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Age-Related Declines in Basic Social Perception: Evidence From Tasks Assessing Eye-Gaze Processing

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Previous research has investigated age differences in complex social perception tasks such as theory of mind and emotion recognition, with predominant findings of age-related declines. The present study investigated whether there are also age-related changes in basic aspects of social perception. Individuals' ability both to detect subtle differences in eye-gaze direction (e.g., where someone is looking in the environment) and to subsequently use these gaze cues to engage in joint attention with others was assessed. Age-related declines were found in the detection of the most subtle differences in gaze aversion. The ability to engage in joint attention by following gaze cues also declined with age. These age differences were not solely attributable to age impairments in visual perception and visual attention. The potential role of age-related neural declines in social perception problems was considered, along with the implications that age deficits in these basic social skills may have for older adults' social perception.

Keywords: eye gaze, gaze following, aging, emotion, social perception

Previous research has investigated age-related changes in complex aspects of social cue decoding such as *theory of mind* (ToM), the ability to represent mental states such as the beliefs, thoughts, and intentions of others (Sullivan & Ruffman, 2004b). The majority of these studies have found evidence of an age-related decline in these abilities (Phillips, MacLean, & Allen, 2002; Slessor, Phillips, & Bull, 2007; Sullivan & Ruffman, 2004b). However age differences in more basic and specific aspects of social perception have not been assessed. One such aspect is eye-gaze detection. *Eye gaze* refers to the direction in which another person is looking in the social environment (e.g., whether someone is looking toward or away from the perceiver; Emery, 2000).

According to Baron-Cohen's (1995) mind-reading model, there is a specialized system responsible for eye-gaze perception, which he referred to as the *eye direction detector*. This system is responsible for three main functions: (a) identifying eyes or eye-like stimuli in the environment, (b) processing gaze direction, and (c) interpreting eye gaze as seeing. Baron-Cohen argued that this basic mechanism is linked to another more advanced component of the mind-reading model, the *shared attention mechanism*. One of the main functions of this mechanism is to identify whether the self and another person in the social environment are attending to the same stimulus. This skill is known as *joint attention* (e.g., the ability to identify where or what someone is attending to in the social environment and orient attention to the same stimulus; Driver et al., 1999). Baron-Cohen considered this ability to be a critical precursor to the development of the ability to interpret and make inferences about the mental states of others. The most common way of engaging in joint attention is to follow the gaze of others. This ability emerges early in development, with children of approximately 3 months successfully engaging in gaze following (Hood, Willen, & Driver, 1998). In order to use gaze cues to establish joint attention with others, the shared attention system must use information from the eye-gaze direction system to detect what another person is looking at. Therefore the ability to detect eye-gaze direction and to subsequently use this information to establish joint attention with others is of particular importance to more complex aspects of social perception such as ToM (Baron-Cohen, 1995). Eye-gaze perception has also been found to play an important role in emotion recognition. According to recent research, gaze direction (direct vs. averted) influences younger adults' perception of emotion faces, with direct gaze enhancing the perception of anger and joy and with averted gaze enhancing the perception of fear and sadness (Adams & Kleck, 2003, 2005).

In addition to their importance for other aspects of social cue decoding, the basic ability to detect eye-gaze direction and subsequently use this information to establish joint attention with others is critical for many components of everyday social functioning (for a review, see Allison, Puce, & McCarthy, 2000; Emery, 2000; Langton, Watt, & Bruce, 2000). Gaze direction provides perceivers with a means of evaluating another person's interest in the external environment (e.g., an object's location), which enables the early detection of socially relevant information from the environment, alerting and orienting information processing toward social cues. Therefore gaze direction is very important for guiding our interactions with other people (Langton et al., 2000).

Due to the significance of eye-gaze perception in everyday life and for more complex aspects of social perception, it is important to discover whether there are any age-related changes in this ability. Age-related declines have been found in other, more complex aspects of social perception such as ToM and emotion recognition (Phillips et al., 2002; Slessor et al., 2007; Sullivan &

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Ruffman, 2004a, 2004b). Older adults are also more likely to show some inappropriate social behaviors in interpersonal situations (Henry, von Hippel, & Baynes, in press; von Hippel & Dunlop, 2005). Deficits in the basic processing of eye-gaze direction have been found in other subpopulations, such as people with autism or schizophrenia, who also have problems with mental state decoding (Rosse, Kendrick, Wyatt, Issac, & Deutsch, 1994; Senju, Hasegawa, & Tojo, 2005; Senju, Tojo, Yaguchi, & Hasegawa, 2005; Senju, Yaguchi, Tojo, & Hasegawa, 2003; Zhu et al., 2007). People with autism have also been found to have fundamental problems engaging in joint attention, and tasks assessing gaze-following ability are one of the best measures of distinguishing between those with and without autism (Dawson et al., 2004; Ristic et al., 2005). Abnormalities in gaze following have also been reported in individuals with schizophrenia (Langdon, Corner, McLaren, Coltheart, & Ward, 2006).

In addition to the specialized mechanisms responsible for eye-gaze detection and gaze following, it has been suggested that there is a neural network centering on the superior temporal sulcus (STS) region, which is dedicated to processing changeable aspects of faces, including eye gaze (Haxby, Hoffman, & Gobbini, 2002). This suggestion is supported with results from electrophysiological studies of nonhuman primates (Perrett, et al., 1985), studies assessing the eye-gaze detection of brain-damaged patients (Akiyama et al., 2006a), and neuroimaging research investigating the neural correlates of eye-gaze perception in healthy younger adults (Hoffman & Haxby, 2000; Hooker et al., 2003; Puce, Allison, Benton, Gore, & McCarthy, 1998; Wicker, Michel, Henaff, & Decety, 1998). It has been argued that populations who have difficulties processing eye-gaze direction have abnormalities in the structure or activation of the STS region (Grice et al., 2005; Rosse et al., 1994; Senju, Tojo, Yaguchi, & Hasegawa, 2005).

The STS region has also been implicated when participants orient their attention in response to the gaze of another person (Pelphrey, Morris, & McCarthy, 2005). In addition, frontal brain regions such as the ventromedial prefrontal cortex and the superior frontal sulcus, which are activated when completing more complex ToM measures, are also involved in joint attention (Williams, Waiter, Perra, Perrett, & Whiten, 2005). Again, research suggests that deficits in the ability to engage in joint attention in autism are associated with abnormalities in the activation of the STS and in the structure of the superior frontal sulcus (Pelphrey et al., 2005; Waiter et al., 2004). A patient with damage to his frontal lobes (Vecera & Rizzo, 2004, 2006) and one patient with a focal lesion in the STS region (Akiyama et al., 2006b) have also been found to have problems orienting their attention in response to gaze cues. The findings of Vecera and Rizzo (2006) suggest that gaze following involves controlled attentional processes.

These finding have important implications for aging research, as the frontal and temporal brain regions show the earliest and greatest age-related deterioration (Greenwood, 2000; West, 1996). In particular, the STS region has been found to be subject to neuronal degeneration with age. For instance, between the ages of 40 and 87 a 24% decline in gray matter density of the STS has been reported (Sowell et al., 2003). Age-related declines in the gray matter density of the prefrontal brain regions, which support joint attention and more complex social cognitions, have also been well documented (see Raz & Rodrigue, 2006, for a review). Therefore the ability to both identify eye-gaze direction (i.e., averted vs. direct) and follow the gaze of others may be impaired with aging.

Given that these findings suggest there may be age differences in basic eye-gaze detection and gaze following, and the potential importance of these abilities to social functioning, it is surprising that age-related changes in these skills have not been previously investigated. The present research intends to fill this gap in the literature by investigating whether there are age-related impairments in basic eye-gaze detection and use of gaze cues to engage in joint attention with others. This will result in a greater understanding of age-related changes in more basic and specific aspects of social perception.

Study 1

Study 1 addresses whether there are age-related declines in the ability to detect subtle differences in eye-gaze direction. Groups of younger and older adults were presented with a series of face images manipulated to portray subtle differences in eye-gaze direction. Given age-related declines in the key brain areas involved in eye-gaze detection, we predicted that gaze detection would be poorer in older adults. An additional question addressed in this study is whether any age-related impairment in gaze detection is related to declining visual perception with age.

Method

Participants

Two groups of participants were recruited: 45 young adults (36 women, 9 men) ranging in age from 17 to 34 ($M = 20.00$, $SD = 3.50$), the majority of whom were students who completed the study for course credit, and 41 older adults (31 women, 10 men) ranging in age from 65 to 79 ($M = 72.63$, $SD = 3.93$), recruited through the local participant panel and reimbursed for their time. All had good command of the English language and were free from past or present neuropsychological disorders. All participants who required corrective lenses wore them while completing the experiment. The groups did not differ in their years of education, $t(84) = -0.12$ (young $M = 13.72$, $SD = 1.16$; old $M = 13.73$, $SD = 3.44$). Younger adults had significantly better visual contrast sensitivity than did older participants, as measured by the Pelli Robson Contrast Sensitivity Chart (Pelli, Robson, & Wilkins, 1988), $t(84) = 4.49$, $p < .001$ (young $M = 1.85$, $SD = 0.13$; old $M = 1.72$, $SD = 0.12$). We screened older adults for dementia using the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975). They all achieved a score greater than 24 ($M = 28.34$, $SD = 1.13$), which is the recommended cutoff point (Chayer, 2002).

Stimuli and Procedure

Four actors (2 men and 2 women), each displaying a neutral facial expression, were selected from the Facial Expressions of Emotions: Stimuli and Test (FEEST; Young, Perrett, Calder, Sprengelmeyer, & Ekman, 2002). All images used were full-face portraits, and therefore we manipulated only eye-gaze direction and not position or direction of head. Adobe Photoshop was used to manipulate the degree of gaze aversion, which involved moving the position of the pupil in both eyes to the left or right. Images with six different degrees of gaze aversion were created (see

Figure 1). For each actor two images with direct gaze and six with averted gaze (each presenting one of the six different gaze aversions) were presented. Therefore in total 32 photographic face images (each image was approximately 14 cm × 16 cm) were presented to participants, individually in the center of a computer screen, in a pseudorandom order.

Participants sat approximately 45 cm from the 23-in. computer monitor on which the stimuli were presented. They were asked to look carefully at the face images and to decide in which direction they thought the photographed person was looking. They were instructed to press the left-hand key (*Z*) if they thought the person was looking to the left, the right-hand key (*M*) if they thought the person was looking to the right, or the spacebar if they thought the person was looking straight ahead. Performance on left- and right-averted gaze conditions were collapsed for each level of gaze aversion, and thus there were four gaze conditions in total: direct (2.04° from the center), 1 pixel (0.13° from direct gaze) averted, 2 pixels (0.25° from direct gaze) averted, and 3 pixels (0.38° from direct gaze) averted.

Results

The descriptive statistics for the performance of older and younger adults on each of the four gaze conditions can be seen in Tables 1 and 2. For percentage accuracy, we conducted a 4 (gaze condition) × 2 (age group) mixed-design analysis of variance (ANOVA) with repeated measures on the first factor. This revealed a significant main effect of gaze condition, $F(3, 252) = 223.43$, $p < .001$, $\eta_p^2 = .73$, with both age groups demonstrating poorest performance on the 1-pixel averted condition. There was also a main effect of age group, $F(1, 84) = 12.82$, $p < .001$, $\eta_p^2 = .13$, with younger adults outperforming older participants on the eye-gaze task. A significant Age × Gaze Condition interaction was also found, $F(3, 252) = 9.39$, $p < .001$, $\eta_p^2 = .10$.

To ascertain for which of the gaze conditions there were significant age differences, we conducted a series of post hoc independent-samples *t* tests. This revealed a significant age-related decline in the 1-pixel averted, $t(84) = 2.99$, $p < .01$, and 2-pixels averted conditions, $t(84) = 4.51$, $p < .001$. In the 1-pixel averted condition, older adults' performance (28.05%) was below chance level (i.e., 33.3%). A one-sample *t* test revealed that the performance of younger participants (38.06%) was not significantly greater than chance, $t(44) = 1.74$, $p = .09$. There were no significant age differences in the detection of gaze direction in the direct, $t(84) = -1.82$, $p = .07$, and 3-pixels averted conditions, $t(84) = 1.59$, $p = .12$.

The key finding from this analysis was an age-related decline in the 2-pixels averted condition. As there was a significant age-related impairment in visual contrast sensitivity, for this gaze condition we carried out an analysis of covariance (ANCOVA) with vision scores on the Pelli Robson Contrast Sensitivity Chart (Pelli et al., 1988) as a covariate. This analysis did not remove the significant effect of age in the 2 pixels condition, $F(1, 83) = 12.07$, $p < .01$, $\eta_p^2 = .13$ (young $M = 82.57\%$; old $M = 64.56\%$).

Age differences in reaction times for each gaze condition were also analyzed. A series of independent-samples *t* tests revealed significant age-related slowing on all gaze conditions (see Table 2).

However, as can be seen from the percentage accuracies in Table 1, there was evidence of a nonsignificant age-related improvement in the ability to detect direct gaze. This suggests that older adults may have a greater propensity than younger adults to respond "direct" regardless of gaze direction. To control for this potential bias, in accordance with previous studies in the social perception literature (e.g., Miles & Johnston, 2007), we carried out a nonparametric signal detection analysis (MacMillan & Creelman, 1991; Pollack & Norman, 1964). First, hit and false alarm rates were calculated for each averted gaze condition. A hit was classified as a correct identification of averted gaze, whereas a false alarm was classified as identifying direct gaze as averted. These hit and false alarm rates were then used to calculate estimates of sensitivity to discriminate between direct and averted gaze (A′) and response bias (B″D) separately for each age group and each gaze condition (see Table 1).

To investigate age differences in estimates of sensitivity for each gaze condition, we then performed a series of independent-samples *t* tests. Sensitivity estimates in the 1-pixel averted, $t(84) = -0.262$, $p = .79$, and 3-pixels averted gaze conditions, $t(84) = -0.310$, $p = .76$, were comparable across younger and older adults. The only significant difference between the age groups was found in the 2-pixels averted condition, $t(84) = 2.04$, $p < .05$, with older adults having a lower sensitivity score.

We also compared estimates of response bias exhibited by each group in each gaze condition using independent-samples *t* tests. Significant age differences were found on the 2 pixels, $t(84) = -4.14$, $p < .01$, and 3 pixels averted conditions, $t(84) = -2.68$, $p < .01$. This age difference approached significance only in the 1-pixel averted condition, $t(84) = -1.92$, $p = .06$. Older adults showed a more conservative bias (i.e., they were more likely to respond "direct") than did younger adults in all gaze conditions.

Figure 1. Example of a set of seven images. Directions of gaze represented in the figure (from left to right) are as follows: 3 pixels (0.38°) left, 2 pixels (0.25°) left, 1 pixel (0.13°) left, direct (2.04° from the center), 1 pixel (0.13°) right, 2 pixels (0.25°) right, and 3 pixels (0.38°) right. Reprinted from *Facial Expressions of Emotions: Stimuli and Tests (FEEST)*, by A. Young, D. Perrett, A. Calder, R. Sprengelmeyer, and P. Ekman, Copyright 2002, with permission from Thames Valley Test Co.

Discussion

The aim of this study was to investigate whether there was an age-related decline in the ability to detect subtle differences in eye-gaze direction (i.e., where someone is looking in the social environment). Our results were consistent with previous findings of age impairments in other aspects of social cue decoding, such as emotion recognition and ToM (Slessor et al., 2007; Sullivan & Ruffman, 2004a, 2004b): Older adults were found to make significantly more errors on the eye-gaze detection task, suggesting that there is also an age-related impairment in this very basic, simple social perception task, which unlike many ToM tasks does not require additional cognitive processes. However, a significant in-

Table 1
Accuracy (Mean Percent Correct) and Standard Deviations for Each Gaze Condition and Overall Total on the Eye-Gaze Task and Summary of Estimates of Sensitivity (A′) and Response Bias (B″D)

	Young				Old			
Condition	Mean % correct	*SD*	A′	B″D	Mean % correct	*SD*	A′	B″D
Direct	77.22	15.61			83.54	16.64		
1 pixel averted	38.06	18.46	.62	.65*	28.05	18.49	.63	.78*
2 pixels averted	83.61	15.27	.87	−.19	63.42	23.45	.83	.41*
3 pixels averted	93.89	10.87	.92	−.58*	89.02	15.36	.92	−.20
Total	73.06	8.77			65.93	9.42		

* $p < .01$.

teraction between age and gaze condition indicated that older adults did not demonstrate impaired performance on all gaze conditions. Detection of direct and clearly averted gaze (e.g., 3 pixels averted) did not significantly differ between the age groups, but there were significant age-related impairments in the ability to detect subtle differences in gaze aversion (e.g., the 1-pixel and 2-pixels averted conditions). However caution must be exercised when interpreting these results, as there was evidence of a floor effect on the ability of both younger and older adults to detect gaze aversion in the 1-pixel averted condition. Age-related declines found on the 2-pixels averted condition remained even after controlling for visual contrast sensitivity, suggesting that all age differences in eye-gaze detection cannot be attributable to age impairments in visual contrast sensitivity.

However the finding of a tendency for older adults to perform better on the direct gaze condition than younger adults suggests that they may have a propensity to respond “direct” in all gaze conditions. Signal detection analysis confirmed that there were significant age differences in the response biases on this task. In all gaze conditions older adults were more likely than younger adults to respond “direct” (i.e., thinking that someone was looking straight ahead). Both older and younger adults had a bias toward responding “direct” in the most subtle gaze-aversion condition (e.g., 1 pixel averted). However as the degree of gaze aversion increased, younger adults were more likely to have a bias to respond “averted.” In contrast, older adults still showed a bias toward responding “direct” in the 2-pixels averted condition. This finding is somewhat consistent with findings in other subpopulations. For example, people with schizophrenia have been found to be more likely to think that a person is looking at rather than away from them (Rosse et al., 1994).

It is unlikely that the bias found in this study was due to older adults immediately pressing the spacebar without fully examining each image, as there was not a ceiling effect on their performance in the direct gaze condition. In addition, analysis of the reaction times revealed significant age-related slowing in all gaze conditions (see Table 2), suggesting that older adults’ responses were carefully considered. However, when investigating age-related declines in the different gaze conditions it is important to control for these age differences in response bias. Therefore estimates of sensitivity were also calculated. This analysis removed the significant difference between older and younger adults’ performance in the 1-pixel averted condition, suggesting that older and younger adults were comparable in their ability to differentiate between direct and 1-pixel averted gaze. Again, there were no age differences in the 3-pixels averted condition. Crucially, however, the age-related decline in the 2-pixels averted condition remained, with older adults being less sensitive to the differences between direct and 2-pixels averted gazes. Therefore neither the greater propensity for older adults to respond “direct” nor the age-related decline in visual contrast sensitivity accounted for all the age-related declines in eye-gaze detection. However, it is important to further investigate age-related changes in the response biases found on this task to discover whether these differences are specific for eye gaze or also extend to the judgment of the direction of nonsocial stimuli. In addition, researchers should continue to explore the age-related impairment found in the 2 pixels condition by investigating age-related changes in the ability to detect

Table 2
Mean Reaction Times and Standard Deviations for Correct Responses in Each Gaze Condition and t-Test Results

	Young		Old		
Condition	Mean RT	*SD*	Mean RT	*SD*	*t*
Direct	871.08	292.71	1,391.34	658.51	6.51*
1 pixel averted	931.72	277.34	2,114.27	1,363.78	7.76*
2 pixels averted	798.23	133.05	1,703.35	798.23	12.37*
3 pixels averted	746.13	101.77	1,422.66	634.65	12.62*
Total	787.87	116.48	1,434.70	598.64	11.82*

Note. Reaction times (RTs) are in milliseconds. The *t* values represent a summary of independent-samples *t* tests comparing young and old individuals’ performance on the gaze-detection task after transforming RTs to reciprocals.
* $p < .01$.

more subtle differences in gaze direction (e.g., by decreasing the changes in degree of visual angle between different gaze conditions).

Study 2

Having demonstrated age-related declines in the basic detection of eye-gaze direction, in Study 2 we examined whether there were also age impairments in the ability to engage in joint attention by using the gaze cues of others. According to Baron-Cohen's (1995) mind-reading model, there is an integral link between the ability to detect eye-gaze direction (eye-gaze direction detector) and share attention with others (shared attention mechanism). He argued that the easiest way to engage in joint attention with others is to use visual cues about where someone else is looking in the social environment, and thus the key function of the shared attention mechanism relies heavily on the eye-gaze direction detector. Therefore it could be argued that the age impairments in gaze detection we found may lead to age-related problems in gaze following. Previous aging research has found evidence of an age-related impairment in attentional processes. However all these studies have used nonsocial attentional cues (Madden, 2007). It is also important to consider age differences in the ability to orient attention in response to social cues.

The most powerful cue to attention in social perception is gaze direction, as this cues others' attention to important events in the social environment. Therefore investigating age-related changes in eye-gaze processing makes an important contribution to the aging and social perception literature. Research investigating gaze following in younger adults found that they did orient their attention to the gaze of others, responding more quickly to gaze-congruent targets compared to gaze-incongruent targets (Bayliss, di Pellegrino, & Tipper, 2005; Driver et al., 1999).

When investigating age-related changes in joint attention, it is also important to consider the emotional expression displayed by the facial cue. In younger adults, emotional expression has sometimes been found to modulate joint attention, as gaze congruency effects are greater when combined with fearful or angry expressions compared to happy or neutral expressions (Holmes, Richards, & Green, 2006; Holmes, Vuilleumier, & Eimer, 2003; Mathews, Fox, Yiend, & Calder, 2003; Putman, Hermans, & van Honk, 2006). However this finding is controversial, with other studies having found that fearful or angry expressions did not enhance the gaze congruency effects of younger adults (Hietanen & Leppanen, 2003). According to the socioemotional selectivity theory, older adults deliberately recruit strategic processes to ignore negative information, instead focusing on more positive experiences (Carstensen, Fung, & Charles, 2003). Evidence from previous aging research suggests that older adults may avoid attending to negative facial expressions of emotion and, in particular, the eye region of negative emotion faces (Mather & Carstensen, 2003; Sullivan, Ruffman, & Hutton, 2007; Wong, Cronin-Golomb, & Neargarder, 2005). This suggests that any age differences in gaze following might be influenced by the emotion present in the face. In particular, older adults may fail to engage in joint attention to negative emotion faces. For this reason, the emotional expressions on the faces shown in the gaze cueing task were varied.

Study 2 investigates the following three research questions: First, are there age-related declines in the ability to follow the eye gaze of others and thus establish joint attention with them? To address this, participants completed a dynamic gaze cueing task in which the gaze of face images was either congruent or incongruent with the subsequent location of a target that the participant was required to respond to. Second, if an age-related impairment in the ability to engage in joint attention is apparent, is it more pronounced for the gaze of negative emotion faces? In addition to neutral face images, positive and negative emotion faces were included. Finally, are any age-related deficits in gaze following attributable to general age-related impairments in other functions known to decline with age (e.g., visual attention and visual contrast sensitivity)? Age-related deficits have been found in other, more general aspects of visual attention (see Madden, 2007, for a review), and thus it is possible that these general impairments contribute to any deficits in joint attention. Therefore, in addition to the gaze-following task participants also completed an attention-cueing task in which the gaze cue was replaced by a nonsocial stimulus (an arrow). Arrows were chosen because they have most frequently been used as the cue in control tasks of previous joint attention studies (e.g., Akiyama et al., 2006b; Bayliss et al., 2005; Bayliss & Tipper, 2005; Frischen, Ristic, & Kingstone, 2004). Again, visual contrast sensitivity was assessed by the Pelli Robson Contrast Sensitivity Chart (Pelli et al., 1988).

Method

Participants

We recruited 45 (36 women, 9 men) younger adults ($M = 20.02$ years, $SD = 3.49$) and 36 (27 women, 9 men) older adults ($M = 72.11$ years, $SD = 3.86$) from the same sample as Study 1. The groups did not differ significantly in years of education, $t(80) = -0.02$ (young $M = 13.67$, $SD = 1.18$; old $M = 13.68$, $SD = 3.58$). Older adults had significantly poorer vision as measured by the Pelli Robson Contrast Sensitivity Chart (Pelli et al., 1988), $t(80) = 4.68$, $p < .001$ (young $M = 1.85$, $SD = 0.13$; old $M = 1.72$, $SD = 0.12$).

Stimuli and Procedure

Gaze cueing task. Facial expressions from the FEEST stimulus set (Young et al., 2002) were employed. Grayscale photographs of four actors (2 men and 2 women) expressing happy, sad, fearful, angry, and neutral expressions were selected and manipulated. These emotions were chosen as frequently occurring examples of positive and negative (threatening and nonthreatening) emotions. In the emotion conditions, expressions of four levels of emotional intensity (0%, 25%, 75%, and 100%) were used. We manipulated gaze direction of these images using Adobe Photoshop so that images at 0% emotional intensity had direct gaze (1.53° from the center), those at 25% intensity had gaze averted 2 pixels (0.13° from direct gaze) to the left or right, those at 75% intensity had gaze averted 4 pixels (0.25° from direct gaze) to the left or right, and those at 100% intensity had gaze averted 6 pixels (0.38° from direct gaze) to the left or right. In the neutral condition degree of gaze aversion was manipulated in the same way, but only 0% emotional intensity faces were used.

For the morphing sequences in all conditions the four face images were presented in the following order: direct gaze, 2 pixels averted, 4 pixels averted, and finally 6 pixels averted. Thus gaze became gradually averted to either the left or the right (see Figure 2), and the emotion became more intense. Each image was approximately 14 cm × 16 cm. This morphing procedure was employed because it is similar to the most recent methodology used to investigate gaze following in younger adults (Putman et al., 2006) and has been found to produce strong congruency effects in this sample. In addition, as in everyday life, both gaze and emotional expression are dynamic social cues, so employing this morphing procedure is also more ecologically valid. Also, previous research has argued that compared to static images dynamic emotional stimuli increase activation in the brain regions (e.g., STS and amygdala) that are involved in eye-gaze perception and emotion processing (Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004). These findings suggest that both younger and older adults would be most likely to demonstrate gaze following when using this paradigm.

The cueing task consisted of 120 trials in total. Two thirds of the trials were valid trials in which gaze direction was congruent with the subsequent position of the target. In the remaining trials gaze direction of the face was incongruent with the subsequent target location. Each trial began with a central fixation cross that remained on the screen for 1,000 ms. Participants were asked to focus on the fixation cross, hold their attention in that location until the target appeared, and then return their gaze to the fixation cross after making their response. The presence of gaze cues was deliberately not mentioned to participants, as the present study aimed to specifically investigate whether participants would spontaneously follow the gaze of others. After 1,000 ms the fixation cross disappeared and the morphing face sequence was presented. Each face display consisted of four gradually morphing images at 40 ms per picture, with a further 60 ms for the final image. The morphing sequence lasted 220 ms in total. Immediately following the presentation of the face sequence, the final face disappeared and the target (an asterisk approximately 1 cm × 1cm) appeared approximately 10.5 cm to the left or the right of the center of the screen.

Participants sat approximately 45 cm from the 23-in. computer monitor on which the stimuli were presented. They were told they would see a dynamic face image on the screen and that following this image a target would appear to either the left or the right of the face. They were asked to respond to the target as quickly and accurately as possible by pressing the left-hand key (*Z*) when the target appeared on the left and the right-hand key (*M*) when the target appeared on the right. Cue direction, target position, actor, and facial expression occurred equally often and were presented in a pseudorandom order.

Arrow cueing task. Similar to the face images created in the gaze-following task, for each trial in the arrow task four arrow images were created and presented. Each trial began with an arrow image with two arrow heads, of equal thickness, pointing to the left and right (4.94° from the center). Following presentation of this initial image one of the arrow heads gradually became thinner while the rest of the arrow image thickened until there was an arrow with a single arrow head pointing to the left or the right (see Figure 3). Immediately following the presentation of the arrow sequence the final arrow image disappeared and the target (an asterisk approximately 1cm × 1cm) appeared approximately 10.5 cm to the left or the right of the center of the screen. Each arrow image was approximately 7.5 cm × 2.5 cm.

The procedure employed in the arrow cueing task was identical to that used in the gaze cueing task. However the dynamic face image was replaced by a dynamic arrow image. Similar to each of the emotion conditions in the gaze cueing task, there were 24 arrow trials in total. One third of these were incongruent trials.

Data reduction. Error rates were low for all conditions of the gaze cueing task and the arrow task (see Table 3). Therefore reaction time (RT) to congruent versus incongruent trials was the main dependent variable. In accordance with previous research (Holmes et al., 2003, 2006), for both the arrow and gaze cueing

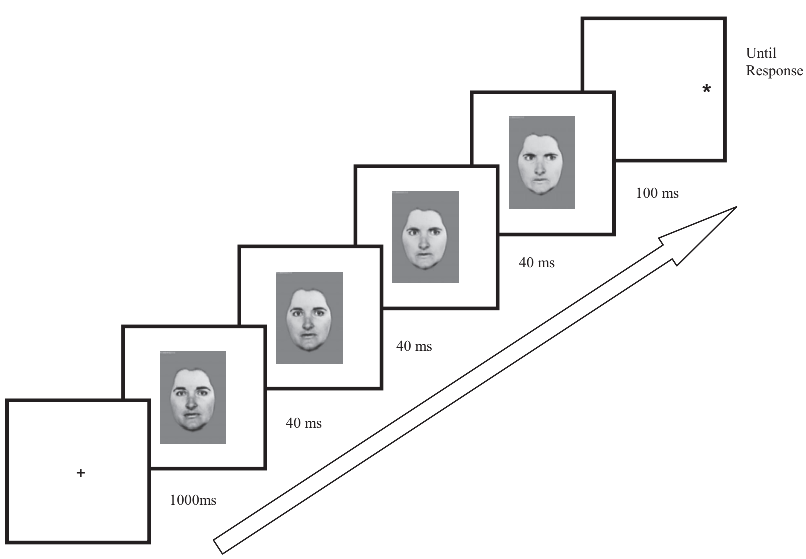

Figure 2. Illustration of stimulus sequence for gaze cueing task. In the trial illustrated, the target (the asterisk) appears on the congruent side.

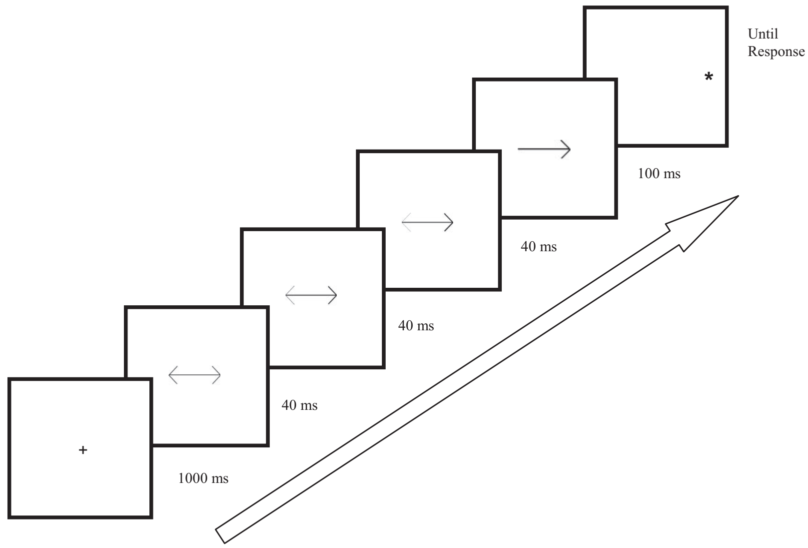

Figure 3. Illustration of stimulus sequence for arrow cueing task. In the trial illustrated, the target (the asterisk) appears on the congruent side.

tasks, error trials and trials with response times of less than 100 ms were removed from each participant's data. Median response times for the correct trials in each condition were then calculated individually for each participant. Each person's data were then transformed to reciprocals in order to reduce the number of outliers and produce a more normal distribution of scores (Howell, 2006). Note that although analyses were carried out on these reciprocal RTs, descriptive statistics of performance are reported in terms of the raw median scores.

Results

Gaze Cueing Task

The descriptive statistics for the performance of younger and older adults on each of the emotion conditions in the gaze cueing task can be seen in Table 3. To assess whether there were any age differences in performance on the gaze cueing task, we conducted a mixed-design ANOVA with two within-subjects factors: expression (joy, sadness, fear, anger, or neutral) and cue congruity (congruent vs. incongruent). Age (young vs. old) was the between-subjects factor. RT analysis revealed a significant main effect of cue congruity, $F(1, 79) = 123.65$, $p < .001$, $\eta_p^2 = .61$, with significantly faster responses to congruent (vs. incongruent) trials. A main effect of emotion was also found, $F(4, 316) = 5.03$, $p < .01$, $\eta_p^2 = .06$. Subsequent analyses using Bonferroni pairwise comparisons revealed that participants responded more slowly in the neutral condition compared to the happy and sad conditions (ps $< .01$). There was also a significant main effect of age, $F(1, 79) = 46.38$, $p < .001$, $\eta_p^2 = .37$, as older adults performed more slowly on both the congruent and incongruent trials across all emotion conditions. A significant Cue Congruity × Age interaction was found, $F(1, 80) = 29.98$, $p < .001$, $\eta_p^2 = .28$, suggesting that the strength of congruency effects (RT difference between congruent and incongruent trials) differed in the two age groups. Both younger, $t(44) = 10.18$, $p < .001$, $d = 1.52$, and older adults, $t(35) = 6.65$, $p < .001$, $d = 1.11$, responded significantly more quickly to congruent trials, showing the expected congruency effect. To investigate the age differences in the strength of the congruity effect on the gaze cueing task, we conducted an independent-samples t test. The independent variable was the proportion of the difference between RT to congruent versus incongruent trials (i.e., the difference between RT to congruent

Table 3
Mean Reaction Times and Standard Deviations for the Gaze Cueing Task (Broken Down by Emotion Condition) and the Arrows Task

	Young				Old			
	Congruent		Incongruent		Congruent		Incongruent	
Condition	*M* (% errors)	*SD*	*M* (% errors)	*SD*	*M* (% errors)	*SD*	*M* (% errors)	*SD*
Joyful gaze	306.79 (0.00%)	51.42	341.51 (3.33%)	49.74	410.03 (0.34%)	134.64	422.68 (1.02%)	136.89
Sad gaze	303.60 (0.14%)	51.41	340.78 (3.61%)	51.36	410.11 (0.67%)	127.08	421.63 (1.01%)	122.78
Fearful gaze	306.67 (0.42%)	50.60	340.28 (6.11%)	49.03	415.63 (1.18%)	135.08	438.61 (0.34%)	130.27
Angry gaze	302.36 (0.42%)	49.89	340.97 (3.06%)	46.19	415.06 (0.17%)	130.27	434.89 (1.01%)	121.21
Neutral gaze	308.18 (0.14%)	46.26	344.26 (4.72%)	43.01	419.06 (0.68%)	131.81	442.01 (1.35%)	117.45
Arrows	314.46 (0.14%)	59.85	390.14 (15.56%)	58.48	411.74 (1.01%)	97.78	472.50 (4.73%)	108.14

minus incongruent trials, divided by congruent RT). The strength of the congruency effect in older adults ($M = 17.97$, $SD = 16.68$) was significantly smaller compared to the congruency effect shown by younger adults ($M = 36.04$, $SD = 21.60$), $t(79) = 5.35$, $p < .001$, $d = 1.16$. None of the remaining two- and three-way interactions was found to be significant: Cue Congruity × Emotion interaction, $F(4, 316) = 1.16$, $p = .33$, $\eta_p^2 = .01$; Emotion × Age interaction, $F(4, 316) = 1.86$, $p = .12$, $\eta_p^2 = .02$; Cue Congruity × Emotion × Age interaction, $F(4, 316) = 0.50$, $p = .74$, $\eta_p^2 = .01$ (see Figure 4).

Similarly to Study 1, in order to discover whether age-related declines in visual perception accounted for older adults' impairments in gaze cueing, we conducted an ANCOVA controlling for visual perception scores on the Pelli Robson Contrast Sensitivity Chart (Pelli et al., 1998). The dependent variable in this analysis was the proportion of the overall size of the gaze congruity effect collapsed across all emotion conditions (i.e., mean RT for congruent trials across all emotion conditions minus mean RT for incongruent trials across all emotion conditions, divided by congruent RT). This analysis revealed that there was not a significant effect of visual perception, $F(1, 78) = 1.93$, $p = .17$, $\eta_p^2 = .02$. The effect of age on the gaze congruity effect remained highly significant even after covarying visual perception, $F(1, 78) = 27.23$, $p < .001$, $\eta_p^2 = .26$.

Arrow Cueing Task

The descriptive statistics for the performance of younger and older adults on the arrow cueing task can be seen in Table 2. To investigate whether there was also an age-related deficit in the ability to perform the arrow cueing task, we carried out a further mixed-design ANOVA, with cue congruity (congruent vs. incongruent) as the within-subjects factor and age (young vs. old) as the between-subjects factor. A significant main effect of cue congruity was found, $F(1, 79) = 155.28$, $p < .001$, $\eta_p^2 = .66$, along with a main effect of age, $F(1, 79) = 37.27$, $p < .001$, $\eta_p^2 = .32$, suggesting that there was a general age-related slowing on this task. As for the emotion gaze cueing task, there was also an Age × Cue Congruity interaction, $F(1, 79) = 20.35$, $p < .001$, $\eta_p^2 = .21$. Paired samples t tests comparing RT in the congruent trials with RT on the incongruent trials showed that both younger, $t(44) = 10.37$, $p < .001$, $d = 1.55$, and older adults, $t(35) = 8.84$, $p < .001$, $d = 1.47$, responded significantly more quickly to congruent (vs. incongruent) trials. We carried out an independent-samples t test to further investigate age differences in the size of these congruity effects. The dependent variable (arrow congruity effect) was calculated as the difference between RT on congruent trials minus RT on incongruent trials, divided by congruent RT. Older adults were found to have a significantly smaller congruity effect than younger adults, $t(79) = 3.33$, $p < .01$, $d = 0.75$ (see Figure 4).

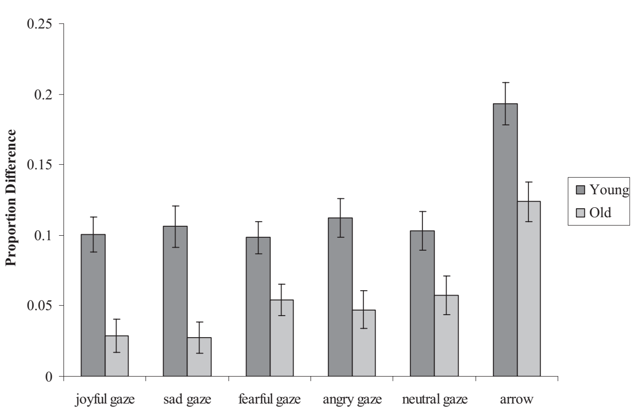

Figure 4. Graph depicting the strength of the congruity effect (proportion difference score between reaction time on congruent and incongruent trials) for younger and older adults on the gaze cueing task (broken down by emotion condition) and the arrows task. Bars represent standard errors of the mean.

To discover whether age-related declines in visual contrast sensitivity contributed to age impairments in the arrows task, we carried out an ANCOVA with performance on the Pelli Robson Contrast Sensitivity Chart as the covariate. Congruity effect on the arrows task was the dependent variable. This analysis revealed that, as for the gaze cueing task, the significant age effect remained, $F(1, 78) = 10.90$, $p < .01$, $\eta_p^2 = .12$, and visual perception was not a significant covariate, $F(1, 78) = 0.51$, $p = .48$, $\eta_p^2 = .01$.

We conducted a further ANCOVA to investigate whether age-related declines on the arrow cueing task contributed to the effect of age on the gaze cueing task. The dependent variable was the gaze congruity effect described above, whereas the covariate was the arrow congruity effect. The size of the arrow congruity effect was found to be a significant covariate, $F(1, 78) = 4.56$, $p < .05$, $\eta_p^2 = .06$. Despite this finding, the significant age group difference on the magnitude of the gaze congruity effect remained, $F(1, 79) = 17.01$, $p < .001$, $\eta_p^2 = .18$.

Discussion

The main aim of this study was to investigate whether there was an age-related decline in the ability to engage in joint attention with others by following their gaze. Findings indicated that older adults showed a significant effect of gaze congruity, indicating that they did follow the gaze of others. However they did so to a significantly lesser extent than did younger adults, and thus there was evidence of an age-related deficit in the ability to engage in joint attention with others. Similar to Study 1, this impairment in gaze following could not be explained by declines in visual perception with age. However, an age-related decline was also found for performance on a control arrow cueing task, suggesting that older adults also have problems orienting their attention in response to a nonsocial stimulus. Again, age-related declines in visual perception did not contribute to this age deficit. Controlling for performance on the arrow cueing task did not remove the significant effect of age on the gaze cueing task. Therefore age-related declines in joint attention were not solely attributable to general impairments in cue-related orienting of visual attention that occur with age. However it could be argued that these findings reflect an improvement in older adults' ability to ignore distracting cues (e.g., incongruent gaze cues), rather than an age-related decline in gaze following. Although this is unlikely, given previous findings of inhibitory deficits in older adults (e.g., Andrés, Van der Linden, & Parmentier, 2004; Houx, Jolles, & Vreeling, 1993; Sweeney, Rosano, Berman, & Luna, 2001), to resolve this issue future research should investigate whether there is also an age impairment when older adults are specifically instructed to use gaze cues.

A secondary aim of the current study was to discover whether an age-related decline in gaze following was more pronounced for negative emotion faces. Previous research has indicated that older adults attend less to negatively valenced stimuli (Mather & Carstensen, 2003). In particular, visual scanning studies have found that older adults tend to avoid looking at the eye region of negative emotion faces (i.e., fear, sadness, and anger; Sullivan et al., 2007; Wong et al., 2005), which could have direct implications for performance on the gaze cueing task (i.e., the congruency effect in older adults may be less pronounced for the gaze cues of negative emotion faces compared to happy and neutral gaze cues). In the present study there was a main effect of emotion, suggesting that both younger and older adults respond more slowly to neutral images than to the emotional faces, although this difference reached significance only for the sad and happy conditions. It is possible that the additional social cues present in the emotional faces aid the processing of these stimuli, allowing both younger and older adults to respond more quickly. However, more importantly, there was no significant interaction between cue congruity, emotion, and age, indicating that age-related differences in gaze cueing effects were consistent across all emotions.

Initially this finding appears to contradict earlier findings of less attention to negative information among older adults. However, according to the socioemotional selectivity theory older adults employ a deliberate controlled strategy to avoid negatively valenced stimuli (Carstensen et al., 2003). In the previously mentioned visual scanning studies participants viewed emotion faces for a longer period of time than in the current study. Therefore, in the present study older adults may not have had enough time to recruit motivationally controlled processes to avoid negative information. This suggestion is in keeping with the recent findings that age differences in these emotion effects occur only in controlled, but not automatic, attentional processes (Knight et al., 2007; Mather & Carstensen, 2005). It would also be interesting in future research to track the eye movements of older and younger adults when completing the gaze-following task used in the present study, as this would reveal which features of the face cues both age groups scan. This would also determine with more precision whether both age groups were following the gaze cue to look precisely at the same location (e.g., the target) or whether these cues result in a more general shift in spatial attention (e.g., toward the same side of space).

General Discussion

The present study is the first to investigate age-related changes in the basic social perceptual skills involved in the detection of eye-gaze direction and the ability to follow the gaze of others in order to establish joint attention with them. In keeping with the previous findings of age-related declines in more complex aspects of social perception (e.g., ToM and emotion perception; Phillips et al., 2002; Slessor et al., 2007; Sullivan & Ruffman, 2004a, 2004b), older adults were found to be poorer at the basic skill of detecting subtle differences in gaze direction. There was also evidence of an age-related impairment in their ability to establish joint attention with others by following gaze cues.

These findings are somewhat consistent with those of previous research that has investigated the eye-gaze processing of other subpopulations that have problems with more complex social perception tasks. For instance, individuals with autism and schizophrenia have deficits in the ability both to detect eye-gaze direction and to use gaze cues to orient their attention to objects of interest in the environment (Dawson et al., 2004; Langdon et al., 2006; Pelphrey et al., 2005; Ristic et al., 2005; Rosse et al., 1994; Senju, Hasegawa, & Tojo, 2005; Senju, Tojo, Yaguchi, & Hasegawa, 2005; Senju et al., 2003; Zhu et al., 2007).

These age-related declines in the ability to both detect subtle differences in eye-gaze direction and follow the gaze of others were not found to be solely attributable to general impairments in other functions known to decline with age (e.g., visual contrast sensitivity and, in the case of gaze following, visual attention). However declines in other aspects of visual perception may have contributed to these age impairments. For example, age-related decreases in fixation stability (Rohrschneider, Becker, Kruse, Fendrich, & Volcker, 1995) may result in difficulties in making the precise localization judgments required for the tasks presented in the current study. In addition, declines in motion sensitivity with age (Gilmore, Wenk, Naylor, & Stuve, 1992; Trick & Silverman, 1991) may have important consequences for older adults' performance on the gaze-following task. Future research is required to develop appropriate, more subtle comparison tasks that can effectively control for these visual perceptual issues, for instance, tasks that involve participants making judgments of fine-grained changes in direction similar to eye-gaze processing but using nonsocial stimuli. Another factor that might be important in age-related changes in eye-gaze processing is the brain regions that are implicated in these skills. For instance, age-related impairments in eye-gaze perception and joint attention may be due to the beginnings of age-related deterioration in the STS (Sowell et al., 2003) and ventromedial prefrontal areas (see Raz & Rodrigue, 2006), key regions in the neural network responsible for gaze processing. This interpretation concurs with the literature on autism, brain damage, and schizophrenia, where it has been argued that impairments in eye-gaze processing are due to anomalies in the STS and prefrontal brain regions (Akiyama et al., 2006a, 2006b; Grice et al., 2005; Pelphrey et al., 2005; Senju, Hasegawa, & Tojo, 2005; Senju, Tojo, Yaguchi, & Hasegawa, 2005; Rosse et al., 1994; Vecera & Rizzo, 2004, 2006; Waiter et al., 2004; Zhu et al., 2007). However, future research incorporating neuroimaging techniques is required to better understand the mechanisms that underlie these age-related declines.

Regardless of the reason for age-related impairments in these basic social skills, the finding that there are declines with age may have important implications for older adults' ability to decode more complex social cues. Gaze is an extremely powerful social cue that reflects the desires and intentions of others. Differences in gaze direction have also been found to be an important influence on the emotion perception of younger adults (Adams & Kleck, 2003, 2005), so age-related declines in eye-gaze detection may also have implications for older adults' emotion recognition. It is important to further investigate gaze processing in older adults using a variety of paradigms such as the tasks employed by Adams and Kleck (2003, 2005). Given the age effects found in both gaze processing and emotion recognition, it would be interesting to discover whether gaze also influences older adults' emotion perception. Baron-Cohen (1995) has also argued that both eye-gaze detection and the ability to follow the gaze of others are precursors to ToM, and therefore deficits in these abilities may underlie the age-related declines previously found in more complex components of social perception such as ToM and the perception of threat (Ruffman, Sullivan, & Edge, 2006). In addition, as these basic social skills are also critical for everyday social functioning, impairments in these abilities may have important implications for older adults' social interaction and interpersonal skills.

Charman (2003) found that the ability of children with autism to engage in joint attention with others was related to their communication and social interaction skills. There is no evidence to suggest that older adults have these same profound problems with social communication, although some subtle impairments in social interaction have been noted (Henry et al., in press; von Hippel & Dunlop, 2005). Age impairments in eye-gaze processing may contribute to age-related decreases found in the frequency of social interactions and social participation (Ajrouch, Antonucci, & Janevic, 2001; Desrosiers, Noreau, & Rochette, 2004). These deficits may also underlie age-related declines in other aspects of social perception (e.g., ToM). Longitudinal developmental research has revealed an association between the joint attention ability of young children and their later performance in ToM tasks (Charman et al., 2001). Conversely, performance on a basic eye-gaze detection task did not correlate with performance on ToM measures in a group of people with schizophrenia (Zhu et al., 2007). Future research should directly investigate whether these age-related declines in eye-gaze detection and gaze following do impact upon the social perception and functioning of older adults.

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