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Age-related decline in the reflexive component of overt gaze following

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Previous research has found age-related declines in social perception tasks as well as the ability to engage in joint attention and orienting covert attention (i.e., absence of eye movements) in response to an eye gaze cue. We used an overt gaze following task to explore age differences in overt gaze following whilst people searched for a target. Participants were faster to detect targets appearing at the looked-at location, and although the gaze cue biased the direction in which saccades were executed, no age differences were found in overt gaze following. There were, however, age effects relating to involuntary eye movements. In the younger adults, anticipatory saccades were biased in the direction of the gaze cue, but this bias was not observed in the older group. Moreover, in the younger adults, saccades that followed the gaze were initiated more rapidly, illustrating the reflexive nature of gaze following. No such difference was observed in the older adults. Importantly, our results showed that whilst the general levels of gaze following were age invariant, there were age-related differences in the reflexive components of overt gaze following.

Keywords: Attention; Social cognition; Ageing; Social attention.

Navigating through our social world demands substantial cognitive resources. For example, successful social interactions require a *theory of mind*, which enables us to judge another person's thoughts, beliefs, and intentions. Social interactions also demand sophisticated attentional systems that allow us to bias our cognitive resources towards processing task-relevant information. Whilst most cognitive processes involved in social interactions are generally taken for granted, it has become apparent that some of these processes become less efficient in old age, which may explain why the elderly find social interactions more challenging with increasing age. For example, there are significant age-related declines in theory of mind tasks, which range from complex tasks such as reading of emotions (Slessor, Phillips, & Bull, 2007; Sullivan & Ruffman, 2004) to more specific aspects of social perception, such gaze detection (Slessor, Phillips, & Bull, 2008) and covert gaze cueing (Slessor, Laird, Phillips, Bull, & Filippou, 2010).

The aim of our paper was to investigate a potential age-related decline in people's ability to follow the gaze of others. Social cues, such as gaze cues, have been shown to influence where people look (i.e., overt gaze following), as well as where they attend to in the absence of an eye movement (i.e., covert gaze following; for review see Frischen, Bayliss, & Tipper, 2007). Whilst previous studies

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have focused on covert gaze following, here we investigate potential age-related decline in overt gaze following and potential changes in the way our oculomotor system is involuntarily misdirected by another person's gaze.

Gaze following refers to people's tendency to look towards objects that are looked at by others (Scaife & Bruner, 1975). As this type of gaze following involves overt eye movements, we define it as overt gaze following. Gaze following has attracted much interest amongst attention researchers, who predominantly investigate gaze following using a Posner-type cueing task (for review see Frischen et al., 2007). In these tasks, participants are asked to detect a target that appears on either side of a face, whilst fixating their eyes on a central fixation point. Results from these studies have shown that participants detect targets that are looked at by the face more rapidly than those appearing in the opposite side of the face. Although this gaze cueing effect cannot be inhibited by direct top-down control, the magnitude of the effect is influenced by individual differences, such as age (Slessor et al., 2010; Slessor et al., 2008). For example, Slessor et al. (2008) showed that whilst both younger and older adults exhibited a significant congruency effect, the effect was significantly smaller in the older than in the younger group. These results were used as evidence to suggest age-related deficits in gaze following and the ability to engage in joint attention with other people. However, the same study also showed that when the eyes were replaced by arrows, similar declines in cueing effects were found, suggesting that the decline may be related to a more general attentional system.

Although little is known about age-related differences in overt gaze following, there are a handful of papers investigating age-related differences in general oculomotor control. In the oculomotor capture paradigm observers are required to fixate a search target whilst ignoring task-irrelevant stimuli (e.g., abrupt onset, colour singleton; Theeuwes, Kramer, Hahn, & Irwin, 1998). Although the distractor stimulus is entirely task irrelevant, participants frequently saccade towards it and are generally faster at identifying targets that coincide with the distractor (valid) than when the distractor appears elsewhere (invalid). The proportion of saccades towards the distractor and the difference in search time for valid and invalid trials are used as measures of oculomotor capture. Although several studies have found general age-related deficits in inhibition (de Fockert, Ramchurn, van Velzen, Bergstroem, & Bunce, 2009; Hasher & Zacks, 1988), Kramer, Hahn, Irwin, and Theeuwes (1999) found that young and older adults made equal number of saccades towards the distractor, thus suggesting that oculomotor control was age irrelevant. However, subsequent studies have shown an age-related effect if the distractor was extra salient (Kramer, Hahn, Irwin, & Theeuwes, 2000). For example, older participants' eyes were particularly misdirected towards very bright distractors. Using an antisaccade task, it has been shown that whilst under normal conditions, both younger and older adults showed comparable levels of errors, the addition of a concurrent working memory task resulted in increased directional errors for older adults but not in the younger group (see also Butler & Zacks, 2006; Eenshuistra, Ridderinkhof, & van der Molen, 2004). Results from the oculomotor control literature seem to suggest that at least under certain conditions, ageing results in lower levels of oculomotor control.

Eye movements involve a multitude of processes, many of which are influenced by social cues. For example, if you are instructed to move your eyes in a particular direction, gaze cues can interfere with the planning and execution of saccades (Kuhn & Benson, 2007; Kuhn & Kingstone, 2009; Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002). Alternatively, gaze cues also bias where you look whilst searching for something (Kuhn & Tipples, 2011), and they can influence the nature of the saccade itself (i.e., change in saccade curvature; Nummenmaa & Hietanen, 2006).

We used a social visual search task in which participants were required to find a target amongst distractors (Kuhn & Tipples, 2011). Simultaneously with the presentation of the search targets, the eyes of a centrally presented face look either towards the target (valid trials) or towards one of the distractors (invalid trials).

Table 1. *Average age, level of visual acuity, digit span, and educational years for both age groups*

	Age (years)		*Visual acuity*		*Digit span*		*Educational years*	
Group	M	SD	M	SD	M	SD	M	SD
Older adults	70.59	5.04	6.83	1.81	7.25	1.22	14.48	3.68
Younger adults	22.8	3.62	5.5	1.81	7.5	1.31	16.9	1.69

Gaze cues can influence different processes within the oculomotor system, and we used this social visual search task to explore the way in which gaze cues influence people's oculomotor behaviour whilst searching for a target. If gaze following is automatic, we would expect people to initiate anticipatory eye movements in the direction of the gaze cue even when instructed to keep their eyes fixated. If older adults are less sensitive towards gaze cues, we would expect less of this spontaneous gaze following than in the younger group. Previous research has shown that participants were more likely to initiate eye movements in the direction of the distractor cue, thus demonstrating overt gaze following (Kuhn & Tipples, 2011). If older adults are less sensitive towards social cues, we would expect a weaker gaze following bias in this group of participants. Moreover, gaze-following saccades are typically executed more rapidly than gaze-avoiding saccades, thus illustrating the reflexive nature of gaze following (Kuhn, 2007; Kuhn & Kingstone, 2009; Muller & Rabbitt, 1989). If older adults are less influenced by social cues, we would expect to find no difference in latencies between these two types of saccades. Finally, participants are typically faster at detecting looked-at targets than those appearing elsewhere (Kuhn & Tipples, 2011). An age-related reduction in gaze sensitivity predicts a reduction in differences in search times for valid and invalid cues.

EXPERIMENTAL STUDY

Method

Participants

There were 23 older adults ($M = 70.6$ years; age range = 63–81 years) who participated in this experiment and 38 younger adults ($M = 22.8$ years; age range = 17–30 years: See Table 1 for demographics). Participants in the older adult group were all community dwelling and recruited from clubs and societies in the local area. All older adults were paid £10 for their time, and the younger adults were recruited from the university or local community and were paid £5. Older participants received a higher payment as in the main they lived further from the laboratory where testing took place. All participants had normal or corrected-to-normal vision. The study was given full ethical approval from the relevant committee of the Brunel University School of Social Sciences Research Ethics Committee according to guidelines stipulated by the British Psychological Society (BPS).

Table 1 displays means for age, visual acuity, digit span, and number of years in education. No group differences were found for digit span, $t(59) = 0.986$, $p = .329$, but as is common in ageing studies, a significant difference was found for number of educational years, $t(59) = 3.25$, $p = .002$. Surprisingly however, older adults had better visual acuity than younger adults, $t(59) = 3.16$, $p = .003$.

Materials

Prior to the experiment, participants' visual acuity was recorded using a Snellen eye chart (six metres viewing distance). Working memory was tested with a digit span task from the Wechsler Adult Intelligence Scale (1999); the experimenter read out strings of numbers starting with a string of three numbers and increasing until the participant was unable to remember the complete string of numbers in the correct order. If participants failed on the first attempt they were given a second

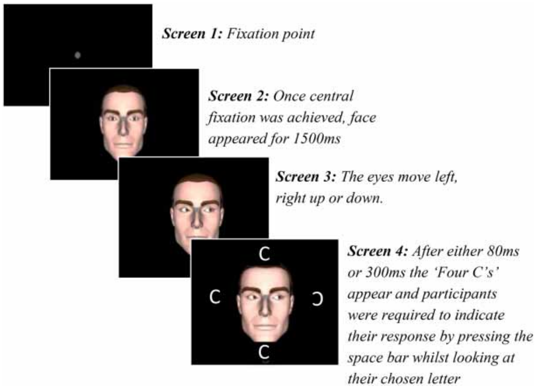

Figure 1. *The sequence of a valid trial. The figure is not drawn to scale, and the targets were less salient in the actual experiment. To view this figure in colour, please visit the online version of this Journal.*

attempt. Eye movements were monitored using an eye tracker (remote; SR Research Ltd, Osgoode, Canada) and were recorded monocularly at 1 kHz. Eye movements were calibrated with a 9-point calibration procedure. The experiment was run on a Pentium D PC, and stimuli were displayed on a 21-inch CRT monitor (1024 × 768 pixels; 85 Hz; viewing distance was 57 cm). The experiment was compiled and run using Experiment Builder (SR Research Ltd, Osgoode, Canada).

We used a modified version of the social visual search task devised by Kuhn and Tipples (2011). Participants were asked to search for a target letter that appeared in one of four locations (see Figure 1) as quickly as possible and to press the space bar once they found it. They were explicitly told to keep fixating on the target whilst pressing the key so that we could verify that they had found the correct target. The manual response time (RT) provides a measure of how long it took to find the target, whilst the eye movements were used to ensure they found the correct target. It is important to note that this manual RT measure differs from that used in covert gaze cueing tasks, as our measure involves both overt and covert attentional processes (i.e., participants frequently fixate several distractors prior to selecting on the target). In the centre of the search display, there was a face whose gaze looked either toward the target location (valid trial) or away (invalid). Participants were asked to find the target whilst ignoring the eyes.

Each trial began with a central white fixation point (0.63° in diameter) on a black background (see Figure 1). Participants were asked to fixate on this central spot, and once fixation was achieved, the experimenter initiated the trial. Each trial started with a neutral face looking ahead (the faces were created using Poser 5.0®, Curious Labs Inc., Santa Cruz, CA). After 1500 ms the eyes looked to the left, to the right, up, or down. In order to investigate potential differences in time course, we added a stimulus onset asynchrony (SOA) manipulation. Volitional attentional effects are more likely to emerge at longer SOAs. After a SOA of either 80 ms or 300 ms, a target letter (letter C) appeared equidistant from fixation (5.2°), left, right, up, or down from the face. Simultaneously with the target onset, three distractor letters (reversed Cs) appeared equidistant from fixation (left, right, up, or down). Participants were required to search for the correct C amongst the reversed Cs as quickly as possible. Once they found it, they were required to fixate the letter and to press the space bar to indicate their selection. Participants were explicitly informed that the eyes were just as likely to look left, right, up, and down, and that the eye gaze was nonpredictive and thus entirely task irrelevant. There were six practice trials, during which participants received feedback to inform them whether they were carrying out the task correctly. This was followed by 128 experimental trials divided in two blocks of 64 trials (32 valid trials and 96 invalid trails), which were presented in a random order.

Results

The eye movement data were analysed using Data Viewer (SR Research Ltd, Osgoode, Canada). Saccades were defined as eye movements with velocities and accelerations exceeding 30° s^{-2}, and 8000° s^{-2}, and exceeding 1° in amplitude.

Anticipatory saccades prior to the search target

Although participants were explicitly instructed not to move their eyes prior to the onset of the target display, they sometimes had difficulties obeying these instructions, resulting in anticipatory saccades. Anticipatory saccades were defined as saccades that were initiated after the distractor cue and prior to the onset of the target display. In the older group, anticipatory saccades were made on 25.5% ($SD = 13.2$) of the trials, whilst in the younger group these accounted for 18.8% ($SD = 14.6$). There was no significant difference in the overall percentage of anticipatory saccades made, $t(59) = 1.77$, $p = .081$. These anticipatory saccades were further classified according to whether they were made in the same direction as the distractor cue (i.e., gaze following), or not (gaze avoiding). Intriguingly, in the younger group there was a significantly higher percentage of gaze-following trials ($M = 33.2\%$, $SD = 13.2$) than in the older group ($M = 23.1$, $SD = 9.64$), $t(59) = 3.17$, $p = .002$. As there were four potential saccade directions, gaze following on more than 25% of the trials would indicate a significant bias. In the younger group, gaze following occurred significantly more than would be expected by chance, $t(37) = 3.80$, $p = .001$, but this was not the case in the older group, $t(22) = 0.94$, $p = .36$. The younger group therefore demonstrated a significantly higher level of spontaneous gaze following than the older group. In fact in the older group, these anticipatory saccades were independent of the distractor eyes.

Saccade direction as a function of gaze cue

Overt gaze following was defined as the tendency to follow the distractor eyes. Eye movements were analysed from the point at which the search display was presented and were classified according to their direction (left, right, up, down). Gaze-following trials were trials on which the first saccade went in the same direction as the distractor eyes. All other trials were gaze-avoiding trials. Figure 2a shows the percentage of gaze-following trials, which were calculated by dividing the total number of gaze-following trials by the total number of saccades made. As there were four target locations and four gaze directions, gaze following on more than 25% of the trials would suggest a tendency to follow the gaze. An analysis of variance (ANOVA) found a significant main effect of SOA, $F(1, 59) = 8.00$, $p = .006$, $\eta^2 = .119$, highlighting stronger gaze following for the 300-ms SOA. However, there was no significant main effect of group, $F(1, 59) = 0.763$, $p = .39$, $\eta^2 = .013$, and no significant group by SOA interaction, $F(1, 59) = 0.062$, $p = .81$, $\eta^2 = .001$. Gaze following was significantly above chance for both groups (all ps $< .001$), and both age groups demonstrated the same level of overt gaze following.

Time to initiate a saccade towards a potential target

Next we analysed the latencies of the saccades initiated after the onset of the search display. Figure 2b shows the mean latencies for gaze-following and gaze-avoiding saccades. Trials with saccade latencies below 80 ms or above 1000 ms were treated as outliers and were removed. There were significantly more outliers in the older than in the younger group, $t(59) = 3.03$, $p = .004$ (older $M = 14.5\%$, $SD = 8.44$; younger $M = 8.71$, $SD = 6.39$). An ANOVA with saccade type (gaze following vs. gaze avoiding) and SOA as within-participant factors and group as the between-subject factor found no significant main effect of saccade type, $F(1, 59) = 0.61$, $p = .44$, $\eta^2 = .01$. However, there was a significant group by saccade type interaction, $F(1, 59) = 9.28$, $p = .003$, $\eta^2 = .14$. In the younger group, gaze-following saccades had significantly shorter saccade latencies than gaze-avoiding saccades at both the 80-ms SOA, $t(37) = 3.07$, $p = .004$, and the 300-ms SOA, $t(37) = 4.42$, $p < .00005$. In the older group, there were no significant differences in saccade latencies [80-ms SOA, $t(22) = 1.34$, $p = .19$; 300-ms SOA, $t(22) = 1.66$, $p = .11$]. Whilst the younger participants showed shorter saccade latencies for gaze-following trials, this was not the case for the older group. There was a significant main effect of SOA, $F(1, 59) = 20.2$, $p < .00005$, $\eta^2 = .26$, illustrating faster saccade latencies at the longer SOA, an effect typically found in these types of experiment (e.g., Kuhn & Kingstone, 2009). Moreover, there was a significant group by SOA interaction, $F(1, 59) = 4.10$, $p = .047$. Whilst the younger group had significantly shorter saccade latencies in the 300-ms

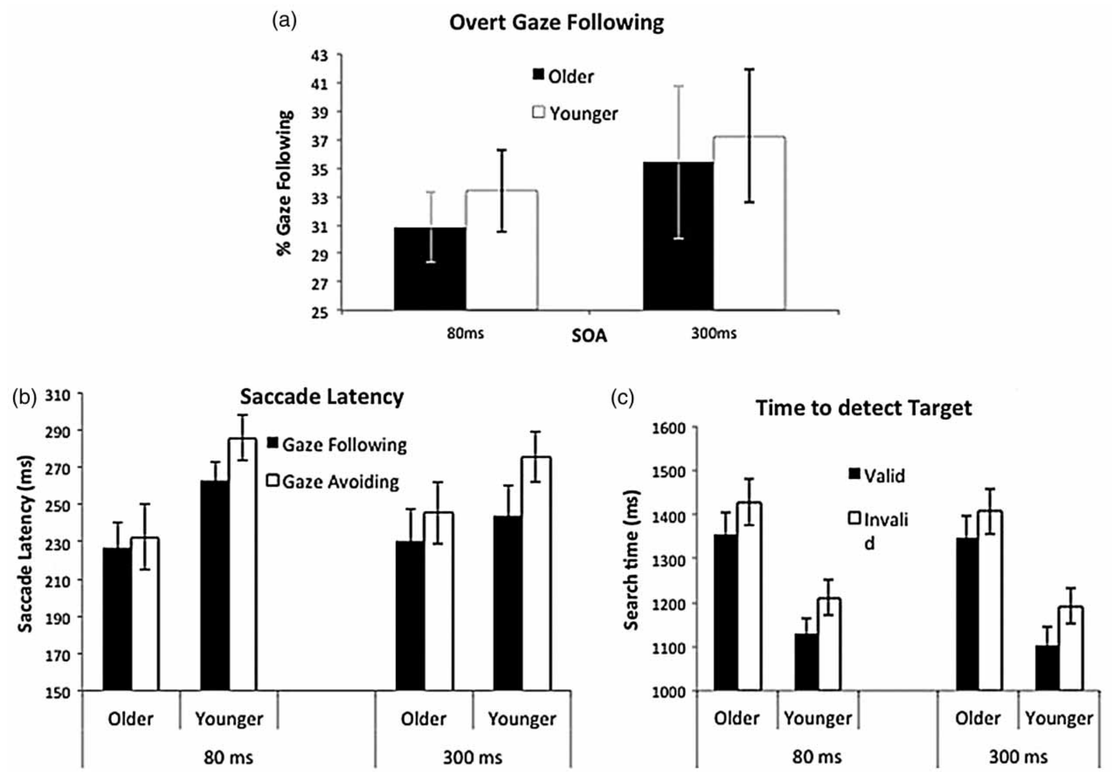

Figure 2. *(a) Percentage of trials on which the first saccade went in the same direction as the gaze cue (i.e., gaze following) for both age groups and stimulus onset asynchronies (SOAs; error bars denote 95% confidence intervals). (b) Saccade latencies for both age groups as a function of SOA and gaze-following and gaze-avoiding saccades (error bars denote standard errors). (c) Time to detect the correct target for both age groups and SOAs for valid and invalid trials (error bars denote standard errors).*

SOA condition than in the 80-ms SOA condition, $t(37) = 3.21$, $p = .003$, this difference was not significant in the older group, $t(22) = 1.37$, $p = .19$. None of the other main effects or interactions were significant: no main effect of group, $F(1, 59) = 2.21$, $p = .14$, $\eta^2 = .036$, no saccade type by SOA interaction, $F(1, 59) = 1.72$, $p = .20$, $\eta^2 = .038$, and no group by SOA by saccade type interaction, $F(1, 59) = 0.005$, $p = .941$, $\eta^2 = .001$.

Manual time to detect target

The next analysis looked at the time taken for participants to detect the correct target. Data from five participants (2 older; 3 younger) were excluded due to a computer error. Search errors were relatively low (older $M = 7.66$, $SD = 8.30$; younger $M = 9.46$, $SD = 9.03$) and did not differ significantly between the age groups, $t(54) = 0.74$, $p = .46$. Search time was defined as the time elapsing between target onset and target selection (key response; Figure 2c). Outliers were defined as search times exceeding 2500 ms, resulting in the removal of 2.10% ($SD = 5.96$) of trials. An ANOVA with validity (valid vs. invalid) and SOA as within-group factor and group as between-group factor found a significant main effect of validity, $F(1, 54) = 18.3$, $p < .00005$, $\eta^2 = .25$, illustrating that targets were found more rapidly on valid than on invalid trials. Moreover, there was a significant main effect of group, $F(1, 54) = 14.0$, $p < .00005$, $\eta^2 = .21$, demonstrating slower search times for the older group. There was also a significant main effect of SOA, $F(1, 54) = 4.94$, $p = .03$, $\eta^2 = .084$, typically found in these types of experiments. None of the other main effects or interactions were significant: no group by SOA interaction, $F(1, 54) = 0.163$, $p = .69$, $\eta^2 = .003$, no group by validity interaction, $F(1, 54) = 0.307$, $p = .58$, $\eta^2 = .006$, no SOA by validity interaction, $F(1, 54) = 0.014$, $p = .91$, $\eta^2 = .0001$, and no group by validity by SOA interaction, $F(1, 54) = 0.132$, $p = .72$, $\eta^2 = .002$.

Discussion

We used a social visual search task to investigate differences in oculomotor behaviour in response to gaze cues whilst searching for a target amongst distractors. Although participants were explicitly instructed not to move their eyes until they were presented with the search display, there were a substantial number of trials on which they failed to follow these instructions and initiated eye movements immediately after the gaze cue. Interestingly, there was no significant overall group difference in these anticipatory saccades. However, the nature of these saccades varied as a function of age. In the older group, the direction of these anticipatory saccades was unrelated to the direction of the distractor gaze. In the younger group though, the anticipatory saccades were systematically biased towards mimicking the distractor gaze, thus illustrating spontaneous gaze following, similar to what was found in previous studies (Kuhn & Tipples, 2011). These results support the view that older participants were less sensitive towards gaze cues (Slessor et al., 2010; Slessor et al., 2008).

Both the older and the younger adults showed a significant bias in mimicking the gaze of the distractor eyes once instructed to move their eyes. This overt gaze following was stronger for the longer SOA manipulation suggesting that it takes time to process. Moreover, this result may also suggest that the tendency to follow the gaze involves a substantial volitional component. There was no group difference in overt gaze following, suggesting that this was independent of age.

We also analysed the time it took for participants to initiate a saccade towards one of the potential search targets. Numerous past papers have revealed that gaze-following saccades are executed more rapidly than gaze-avoiding saccades (Hermens & Walker, 2010; Koval, Thomas, & Everling, 2005; Kuhn & Benson, 2007; Kuhn & Kingstone, 2009; Kuhn et al., 2011; Kuhn & Tipples, 2011), which illustrates their reflexive nature (Theeuwes et al., 1998). Whilst this was indeed the case in the younger group, there was no significant difference in saccade latencies between gaze-following and gaze-avoiding saccades in the older group. These findings again suggest that the older group was less sensitive towards the social cues.

The final analysis looked at whether gaze cues facilitated target detection. Search times were significantly shorter on valid than on invalid trials, thus demonstrating that gaze cues facilitated target detection. Moreover, there was no difference between the older and the younger adults in this gaze facilitation effect. Overall however, older adults were significantly slower to find the target than the younger group, thus illustrating an age-dependent search impairment that was independent of social cues. Slessor et al. (2007, 2008) used manual RTs to measure covert orienting of attention. Unlike in these previous studies, our participants were encouraged to move their eyes, which means that our target detection measure involves overt and covert attentional orienting and thus cannot be directly compared with the results from these previous studies. However, future work will hopefully shed light onto the direct relationship between overt and covert gaze following.

Slessor et al. (2008) used a covert gaze cueing task to demonstrate age own-age bias (AOB) towards gaze distractors in younger adults but not in older adults. Moreover, Ciardo et al. have recently found an AOB for voluntary saccades in younger but not older adults (Ciardo, Marino, Actis-Grosso, Rossetti, & Ricciardelli, 2014). Here participants were asked to execute a volitional saccade that was either congruent or incongruent with centrally presented distractor gaze. The authors reported two measures: (a) difference in saccade latency for congruent and incongruent trials and (b) differences in errors for congruent and incongruent trials. They found an age AOB for saccade latency measures and error measures for the middle-aged adults but not for the older adults. The face used in the current experiment portrayed that of a person whose age was closer to the younger group than to the older participants, and since we did not manipulate the age of the person depicted in the image, we cannot rule out any own-age biases. However, as the AOB is generally only found for younger participants, it is unlikely that this can account for the current findings.

In conclusion, we have shown that age-related differences in overt gaze following are only observed in the reflexive component of initiated saccades. Attention is an immensely complex process involving numerous different cognitive components. As gaze following generally refers to the way in which gaze cues influence where we attend to, there is great danger in assuming that gaze cues influence all attentional processes equally. Here we have shown that even the concept of overt gaze following may be an oversimplification. Researchers rarely distinguish between overt and covert gaze following, yet even covert gaze following may be more complex than originally though. People can programme volitional and reflexive saccades in parallel, and these two types of saccades have different properties (Theeuwes et al., 1998) and are also driven by different neuroanatomical structures (LaBerg, 1995). We used four different metrics to measure overt gaze following, and it is likely that these metrics measured reflexive and volitional components of gaze following. For example, the metrics looking at anticipatory gaze-following saccades and the difference in saccade latency for gaze-following and gaze-avoiding intentional saccades measure reflexive components. Biasing where you look for the target as well as target detection times (in our task the target needs to be foveated before it can be detected) may be more volitional. Our results suggest that age-related differences are found for the reflexive components of overt gaze following whilst the more volitional components seem to be age invariant.

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