gaze cues of realistic human avatars on working memory and observed that both older and younger adults made use of the social cues and appeared to benefit from sharing attention. Interestingly, mainly the interpretation and use of neutral gaze cues appeared to differ between age groups, warranting further investigation. This research questions standard notions of age-related cognitive decline, adding to our understanding of social factors that may counteract such decline.

Social cognitive abilities are known to change as we age (for a recent review see Fernandes et al., 2021), key examples include declines in the ability to decode facial expressions (Gonçalves et al., 2018; Phillips et al., 2002), declines in visual perspective taking abilities (Martin et al., 2019), and declines in theory of mind abilities (Grainger et al., 2019; Slessor et al., 2007; Sullivan & Ruffman, 2004, although see Rahman et al., 2021). These general difficulties in mental state attribution have been linked to age related declines in joint attention, i.e., the shared attention of two or more individuals on an object, person, or event (Henry et al., 2013; Slessor et al., 2008). Eye gaze is a highly important communicative tool that underpins joint attention (Kleinke, 1986) by signaling where in the environment a persons' attention is directed (Land & Tatler, 2009), relaying information about what may be important to others. However, older adults tend to pay less attention to the eye region of others' faces compared to younger adults (Grainger et al., 2017, 2019; Murphy & Isaacowitz, 2010; Slessor et al., 2013; Sullivan et al., 2007), which in turn may reflect reduced joint attention capacity.

Joint attention effects are often studied using a Posner style (e.g. Posner, 1980) gaze cuing task whereby faces are presented as cues with averted gaze to direct attention. In these tasks, targets presented in the looked towards (congruent) location are generally responded to more quickly than those presented in the looked away from (incongruent) location, with similar attentional affects being also seen for arrow cues (e.g. Frischen et al., 2007). Further, to help understand the nature of cuing effects a cost/benefit analysis can also be conducted by using a neutral cue condition that provides no information about the subsequent target location. A beneficial facilitation effect is seen if responses in the congruent condition are faster compared to the neutral condition, indicating that participants directed their attention to the congruent location and therefore responded more quickly to the target item. An attentional cost is seen if responses in the incongruent condition are slower compared to the neutral condition, indicating that participants directed their attention to the incongruent location and struggled to disengage from that location to respond to the target item.

Research investigating age differences in joint attention has shown that older adults follow gaze cues to a significantly lesser extent than younger adults (e.g. Deroche et al., 2016; Slessor et al., 2008, 2010, 2016). Further, while younger adults can be found to show both cost and benefit effects of gaze cues, older adults appear to only show a cost effect, with this being significantly weaker than that seen for younger adults (Slessor et al., 2016). Further, this effect appears to be unique to gaze cues with no differences in arrow cuing seen between the age groups, indicating that older adults are not strategically ignoring the cues but instead are less efficient at extracting important information from the eyes (Slessor et al., 2016).

In addition to affecting basic attentional processes, joint attention has also been found to influence working memory. Research shows that congruently gaze cued items are remembered significantly better than those in the incongruent, gazed away from location (Gregory, Wang, et al., 2021; Gregory & Jackson, 2017, 2019), as well as showing benefits for congruent items when using a neutral cue (Gregory & Jackson, 2017). These findings therefore indicate that joint attention leads to an improvement in working memory, with evidence from neuroscience suggesting that this may be due to the sharing of attention making it easier to process the shared information (Gregory, Wang, et al., 2021). Working memory, essential for reasoning, comprehension, and planning (Baddeley, 2007), is a key executive function which can show age related decline (Hedden & Gabrieli, 2004). Given the age related differences in attentional effects of gaze cues outlined above, it is therefore important to understand if and how gaze cues influence working memory in older adults. Therefore, the aim of this research is to understand if comparative effects of gaze on working memory can be seen for older and younger adults, with results providing insight into age related differences in social cognition.

Therefore, here in this pre-registered study (osf.io/9g5qk) we investigated age related differences in joint attention, investigating congruency effects by comparing working memory for congruently versus incongruently cued items, as well as investigating the nature of the effect by employing a neutral condition, allowing additional cost/ benefit analysis. A benefit would indicate that the gaze cue helped with processing the memory stimuli, a cost would indicate that the cue was followed and was hard to disengage from, thus impeding successful encoding of the memory item.

In investigating these social cognitive effects, an important factor to consider is context. In comparison to younger adults, older adults tend to rely more on contextual cues for information processing (Lindenberger & Mayr, 2014; Smith et al., 1998) including social information such as emotion perception (Ngo & Isaacowitz, 2015; Noh & Isaacowitz, 2013; Vetter et al., 2019). In gaze cuing research, context is often neglected, for example, often disembodied heads or eyes serve as gaze cues and targets are simple shapes which appear floating in space to the side of the cue. Further in Slessor et al. (2016), due to the use of a neutral cue, the eye gaze of the faces was presented already shifted to the left, right, or remained fixed at center. This lack of initial engagement (eye contact) from the congruent/incongruent cues as well as the sustained eye contact from the neutral cue is not akin to real world gaze behavior. These factors may be more influential for older adults with their greater reliance upon context. Therefore, here we used realistic human avatars (see Gregory, Kelly, et al., 2021) who engaged joint attention by looking at the participant prior to making an eye or head movement to look down to a table where contextually relevant objects were presented for encoding. In experiment 1, the avatar’s head moved, presented via a video recording, to look down towards the left, right, or center (neutral) of the table. This situation is akin to how gaze cues might be seen in real life where a person might turn their head to look at an item and others may follow the gaze through the direction of the head turn. Recent investigation using this dynamic gaze cue with a younger adult population showed a general facilitation effect on attention (Gregory, 2021). However, while this is a more realistic scenario, it also makes it difficult to separate the effects of motion on attention (i.e., the movement of the head) from the social effects of eye gaze. Therefore, in experiment 2, only the eyes of the avatar moved, allowing investigation of more subtle effects of gaze, while retaining the contextual aspects of the task (i.e., a table scene).

For both experimental conditions (head movement and eye movement only) we predicted (pre-registered: osf.io/9g5qk) that working memory performance (d’) would be facilitated by gaze, with better working memory performance in the congruent compared to both the incongruent (congruency effect) and neutral conditions (beneficial facilitation effect), with no difference between the neutral and the incongruent condition (i.e. no 'cost', as found in; Gregory & Jackson, 2017). If effects are due to the social signal alone there should be no difference in the effects between experiment 1 (head movement) and experiment 2 (eye movement), however, if the movement of the cue is contributing to the effects, then we would expect a difference in the effect of the cue in experiment 2, where only the eyes of the avatar move.

Potential age related differences in the gaze cueing effect were expected to be observed in addition to general age-related differences in working memory performance, which has been shown repeatedly in the literature (e.g. Hedden & Gabrieli, 2004; Salthouse, 1994; Zuber et al., 2019). With regards to the specific nature of age differences in the influence of the cues we did not pre-register any predictions due to the exploratory nature of the study. If the effect of gaze on working memory corresponds directly to the effect of gaze on attention, we would expect to see a similar pattern of effects to that seen in the attention literature (i.e. Deroche et al., 2016; Slessor et al., 2008, 2010, 2016) with older adults showing a congruency effect but to a significantly lesser degree than younger adults, as well as showing a small working memory cost related to the incongruent cues, but no working memory benefit related to the congruent cues. It is also possible that the effect on memory does not correspond directly to the effect on attention. While related, attention and memory are different cognitive processes (e.g. Awh et al., 2006), for example while both arrow cues and gaze cues are found to affect attention, their effects on working memory differ, with gaze and not arrow cues affecting working memory (Gregory & Jackson, 2017). Therefore, it is possible that though there are differences in the attentional effects of gaze cues between older and younger adults, there may be no such differences in the effect of these cues on working memory between these age groups. A modulation of working memory performance by joint attention in older age – or a lack thereof – would significantly add to our understanding of age-related decline and potentially mediating and mitigating factors.

Experiment 1: Head turn

Method

Transparency and Openness

We report how we determined our sample size and describe all manipulations and measures that were collected, as described in our pre-registration. Any data exclusions are described below. Deidentified data and analysis materials are openly available.

Participants

Based on power analyses (pre-registered) conducted through PANGEA (Westfall, 2016, https://jakewestfall.shinyapps.io/pangea/) using a 3 (shared attention condition) * 2 (subjects age group) mixed within and between subjects' design with 32 trials per condition, to achieve 90% power to find a within between interaction with a realistic low to moderate effect size of Cohen's d = 0.25, we required 60 participants per age group. Older adult (aged over 65) and younger adult (aged 18 – 35) participants were recruited through Prolific (www.prolific.co) for payment by pre-screening for age. We recruited 60 older adult participants however, one man was found to not fit into the age requirements through self-declared age, thus there were 59 participants in the final sample (30 women, 29 men, mean age 68.8 years (SD = 4.1 years), range: 65 – 83 years) and 62 younger adult participants (30 women, 32 men, mean age 24.3 years (SD = 3.6 years), range: 19-34 years). All participants reported having normal or corrected to normal vision. Participants were not pre-screened for any memory impairments. Prolific allows participants to be recruited globally with access available from most OECD countries as well as South Africa. The ethnicity of the sample in the current study is not known. Ethical approval was obtained from the Aston University Research Ethics Committee.

Apparatus* and *stimuli

The study was programmed in PsychoPy3 (v2020.1.0) and hosted online using Pavlovia (pavlovia.org; see Bridges et al., 2020). Participants completed the task in a web browser using their own desktop/ laptop computers.

Stimuli

Human avatar cue. Four male and four female identities showing neutral facial expressions and wearing plain grey clothing were created using Adobe Fuse (discontinued software), and animated using Adobe Mixamo (www.mixamo.com). These avatars were recorded in the Unity game engine making the head turn movements described in the procedure, recordings were then used within PsychoPy3 to devise the online study presented via Pavlovia. We have previously demonstrated the effects of these cues on attention in a basic cuing paradigm (Gregory, 2021) and have argued that virtual avatars provide a realistic, yet fully controlled methodological approach to studying joint attention via dynamic gaze manipulations (Gregory, Kelly, et al., 2021).

Memory items. Seven items representative of items commonly found on a table were used; a teapot, bowl, cup, plate, banana, apple, and orange, all adapted from the unity asset store (Citrus Fruits Pack, 3D.RINA, 2019 (assetstore.unity.com/publishers/2703); white porcelain dish set demo, Büttner, 2017 (assetstore.unity.com/publishers/27037); Fruit Pack, PINATAA, 2017 (assetstore.unity.com/publishers/26225)). These were taken from Unity and converted to .png images with transparent background to impose over the avatar scenes within PsychoPy3. Items were displayed in color at encoding and in grey scale at retrieval to test working memory by probing memory for object identity rather than color matching.

Design

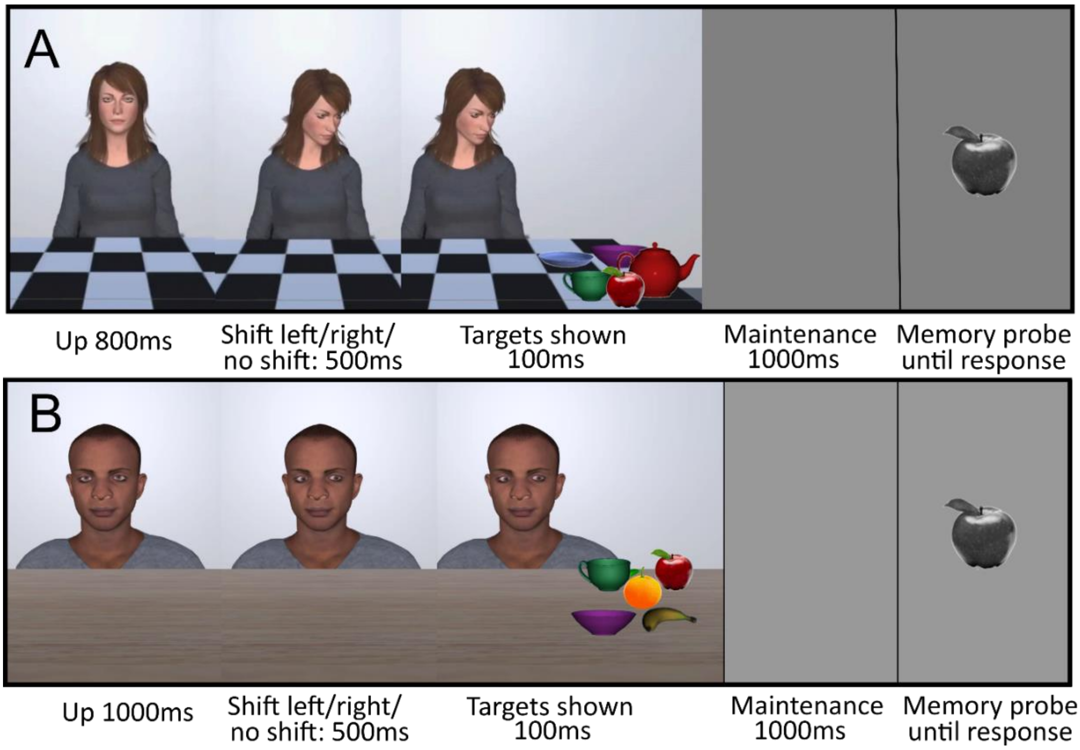
Within subjects' independent variables were cue-target congruency (1/3 congruent, 1/3 incongruent, 1/3 neutral; where gaze was directed down at the center of the table) pseudorandomized. Other manipulated variables were probe item presence (50% present, 50% absent) and encoding items location (50% left, 50% right). The avatar and objects seen in each condition were pseudorandomized. There were 192 trials divided equally such that there were 32 trials per condition (congruent present, congruent absent, incongruent present, incongruent absent, neutral present, neutral absent). Conditions were randomized and presented as two blocks of 96 trials. The dependent variable was accuracy to correctly identify whether the probe item had been present in the previous array.

Procedure

To become familiar with the task a 10-trial practice session preceded the main experiment. A trial proceeded as follows, a fixation cross was presented at the center of the screen for 1200ms, then replaced by the video of the cue. The cue was initially presented looking at the participant (800ms), and then the head turned either to the left, right or down to the center of the table (neutral gaze condition, see Figure 2 (A) for an example of this condition), this head turn took 500ms with the eyes moving within the first 30ms. After the cue shift (500ms stimulus onset asynchrony (SOA) from start of shift) 5 memory items were presented for 100ms on the left or right side of the table for encoding. After a 1000ms maintenance interval participants were presented with 1 item and required to indicate whether this matched any of the items seen in the previous display. There was no response window cut off and feedback was presented throughout to keep participants engaged. Figure 1A illustrates an example trial sequence.

Figure 1

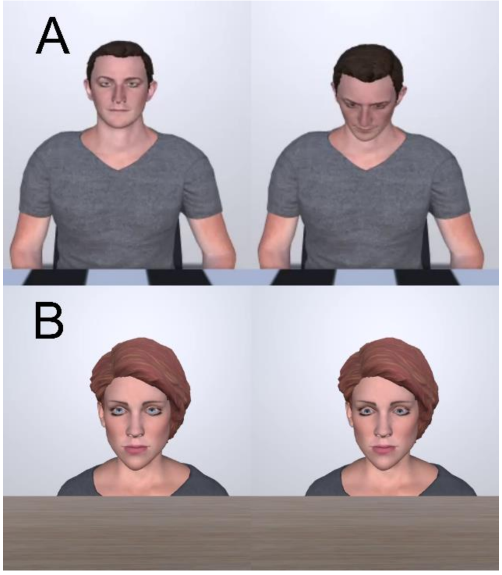
Illustration of the trial procedure for Experiment 1 (A) and Experiment 2 (B)



Note. Adopting the parameters of the traditional central cuing paradigm the cue remained on screen during presentation of the memory targets (e.g. Driver et al., 1999; Friesen & Kingstone, 1998). Images are not to scale.

Figure 2

Examples of the transition from the avatar looking at the participant to the center of the table in the neutral cue condition for experiment 1 (A) and experiment 2 (B).



Data Analysis

The following data analysis plan was pre-registered on the OSF (osf.io/9g5qk). Statistical analysis was conducted on d' values as a measure of WM accuracy. Hit rates and FA rates for each condition were entered into the following formula: d' = z(Hit rate) – z(FA rate) allowing investigation of memory sensitivity. The hit rate is the probability of correctly responding that the probe item had been present in the preceding array (i.e., the item was present, and the participant responded present), the false alarm rate is the probability of incorrectly responding that the probe item had been present in the preceding array (i.e., the item was absent, but the participant responded present). This method is useful as it can account for response bias, for example a d' of 0 could indicate that a participant always made a probe present response which would give a perfect score in the probe present trials, and 0 in the probe absent trials. A d' of 4.66 would indicate perfect performance in both probe present and probe absent trials (100% accuracy). Additional analysis of hit rate and false alarm rate data is presented in the supplementary materials, with key difference signposted. This additional analysis is conducted due to a general imbalance in age-related differences in Hit and False Alarm rates (e.g. Carr et al., 2015; Edmonds et al., 2012; Trahan et al., 1986) which may not be reflected in the d' calculations. Hit rate, false alarms, d', and reaction times data is presented in Table 1.

As stated in the pre-registration accuracy outliers for the d' data were identified using the median absolute deviation (MAD; Leys et al., 2013) at the recommended threshold of the median - 2.5 times the MAD. This was calculated on participant accuracy (d') collapsed across conditions. MAD is used in preference to standard deviation (SD) because outliers can adversely skew calculation of SD but not MAD. No participants were excluded from Experiment 1 with d' scores < -0.25 (median = 0.62; MAD = 0.35).

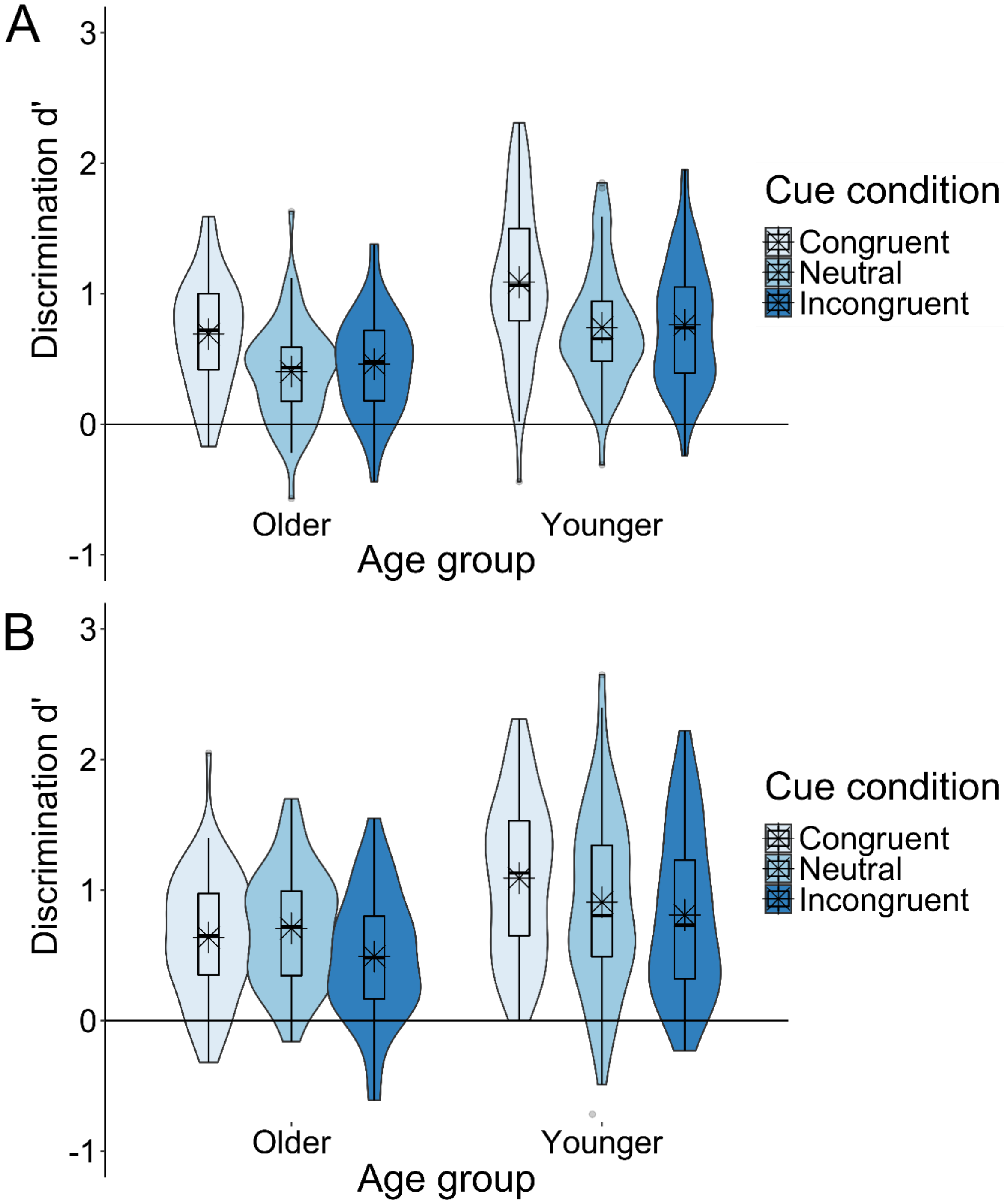
We conducted a mixed design ANOVA with cue-target congruency (congruent, incongruent, neutral) as the within subject factor, and age group (older, younger) as the between subjects' factor. Planned Holm-Bonferroni corrected follow up tests were conducted where appropriate. In addition to null hypothesis significance testing, equivalent Bayesian analysis was conducted using JASP (Version 0.14.1; Love et al., 2015) to help interpret the robustness of any findings and understand the nature of any null results. For Bayesian ANOVAs we used analysis of effects across matched models (see: Van Den Bergh et al., 2020). Using Bayes factor $BF_{10/\mathrm{incl}}$ results are considered anecdotal evidence that H1 is true when $BF_{10/\mathrm{incl}}$ is between 1 and 3, moderate between 3 and 10, and strong evidence above 10. Additionally, $BF_{10/\mathrm{incl}} = 1$ indicates that the data lends equal support to H1 and H0. Moderate support for H0 is indicated when $BF_{10/\mathrm{incl}}$ is between 0.33 and 0.10, and strong evidence for accepting the null is indicated when $BF_{10/\mathrm{incl}} \leq 0.10$

Results

There was a significant main effect of cue-target congruency, $F(2, 238) = 29.446$, $p <.001$, $\eta p^2 = .198$, ($BF_{\text{incl}} > 100$, extreme evidence, see Figure 3A) with no significant interaction between cue-target congruency and age group, $F(2, 238) = 0.650$, $p = .523$, $\eta p^2 = .005$, ($BF_{\text{incl}} = 0.100$ moderate evidence for H0) meaning that cue effects on memory were not modulated by participant age group. Holm-Bonferroni pair-wise comparisons showed that WM discrimination was significantly better in the congruent (M = 0.89, SD = 0.55) compared to the incongruent condition (M = 0.62, SD = 45), $t(120) = 6.091$, $p < .001$, Cohen's $d = 0.554$ ($BF_{10} > 100$, extreme evidence for H1), showing a clear congruency effect. WM discrimination was also significantly better in the congruent compared to the neutral condition (M = 0.57, SD = 0.45), $t(120) = 7.088$, $p < .001$, Cohen's $d = 0.644$ ($BF_{10} > 100$, strong evidence for H1), showing a beneficial facilitation effect. Finally, no significant difference in WM discrimination was observed between the neutral and incongruent conditions, $t(120) = 0.998$, $p = 0.319$, Cohen's $d = -0.091$ ($BF_{10} = 0.169$, moderate evidence for H0), indicating that there was no working memory cost effect. Finally, there was a significant main effect of age group on WM discrimination, $F(1,119) = 29.853$, $p < .001$, $\eta p^2 = .201$ ($BF_{\text{incl}} > 100$, extreme evidence for H1). As expected, working memory discrimination was better in the younger adults group (M = 0.86, SD = 0.40) than the older adults group (M = 0.52, SD = 0.29).

Figure 3

Results from Experiment 1 (head turn; A) and Experiment 2 (eye movement only; B)



Note. WM performance scores presented using d’ plotted as a function of cue-target congruency. Boxplots indicate the median and quartiles (whiskers 1.5 times interquartile range), violin overlay shows the distribution of the data (kernel probability density), mean is marked by an asterisk.

Table 1

Cuing results for d', hits, false alarms (FA), and reaction times (RT, ms) data in each experiment for each age group.

Data	Condition	Congruent	Incongruent	Neutral	Congruency	Benefit	Cost
				Experiment 1			
d'	Older	0.69 (0.42)	0.46 (0.37)	0.40 (0.37)	0.22 [0.11, 0.34]	0.29 [0.16, 0.42]	-0.07 [-.18, 0.04]
	Younger	1.09 (0.59)	0.76 (0.46)	0.74 (0.74)	0.33 [0.17, 0.48]	0.35 [0.23, 0.46]	-0.02 [-0.15, 0.11]
Hit rate	Older	0.64 (0.13)	0.60 (0.15)	0.57 (0.15)	0.04 [0.01, 0.07]	0.07 [0.04, 0.10]	-0.03 [-0.06, -0.01]
	Younger	0.68 (0.15)	0.61 (0.13)	0.60 (0.13)	0.07 [0.03, 0.10]	0.08 [0.05, 0.11]	-0.01 [-0.04, 0.02]
FA rate	Older	0.39 (0.18)	0.43 (0.17)	0.43 (0.18)	-0.04 [-0.07, -0.01]	-0.04 [-0.07, -0.00]	-0.01 [-0.04, 0.02]
	Younger	0.30 (0.16)	0.34 (0.17)	0.33 (0.15)	-0.4 [-0.07, -0.00]	-0.03 [-0.06, 0.00]	-0.1 [-0.04, 0.02]
RT (ms)	Older	1317 (425)	1333 (479)	1349 (479)	-16 [-47, 17]	-32 [-60, -5]	17 [-7, 40]
	Younger	928 (190)	889 (194)	921 (199)	39 [21, 57]	7 [-15,28]	32 [10, 55]
				Experiment 2			
d'	Older	0.64 (0.47)	0.49 (0.47)	0.71 (0.43)	0.15 [0.02, 0.28]	-0.70 [-0.19, 0.05]	0.22 [0.09, 0.34]
	Younger	1.09 (0.59)	0.81 (0.62)	0.95 (0.73)	0.28 [0.17, 0.39]	0.14 [0.02, 0.27]	0.14 [0.01, 0.27]
Hit rate	Older	0.65 (0.13)	0.62 (0.13)	0.66 (0.12)	0.03 [-0.01, 0.06]	-0.01 [-0.04, 0.02]	0.04 [0.01, 0.07]
	Younger	0.72 (0.13)	0.65 (0.15)	0.67 (0.14)	0.08 [0.05, 0.1]	0.05 [0.02, 0.08]	0.02 [-0.01, 0.05]
FA rate	Older	0.41 (0.18)	0.44 (0.19)	0.40 (0.17)	-0.02 [-0.05, 0.01]	0.01 [-0.02, 0.04]	-0.03 [-0.06, -0.01]
	Younger	0.34 (0.15)	0.36 (0.16)	0.34 (0.16)	-0.03 [-0.05, 0.00]	-0.01 [-0.03, 0.02]	-0.02 [-0.05, 0.01]
RT (ms)	Older	1295 (348)	1309 (387)	1304 (353)	-14 [-40, 12]	-9 [-28, 10]	-5 [-31, 21]
	Younger	968 (262)	971 (274)	992 (283)	-2 [-27, 22]	-23 [-46, -1]	21 [0, 42]

Note. For each data type the results in the congruent, incongruent, neutral conditions are shown, along with the crucial cuing effects: congruency (congruent – incongruent), benefit (congruent – neutral) and cost (neutral – incongruent). Means are shown for d', hits, false alarms data, with medians being used for the reaction times data. Standard deviation is presented in parenthesis and square brackets show 95% confidence interval.

Experiment 2: Eye movement only

While the results of experiment 1 indicate that older and younger adults show an equivalent effect of eye gaze on working memory, the cues used have an extremely strong element of motion in the form of the head movement. This was done deliberately to assess the effect of cues in a scenario that would be more akin to real life looking behavior, which would generally be less subtle than a simple eye movement. However, in order to fully understand potential age-related differences in gaze decoding, it is also important to investigate the effect of the cues using a more subtle gaze shift, as used in Gregory and Jackson (2017), while keeping the realistic contextual elements of the task, i.e. the use of context-relevant memory objects which are presented on a table and the cue being conveyed by more than just a head without a body. This therefore allows an understanding of whether the absence of age differences seen in experiment 1 was reliant upon the potent head movement.

In experiment 2 we therefore presented gaze cues where the eyes moved from looking at the participant down to the left, right or center to look at the table, while the head remained stationary (see Figures 1 and 2, Panel B). Importantly, prior to conducting the main memory study, we piloted (ethical approval obtained) how well the avatars could cue attention in the general population using this eye gaze shift in a simple gaze cuing task where the participants responded to whether a target cup was presented to the left or right using the arrow keys on their keyboard. Using the setup from experiment 1, and just moving the eyes instead of the whole head we tested 39 participants and used a 500ms SOA. To reduce distraction from the table itself we changed the table to give it a plain wood style top, (see Figure 1, panel B). We tested the hypothesis that congruent items (M_{RT} = 378ms) would be responded to more quickly than incongruent items (M_{RT} = 374ms) and found no significant effect of the cues on attention; $t(38) = 1.625$, $p = .944$, Cohen's $d = 0.260$. This was potentially due to the subtlety of the eye movement and the fact that the target appearance itself was a salient peripheral cue at quite a distance away from the avatar's face. We therefore changed the stimuli by lifting the table such that just the avatar's neck and shoulders were visible (see Figure 1B), and then presented the object close to the face, while still on the table. This made the experimental set up more comparable to previous research using just faces as gaze cues where targets are presented close to the side of the face (e.g. Gregory & Jackson, 2017). Using another 39 pilot participants with a 500ms SOA we again tested the hypothesis that congruent items (M_{RT} = 396ms) would be responded to more quickly than incongruent items (M_{RT} = 408ms) and here we found a significant cuing effect, $t(39) = -1.845$, $p = .036$, Cohen's $d = -0.295$ (stimuli and data for both pilot studies available here: osf.io/vaby2/files/). Therefore, in experiment 2 we used this setup to investigate age group differences.

Method

Participants

Participant screening methods matched Experiment 1. No participants were excluded from Experiment 2 with d' scores < -0.61 (median = 0.66; MAD = 0.51). We recruited 65 older adult participants through Prolific, however one man and two women were found to not fit into the age requirements through self-declared age, thus, there were 62 older adult participants in the final sample (30 women, 32 men, mean age 69.7 years (SD = 5.0 years), range: 65 – 87 years). We recruited 64 younger adult participants with one woman not fitting the criteria through self-declared age, thus there were 63 younger adult participants in the final sample (32 women, 31 men, mean age 23.9 years (SD = 3.7 years), range: 18-34 years). All participants reported having normal or corrected to normal vision. Participants were not pre-screened for any memory impairments. Ethical approval was obtained from the Aston University Research Ethics Committee.

Apparatus* and *stimuli

Apparatus and stimuli matched Experiment 1, except for the following changes. As described, the table that the avatars were sat behind was higher, showing from their shoulders up (see Figure 1B). The table was plain instead of showing a checked pattern to ensure that the table was not distracting. Only the eyes of the avatars moved, with the motion being completed within 2 frames: one image showing direct gaze and the next showing averted gaze (see Figure 2B). The study, materials and data can be downloaded here: osf.io/vaby2/files/.

Design and procedure

The design and procedure matched experiment 1, except for the following changes. Here the fixation cross was presented for 1000ms then replaced by an image of the avatar looking at the participant. After 1000ms this image was replaced by an image of the avatar looking to the left, right or down at the table. Replicating the timing from experiment 1, after 500ms five memory items were presented for 100ms on the left or right side of the table for encoding. The rest of the memory task matched experiment 1. Figure 1B illustrates an example trial sequence.

Results

Crucially, alongside a significant main effect of cue-target congruency, $F(2, 246) = 13.737$, $p <.001$, $\eta p^2 = .100$ ($BF_{\text{incl}} > 100$, extreme evidence for H1), there was a significant interaction between cue-target congruency and age group, $F(2, 246) = 3.058$, $p = .049$, $\eta p^2 = .024$, ($BF_{\text{incl}} = 0.73$ inconclusive evidence). We therefore explored this pattern further by analyzing the two age groups separately to establish if cuing effects occurred as well as comparing the size of effects seen. It is important to note that this is not a strong interaction effect and has to be interpreted with caution.

Younger adults' group:

The younger adult's data showed a significant main effect of cue-target congruency, $F(2, 124) = 11.006$, $p < .001$, $\eta p^2 = .151$, ($BF_{\text{incl}} > 100$, extreme evidence for H1). Holm-Bonferroni pair-wise comparisons showed that WM discrimination was significantly better in the congruent compared to the incongruent condition, $t(62) = 4.691$, $p < .001$, Cohen's $d = 0.591$ ($BF_{10} > 100$, extreme evidence for H1; see table 1 for means and standard deviations), showing a clear congruency effect. WM discrimination was also significantly better in the congruent compared to the neutral condition, $t(62) = 2.393$, $p = .036$, Cohen's $d = 0.302$ ($BF_{10} = 1.824$, anecdotal evidence for H1) showing a beneficial facilitation effect. Finally, discrimination was significantly better in the neutral condition compared to the incongruent condition, $t(62) = 2.298$, $p = 0.036$, Cohen's $d = 0.290$ ($BF_{10} = 1.208$, anecdotal evidence for H1) thus showing a working memory cost effect for the incongruent condition.

Older adults' group

For the older adults' group there was also a significant main effect of cue-target congruency, $F(2, 122) = 6.041$, $p = .003$, $\eta p^2 = .090$, ($BF_{\text{incl}} = 9.271$, moderate evidence for H1). Holm-Bonferroni pair-wise comparisons showed that WM discrimination was significantly better in the congruent compared to the incongruent condition, $t(61) = 2.308$, $p = .045$, Cohen's $d = 0.293$ ($BF_{10} = 1.392$, anecdotal evidence for H1), thus, as seen for the younger adults, showing a congruency effect. However, WM was not significantly different for items in the congruent compared to the neutral condition, $t(61) = -1.097$, $p = .275$, Cohen's $d = - 0.139$ ($BF_{10} = 0.262$, moderate evidence for H0), thus, in contrast to the younger adults, the older adults did not show a beneficial facilitation effect. Finally, items encoded in the neutral condition were remembered significantly better than those in the incongruent condition, $t(61) = 3.405$, $p = 0.003$, Cohen's $d = 0.432$ ($BF_{10} = 19.884$, strong evidence for H1), thus, as was seen for the younger adults, the older adults show a working memory cost effect for the incongruent condition.

Older versus younger adults' group

Both the older and younger adult groups showed congruency and cost effects with only the younger adults showing a beneficial effect of the cue. To understand how similar or different these social cuing effects are between the older and younger adults it is important to also compare the size of these effects between the two groups. Comparing the size of the congruency effect (i.e., the size of the difference between the congruent and incongruent condition), for which both groups showed a significant effect of the cue, showed that there was no significant difference in the size of this effect between the older (M = 0.15, SD = 0.52) and younger (M = 0.28, SD = 0.44) adult groups $t(123) = -1.582$, $p = 0.116$, Cohen's $d = -0.283$ ($BF_{10} = 0.591$, anecdotal evidence for H0). Comparing the size of the cost effect (i.e., the size of the difference between the incongruent and neutral condition), for which both groups again showed a significant effect of the cue, showed again that there was no significant difference in the size of this effect between the older (M = 0.22, SD = 0.51) and younger (M = 0.14, SD = 0.51) adult groups $t(123) = 0.857$, $p = 0.393$, Cohen's $d = 0.153$ ($BF_{10} = 0.266$, moderate evidence for H0). Finally, comparing the size of the beneficial facilitation effect (i.e., the size of the difference between the congruent and neutral condition), which was only seen for the younger adults, showed that there was a significant difference in the size of this effect between the older (M = -0.07, SD = 0.47) and younger (M = 0.14, SD = 0.48) adult groups $t(123) = -2.495$, $p = 0.014$, Cohen's $d = -0.446$ ($BF_{10} = 3.082$, moderate evidence).

Finally, there was a significant main effect of age group on WM accuracy, $F(1,123) = 14.836$, $p < .001$, $\eta p^2 = .108$ ($BF_{incl} > 100$, extreme evidence for H1). As expected, working memory was better in the younger group (M = 0.95, SD = 0.59) than the older group (M = 0.61, SD = 0.34).

General discussion

The aim of the current study was to determine whether equivalent effects of joint attention on working memory can be seen in older and younger adults. In experiment 1 we tested this using a dynamic gaze cue in the form of a virtual human avatar which turned its head to look down to the left, right or center of a presented table. In experiment 2 we used a more subtle gaze cue whereby the eyes moved to look at the table (left, right or center), but the head remained stationary, allowing us to separate any effects of motion on working memory from the social effects of eye gaze.

The results of experiment 1, where the avatar cues made a head movement, showed no differences (moderate evidence for H0) in cue-target congruency effects between older and younger adults. This therefore indicates that the older adults used these social cues in a similar way to the younger adults. Results showed a congruency effect with significantly better working memory in the congruent compared to the incongruent condition, a beneficial facilitation effect with better working memory in the congruent compared to the neutral condition, and no detrimental cost effect with no difference in working memory between the neutral and incongruent conditions. In contrast, results of experiment 2, where the avatar cues only moved their eyes, showed a significant, though minor difference between age groups. For the younger adults, results showed a congruency effect, a beneficial facilitation effect, and, unlike in experiment 1, a detrimental cost effect with better working memory in the neutral compared to the incongruent conditions. For the older adults, results also showed congruency and detrimental cost effects but did not show the beneficial facilitation effect. Comparing the size of the effects showed that the congruency and cost effects did not differ in magnitude between age groups, yet, there was a significant difference in the size of the beneficial facilitation effect. Given that the commonalities between age groups outweigh the sole difference, the results of these experiments appear to show that joint attention affects working memory for both older and younger adults.

Despite the general effect of cue congruency on working memory, the lack of a beneficial effect for the older adults in experiment 2 may be interpreted to show that older adults do not benefit from the gaze cues looking at the objects. However, both the older and younger adults did show a beneficial effect of the cues in experiment 1. This therefore indicates that the differences between experiments in the use of motion to signal looking direction may have affected the way the cues were interpreted. In experiment 1 the cue performed a head turn, whereas in experiment 2 only the eyes moved, thus it is possible that the motion of the head turn in experiment 1 superseded the social element of the cue in directing attention, potentially meaning that effects seen are unrelated to social processes. Indeed, evidence suggests that the use of non-social cues such as arrows or location cues is not affected by age (Brodeur & Enns, 1997; Slessor et al., 2016). This possibility is therefore supported by the results of experiment 2, where the more subtle eye gaze cues revealed a difference between younger and older adults.

However, it is important to note that the differences seen in experiment 2 are minor compared to those seen in Slessor et al. (2016). As well as finding that while younger adults showed congruency, facilitation, and cost effects, older adults showed only congruency and cost effects, Slessor et al. (2016) also found differences in the magnitude of the congruency and cost effects, with older adults showing much weaker effects. In contrast, here the congruency and cost effects did not differ in magnitude between age groups, indicating that the older adults engaged with and used the eye gaze cues to a much more comparable degree to the younger adults while participating in the task.

The differences seen between the results here and those of Slessor et al. (2016) may be due to differences between the processes of attention and memory. Though working memory processes and attention processes are linked (Awh et al., 2006; Kane et al., 2001), working memory is also linked to goal directed processes (Altmann & Trafton, 2002; Montagrin et al., 2013). Therefore the experience of joint attention in a working memory task may be different to that seen in a basic attention task, with older adults making successful use of the social information when the task relates to goal-directed working memory processes (Gregory & Jackson, 2017).

The experiments presented here also differed from Slessor et al. (2016) in terms of the nature of the cues themselves. The cues presented here were realistic human avatars who dynamically looked at the participant, engaging eye contact before cuing the potential location of contextually relevant target items. In contrast, Slessor et al. (2016) used disembodies heads as cues which were presented already shifted to the left, right, or remained fixed at center, thus failing to engage eye contact in the averted gaze conditions. Research shows that older adults rely on contextual cues to a greater extent than younger adults (Lindenberger & Mayr, 2014; Ngo & Isaacowitz, 2015; Noh & Isaacowitz, 2013; Smith et al., 1998; Vetter et al., 2019), further, initiation of eye contact has been found to enhance the gaze cuing effect (Bristow et al., 2007; Xu et al., 2018). Therefore, the use of more ecologically valid cues as well as the engagement of eye contact may have meant that the older adults made greater use of the gaze cues than they would if just static heads were used.

Due to the engagement of eye contact and the differences in how dynamic the cues were, the gaze cues in experiments 1 and 2 also differed in how much the cue appeared to disengage from the participant in the neutral cue condition (see Figure 2). In experiment 1 the avatars lowered their head from looking straight ahead to look at the table for the neutral cue, whereas in experiment 2 the avatar simply moved their eye gaze direction from straight ahead to downwards to the center of the table (see Figure 2). While seeing someone turn to the side, as seen in the congruent and incongruent conditions of experiment 1, may seem purposeful, looking down with a full head movement may be perceived as a deliberate ignoring of the participant and the task at hand, thus causing a perceived divergence in goals between the avatar and the participant. This difference in disengagement may therefore be responsible for the difference in effects between experiments 1 and 2 here. If the neutral cue in experiment 1 was perceived as deliberately ignoring the task, this may have caused a similarly detrimental effect on memory in the neutral condition to that found in the incongruent condition in experiment 1, resulting in the absence of a cost effect. In addition, the more subtle neutral cue shift in experiment 2 means that the gaze of the avatar appears to be focused on the table. This could be interpreted as the cue deliberately trying to take in information from both sides of the table. It is therefore possible that the older adults interpreted the neutral cue in experiment 2 to have similar goals to the congruent cue in terms of engaging with the memory items and may therefore be why they showed a similar effect for the neutral and congruent cues, but a detriment in the incongruent condition.

The differences seen between the older and younger adults' groups in experiment 2 may also be explained by the participants' interpretation of the neutral gaze cue. Previous research has shown that older adults tend to be more likely than younger adults to perceive gaze direction as direct when presented with subtly averted gaze (Slessor et al., 2008). In addition, research suggests that people tend to interpret ambiguous gaze as looking at an object if there is an object present somewhere in the general direction in which a person is shown to be looking (Lobmaier et al., 2006). While there does not appear to be research showing that older adults are more likely than younger adults to perceive gaze as directed at an object, the interpretation of direct gaze does appear to be more ambiguous for older adults (i.e. Slessor et al., 2008). Therefore, it is possibly more likely that direct gaze is interpreted by the older adults as looking towards a presented object, thus resulting in the similar effect for congruent and neutral cues seen for the older adults' group in experiment 2, as both congruent and neutral gaze might be perceived as looking at the objects. This may also explain the difference in effects between experiment 1 and 2 for the older adults' group, as the head turn in experiment 1 made it much easier to interpret the direction of the avatar's attention than the subtle eye movement in experiment 2, however, further research is required to assess if this is the case.

An important limitation to consider when interpreting the results of this research is that if the neutral conditions were interpreted as described above, then these cannot be true neutral cues. Indeed, it is difficult to create a true neutral condition in cuing experiments (Jonides & Mack, 1984). Therefore, it is important to be cautious in interpretation of the cost/ benefit effects, particularly for the older adults. Indeed, cost/ benefit effects in gaze cuing are generally mixed, both when investigating attention (Friesen & Kingstone, 1998; Green et al., 2013; Gregory, 2021; Hietanen, 1999; Hietanen et al., 2008; Langdon & Smith, 2005) and working memory (Gregory & Jackson, 2017, 2019). These conditions do however reveal interesting age differences in how eye gaze may be interpreted and generalized in an attention sharing situation. Importantly, while differences in interpretation and use of cues may be present, crucially the results show that older adults make use of these social cues to a comparable amount to younger adults.

A further potential limitation to consider is the change in the design of the table environment between experiments 1 and 2. In experiment 2 the checkered table was replaced by plain wood and raised such that the face and memory items appeared closer together. This change was made due to the reduced potency of the cue's effects on attention when only the eyes moved in experiment 2. The changes likely resulted in making the task easier due to the objects being presented closer to center as well as the reduced distraction from the avatars head movement. It is possible that the change in the table environment rather than the change in the nature of the cue resulted in the differences seen between the two studies. However, for the younger adults the difference between the two experiments was more subtle than the difference seen for the older adults, indicating that age factors are more important here than the change in stimuli.

Despite the limitations outlined above, the use of realistic cuing scenarios here allows us to be relatively confident that the results seen would translate to real world settings, as compared to traditional studies with static gaze cues delivered by a face “floating” in 2D space. In the real world, people are likely to turn towards shared events, or signal event sharing in other ways as well as gaze, such as through vocal signals or pointing. This means that if indeed older adults do struggle to interpret gaze signals, this would be mitigated, and older adults would benefit from overt social signals, as seen in experiment 1. Further it is important to note that even though clear beneficial effects of the cues were not seen in experiment 2 for older adults, the cues did affect working memory. However, further research is required to better understand how social cues benefit working memory and other cognitive processes in both older and younger adults. A key area for further study is in the use of predictive cues, as this would allow investigation of age differences in how congruent cues are used to benefit cognition when they are known to be useful (see McKay et al., 2022).

To conclude, these experiments indicate that the sharing of attention benefits cognition across the lifespan. While social cognitive abilities and susceptibilities are known to change as we age, including a decline in the potency of the gaze cuing effect, the results indicate that social cues remain beneficial to higher cognitive processes such as working memory. Evidence from neuroscience suggests that sharing attention makes it easier to process the shared information (Gregory, Wang, et al., 2021), therefore this effect of shared attention on working memory may be one of the reasons that older adults with strong social networks fair better cognitively (e.g. Kelly et al., 2017; Livingston et al., 2017). These results may therefore lead to further insight into age related differences in cognition, aiding understanding of how social contact can be protective against cognitive decline.

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Supplementary materials for: Investigating age differences in the influence of joint attention on working memory

Rationale for analyzing hit rate and false alarms data separately:

While d' is made up of both hit rate and false alarm rate data, separate analysis is presented here due to a general imbalance in age-related differences in hit and false alarm rates (e.g. Carr et al., 2015; Edmonds et al., 2012; Trahan et al., 1986) which may not be reflected in the d' calculations. This analysis was not included in the pre-registration. This distinction between hit rate and false alarm rate is of interest because there are two possible explanations for how the cue may be impacting participants in the task. First, it is possible that the cue effects memory processing by sharpening the objects in memory, thus making recognition judgements easier, resulting in higher hit and lower false alarm rates for congruently cued objects, i.e. improving the memory for the items. Alternatively, the cue may instead be causing the participant to be more likely to respond positively to the probe if the cue is a congruent trial (higher hit rate, and higher false alarm rate for congruent trials), with a more discriminatory approach being taken in incongruent conditions (lower hit rate but also lower false alarm rate for incongruent trials). Importantly, the nature of these effects may differ by age group, research is somewhat inconclusive with regards to how older and younger adults compare in terms of the conservative or liberal nature of their responses, with some research showing older adults to be more conservative (e.g. Cowan et al., 2006; Read et al., 2016), and other work showing them to be more liberal in their responses than younger adults (e.g. Bender et al., 2010).

Experiment 1

Hit rate

As was seen for d' data (see main paper), for the hit rate data there was no significant interaction between cue target congruency and age group; $F(2,238) = 0.939$, $p = .393$, $\eta p^2 = .008$, ($BF_{\text{incl}} = 0.128$, moderate support for H0).

There was a significant main effect of cue-target congruency, $F(2,238) = 25.369$, $p < .001$, $\eta p^2 = .176$, ($BF_{\text{incl}} > 100$, extreme evidence for H1). Holm-Bonferroni pair-wise comparisons showed that the hit rate was significantly higher in the congruent (M = 0.66, SD = 0.14) compared to the incongruent condition (M = 0.61, SD = 0.14), $t(120) = 4.927$, $p < .001$, Cohen's $d = 0.448$ ($BF_{10} > 100$, extreme evidence for H1) showing a congruency effect, as well as in the congruent compared to the neutral condition (M = 0.59, SD = 0.15), $t(120) = 6.918$, $p < .001$, Cohen's $d = 0.629$ ($BF_{10} > 100$, extreme evidence for H1), showing a beneficial facilitation effect. Finally, contrary to the result seen with d' data there was a significant difference in hit rate between the neutral and incongruent conditions, with a significantly higher hit rate being seen in the incongruent condition compared to the neutral condition $t(120) = - 1.991$, $p = 0.048$, Cohen's $d = -0.181$ ($BF_{10} = 1.001$, no evidence either way) showing a cost in the neutral condition.

There was no significant main effect of age group on the hit rate data between the younger adult group (M = 0.63, SD = 0.12) and the older adult group (M = 0.60, SD = 0.13), $F(1,119) = 1.641$, $p = .203$, $\eta p^2 =$ ($BF_{\text{incl}} = 0.471$, anecdotal evidence for H0).

False Alarms

As above, there was no significant interaction between cue-target congruency and age group for the false alarms data; $F(2, 238) = 0.055$, $p = .947$, $\eta p^2 < .001$, ($BF_{\text{incl}} = 0.063$, strong evidence for H0).

There was a significant main effect of cue-target congruency, $F(2,238) = 7.310$, $p < .001$, $\eta p^2 = .058$, ($BF_{\text{incl}} = 22.699$, strong evidence for H1). Holm-Bonferroni pair-wise comparisons showed that the false alarm rate was significantly lower in the congruent (M =

0.35, SD = 0.18) compared to the incongruent condition (M = 0.39, SD = 0.18), $t(120) = -3.611$, $p = .001$, Cohen's $d = -0.328$ ($BF_{10} = 37.846$, strong evidence for H1), showing a congruency effect. The false alarm rate was also significantly lower in the congruent compared to the neutral condition (M = 0.38, SD = 0.18), $t(120) = -2.894$, $p = .008$, Cohen's $d = -0.263$ ($BF_{10} = 5.507$, moderate evidence for H1), showing a beneficial facilitation effect. Finally, there was no significant difference for false alarm rate between the neutral and incongruent conditions, $t(120) = -0.717$, $p = 0.474$, Cohen's $d = -0.065$ ($BF_{10} = 0.131$, moderate evidence for H0).

There was a significant main effect of age group on false alarm rate, $F(1,119) = 10.427$, $p < .001$, $\eta p^2 = .081$ ($BF_{\text{incl}} = 19.429$, strong evidence for H1), the false alarm rate was significantly lower in the younger adult group (M = 0.33, SD = 0.15) than the older adult group (M = 0.42, SD = 0.16).

Results summary

Results from the hits and false alarms data show that items in the congruent condition were remembered significantly better than those in both the incongruent and the neutral condition, replicating the results seen with the d' data (see main paper). Therefore, these results indicate that the effects seen in the d' data are likely to be due to a change in memory encoding rather than an increased bias towards a positive response to congruently cued trials, with this effect not differing by age. However, it is also important to note that the hit rate was also significantly higher for the incongruent compared to neutral condition, indicating that this condition may not be a true neutral condition, though note that there was no such difference present for the false alarm and d' data. Further, this result is considered inconclusive based upon the Bayesian analysis. Finally, it is interesting to note that the general difference between age groups in overall memory ability appears to be driven by the false alarm rate, thus results appear to show a characteristic response bias in older adults towards saying that an item was present (e.g. Costello & Buss, 2018).

Experiment 2

Hit rate

As seen for the d' result (see main paper), alongside a significant main effect of cue-target congruency, $F(2, 246) = 11.507$, $p <.001$, $\eta p^2 = .086$ ($BF_{\text{incl}} > 100$, extreme evidence for H1), there was a significant interaction between cue target congruency and age group, $F(2, 246) = 4.418$, $p = .013$, $\eta p^2 = .035$, ($BF_{\text{incl}} = 2.379$, anecdotal evidence for H1) indicating that participant age may have some influence on the effect of cue congruity on memory performance in terms of the hit rate. We therefore explored this pattern further by analysing the two age groups separately.

Younger adults group. There was a significant main effect of cue target congruency, F (2, 124) = 13.102, $p < .001$, $\eta p^2 = .174$, ($BF_{\text{incl}} > 100$, extreme evidence for H1). Holm-Bonferroni pair-wise comparisons showed that the hit rate was significantly higher in the congruent (M = 0.73, SD = 0.13) compared to the incongruent condition (M = 0.65, SD = 0.15), $t(62) = 5.002$, $p < .001$, Cohen's $d = 0.630$ ($BF_{10} > 100$, extreme evidence for H1), thus showing a congruency effect. The hit rate was also significantly higher in the congruent compared to the neutral condition (M=0.67, SD = 0.14), $t(62) = 3.442$, $p = .002$, Cohen's $d = 0.434$ ($BF_{10} = 21.906$, strong evidence for H1), showing a beneficial facilitation effect. Finally, the hit rate was not significantly different between the neutral and incongruent conditions, $t(62) = 1.560$, $p = 0.121$, Cohen's $d = 0.197$ ($BF_{10} = 0.405$, anecdotal evidence for H0), thus not showing a detrimental cost effect.

Older adults group. There was a significant main effect of cue target congruency, $F(2, 122) = 3.296$, $p = .040$, $\eta p^2 = .051$, ($BF_{\text{incl}} = 0.973$, inconclusive evidence). Holm-Bonferroni pair-wise comparisons showed that the hit rate was not significantly different between the congruent (M = 0.65, SD = 0.13) and incongruent condition (M = 0.62, SD = 0.13), $t(61) = 1.813$, $p = .145$, Cohen's $d = 0.230$ ($BF_{10} = 0.476$, anecdotal evidence for H0), thus not showing a significant congruency effect. The hit rate was also not significantly different between the congruent compared to the neutral condition (M=0.66, SD = 0.12), $t(61) = -0.668$, $p = .505$, Cohen's $d = -0.085$ ($BF_{10} = 0.187$, moderate evidence for H0), showing a beneficial facilitation effect. Finally, the hit rate was significantly higher in the neutral compared to the incongruent conditions, $t(61) = 2.481$, $p = 0.043$, Cohen's $d = 0.315$ ($BF_{10} = 2.202$, anecdotal evidence for H1), thus showing a cost effect.

Comparing older and younger adults' groups. Comparing the size of the congruency effect between the two groups (i.e. the size of the difference between the congruent and incongruent condition) showed that for the hit rate data the size of the difference was significantly smaller in the older (M = 0.03, SD = 0.14) compared to the younger (M = 0.08, SD = 0.11) adult groups: $t(123) = -2.051$, $p = .042$, Cohen's $d = -0.367$ ($BF_{10} = 1.264$, anecdotal evidence for H1). Comparing the size of the facilitation effect between the two groups (i.e. the size of the difference between the congruent and neutral condition) showed for the hit rate data that there was a significant difference in the size and direction of this effect between the older (M = -0.01, SD = 0.11) and younger (M = 0.05, SD = 0.12) adult groups: $t(123) = -3.059$, $p = .003$, Cohen's $d = -0.547$ ($BF_{10} = 12.057$, strong evidence for H1). Finally, comparing the size of the detrimental effect of incongruent cues vs neutral cues in both groups showed that there was no significant difference in the size of this effect between the older (M = 0.04, SD = 0.13) and younger (M = 0.02, SD = 0.12) adult groups $t(123) = 0.707$, $p = 0.481$, Cohen's $d = 0.127$ ($BF_{10} = 0.239$, moderate evidence for H0).

Finally, there was no significant main effect of age group on hit rate, $F(1,123) = 3.765$, $p = .055$, $\eta p^2 = .030$ (BF_{incl} =1.280, anecdotal evidence for H1) for the older (M = 0.58, SD = 0.17) compared to the younger (M = 0.65, SD = 0.14) adults' group.

False alarms

For the false alarms data there was a significant main effect of cue-target congruency, $F(2,246) = 4.558$, $p = .011$, $\eta p^2 = .036$, (BF_{incl} =1.597, anecdotal evidence for H1), which was not moderated age group; no significant interaction between cue target congruency and age group; $F(2,246) = 0.416$, $p = .660$, $\eta p^2 = .003$, (BF_{incl} = 0.078 Strong evidence for H0). Holm-Bonferroni pair-wise comparisons showed that the false alarm rate was significantly lower in the congruent (M = 0.38, SD = 0.17) compared to the incongruent condition (M = 0.40, SD = 0.18), $t(124) = -2.454$, $p = .030$, Cohen's $d = -0.220$ (BF_{10} = 1.764, anecdotal evidence for H1), showing a congruency effect. The false alarm rate was not significantly different for the congruent compared to the neutral condition (M = 0.37, SD = 0.17), $t(124) = 0.296$, $p = .768$, Cohen's $d = 0.026$ (BF_{10} = 0.104, moderate evidence for H0), thus not showing a beneficial facilitation effect. Finally, the false alarm rate was significantly lower in the neutral compared to the incongruent condition, $t(124) = -2.750$, $p = 0.019$, Cohen's $d = -0.246$ (BF_{10} = 3.446, moderate evidence for H1), thus showing a detrimental cost effect.

There was a significant main effect of age group on false alarm rate, $F(1,123) = 6.348$, $p = .013$, $\eta p^2 = .049$ (BF_{incl} = 3.954, moderate evidence for H1). The false alarm rate was lower in the younger group (M = 0.35, SD = 0.14) compared to the older group (M = 0.42, SD = 0.17).

Results summary

While there was a significant interaction between age groups and congruity for the hits data, there was no such interaction for the false alarm data. This indicates that the age-related differences in the d' data described in the main paper were driven by the between groups differences in the hits data where the older adult’s group only showed a cost effect of the cue on working memory, whereas the younger adults showed a congruency (congruent > incongruent) and facilitation (congruent > neutral) effect. Further, the false alarms results contributed to the cost effect seen in the d’ data for the older and younger adults. Specifically, for the false alarms data there were significantly fewer false alarms in the neutral condition compared to the incongruent condition.

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