Age differences in gaze following: Older adults follow gaze more than younger adults when free-viewing scenes

Eunice G. Fernandes[1,2], Benjamin W. Tatler[3], Gillian Slessor, & Louise H. Phillips[4]

2 https://orcid.org/0000-0002-1448-3256

3 https://orcid.org/0000-0002-5316-766X

5 https://orcid.org/0000-0002-0988-3028

School of Psychology, University of Aberdeen, Aberdeen, Scotland AB24 3FX, UK

Corresponding author: Eunice G. Fernandes, e.fernandes1977@gmail.com

[1] Eunice G. Fernandes is now at Universitet i Agder.

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Abstract

Previous research investigated age differences in gaze following with an attentional cueing paradigm where participants view a face with averted gaze, and then respond to a target appearing in a location congruent or incongruent with the gaze cue. However, this paradigm is far removed from the way we use gaze cues in everyday settings. Here we recorded the eye movements of younger and older adults while they freely viewed naturalistic scenes where a person looked at an object or location. Older adults were more likely to fixate and made more fixations to the gazed-at location, compared to younger adults. Our findings suggest that, contrary to what was observed in the traditional gaze-cueing paradigm, in a non-constrained task that uses contextualized stimuli older adults follow gaze as much as or even more than younger adults.

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Introduction

Gaze following refers to the propensity to direct our attention towards where others are looking (see Frischen, Bayliss, & Tipper, 2007, for a review). Such behaviour is a way of engaging in joint attention and thus plays an important role in social interactions and communication with others (e.g., Emery, 2000; Langton, Watt, & Bruce, 2000). Previous research suggested that older adults follow gaze less than their younger counterparts (e.g., Slessor, Phillips, & Bull, 2008). However, this conclusion depends on an attentional gaze-cueing paradigm which differs radically from the way that we use gaze cues in everyday life in two key aspects: (i) there is no contextual information, and (ii) the task sets up a conflict between attention to an irrelevant gaze cue and a relevant target. As older adults' perception is particularly influenced by context (Kunzmann & Isaacowitz, 2017), and older people may process task conflict in different ways to younger counterparts (Hämmerer, Li, Müller, & Lindenberger, 2010), it is important to understand how age influences gaze following in a more naturalistic task which includes context without task conflict. We evaluated this issue by employing an eye-tracking paradigm where participants freely viewed naturalistic scenes. We found that, in this situation, older adults followed the gaze of people in a scene to direct their visual attention to gazed-at areas more than younger people did.

Most research investigating gaze following in human adults has used an experimental attentional cueing paradigm where a face whose eyes are averted left or right is presented, followed by a target to which participants have to respond to (e.g., Driver et al., 1999; Friesen & Kingstone, 1998). The target can appear either to the left or the right of the face, that is, in the location 'cued' by the gaze (congruent trials) or in the opposite direction (incongruent trials), and gaze cueing is indexed by longer response times on incongruent compared to congruent trials. Research using this variant of Posner's (1980) spatial cueing task found a significantly smaller gaze cueing effect in older compared to younger adults (Slessor et al., 2008; see also Slessor, Laird, Phillips, Bull, & Filippou, 2010; Slessor et al., 2016; and see recent meta-analysis by McKay, Talipski, Grainger, & Henry, 2022). But the use of this gaze cueing paradigm can be criticized in two main aspects. The first concerns the stimuli. As discussed elsewhere (e.g., Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012; Skarratt, Cole, & Kuhn, 2012), initial research with the gaze cueing paradigm used schematic faces or photographs of faces in isolation that do not provide the visual and social context of real life environments. Further research used naturalistic scenes to address this issue, and showed that observers look more at the objects gazed at by people in the scenes than objects which are not gazed at (e.g., Borji, Parks, & Itti, 2014; Castelhano, Wieth, & Henderson, 2007, Freebody & Kuhn, 2018; Kuhn, Vacaityte, D'Souza, Millett, & Cole, 2018). However, none of these studies investigated whether younger and older adults differed in gaze following.

Scenes are semantically coherent views of real-world environments comprising background elements and discrete objects arranged in space (Henderson, & Hollingworth, 1999). They thus provide a context that is absent when faces are presented in isolation. This is particularly relevant for the investigation of age-related differences, as older adults seem to rely more on contextual information when processing social information than young people do. In particular, it has been shown that older adults are more influenced by contextual information than younger counterparts when making facial emotion judgements (e.g., Ngo & Isaacowitz, 2015, Noh & Isaacowitz, 2013). Also, older adults make more use of contextual information when viewing scenes (Borges, Fernandes, & Coco, 2019; Neider & Kramer, 2011; see Zanto, & Gazzaley, 2014, for a review). For example, Nuthmann, Schütz, and Einhäuser (2020) showed that, in scene viewing, older adults allocated visual attention to objects (meaningful entities in a scene) more than younger adults did. Conversely, eye movements of the younger participants were better explained by object-independent image properties such as visual salience. In our own work on age differences in gaze following in scenes, older adults benefited more than younger adults from the semantic consistency between the target object and the scene while searching for objects (Fernandes, Phillips, Slessor, & Tatler, 2021). Such evidence suggests that older adults rely more on high-level information such as the context and meaning of scenes when processing rich visual information.

Whilst Fernandes et al. (2021) used naturalistic scenes, in their study participants were asked to look for a target object in the scene (i.e., a visual search task). The task in their experiment therefore resembled the Posner-like gaze cueing paradigm in that participants were asked to detect a target. This brings us to the second concern about the use of such traditional gaze cueing paradigms: the task demands. In the predominant Posner-style attentional cueing tasks, participants are asked to respond to a target location, and are often told to ignore or treat the gaze cues as irrelevant. The tasks therefore involve a conflict between the purported automatic tendency to follow gaze, and the controlled task demands to respond as quickly as possible to the location of the target. Prior research suggested that the smaller gaze-cueing effect observed for older adults might reflect impaired ability to engage in joint attention with increased age (Slessor et al., 2008; 2010). However, such differences might also reflect greater motivation to follow instructions and ignore the gaze cues, in line with evidence for better performance by older adults when required to follow instructions and suppress emotions (Phillips, Henry, Hosie & Milne, 2008; Scheibe & Blanchard-Fields, 2009). To address these questions, the current study evaluates whether there are age differences in the naturalistic processing of gaze cues without the influence of a superimposed attentional task.

The seminal work by Buswell (1935) showed that, in scene viewing, searching for a target promotes viewing patterns different from freely observing a scene. With regard to gaze following, Kuhn et al. (2018) recorded the eye movements of younger adults while they freely viewed (Experiment 1) or searched for a prespecified target (Experiment 2) in photographs where a model either looked towards an object/ location or away from it. The photos also contained an object that could act or not as a barrier between the model and object, so that the target object/ location was invisible or visible to the actor in the photo. Besides a general gaze cueing effect (with faster fixation of the gazed than the non-gazed object), participants were faster fixating the object when it was visible to the actor than when it was invisible to the actor, but only during free-viewing. Kuhn et al. (2018) suggested that different components of gaze following are involved during search for a target and free viewing. Higher-level processing of the viewing perspective and a process of mental state attribution only occurred in the free-viewing task where there was more time available and attention was not constrained by the demands associated with a search task. It is important, therefore, to characterise how older adults follow gaze when freely viewing rather than searching scenes (as was the case in Fernandes et al., 2021) because the task constraints of the latter may remove aspects of high level processing of social scenes.

We recorded observers' eye movements while they freely viewed natural scenes containing one person gazing at a location or object in the scene, and analysed fixations both to that gazed-at location and to the person's face. The timecourse and prevalence of fixations to the gazed-at location are measures that index gaze following (e.g., Kuhn et al., 2018). In line with previous literature, we considered measures that reflect both prioritization of regions and further visual inspection, while exploring the scene, such as the time to first fixation and the total time fixating the gazed-at location, and we further analysed the percentage of trials when a region was fixated and the mean number of fixations to a region (e.g., Birmingham, Bischof, & Kingstone, 2008; Castelhano et al., 2007). Fixations to a gazed-at location can occur even prior to (and therefore in the absence of) fixations to the face of the person who gazes (Castelhano et al. 2007; observers can process peripherally the face, and they can also pick up gaze information from body and head positions, e.g., Bayliss, di Pellegrino & Tipper, 2004; Moors, Germeys, Pomianowska, & Verfaillie, 2015). Therefore, we did not restrict our analyses to fixations to the gazed-at location that started on the face region as was done in prior studies (Borji et al., 2014). We also quantified fixations to the face of the person in the scene, which allows us to address the hypothesis that older adults show less gaze following because they attend less to faces (e.g., De Lillo et al., 2021).

Finally, in order to rule out a potential influence of visual salience in the patterns of fixations in our study, we calculated visual salience in our scenes, and included the maximum salience of a region as a predictor in all analyses for that region. There has been extensive research on what factors determine how we select where to look at in the visual environment, including the relative importance of low- and high-level characteristics in scenes and of internal goals for deciding where to look in scenes (see Tatler, Hayoe, Land, & Ballard, 2011, for a review). Importantly, age-related differences in how different sources of information influence the viewing behaviour have been reported recently. In particular, it was shown that younger adults' viewing behaviour is more closely associated with visual salience in scenes, whereas older adults' viewing behaviour is better explained by higher-level processing of, for example, object entities (Nuthmann et al., 2020; see also Açik, Sarwary, Schultze-Kraft, Onat, & König, 2010). We thus control for this potential confound by accounting for any effects driven by image visual salience.

To the best of our knowledge, our study is the first comparison of how younger and older adults allocate attention to gazed-at objects while freely observing complex scenes. We aimed to test age-differences in gaze following in a task which more closely resembles the way that we process social information about people in everyday life, as compared to an attentional cueing task which sets up an artificial conflict between processing gaze cues and targets. Moreover, the use of people within scenes instead of faces in isolation provides a context to the visual environment and to the social cues within it, and this may be particularly relevant for older people. In relation to another key task of interpersonal perception (facial emotion identification), age deficits in decontextualized tasks can be reversed to result in age-related benefits in processing contextualized emotions (Noh & Isaacowitz, 2013). We therefore hypothesize that older adults' low levels of gaze cueing in attentional cueing tasks (e.g. Slessor et al., 2016) can either be reduced or even reversed when a more contextualized and realistic task is used.

Materials and Methods

Participants

We initially recruited 40 older and 46 younger adults (aged M=71.2 and M=24.01, respectively). From these, we could not obtain initial calibrations of the eye-tracker with errors <.5º (average) and <1º (maximum) for 31 participants, mainly because of the use of strong eyeglasses or varifocal lenses that caused distortions. We also rejected the data from a participant aged 50. We thus report results on 24 older (9 males; age M = 71.58 years, SD = 5.29) and 30 younger (three males; age M = 23.38 years, SD = 3.22) participants.

Older participants were recruited through the participant panel of the University of Aberdeen, who are usually invited to take part in psychology experiments, and the younger adults were recruited among students from the University of Aberdeen. Older participants were screened for mild cognitive impairment through the Montreal Cognitive Assessment questionnaire (Nasreddine, Phillips, Bédirian, et al., 2005), and all achieved a score equal or higher than 23, the cutoff point recommended by Carson, Leach, and Murphy (2018). All participants had normal or corrected-to-normal vision, gave written informed consent, and were paid £10 for their participation. The study was approved by the Psychology Ethics Committee from the University of Aberdeen.

Stimuli

The stimuli were 120 color photographs collected from the Web (mostly from https://www.flickr.com; refer to Figure 1A). We chose images to meet the criteria that (a) there was one person clearly shown in the picture, (b) the direction of their gaze could be clearly seen, (c) the gaze direction was not looking directly at the camera but instead at an object or location within the scene, and (d) they had the same aspect ratio (i.e., ratio of width to height; this was of 1.5:1). We tried to select images which included a range of ages, but there were few pictures including older adults which met the criteria. Images were resized to 1620x1080 pixels, to maintain the aspect ratio, and displayed centrally on a 1920x1080 background. Miniatures of our stimuli can be found in Supplementary material.

Apparatus and procedure

The experiment was generated in SR Research Experiment Builder 1.10.165 (2011), and conducted on an Asus TX650 computer running OS Windows7 Pro. Stimuli were presented on a BenQ XL2420Z 24-in. monitor with 1920 x 1080-pixel image resolution, and a refresh rate of 120 Hz. Eye movements were recorded via a desk-mounted eye-tracker EyeLink 1000 at a sampling rate of 1,000 Hz. Viewing was binocular but only the participant's dominant eye was tracked, as determined by the USAEyes Dominant Eye Test Card (https://www.usaeyes.org/lasik/library/Dominant-Eye-Test.pdf).

Participants sat approximately 72 cm away from the display, and a forehead and chin rest was used for head stabilization. They were shown the 120 images, one at a time, in a randomised order, and they were asked to look freely at each image for the 5s for which it remained on the screen. No responses were made.

The experiment began with a 9-point calibration and validation procedure. Calibration was accepted if the average and worst calibration errors were below 0.5° and 1° of visual angle, respectively. A new calibration was repeated whenever the experimenter found it necessary – namely, when the pre-trial calibration check shown at each trial onset indicated an error above 1° for three successive trials.

Analysis

We considered two regions of interest (ROI) as illustrated in Figure 1B. The first ROI was the location/object which the person was looking at (Gazed-at Location), and the second was the Face of the person in the image. We estimated the ground-truth Gazed-at Location (i.e., the location the person in the photograph is looking at) by asking a different set of participants (eight older adults and 12 younger adults,) to indicate, for each image, where the person in the image was looking at. They indicated this location with a mouse click, and they could indicate if the person was looking outside the image by pressing 'O'. For each image, our Gazed-at location ROI was computed as an ellipse that contained 80% of the 20 annotated points. We eliminated from our analyses one image, for which 16 of the annotators indicated that the region where the person was looking at was outside of the screen. We used the 'drawpolygon' function in MATLAB (version R2019a) to draw the contours of the Face area.

From the data collected on 54 participants and 119 images (6426 trials) we discarded 79 trials with mean calibration error above 0.5º or maximum calibration error above 1º, and 11 trials that contained only one fixation (together corresponding to 1.40% of trials).

For each trial, we considered fixations that started after the scene onset, until the last fixation that started before the scene offset. We mapped each fixation onto one of the two ROIs or 'other' location on the screen. Fixations distancing less than 1.5º of visual angle from a ROI were assigned to that ROI.

To account for possible differences in the association between fixations and image properties in younger and older adults (e.g., Nuthmann et al., 2020), we calculated visual salience in the ROIs. A salience map was calculated for each image using the RARE2012 salience model (Riche, Mancas, Gosselin, & Dutoit, 2013). From this, the maximum salience within each ROI was calculated and used as a predictor in our models.

We analysed five eye movement measures for each trial: (a) the probability of fixating the ROI during the trial (binomial coded 1) or not (coded 0). For the subsets of data where the ROI was fixated (98.9% of trials for Face; 87.6% of trials for Gazed-at location) we then considered: (b) the number of fixations to the ROI; (c) the time to first fixate the ROI (i.e., time elapsing between the onset of the scene and the starting time of the first fixation at a ROI); (d) the total time fixating the ROI (sum of the durations of all fixations at a ROI during the analysed time window), and (e) the probability of fixating a ROI at each ordinal fixation (i.e., whether, at each fixation ordinal number, the ROI was or was not fixated; a binomial coded 1 and 0, respectively).

For the time-based measurements, we first transformed our measures because of the typically skewed distributions of time to first fixate a region (e.g., Spotorno, Malcolm & Tatler, 2015) and total fixation time within a region (e.g., Tatler et al., 2013). We chose the log transformation based on the estimation of the optimal values of the λ-coefficient for the Box-Cox power transformation, which were: For time to first fixate, -0.1, and -0.1, for Face and Gazed-at Location, respectively; For total time fixating, 0.38 and 0.18 for Face and Gazed-at Location, respectively. These are closer to 0 (the estimate for which a log transformation is used) than to 1 or -1 (used for keeping the original metric or using the reciprocal transformation, respectively), making log transformation more appropriate for our data (Box & Cox, 1964; Venables & Ripley, 2002; as cited by Kliegl, Masson, & Richter, 2010). As linear regression statistsics assumes normality in the data, we inspected normality through QQ-plots and further removed, for each participant, values more than 2.5SD from their mean (log-transformed) times (as recommended in Howell, 2006; Ratcliff, 1993; see Results section for the amount of excluded data on each case).

We fitted to each of these eye-movement measures linear-mixed effects models (LMM; Baayen, Davidson, & Bates, 2008), as implemented by lme4 (Bates, Mächler, Bolker, & Walker, 2015) package in *R*. LMMs allow for simultaneous estimation of between-participants and between-items (i.e., scenes) variance. Accordingly, we had participants (54) and scene (119) as random factors in each analysis. Our fixed effect was group (contrast coded by centering; refer to notes on the summaries of models). We fitted full models (all main effects and possible interactions) with a maximal-random structure when justified by the design (Barr, Levy, Scheepers, & Tily, 2013) and if convergence occurred (refer to the summaries of models for its syntax). We report the predictors' coefficients (β values), SE, t (or z) values, and the derived p significance values (by treating the t-statistic using the standard normal distribution as a reference; e.g., Baayen et al., 2008, footnote 1).

Results

Probability and Number of fixations

We first analysed how likely participants were to look at the Gazed-at Location and at the Face. The mean percentage of trials when each ROI was fixated is depicted in Figure 2 (left). For statistical evaluation, we fitted to the binomial outcome (i.e., whether the ROI was fixated or not), a mixed logit regression (Jaeger, 2008) using the 'glmer' function (specifying a 'logit' link) in R. As shown in Table 1 (left), we found that older adults were significantly more likely to fixate the Gazed-at Location than younger adults. No age differences were observed in the likelihood of fixating the Face. For both regions, we found a significant main effect of salience, indicating that participants were more likely to fixate the Face and the Gazed-at Location when these regions had higher visual salience.

Next, we analysed the number of fixations at each ROI. A mixed linear regression (Table 1, right) found a significant main effect of Group for the fixations to the Gazed-at Location: Older adults fixated more times the Gazed-at Location than younger participants, as can be seen in Figure 2 (right). There was again a main effect of visual salience, with more fixations as a function of increasing salience. There were no age differences in the number of fixations to the Face, but the effect of Group interacted with visual salience indicating that, for older adults, the higher the visual salience of the face the more times they looked at it.

Time to first fixate and Total time fixating

For the time to first fixate each ROI (i.e., the time in ms between the onset of the scene and the starting time of the first fixation at that ROI), we eliminated, for each participant, observations that distanced more than 2.5 SD from the mean time. This corresponded to 4.1% and 1.28% of data for the sets corresponding to fixations to the Face and fixations to the Gazed-at Location, respectively. Figure 3 (left) shows the mean (non-transformed) time[2] to first fixate each ROI for the Older and Younger Age groups, and Table 2 (left) presents the output of the LMM models on transformed times. There was a trend for older adults to be faster than younger adults at fixating the Gazed-at Location, but the effect did not reach significance. We found no difference between age groups on the time to first fixate the Face. The main effect of salience shows once more an association between salience and fixations.

For the total time fixating each ROI (sum of the durations of all fixations at a ROI during the analysed time window), we again eliminated, for each participant, observations that distanced more than 2.5 SD from the mean time. This corresponded to 1.69% and 0.77%

[2] Figure 3 plots the raw time measures for easier visualization, but our analyses were conducted on the log-transformed measures (cf. Analysis section). Please note that the raw data includes the influences of other fixed and random effects in the model on the outcome variable which are accounted for in the model. Therefore, patterns in the raw data may not always correspond to significant (partial) effects in the model. Asterisks indicate significant effects in the model.

of data for the sets corresponding to fixations to the Face and fixations to the Gazed-at Location, respectively. Figure 3 (right) shows the mean total time (non-transformed) spent fixating each ROI for the Older and Younger Age groups, and Table 2 (right) presents the output of the LMM models on transformed times. We found no age-differences in the time spent inspecting the Gazed-at Location. Conversely, an effect of Group on the total time fixating the Face indicated that youngers adults spent significantly more time inspecting this ROI. Visual salience predicted longer total fixation times for both groups.

Probability of fixating ROI at each ordinal fixation

Our analyses so far suggest that older adults looked more often at the gazed-at object than younger adults, while younger adults spent longer than older looking at the face of the person in the scene. However, those measures are not informative about whether prioritzation of social information in scenes occurred immediately after stimuli presentation or later in the presentation period. Moreover, age differences in eye movement characteristics (namely, that older adults take more time to execute an eye movement than younger adults do; e.g., Klein, Fischer, Hartnegg, Heiss, & Roth, 2000; Munoz, Broughton, Goldring, & Armstrong, 1998[3]) might be a confound in time measures. To address these issues, we further analysed the probabilities of fixating each ROI at the first few fixations made after scene onset. The meaning of a scene can be perceived very quickly (Potter, 1976), and prioritazation of objects for visual inspection in scenes happens from the first fixation (e.g., Henderson, Weeks, & Hollingworth, 1999; Spotorno & Tatler, 2017), so prioritization of social information may occur very early in viewing (e.g., Fernandes et al., 2021).

[3] In our data, first saccade latency was significantly higher for older compared to younger adults (M=200.81 and 191.31, SD=92.96 and 166.06, t = 2.88, df = 5676.2, p-value = 0.004045). Older participants also made significantly more fixations than the younger participants (M=17.58 and 16.04, SD=2.88 and 3.77, t = 18.473, df = 6311.3, p-value < .001).

Figure 4 plots the probabilities of fixating each ROI at each ordinal fixation from the first to the fifth fixation. For our analysis, we first computed the mean probabilities of fixation to each ROI for each participant and each ordinal fixation: For example, for participant x, the probability of fixating the Face at the first fixation corresponds to the number of trials when the participant fixated the Face at the first fixation divided by the number of trials the participant was presented (thus, for each participant, the mean is aggregated across items). We then fitted to those mean probabilities a growth-curve analysis (Mirman, Dixon, & Magnuson, 2008) whereby ordinal fixation is a 'time' predictor alongside age group. This approach allows to capture the non-linear distribution of the data over the sequence of fixations: Ordinal fixation was modelled as an orthogonal polynomial of order 2. The linear term of the polynomial ($Order^1$) has the same interpretation as a linear regression of probability of fixations over sequence of fixations. The quadratic term ($Order^2$) can be used to identify changes in the linear trend, e.g., a decrease followed by an increase.

Table 3 presents the output of the models. For the Face, the negative term $Order^1$ indicates that fixations on the face overall decreased as observers made progressive fixations, and the positive term $Order^2$ indicates that the evolution had a convex form, i.e., the decrease in fixations was sharp in the beginning and then slower. Younger adults fixated more the Faces than older adults (main effect of Group), but by the fifth fixation the probability of fixating the Face is similar for both groups (stronger decrease in probability for younger adults, as indicated by the Group:$Order^2$ interaction).

For fixations to the Gazed-at Location, $Order^1$ and $Order^2$ have opposite signs to the ones observed for fixations to the Face. There was an overall linear increase of fixations to this ROI, and the evolution along the sequence of fixations was concave, meaning there was an initial increase followed by a decrease in fixations. In this case, older adults fixated the ROI more (main effect of group). This main effect was modulated by the term $Order^2$, indicating that the increase and subsequent decrease of the probability of fixation on the Gazed-at Location was of larger magnitude for the older participants.

As for the previously analysed measures, higher visual salience was associated with higher likelihood of fixation.

Discussion

Previous research has investigated age-related differences in gaze following with an attentional cueing paradigm where participants detect a target that can appear on a location congruent or incongruent with the averted gaze of a presented face. In those studies, younger adults were faster to detect targets on the cued location compared to the non-cued location, but older adults were less sensitive to gaze cues. Here we recorded the eye movements of participants who simply looked at social scenes, and we found that older adults followed the gaze of people in the scenes more than their younger counterparts. These results challenge previous assumptions of reduced gaze following in older age, and highlight the limitations of the gaze-cueing paradigm to investigate gaze following.

In the current study participants looked freely at scenes that were presented for 5 seconds. We found that older adults were more likely to look at the region where the person in the photograph was looking, and made more fixations to it during a trial, compared to younger participants. They also prioritized this Gazed-at Location for visual inspection soon after scene onset to a greater extent than the younger group. Group differences in these measures are not likely due to any age-differences in eye movements' characteristics. First, although older adults might make overall more eye movements (e.g., Açik et al., 2010; Ho, Scialfa, Caird, & Graw, 2001), there were age-differences in the probability and number of fixations to the Gazed-at Location but not to the Face region. Second, our analysis of the probability of fixating the Gazed-at Location at each ordinal fixation from the beginning of the trial is independent of the durations of fixations and the total number of fixations in the trial: whatever the time spent to make an eye movement (saccade latency, which increases with age, Klein et al., 2000; Munoz et al., 1998), older adults were more likely to select the Gazed-at Location for early visual inspection (first five fixations) than the younger adults. Moreover, concerning this Gazed-at Location, we found no interactions between group and salience, showing that the age-differences were not due to any differences in utilizing low-level image properties. Therefore, our results indicate that older adults prioritized the gaze cues of depicted persons more than younger counterparts.

We did not find group differences on the time to first fixate the Gazed-at Location. Even though older participants fixated the Gazed-at Location at an earlier ordinal fixation than younger participants did, age-related increases in saccade latency may have equalised the latency of initial looking at this location. We also found no age-differences in total time fixating the Gazed-at Location across the 5s available for each scene, and this likely indicates that, at later stages of visual inspection, younger and older participants allocate similar visual attention to this region.

We also measured fixations to the Face region. We found that younger adults spent reliably more time looking at the face, and prioritized the face for visual inspection more than older adults (as indexed by longer total fixation times and probability of fixating during the first five fixations). This builds upon other studies using videos or real social interactions which indicate similar age-related reductions in fixating on the face region (e.g., De Lillo et al., 2021; Grainger, Steinvik, Henry, & Phillips, 2018; Vicaria, Bernieri, & Isaacowitz, 2015). Yet, older adults also allocated more visual attention to the Gazed-at Location, suggesting that gaze following is independent of foveal scrutiny of the Face, and age-differences in it are not due to differences in attention to faces. Thus, previously-reported findings that older adults look less at the faces of others should not be interpreted as implying that this results in less gaze following in older than younger adults.

In the number of fixations to Face, the main effect of visual salience was qualified by an interaction with group, indicating that younger adults fixated the face more times when it was more salient. This finding is consistent with the idea that younger adults' viewing behaviour is more closely associated with visual properties of the scenes (e.g., Nuthmann et al., 2020). In a supplementary analysis[4] we considered the association between salience and all fixations made during the 5s viewing period and found that this association was larger for younger than for older participants, although the magnitude of this difference was small. In all other measures for the Face region, and for the Gazed-at Location, salience did not interact with group. Therefore, while the salience of Face regions might have contributed to the reported age-differences in how faces in our scenes were inspected, it was not a confounding factor in the gaze following behaviour: older adults prioritized and looked more at where people in the scenes where looking, regardless of visual properties of that region.

Our results stand in contrast with evidence from prior studies using the Posner-style gaze cueing paradigm which indicate that older adults show reliably less gaze cueing than younger counterparts (as reviewed by McKay et al., 2022). Those tasks involve viewing disembodied heads with no semantic context, and often contain task demands which explicitly discourage gaze following. Here we have used photographs of real scenes and allowed naturalistic viewing. The current results suggest that older adults may engage in more gaze following under these conditions, which reflect more the way we are likely to process gaze cues in everyday life. Also, the current task measured overt attention to gaze

[4] We calculated the area under the receiver-operator curve – AUC – with the correspondence between salience and fixations providing the hit rate and the correspondence between control locations and salience providing the false alarm rate. Confidence intervals were calculated from 10,000 bootstrapped samples of the data. The AUC for older participants was 0.6858 [95%CI: 0.6858-0.6859] whereas for younger participants it was 0.6997 [95% CI: 0.6997-0.6997].

cues with eye movements, whereas the Posner cueing tasks generally assess covert attention using target detection response times. Based on previous findings of reduced gaze following for older adults in Posner-like tasks, together with the present findings of increased overt gaze following in older adults when freely viewing scenes, it might be hypothesized that adult aging causes less covert attention to be guided by gaze direction while overt attention to gaze direction is preserved or even increased with age. Kuhn, Pagano, Maani, and Bunce (2015) also reported that, in a variant on a Posner-style task where participants were instructed to fixate on a target, there were no age-differences in overt attention to gaze cues. Covert attention has the potential to be a more efficient way to detect the target of anothers' gaze compared to overt movement. This highlights the importance of future studies to understand age-differences in both overt and covert attention to gaze cues, using both eye movements and response times in a range of gaze cueing tasks.

In our study participants had no specific task to perform and could look to wherever they liked in the photograph. As suggested in prior studies (Kuhn et al., 2018), demands of tasks such as searching for an object may override spontaneous gaze following. Free viewing is in stark contrast with the gaze cueing paradigm (e.g., Driver et al., 1999; Friesen & Kingstone, 1998), where participants have to search for a target and, moreover, the task sets up a conflict between attention to an irrelevant gaze cue and a relevant target. Therefore, one possible explanation for why prior gaze cueing studies reported greater gaze following by younger compared to older adults is that older participants might be more engaged with the instruction to ignore gaze cues, or even have better capacity to supress non-predictive gaze cues. While this seems counter to extensive evidence of age-related decline in inhibitory processing (Campbell, Lustig & Hasher, 2020), there is evidence from the field of socioemotional cognition that older adults may be particularly efficient in following instructions to suppress emotions (Phillips et al., 2008; Scheibe & Blanchard-Fields, 2009).

Future research could use instructional and motivational manipulations to more clearly delineate the role of these factors in age-differences in social gaze behaviour. A further difference in our study is that we used real photographs as stimuli. These provide a social context that is lacking in the presentation of faces in isolation, and may be particularly relevant for older adults. With aging there is an increased use of context information in cognitive processing (Lindenberger & Mayr, 2014; Madden, 2007), and the use of context should be even more important for social attention mechanisms. It is thus important for future research on age-differences in gaze following to use tasks and techniques that resemble more real life situations.

Our results are consistent with the idea of developmental changes in the dynamics of gaze cueing. Frischen et al. (2007) noted that, although the use of gaze cues can be observed from the first year of life, this early sensitivity to gaze seems to be more based on low-level/ perceptual processes, but soon infants process gaze in a way that is affected by more complex processes such as emotion, and so gaze following 'quickly becomes sensitive to the context in which the observed gaze behavior occurs' (p. 698). This context sensitivity of gaze following might be even greater in old age, consistent with a stronger reliance on contextual information for stimuli processing. However, further research would be needed to assess in detail how age-differences in gaze following are modulated by the contextualization of stimuli.

Likewise, it would be interesting to investigate own-age biases in gaze following with more naturalistic tasks. In the study by Slessor et al. (2010) using the gaze-cueing paradigm, young adults followed the gaze of faces in their own age range more than the one of older adults' faces, but an own-age bias was not observed for younger adults. However, Freebody and Kuhn (2018) found no own-age bias in gaze following when both children and young adults freely viewed scenes. Most of the photographs used in the current study depicted young adults, and thus we did not have sufficient variability in our stimuli to test for own-age biases. Therefore, it remains to be seen whether own-age biases are observed in older adults in more naturalistic tasks.

To the best of our knowledge, our study is the first to use an eye tracking paradigm where participants freely observe complex scenes to investigate gaze following in the old age. Our results illustrate that, in more naturalistic settings, older adults follow gaze more than younger counterparts. By using a scene free-viewing task we address the concerns for the lack of social context in the gaze cueing paradigm (e.g., Risko et al., 2012), and contribute to the more naturalistic measuring of social attention processes (Cole, Skarratt, & Kuhn, 2016). As a further step, it is important to extend the current research to look at gaze following using real social interactions where eye movements can be registered through mobile eye trackers (e.g. de Lillo et al., 2021).

Conclusion

We asked older and younger adults to freely view photographs of real-world scenes with one person gazing at an object or location while we recorded their eye movements. We found that older adults prioritized and allocated more visual attention to the gazed-at location in the scene, compared to younger adults. Our results stand in stark contrast with prior evidence from the standard decontextualised Posner-style gaze cueing paradigm where instructions discourage following gaze cues. We suggest that the fact that older adults follow gaze cues less than younger adults in that standard task may reflect the task instructions and decontextualised stimuli used. Our current results, using eye-tracking to assess more naturalistic aspects of social attention, indicate instead that older adults may follow gaze more than younger adults in settings that resemble more real life situations.

Data availability statement

The data that support the findings of this study are available from the corresponding author, E. G. F., upon reasonable request.

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Declaration of interest statement

The authors report there are no competing interests to declare.

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Table 1. Summary of the linear mixed effects models (LMM) fitted to the probability and number of fixations the Face and the Gazed-at Location.

	Fixations to Face							
	Probability of fixating				**Number of fixations**			
(Intercept)	6.73	0.50	13.45	<.01	5.813	0.24	24.16	<.01
group [O, -0.55; Y, 0.45]	0.10	0.58	0.18	0.86	-0.18	0.35	-0.52	0.61
ROI_salience_max [-1.9 to 2.7]	**0.51**	**0.24**	**2.13**	**0.03**	**0.459**	**0.17**	**2.74**	**0.01**
group:ROI_salience	0.51	0.31	1.66	0.10	**0.11**	**0.06**	**1.95**	**0.05**
	Fixations to Gazed-at Location							
	Probability of fixating				**Number of fixations**			
(Intercept)	2.78	0.17	15.96	<.01	3.4	0.14	24.15	<.01
group [O, -0.55; Y, 0.45]	**-0.55**	**0.22**	**-2.45**	**0.01**	**-0.43**	**0.14**	**-3.13**	**<.01**
ROI_salience_max [-1.7 to 5.4]	**0.56**	**0.14**	**3.89**	**<.01**	**0.379**	**0.13**	**3.01**	**<.01**
group:ROI_salience	0.05	0.10	0.53	0.60	-0.02	0.05	-0.32	0.75

Note: syntax of models are: Probability: glmer(Fixation ~ 1 + group + ROI_salience + group:ROI_salience + (1 | item) + (1 | subj), family = binomial(link = "logit"), data = dataset); Number of Fixations: lmer (NumberFixations ~ 1 group + ROI_salience + group:ROI_salience, data=dataset)

Table 2. Summary of the linear mixed effects models (LMM) fitted to time to first fixate and to total time fixating Face and Gazed-at Location.

	Fixations to Face							
	Time (log(ms)) to First Fixate				**Total Time (log(ms)) Fixating**			
Predictors	Est.	SE	t	p	Est.	SE	t	p
(Intercept)	5.65	0.04	126.43	<.01	7.29	0.05	144.67	**0.01**
group [O, -0.55; Y, 0.45]	-0.12	0.07	-1.64	0.10	**0.15**	**0.07**	**2.11**	**0.04**
ROI_salience_max [-1.9 to 2.7]	**-0.08**	**0.03**	**-2.73**	**0.01**	**0.10**	**0.04**	**2.72**	**0.01**
group:salience	-0.01	0.01	-0.54	0.59	0.00	0.01	0.35	0.72
	Fixations to Gazed-at Location							
	Time (log(ms)) to First Fixate				**Total Time (log(ms)) Fixating**			
(Intercept)	6.79	0.05	128.01	<.01	6.64	0.05	144.26	<.01
group [O, -0.55; Y, 0.45]	0.12	0.07	1.70	0.09	-0.04	0.05	-0.69	0.49
ROI_salience_max [-1.7 to 5.4]	**-0.16**	**0.04**	**-3.74**	**<.01**	**0.13**	**0.04**	**3.36**	**<.01**
group:salience	0.01	0.02	0.43	0.67	0.01	0.02	0.70	0.49

Note: syntax of models is lmer(depM ~ 1 + group + salience + group:salience + (1 | item) + (1 | subj), data = dataset, control = lmerControl(optimizer ="Nelder_Mead")

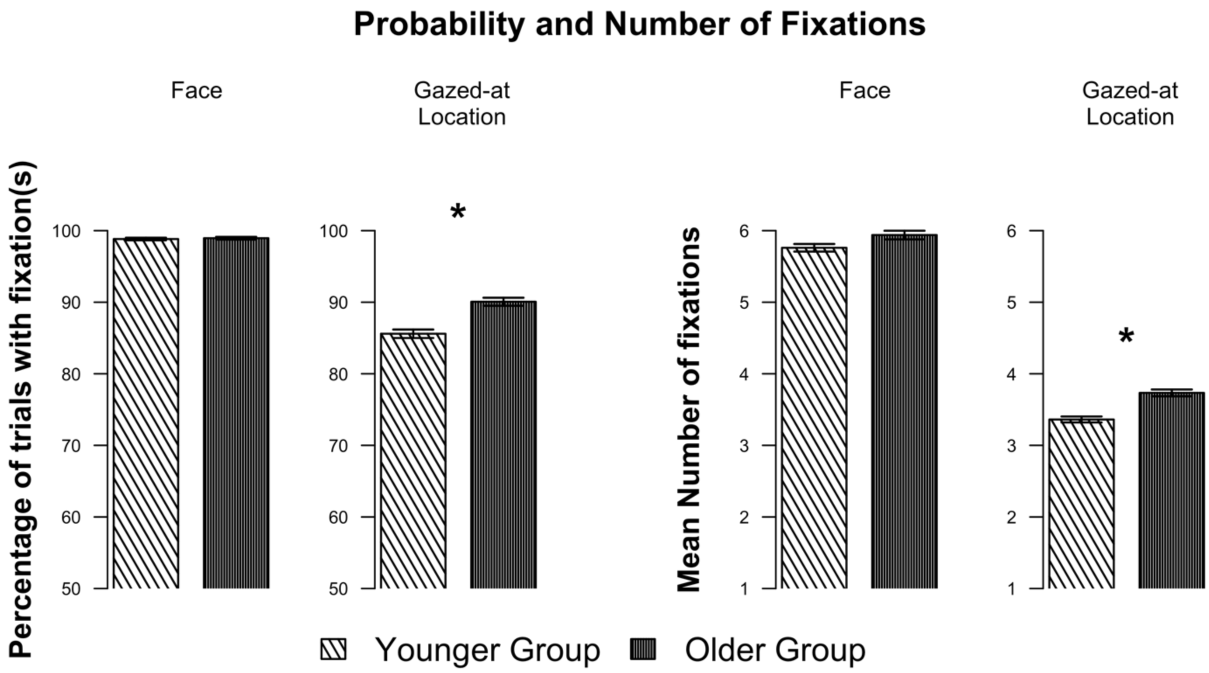
Table 3. Summary of the linear mixed effects models (LMM) fitting the mean probabilities of fixations to the Face and the Gazed-at Location along the first five fixations.

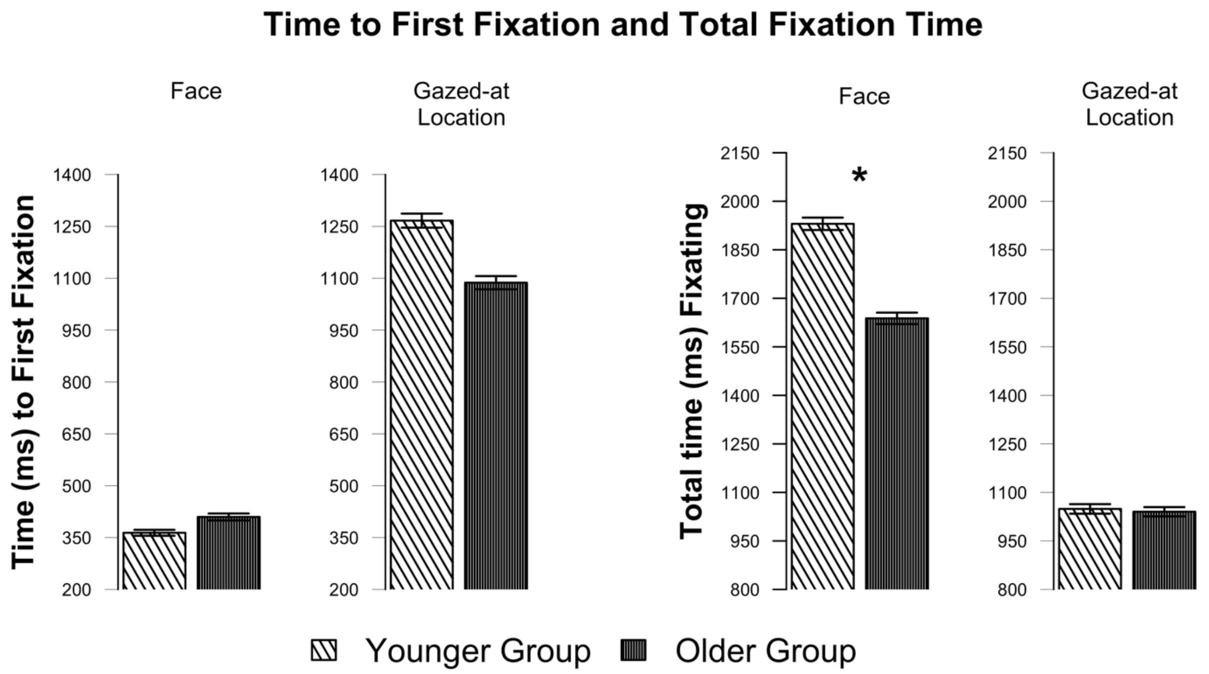
Prob. of Fixating Face at Ordinal Fixation				
Predictors	Estimate	SE	t value	p value
(Intercept)	0.46	0.01	41.43	<.01
group [O, -0.55; Y, 0.45]	**0.04**	**0.01**	**6.09**	**<.01**
Order1	**-0.39**	**0.01**	**-28.12**	**<.01**
Order2	**0.12**	**0.01**	**8.99**	**<.01**
ROI_salience_max [-1.9 to 2.7]	**0.03**	**0.01**	**2.78**	**0.01**
group: Order1	0.00	0.01	0.03	0.98
group: Order2	**-0.03**	**0.01**	**-2.02**	**0.04**
group:salience	0.01	0.01	0.88	0.38
Order1:salience	-0.01	0.01	-0.71	0.48
Order2:salience	0.00	0.01	0.32	0.75
group: Order1:salience	0.01	0.01	0.84	0.40
group: Order2:salience	0.00	0.01	-0.16	0.87
Prob. of Fixating Gazed-at Location at Ordinal Fixation				
Predictors	Estimate	SE	t value	p value
(Intercept)	0.29	0.01	24.98	<.01
group [O, -0.55; Y, 0.45]	**-0.04**	**0.01**	**-6.70**	**<.01**
Order1	**0.13**	**0.02**	**7.66**	**<.01**
Order2	**-0.15**	**0.01**	**-13.03**	**<.01**
ROI_salience_max [-1.7 to 5.4]	**0.05**	**0.01**	**3.93**	**<.01**
group: Order1	-0.01	0.01	-0.62	0.54
group: Order2	**0.06**	**0.01**	**4.36**	**<.01**
group:salience	-0.01	0.01	-1.86	0.06
Order1:salience	0.00	0.02	-0.21	0.83

Order2:salience	**-0.03**	**0.01**	**-2.50**	**0.01**
group: Order1:salience	-0.01	0.01	-0.52	0.60
group: Order2:salience	0.00	0.01	0.21	0.83

Note: $Order^1$ is the linear term and $Order^2$ is the quadratic term coding the sequence of ordinal fixations. syntax of model is lmer(meanProbability ~ 1 + group + Order1 + Order2 + group:Order1 + group:Order2 + group:salience + Order1:salience + Order2:salience + Order1:group:salience + Order2:group:salience + + (1 | image) + (0 + Order1 | image) + (0 + Order2 | image), data = dataset)


A
B


Probability and Number of Fixations
Face
Gazed-at Location
Face
Gazed-at Location
Percentage of trials with fixation(s)
100
90
80
70
60
50
*
Mean Number of fixations
6
5
4
3
2
1
*
Younger Group
Older Group


Time to First Fixation and Total Fixation Time
Face
Gazed-at Location
Face
Gazed-at Location
Time (ms) to First Fixation
Total time (ms) Fixating
1400
1250
1100
950
800
650
500
350
200
2150
2000
1850
1700
1550
1400
1250
1100
950
800
*
Younger Group
Older Group

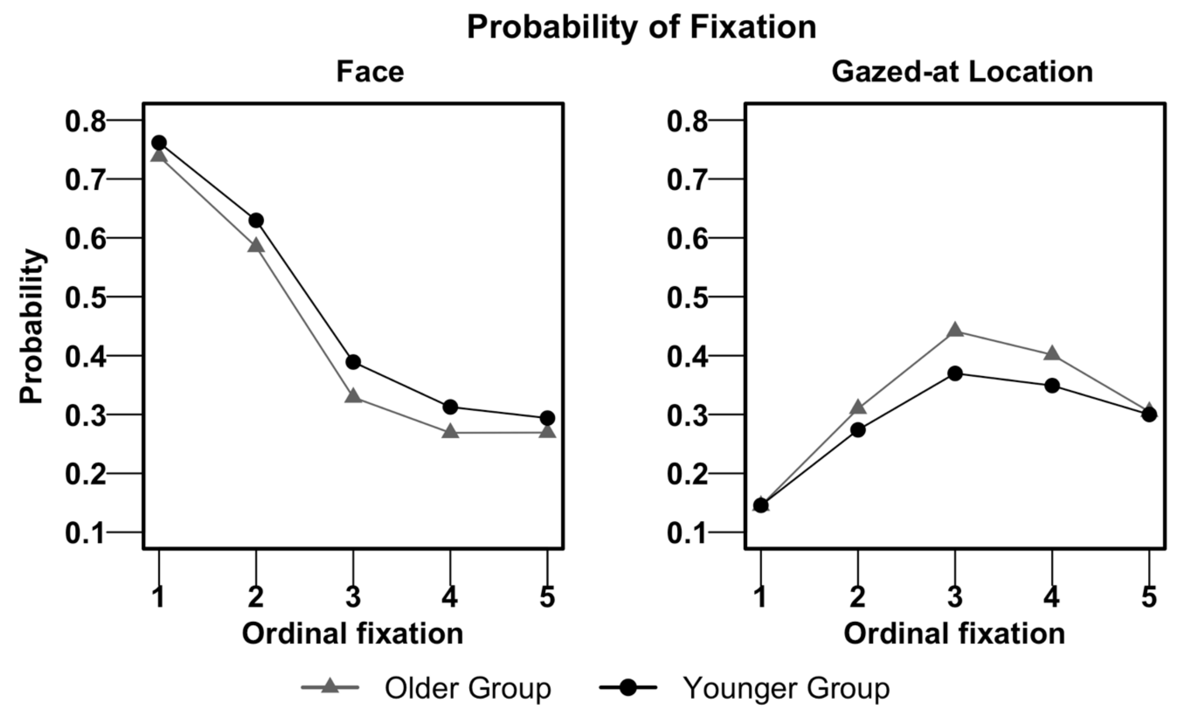

Probability of Fixation
Face
Gazed-at Location
Probability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
Ordinal fixation
Older Group
Younger Group

Figure 1. Sample images that were stimuli in the experiment (A) and an example of the ROIs 'Gazed-at location' and 'Face' (B).

Figure 2. Mean percentage of trials with at least one fixation (left) and mean number of fixations (right) to the Face and to the Gazed-at Location, for the Older and Younger Age groups. Error bars represent standard errors of means, and the asterisk indicates significant difference.

Figure 3. Time to first fixate (left) and total time fixating (right) the Face and the Gazed-at Location, for the Older and Younger Age groups. Error bars represent standard errors of means, and the asterisk indicates significant difference.

Figure 4. Mean probability of fixation to the Face (left) and Gazed-at Location (right) at each ordinal fixation number for the Older (grey triangles) and Younger (black circles) groups.