Barriers block the effect of joint attention on working memory: Perspective taking matters.

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Abstract

Joint focus of attention between two individuals can influence the way that observers attend, encode and value items. Using a non-predictive gaze cuing task we previously found that working memory (WM) was better for jointly attended (validly cued) versus invalidly cued coloured squares. Here we examine whether this influence of gaze on WM is driven by observers sharing the perspective of the face cue (*mental state account*), or simply by increased attention to the cued location (*social attention account*). To manipulate perspective-taking, a closed barrier obstructed the cue face's view of the memoranda, while an open barrier allowed the cue face to 'see' the colours. A central cue face flanked by two identical barriers looked left or right, followed 500ms later by coloured squares for encoding which appeared equally often in the validly and invalidly cued locations. After a blank 1000ms maintenance interval, participants stated whether a probe colour was present or not in the preceding display. When the barrier was open, WM was significantly impaired for invalidly versus validly cued items. When the barrier was closed, the effect of gaze cues on WM was abolished. In contrast, further experiments showed a significant cuing effect on the speed of simple target localisation and colour discrimination regardless of barrier type. These findings support the *mental state account* of joint attention in WM, whereby the attentional focus of another alters WM via higher-level engagement with the second person perspective. A goal-specific model of perspective taking is proposed.

Joint attention is defined as the mutual focus of two individuals on an object, person, or event. Individuals can engage in joint attention on two levels. (1) Shared gaze - one person follows another's gaze, resulting in the alignment of attentional focus. This basic level of joint attention provides a reference frame for social interaction to develop (Tomasello, 1995). (2) Intention processing – once attentional focus is synchronised, we can then infer why a person is looking at something and what their feelings and intentions might be. This deeper level of joint attention engages theory of mind - the understanding that other individuals have different perspectives and knowledge than we ourselves do (e.g. Charman et al., 2000), and mentalization skills - the ability to make inferences about the mental states of others and understand their perspective (Frith & Frith, 2006).

The effects of shared gaze have been studied extensively. Humans cannot help but follow others' eye gaze, a phenomenon termed the gaze cuing effect (e.g. Frischen, Bayliss, & Tipper, 2007). This has been investigated using a variation of the traditional Posner cueing task (Posner, 1980) where a central cue face looks left or right and a subsequent target is presented in either the looked at (validly cued) or looked away from (invalidly cued) location (e.g. Friesen & Kingstone, 1998). It is reliably found that perceptual detection, localisation, and discrimination is faster and more accurate for target items in the valid versus invalid gaze condition, even when the gaze cues do not predict where the target will appear and are therefore best ignored (Frischen et al., 2007).

Shared gaze has also been found to influence higher-level processes such as object appraisal and memory, with no equivalent influences found using non-social cues such as arrows. Studies show that items looked at by the cue face (validly cued), and thus jointly attended, are liked more by observers than invalidly cued items that the cue face looked away from (Bayliss, Paul, Cannon, & Tipper, 2006; Capozzi, Bayliss, Elena, & Becchio, 2015; van der Weiden, Veling, & Aarts, 2010), despite the gaze cue being entirely non-predictive of where the information appears. It has been suggested that looking signals interest (e.g. Shimojo, Simion, Shimojo, & Scheier, 2003) and that observers align their preferences with that of others in the manner of social reinforcement (Bayliss et al., 2006). In the memory domain, joint attention has been shown to enhance long term memory (LTM) for words (Dodd, Weiss, McDonnell, Sarwal, & Kingstone, 2012). We recently extended this line of investigation to examine the influence of joint attention on working memory (WM) (Gregory & Jackson, 2017). In this study, a central non-predictive cue face looked left or right, and 500ms later coloured squares were presented equally in either the validly or invalidly cued location, or under the condition of no gaze shift (direct gaze baseline) for encoding into WM. The squares and face disappeared from view for 1000ms (thus engaging WM), then participants stated whether a singularly presented test square was present or not in the preceding array. WM was significantly enhanced for jointly attended squares, indicating that immediate goal-directed cognitive processes can be altered by the looking behaviour of others.

However, it is important to question whether this influence of eye gaze on WM is simply caused by an attention boost at the looked-at location (the *social attention account*), or if it reflects intention processing wherein observers adopt the perspective of the cue (the *mental state account*). To examine this question we consider two ways in which visual attention can be directed, (a) in a space-based manner, and (b) in an object-based manner (e.g., Marotta, Casagrande, & Lupiáñez, 2013; Yantis & Serences, 2003). Space-based guided attention occurs when we broadly align our attention in the direction indicated by another's gaze. Information that then appears in the attended location is processed more effectively and efficiently, due to a temporary boost of attentional resource to that area of space. The *social attention account* reflects space-based attentional enhancement of information that appears in the attended versus unattended location. It is labelled *social attention* here because only gaze cues were shown to modulate WM - arrows and moving line cues did not (Gregory & Jackson, 2017). However, this specificity of the gaze cuing effect in WM does not necessarily imply that perspective taking was engaged during this task. Perhaps gaze cues were stronger arbiters of space-based attention orienting than non-socio-biological cues, and were thus the only cue that could direct sufficient attentional resource to exert a measurable impact on memory accuracy. The *social attention account* could plausibly explain enhanced WM for jointly attended items because items that receive more attention are preferentially encoded into WM (Awh, Vogel, & Oh, 2006).

In contrast to space-based attention, object-based attention involves more discrete attention allocation to specific information that inhabits a particular location, in order to process the detail of that information, such as item identity (Yantis & Serences, 2003). Importantly, the belief that another individual is looking *at* an object, and not just looking in the direction of an object, is considered to be a critical precondition of intention processing and perspective taking (Nuku & Bekkering, 2008; Teufel et al., 2009; Teufel, Fletcher, & Davis, 2010). This is stated as the attribution of ‘seeing’ versus ‘looking’ (Manera, Elena, Bayliss, & Becchio, 2014).

The distinction between space-based social attention and object-based perspective-taking is important when considering the significant relationship between joint attention and learning; joint attention has been linked to language learning (e.g. Tomasello & Farrar, 1986), object learning (e.g. Cleveland, Schug, & Striano, 2007; Striano, Chen, Cleveland, & Bradshaw, 2006; Wu, Gopnik, Richardson, & Kirkham, 2011), and spatial learning (Wu & Kirkham, 2010). Working memory is a critical component to learning (Baddeley, 2003), thus it is essential to understand the depth to which gaze cues engage social processing and theory of mind to influence WM performance in our task.

One method used to directly test perspective taking in gaze cuing tasks is to block the view of the cue face by using a barrier (e.g., Cole, Smith, & Atkinson, 2015; Manera et al., 2014). This involves showing the cue face in a way that implies that on certain trials it cannot see the items presented as they are occluded from its line of sight. Crucially, the observer can always see both the items and the gaze of the cue face. In this scenario, when a barrier is present the cue face is perceived as being unable to see past it. Therefore any items positioned in the looked towards location beyond the barrier are not jointly attended per se, although the cue face is looking in that direction (i.e., the cue face is looking but not seeing). The contrasting condition presents a physical structure through which the cue face can 'see', for example by use of a window or gap in the barrier. This allows researchers to test whether any effects of gaze cues are due to a shared perspective (*the mental state account*) or a simple effect of attention being boosted by the looking direction of the eyes, regardless of whether or not they can 'see' the object (*social attention account*). Support for the *mental state account* is provided if a closed or opaque barrier abolishes any gaze cuing effect that an open barrier affords. Support for the *social attention account* is provided if gaze cuing effects are found regardless of whether the barrier enables or disables the ability of the cue face to see the target information.

In a comprehensive study that used a variety of identification and change detection target tasks and gaze cue types (e.g., avatar versus human), there was found to be no modulation of the basic cuing effect on reaction times or task accuracy by the presence of a barrier that could be seen through or not (Cole et al., 2015; but see Kawai, 2011). This suggests that the effect of gaze cues on relatively simple perceptual tasks can be explained by the social attention account. However, researchers investigating the influence of gaze on object appraisal – a higher-level process that requires deeper cognitive involvement – did find that a barrier modulated the effect. Manera et al. (2014) used panels as barriers to occlude a non-predictive gaze cue and the target items such that the participant would interpret the gaze cue either as having seen or not seen the target items (separate experiments). They found that when participants interpreted the cues as not having seen the items, there was no influence of gaze upon item appraisal. However, in the study where the cue faces were interpreted as having seen the items, the looked at items were rated more favourably. In contrast, the barrier condition was not found to modulate the basic attention orienting effect - validly cued items were categorised as garage vs. kitchen objects faster than invalidly cued items regardless of whether the cue face could 'see' the items or not, replicating Cole et al. (2015). These findings therefore indicate that perspective taking was engaged during object appraisal but not for object categorisation, and suggest perhaps that a mental state account is supported when the task requires more in-depth processing and decision-making.

Here we adopted this methodology to test the *mental state account* of how gaze cues influence WM. We developed a barrier that could be easily incorporated into our previous paradigm (Gregory & Jackson, 2017), thus limiting task variation. In Experiment 1, we used the barrier to block or reveal coloured squares memoranda from the perspective of the cue face. The barrier was opaque and either had a window through which the cue face could 'see' the coloured squares (open barrier), or had no window so the face could 'not see' the squares (closed barrier). A closed barrier obscures the cue face's view of the objects and is predicted to disrupt object-based attention, but the cue still looks in that direction and thus space-based attention should be preserved. According to the *mental state account,* the influence of gaze cues on WM should only be observed when there is the impression that the cue face can see the coloured squares (open barrier) and not when the cue face cannot see the squares (closed barrier). Alternatively, if gaze cues influence WM regardless of the nature of the barrier and we find cuing effects on WM in both open and closed barrier conditions, then this would provide evidence in favour of the *social attention account*.

In order to determine the specificity of perspective-taking in WM and employ a further test of the social attention account, we also measured the effect of our barrier on the speed of attention orienting using a simple target localisation task (Experiment 2) and a colour discrimination task (Experiment 3). As Cole et al. (2015) and Manera et al. (2014) found cuing effects on simple reaction time tasks regardless of barrier type, here we predict to find the same pattern of results in Experiments 2 and 3 and thus support for a social attention account when task demands are low.

In all experiments, in addition to presenting valid and invalid gaze cues we also included a direct gaze condition in which the cue face continued to look straight ahead during target information presentation. This condition was absent in previous investigations of perspective taking in gaze cuing (Cole et al., 2015; Manera et al., 2014; Teufel et al., 2010). Direct gaze trials provide a useful control measure of whether barrier type influences task performance in the absence of any gaze shift / looking behaviour (it is not expected to). It also allows us to examine the mechanisms underpinning any gaze cuing effects we find. If only valid and invalid cuing manipulations are measured, where cuing effects exist we do not know whether valid cues served to facilitate performance or whether invalid cues impaired performance. Using the direct gaze measure, higher accuracy or faster reaction times in the valid versus direct condition provides evidence of a facilitation effect, while lower accuracy or slower reaction times in the invalid versus direct condition provides evidence of an attentional cost / impaired performance (e.g., see Friesen & Kingstone, 1998).

Experiment 1 – Working Memory Task

Method

Participants & Apparatus

Sixty-six adult volunteers from the University of Aberdeen participated in exchange for course credit or monetary reimbursement. Two participants aged over 60 were excluded because older adults (over 60 years) are found to show weaker gaze cuing responses (e.g. Slessor et al., 2016). Thus, 64 participants were included in the final analysis (48 female, 16 males, mean aged 24, age range 19-55), comparative to the sample in Gregory and Jackson (2017). All reported normal or corrected to normal vision, including no colour vision deficiency. Sample size was based on that used in Gregory and Jackson (2017) where the effect of the gaze cue on WM was a strong effect (ηp^2=.202, power >.99), therefore we are confident there is enough power here. The University of Aberdeen ethics committee approved all experiments, and all ethical procedures were upheld. Stimuli were presented using E-prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002) on a Dell LCD monitor (32-bit true colour; resolution 1280 X 1024 pixels Dell P190S 19 in. 4:3).

Stimuli

Face and memoranda stimuli were the same as those used in Gregory and Jackson (2017). The barrier consisted of a rhombus shape (50 X 260 pixels) made to have a 3-dimensional appearance. For the barrier with a window, the inside was removed to create an opening (45 X 168 pixels; see Figure 1). The barrier fit comfortably between the squares and the face, and the same distance was maintained from our previous study (Gregory & Jackson, 2017).

Design & Procedure

Initiation phase

In Manera et al.'s (2014) object evaluation barrier study, a post-hoc manipulation check assessed whether participants had the impression that the cue could or could not 'see' the items. Due to forming an inaccurate impression of the cue face's ability to see or not see the items, Manera et al (2014) needed to exclude 21 of 49 participants from experiment 2, and 7 of 34 participants from experiment 3 in their study. Therefore, to maximise the likelihood that participants had the intended impression of the barriers used in the current study, we employed a 24 trial initiation phase before the main experiment. Here gaze cues always looked towards an array of dots numbering from 1-6 (e.g. Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010) . The barrier was presented between the face and dots, with or without a window (see Figure 1) and all stimuli were presented simultaneously. Participants were required to report the number of dots that the face could see. If the barrier had a window (open barrier), participants were told the face could see the dots, thus should respond with the number seen using the keyboard (Figure 1A), and the trial ended when participants responded. If the barrier did not have a window (closed barrier) participants were told the face could not see the dots (Figure 1B) thus should press '0', otherwise a message said '*Incorrect - Only the faces with windows can see the items'*. Participants were also informed if the response was correct, they could then start the next trial by pressing spacebar. These responses were not recorded as part of this experiment.

Figure 1 about here

Main experiment

A 16-trial practice preceded the main experiment, 8 trials per barrier condition, blocked, counterbalanced. In the main experimental task critical within-subjects conditions were barrier type (open, closed) and cue validity (valid, invalid, direct gaze). The barrier type was presented in six alternating blocks, counterbalanced by participant number (i.e. a full block of open barrier, followed by a full block of closed barrier, or vice versa). A third of trials in each barrier condition were valid, invalid and direct, pseudorandomised. WM load (4, 6, and 8 squares, balanced, randomised) was varied in order to maintain contextual consistency in task difficulty and the unpredictable nature of task demands as per our previous study (Gregory & Jackson, 2017). For analysis, loads were collapsed, as we previously found no load by validity interaction and load effects were not of interest here[1]. Squares appeared equally to the left or right of the cue. A final condition manipulated test probe item at retrieval – present or absent in the preceding display – yielding 12 experimental conditions in total. There were 36 trials in each of the 12 conditions, thus 432 trials in total. Square colour combinations and face identities were pseudorandomised.

Figure 2 illustrates a trial sequence in each barrier condition. A trial began with a central fixation-cross (1000ms), replaced by the direct version of the gaze cue flanked on both sides by the barrier stimuli. After 750ms, the cue's gaze shifted left/right, or remained direct. After a stimulus onset asynchrony (SOA) of 500ms, coloured squares were presented for 100ms for encoding on one side of the cue. The squares, cue and barrier were replaced by a central fixation cross for a 1000ms WM maintenance interval. A single probe square was presented at centre and participants indicated via a key press using their right and left index fingers (Q for no, P for yes) whether this square had been present or not in the immediately preceding array (3000ms response window, all participants responded within this time frame). Regardless of barrier condition, participants were instructed to look at the centre at the start of each trial, remember all presented squares, and that cue direction did not predict square location. Though we asked them to look at the centre, in order to create realistic viewing conditions there was no requirement for participants to maintain fixation during the study, and we make no predictions based on whether attention is oriented in a covert or overt manner.

Figure 2 about here

Data analysis

Hits and FAs (see Table 1) were converted to d' for statistical analysis: d' = z(Hits) – z(FAs). Results are reported using standard null hypothesis significance testing with

[1] Analysis of the data by load showed no significant interaction effects: Barrier*Load, p=.395; Gaze*Load, p=.282; Barrier*Gaze*Load p=.919.

additional Bayesian analysis (BF_{10}) using default priors in JASP. For experiments that are not full and direct replications (such as here), it is recommended that default priors are used as it limits subjective influence and experimenter bias (JASP Team, 2017; see also Marsman & Wagenmakers, 2017). Results are considered anecdotal evidence that the experimental hypothesis (H1) is true when BF_{10} is between 1 and 3, moderate between 3 and 10, and strong above 10. $BF_{10} = 1$ indicates that the data lends equal support to H1 and the alternative hypothesis (H0). Moderate support for H0 is indicated when BF_{10} is between 0.33 and 0.10, and strong evidence is indicated when $BF_{10} \leq 0.10$. Median reaction times (RTs) from correct response trials only (as per Bayliss et al., 2006) were also analysed to check for speed accuracy trade off.

Results

Accuracy (d')

A repeated-measures ANOVA on d' values with barrier (open, closed) and cue validity (valid, invalid, direct) as within-subjects variables showed that there was a significant interaction between barrier type and cue validity on WM accuracy, $F(2,126) = 3.378$, $p=.037$, $\eta p^2=.051$ ($BF_{10} = 1.727$). Planned follow up *t* tests demonstrated that when the barrier was open, thus the gaze cue could 'see' the items, squares in the valid condition were remembered significantly better than those in the invalid condition, $t(63)= 2.413$, $p=.018$, Cohen's $d= 0.302$ ($BF_{10} = 3.948$) (see Figure 3). Crucially, when the barrier was closed, thus the squares could not be seen from the cue's perspective, there was no difference in memory for squares seen in the valid condition as compared to the invalid condition, $t(64)= -0.869$, $p=1$, Cohen's $d= -0.109$ ($BF_{10}=0.078$; Figure 3). Thus, gaze cues only influenced WM when the gaze cue could 'see' the items, demonstrating a clear influence of the barriers on the gaze cuing effect.

In order to examine the mechanism underpinning the gaze cuing effect in the open barrier condition, further *t*-tests compared performance on valid and invalid trials with direct gaze trials. There was a non-significant difference between valid vs. direct; *t*(63)= 0.848, *p*=.400, Cohen's *d*= 0.106 (BF_{10} = 0.193), but the invalidly cued items were recalled significantly worse than those encoded under direct gaze *t*(63)= 2.065, *p*=.043, Cohen's *d*= 0.258 (BF_{10} = 1.995), see Table 1. This contrasts with the mechanism of the cuing effect found in Gregory and Jackson (2017) when no barrier was present. In that study we found that validly cued items were recalled better than those encoded under direct gaze (a facilitation effect), and there was no cost to WM from an invalid cue vs. direct gaze. This contrast in cuing mechanisms between studies is addressed in the general discussion.

Figure 3 about here

Overall, the main effect of cue validity on WM accuracy was not significant, $F(2, 126) = 1.120$, *p*=.329, ηp^2=.017 (BF_{10} =.071). However, participants were significantly more accurate when the barrier was closed (M=1.056) than when it was open (M=0.984), $F(1,63) = 5.053$, *p*=.028, ηp^2=.074 (BF_{10} =1.007). A planned comparison of the direct gaze condition in the open barrier condition with the direct gaze condition in the closed barrier condition shows that barrier type did not impact WM accuracy in this direct gaze condition, *t*(63)= 0.185, *p*=.854, *d*= 0.023 (BF_{10} = 0.139). This indicates that it is not the barriers per se that affected accuracy. Instead, this main effect appears to have been driven by poorer WM for invalidly cued items in the open versus closed barrier condition, *t*(63)=2.973, *p*=.012, Cohen's d= 0.372 (BF_{10} = 7.325), as there was no effect of barrier type on WM when gaze cues were valid, *t*(63)= 0.008, *p*=1, Cohen's *d*= 0.001 (BF_{10} = 0.137).

Table 1 about here

RTs

A repeated-measures ANOVA on RTs from correct response trials only (probe present and absent combined, 67% of responses included), with barrier type and gaze direction (valid, invalid, direct) as within-subjects variables, showed a significant main effect of barrier type on RTs, $F(1,63) = 4.431$, $p=.039$, $\eta p^2 = .066$ ($BF_{10} = 9.527$), with RTs being faster when the barrier was open (781ms) versus closed (795ms). This may reflect some form of speed-accuracy trade-off as WM was poorer when the barrier was open versus closed, although note that the difference in retrieval RTs was only 14ms so any conclusion based on this is spurious. There was no significant main effect of validity on RTs, $F(2,126) = 0.871$ $p=.421$, $\eta p^2 = .014$ ($BF_{10} = 0.054$), nor a significant interaction between barrier type and gaze, $F(2,126)=.756$, $p=.472$, $\eta p^2=.012$ ($BF_{10} = 0.087$).

Summary and Interim Discussion

The results of Experiment 1 showed that barrier type influenced the effect of gaze cues on WM. When the barriers were open, a gaze cuing effect on WM was present. However, when the barriers were closed, thus the gaze cue could not see the items, gaze cuing effects on WM were abolished. These findings appear to support the *mental state account* of the influence of gaze cues on WM, indicating that participants engaged in perspective taking. This aligns with evidence for engagement of perspective taking during an object evaluation task (Manera et al., 2014), but contrasts with other work which shows no influence of barrier type on speed or accuracy during simple perceptual tasks (e.g., Cole et al., 2015).

However, while the closed barrier abolished gaze cuing effects in WM, it is not conclusive that disrupted perspective taking could account for this. It may be that modulated social attention drove the pattern of results, with greater, and more efficient space-based attentional resource allocated to the validly versus invalidly cued side of the screen when the barrier was open versus closed. While the complete lack of any modulation of WM in the closed barrier condition argues against this notion, it is unknown if the barriers we used also modulate the basic influence of gaze cues on attention orienting. In Manera et al. (2014) for example, it was found that while the barriers used disrupted the gaze cue's influence on object evaluation, there was no such influence seen on the speed of object categorisation (validly cued objects were categorised faster than invalidly cued objects, regardless of barrier condition). This suggests perhaps that the effect of gaze on liking was object-based and engaged perspective taking while the influence on speed of categorisation was space-based and did not. Due to the nature of Experiment 1 we cannot isolate the influence of the barrier on attention orienting. Therefore to examine this in Experiment 2 we tested the impact of the barrier manipulation on attention orienting within a traditional target localisation task commonly used to index joint attention in a gaze cuing paradigm. Based on results of previous cuing studies where a variety of barriers were not found to modulate gaze cuing during simple tasks (e.g., Cole et al., 2015), it was predicted that reaction times would be faster to localise targets displayed in the validly versus invalidly cued locations in both the open and closed barrier conditions. This pattern of effects would provide support for the *social attention account*.

Experiment 2 – Target Localisation Task

In this speeded task, participants had to locate an asterisk that appeared to the left or right of a central cue face. To match the cuing parameters of Experiment 1, gaze cues were valid, invalid, and direct, and the SOA was 500ms.

Method

Participants & Apparatus

Fifty-three volunteers were recruited from the University of Aberdeen in exchange for course credit or monetary reimbursement (41 females, 12 males, mean aged 20, age range 18 – 23 years). Of these, 8 participants (2 males, 6 females) were removed for poor accuracy on the initiation procedure (now recorded) and/or poor accuracy on the localisation task[2]. This sample size was used in order to ensure that if we failed to find an effect of barrier (as is predicted), that it would be unlikely to due to the study being underpowered (e.g., Cole et al., 2015 had a sample of 16 to 38 participants). All participants reported normal or corrected to normal vision.

Stimuli, Design & Procedure

The gaze, barrier and initiation task stimuli matched those used in Experiment 1. The target was an asterisk (26 X 26 pixels) presented 110 pixels to the left or right of the cue face. Within subjects' independent variables were barrier type (open, closed) and cue target validity (valid, invalid, direct). We presented 40 trials per condition (240 trials in total) pseudorandomised into 4 balanced blocks, two blocks with the open barrier and two blocks with the closed barrier. Blocks were presented such that an open barrier block was followed by a closed barrier block and block viewing order was counterbalanced. The dependent variable was RT to locate the target on correct trials. The main target experiment was preceded by a two block (open/closed barrier) practice, with 8 trials per block. The initiation procedure from Experiment 1 preceded the main experiment, here accuracy was recorded and we used an accuracy threshold of 78% correct response, ensuring that participants understood the different barrier types. This was followed by the target localisation task - see Figure 4. On each trial, a fixation cross was presented at centre (1000ms) and then replaced by the gaze cue flanked by the barriers for 750ms. The gaze then shifted to the left or right and remained on screen for 500ms before the target appeared in the validly cued (one third of trials) or invalidly cued (one third of trials) location. On the remaining third of trials the cue face

[2] Accuracy outliers were determined using the median absolute deviation (MAD; Leys, Ley, Klein, Bernard, & Licata, 2013) at the threshold of the median ± 3 times the MAD. We used MAD in preference to standard deviation (SD) because outliers can adversely skew calculation of SD but not MAD. Six participants with accuracy below 78% on the initiation task were removed due to being outliers (MAD=5.9%, 3*MAD=17.8%, median = 96%). A further participant was removed for poor accuracy (60% accuracy) on the localisation task (MAD=1.5%, 3 X MAD=4.45, median = 99%).

remained looking directly ahead. Participants were informed the gaze was non-predictive and were instructed to maintain focus at centre. Participants had to state the left/right location of the target as quickly and as accurately as possible using the 'Q' key (left index finger), and the 'P' key (right index finger). The target and cue remained on screen until response. The inter-trial interval was 1000ms.

Figure 4 about here

Results

Results are displayed in Figure 5. A 2 (barrier) x 3 (validity) repeated measures ANOVA on median RTs (correct response trials only[3]) showed a non-significant main effect of barrier type on target detection speed overall, $F(1,44)=0.065$, $p=.801$, $\eta p^2=.001$ (BF_{10} =0.135). There was a significant main effect of cue validity, $F(2,88)$ =77.418, $p<.001$, $\eta p^2=.638$ (BF_{10} >10). Validly cued targets (315ms) were located significantly faster overall than invalidly cued targets (332ms), $t(44)=7.205$, $p<.001$, Cohen's d= 1.074 (BF_{10} >10). Validly cued targets were also located significantly faster overall than targets seen under the direct gaze condition (347ms), $t(44)=11.077$, $p<.001$, Cohen's d= 1.651 (BF_{10} >10). Further, invalidly cued targets were located significantly faster overall than targets see under the direct gaze condition, $t(44)=5.684$, $p<.001$, Cohen's d= 0.847 (BF_{10} >10). Faster RTs for both valid and invalid cues in comparison to direct gaze reflects a facilitation effect of a gaze shift versus no gaze shift, and may be driven to some degree by motion priming (the eyes moved during gaze shift conditions but not during the direct gaze condition, i.e. Abrams & Christ, 2003). Alternatively, there may have been delayed disengagement from the direct gaze face which slowed attention orienting to the target location at its onset (e.g. Senju & Hasegawa,

[3] For the participants included (N = 45) accuracy was 99% overall with no significant main effects of barrier type (p=.135), or cue validity (p=.070) and no significant interaction between barrier and validity (p=.651) on accuracy. Across all included participants, 120 incorrect trials were removed (1.12%) in total.

2005). Crucially, the interaction between barrier type and validity was not significant, $F(2,88) = 0.683$, $p = .508$, $\eta p^2 = .015$ ($BF_{10} = 0.10$), see Figure 5. Planned *t*-tests comparing valid versus invalid RTs in each barrier condition separately confirmed that significant cuing effects were present when the barrier was open ($t(44) = 5.862$, $p < .001$, Cohen's d= 0.874 ($BF_{10} > 10$)) and closed ($t(44) = 4.988$, $p < .001$, Cohen's d= 0.744 ($BF_{10} > 10$)). In another study which used goggles (instead of barriers) to either reveal or obscure the view of the cue face, Teufel et al. (2010) found that manipulating perspective taking reduced but did not eliminate the cuing effect during a letter discrimination task. However, we found no such pattern here, with very similar cuing magnitudes (difference in RTs between invalid and valid cues) in the open barrier (18ms) and the closed barrier (15ms) conditions, supported by a non-significant barrier x validity interaction when the direct gaze condition was excluded, $F(1,44) = 0.554$, $p = .461$, $\eta p^2 = .012$ ($BF_{10} = 0.264$). Finally, a planned comparison of the direct gaze condition in the open barrier condition with the direct gaze condition in the closed barrier condition showed that barrier type did not impact RTs in this direct gaze condition, $t(44) = 0.677$, $p = .502$, $d = 0.101$ ($BF_{10} = 0.201$).

Figure 5 about here

Summary and Interim Discussion

This experiment clearly demonstrates that, unlike during the WM task, the closed barrier did not abolish the cuing effect found with an open barrier, and suggests that perspective taking is not engaged during a simple target localisation task. This concurs with our prediction based on null effects of barrier type on gaze cuing found during more simple discrimination or categorisation tasks (Cole et al., 2015; Manera et al., 2014).

However, the left/right response to leftward and rightward presented targets may produce a stimulus-response compatibility effect that is confounded by gaze cue validity. It is possible that there is no effect of barrier type on gaze cuing in Experiment 2 due to stimulus-response compatibility effects masking the effect of perspective taking on attention orienting[4]. But note that other simple tasks which did not allow for stimulus-response compatibility effects similarly found no influence of barrier type on gaze cuing (Cole et al., 2015; Manera et al., 2014).

Another possible reason for the lack of barrier effect on gaze cuing in Experiment 2 is that in a localisation task the identity of the target object is irrelevant, thus, the nature of this task is space-based rather than object-based. In contrast, the WM task is clearly object-based, as participants had to encode square colours. One might therefore question whether the absence of object-based processing in the Experiment 2 task led to the absence of any evidence for perspective taking (i.e., lack of barrier effect). As stated earlier, the belief that someone is looking at a specific object and not just in the general direction of an object is considered to be a critical precondition of perspective taking (Manera et al., 2014; Nuku & Bekkering, 2008; Teufel et al., 2009, 2010). So perhaps the degree of object-based processing of target information required of observers is an important factor in determining whether perspective taking is engaged or not. Note, however, that the tasks used in Cole et al. (2015) and Manera et al. (2014) were object-based, as they involved letter identification and object categorisation respectively, yet no evidence of perspective taking via barrier manipulation was found.

Nevertheless, to control for stimulus/response compatibility effects and investigate whether a simpler object-based task might show an effect of barrier type on gaze cuing, we conducted a third experiment in which participants stated whether a single square was blue or purple in colour. We chose this colour discrimination task to match more closely the stimuli used in the WM task, and used response keys that did not map onto left-right manual responses or target locations.

[4] We thank an anonymous reviewer for this suggestion.

Experiment 3 – Colour Discrimination Task

Method

Participants & Apparatus

Forty-eight volunteers were recruited from the University of Aberdeen in exchange for course credit or monetary reimbursement (44 females, 4 males, mean aged 22, age range 20 – 27 years). Of these, three female participants were removed, one due to poor accuracy in the target discrimination task[5], and two others due to failing to follow the instruction to respond as quickly as possible to the target. All participants reported normal or corrected to normal vision and none reported that they were colour blind. Due to the explicit colour discrimination nature of this task, participants were given the City University web-based colour vision test[6] (see Barbur, Harlow, & Plant, 1994) at the start of the session to ensure that colour-blind individuals were not inadvertently tested – all participants passed this test.

Stimuli, Design & Procedure

The gaze, barrier and initiation task stimuli matched those used in Experiments 1 and 2. The target coloured squares were taken from those used in Experiment 1. We specifically chose a blue square and a purple square as discrimination targets as they are close to one another on the colour wheel but considered not too difficult (or easy) to discriminate. The squares were presented 110 pixels to the left or right of the cue face. The task set up, including trial structure and initiation task matched that of the localisation task except that here participants were required to discriminate the colour of the square (see Figure 6). Participants had to state whether the target was blue or purple using the up (blue) or down (purple) arrow keys as quickly and as accurately as possible. The target and cue remained on screen until response. Participants were given accuracy feedback on all trials; this simply said 'correct' or 'incorrect' and was displayed for 500ms before the next trial began after a

[5] The participant had 79% accuracy, MAD=0.044, 3 X MAD=0.133, median = 0.83.

[6] https://www.city.ac.uk/health/research/centre-for-applied-vision-research/a-new-web-based-colour-vision-test

1000ms inter-trial interval. As in Experiment 2, we used valid, invalid, and direct gaze conditions with a 500ms SOA, in open and closed barrier conditions. The number of trials per condition and the block/trial structures exactly matched those in Experiment 2. Accuracy on the initiation procedure was 79% and above, with the majority of participants having accuracy above 90%, demonstrating participants engaged with the task.

Figure 6 about here

Results

Results are displayed in Figure 7. A 2 (barrier) x 3 (validity) repeated measures ANOVA on median RTs (correct response trials only[7]) showed a non-significant main effect of barrier type on colour discrimination speed overall, $F(1,44)=3.460$, $p=.070$, $\eta p^2=.073$ (BF_{10} = 1.408). There was a significant main effect of cue validity, $F(2,88)=27.318$, $p<.001$, $\eta p^2=.383$ ($BF_{10}>10$). Validly cued targets (513ms) were discriminated significantly faster than invalidly cued targets (528ms), $t(44)=4.643$, $p<.001$, Cohen's d= 0.692 ($BF_{10}>10$). Validly cued targets were discriminated significantly faster than targets seen under the direct gaze condition (540ms), $t(44)=7.455$, $p<.001$, Cohen's d= 1.111 ($BF_{10}>10$). Invalidly cued targets were also discriminated significantly faster than targets see under the direct gaze condition, $t(44)=2.993$, $p=.014$, Cohen's d= 0.446 ($BF_{10}=7.779$). This mirrors the cuing effect found in Experiment 2, and may reflect either motion priming from the dynamic gaze or delayed disengagement of attention from the direct face. Crucially, the interaction between barrier type and validity was not significant, $F(2,88)= 2.195$, $p=.117$, $\eta p^2=.048$ ($BF_{10}=0.233$). Planned *t*-tests comparing valid versus invalid RTs in each barrier condition confirmed that significant cuing effects were present when the barrier was open ($t(44)= 4.00$, $p<.001$, $d=$ 0.596 ($BF_{10}>10$)) and closed ($t(44)= 2.657$, $p=.011$, $d= 0.396$ ($BF_{10}= 3.620$)). A non-

[7] For the participants included, (N = 45), accuracy was 96% overall with no significant main effects or interactions from barrier type, all ps ≥.442. Across all included participants, 456 incorrect trials were lost (4.23%) in total.

significant barrier by validity interaction with direct gaze excluded confirmed that the difference in cuing magnitude was not significant between barrier conditions, $F(1,44)= 1.925$, $p=.172$, $\eta p^2=.042$ ($BF_{10}=0.393$). Finally, a planned comparison of the direct gaze condition in the open barrier condition with the direct gaze condition in the closed barrier condition showed that barrier type did not impact RTs in this direct gaze condition, $t(44)= 0.391$, $p=.698$, $d= 0.058$ ($BF_{10} = 0.174$).

Figure 7 about here

Summary and Interim Discussion

The results of Experiment 3 show that the barrier did not modulate the influence of gaze cues on attention during a simple colour discrimination task - attentional cuing was present whether or not the cue face could 'see' the target. This provides evidence in support of the *social attention account,* and replicates Cole et al. (2015) and our effects seen in Experiment 2 where a localisation task was used. But crucially, this contrasts with the effect seen in Experiment 1, where a significant gaze cuing effect on WM was observed with an open barrier but a closed barrier abolished this effect. Thus we can more firmly conclude that (1) the pattern of results found in the WM task in Experiment 1 can be attributed to perspective-taking rather than a more general space-based social attention effect, and (2) that the null effects of the barrier in Experiment 2 were unlikely driven by stimulus-response compatibility issues or the space-based nature of the localisation task.

General Discussion

Here we examined whether the influence of joint attention on WM (Gregory & Jackson, 2017) reflects perspective taking (the *mental state account*) or is simply driven by enhanced attention (the *social attention account*). In Experiment 1 we measured WM for coloured squares that were looked towards (validly cued) versus looked away from (invalidly cued) by a central cue face, or were seen under the presence of direct gaze, and used a barrier to manipulate whether the cue face could ‘see’ the squares or not. An open barrier gives the impression that the cue face can see the memoranda while a closed barrier is designed to obscure this view. If perspective taking is engaged during this task (*the mental state account*), we predicted that gaze cue validity would influence WM accuracy when the barrier was open, but not when it was closed. In contrast, evidence for a *social attention account* would be indexed by a significant gaze cuing effect in both barrier conditions. We found that WM was better for validly than invalidly cued squares only when the items could be ‘seen’ by the cue face through the open barrier. When the barrier was closed and thus the items could not be ‘seen’ by the cue, there was no influence of gaze on WM. This pattern of results provides support for the *mental state account* in which observers took the perspective of the cue.

These results align with Manera et al. (2014) who demonstrated that gaze cues influenced the likability of objects only when the face was perceived to be able to see the items. However, this is contrary to findings from more simple discrimination or object categorisation tasks, for example results reported by Cole et al. (2015), and also Manera et al. (2014) specifically when investigating speed of object categorisation. Therefore, in order to establish that the influence of our barriers was specific to WM, we also examined the influence of our barrier on a simple localisation task (Experiment 2) and a colour discrimination task (Experiment 3), using the same gaze and barrier manipulations. We predicted to find no evidence of perspective taking in both these experiments, indexed by the presence of a gaze cuing effect on reaction times in both open and closed barrier conditions, and our results confirmed this. In both barrier conditions, we found significantly faster RTs to locate an asterisk (Experiment 2) and discriminate a colour (Experiment 3) when the gaze cue was valid versus invalid, and the magnitude of these cuing effects did not differ significantly between barrier types. This replicates the results seen in Cole et al. (2015) and the object categorisation task in Manera et al. (2014), and suggests that while social attention is modulated by gaze during simple tasks, perspective taking is not engaged.

Together, these findings provide strong support for a *mental state account* of how gaze cues influence WM, indicating that participants adopt the perspective of the cue face rather than simply share their focus of attention in this more complex task. We therefore propose a *'goal-specific'* model of perspective taking, in which task goals and related cognitive demands determine whether perspective taking is engaged or not. When the task is simple and requires relatively little goal-directed behaviour, as in a basic localisation or item discrimination task (e.g., Cole et al., 2015, and in Experiments 2 and 3 here), perspective taking is not engaged. In contrast, when the task is more cognitively demanding, object-based, and goal-directed (i.e., involves WM as in the current Experiment 1, or decision-making on object preference judgments as in Manera et al., 2014), then perspective taking is engaged. This also fits with the findings of other studies using barriers to investigate the presence of perspective taking, such as dot-perspective-task studies. Cole, Atkinson, Le, and Smith, (2016) found that barriers did not disrupt the effect of gaze cues on participants' speed of ability to judge the number of dots in a display when a human avatar looked towards all of the dots, compared to when the avatar could only see a subset of dots. As the barrier did not disrupt the effect, it is unlikely that this numeration task reflects perspective taking (see also Langton, 2018). Indeed, results in the dot perspective task have also been replicated with non-social arrow cues (e.g. Santiesteban, Catmur, Hopkins, & Bird, 2014), demonstrating that the effect is likely due to basic attentional orienting effects, as is seen when the gaze cuing effect on attention is compared to non-social arrow cues (e.g. Tipples, 2002). In contrast, both the effect of gaze on WM (Gregory & Jackson, 2017) and the effect of gaze on object appraisal (Bayliss et al., 2006) were found not to be replicated using arrow cues, demonstrating the uniquely social nature of these effects. It is therefore likely that the barrier abolished the influence of the gaze cues in the WM task used here, and the object appraisal task used by Manera et al. (2014), because these tasks utilise deeper, goal-based cognitive processes that may be more prone to social reinforcement from others.

It is possible that goal-directed tasks which involve deeper level processing of specific object-based information engage perspective taking in order to facilitate learning (e.g. Cleveland et al., 2007; Striano et al., 2006; Wu, Kirkham, Swan, & Gliga, 2011). Tasks which are space-based (i.e., involve target localisation) and object-based but require less complex processing (e.g., perceptual discrimination), may not engage perspective taking as there is little goal-directed behaviour and thus little consequence to processing beyond the initial perceptual encounter.

In all three experiments reported here we also examined the nature of any cuing effects found, by using a direct gaze control condition in which the cue face did not shift gaze. This allowed us to determine whether cuing effects are facilitative in nature (better performance for valid versus direct trials) or reflect an attentional cost (poorer performance for invalid versus direct trials). A direct gaze condition was not included in other studies of perspective taking (e.g., Cole et al., 2015; Manera et al., 2014; Teufel et al., 2010) so here we can add further insight into gaze cuing effects in complex WM tasks and more simple perceptual tasks. In Experiment 1 here, it is notable that the mechanism underpinning the gaze cuing effect in WM when the barrier was open contrasts with that found in Gregory and Jackson (2017) when no barrier of any kind was present. In our previous study the gaze cuing effect in WM was facilitative in nature, with better WM accuracy for validly cued colours versus colours encoded under direct gaze, and no difference between invalid and direct conditions. However, here we found that the effect of gaze in the open barrier condition was driven by impaired WM for invalidly cued versus direct gaze items, with no difference between valid and direct conditions. To account for this, it is possible that the barrier changed the context in which the gaze cue operates. In the original study there was no barrier at all, so throughout the session the cue face always had the ability to 'see' the memoranda (Gregory & Jackson, 2017). Here, the variation between blocks in which the cue face could see and could not see the memoranda perhaps served to cognitively devalue invalidly cued items in WM in the open barrier condition. This is the only condition in which the cue face could have looked at and seen the items but instead looked away. When the barrier was closed, it did not matter whether the items were looked towards or not as the cue face's perspective was obstructed, thus it was not perceived to be looking at the items even in the valid condition. Therefore, this looking away behaviour in the open barrier condition may be interpreted as a lack of interest, and here when the cue face only has a limited opportunity to see the items perhaps a perceived lack of interest may have impaired WM on invalidly cued trials. Future work is required to probe this speculation in more detail.

In Experiments 2 and 3, where no evidence for perspective taking was found, comparison of the valid and invalid gaze shifts with direct gaze show a distinct pattern from that seen in WM. For both studies the cuing effects reflected facilitation of both valid and invalid gaze shifts versus direct gaze, indicating either motion priming from the gaze shift or delayed disengagement from the direct gaze face (e.g., Senju & Hasegawa, 2005). Regardless of what drives this pattern of effects, these results show that cuing mechanisms may be qualitatively different depending on task demands (goal-based versus simple perception) and performance measures (accuracy versus reaction time). Cole et al. (2015) found cuing in both barrier conditions regardless of whether the task measured reaction time or accuracy, but lack of a direct baseline in their study does not permit examination of whether the mechanisms underlying these cuing effects were similar or different.

In the current WM task (Experiment 1), we also found a main effect of barrier type, with better WM overall for items in the closed versus open barrier conditions. This is somewhat surprising, as one might have expected a disruptive effect of the closed barrier on WM performance if joint attention were disabled. Furthermore, no such main effect of barrier was reported in previous perspective taking studies, with Manera et al, (2014) investigating the effect of barriers between subjects in separate studies, and Cole et al, (2015) showing no effect of barriers across their studies. With evidence for perspective taking in this task, we speculate that the perceived inability of the cue face to see the items in the closed barrier condition may create a social disconnect between the observer and the cue. This social disconnect may have been beneficial to WM performance in that it served to remove any potential distraction of the cue's behaviour, and thus increase the autonomy of the observer to encode the items independently and more effectively.

In conclusion, our findings demonstrate that the influence of joint attention on WM reflects engagement in perspective taking, with eye gaze influencing WM only when the cue face is perceived to see the items. In contrast, no effect of perspective taking was found in simple perceptual tasks. Therefore adopting the perspective of another may be *goal-specific* and unique to tasks engaging higher-level processes such as WM. Eye gaze provides information about a person's intentions to act upon objects of interest in the environment in a goal-directed manner (e.g., Johansson, Westling, Bäckström, & Flanagan, 2001; Land, Mennie, & Rusted, 1999; Land & Tatler, 2009), for which WM is essential (Baddeley, 2007). Even in the absence of bodily action cues (as in the current study), social gaze is anticipatory in nature and generates expectations of others' goals (e.g. Teufel et al., 2010). Bach & Schenke (2017) propose a social prediction model of how perception and action interact. In particular, they state that "…higher level person knowledge is constantly integrated with the current environmental constraints to predict others' most likely behaviour…" (Bach &

Schenke, 2017, pg 10).Therefore when we share the perspective of others we may also share their short-term goals in order to predict what may unfold next during a social interaction episode.

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Tables and Figures

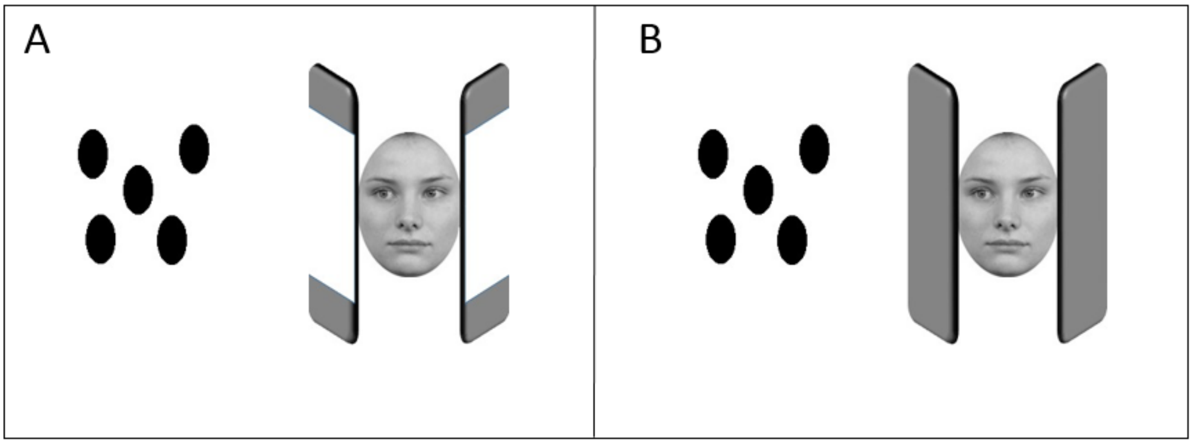

Figure 1. Illustration of the dot counting task, showing the open barrier (panel A – correct answer = 5), and the closed barrier (panel B – correct answer = 0). Faces from the Radboud Faces Database (Langner et al., 2010).

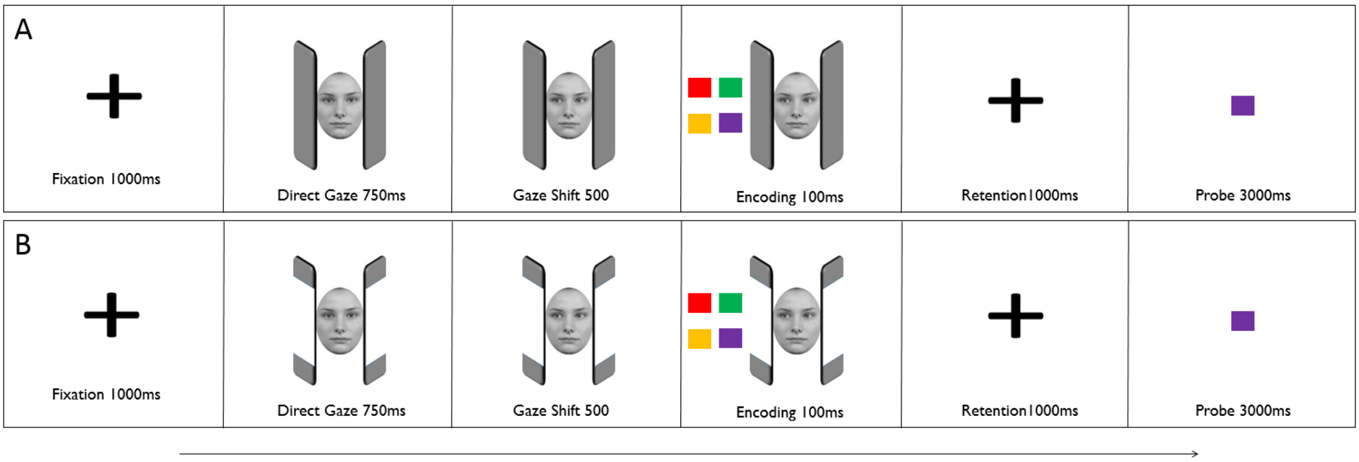

Figure 2. Illustration of the WM trial procedure, showing the closed barrier (A), and the open barrier (B). Both show the valid, probe present condition. At the start of each block, the participants were informed of the barrier condition: closed barrier- *In this block, the barrier is always completely filled in. Thus, the faces presented cannot see the squares*; Open barrier - *In this block, the barrier always has windows. Thus, the faces presented can always see the squares*. Participants received accuracy feedback throughout with encouragement to keep their score as high as possible.

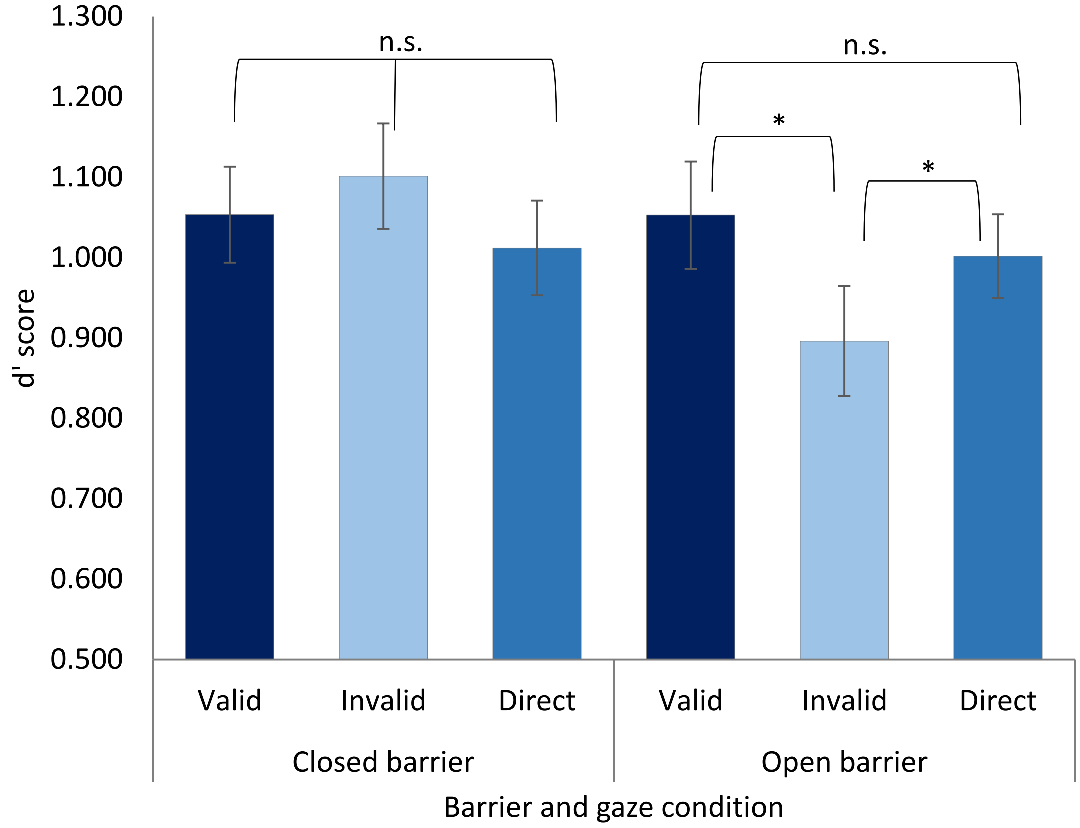

Figure 3. Results from Experiment 1. WM performance scores using d' are plotted as a function of barrier condition and cue validity. Error bars represent 1 standard error above and below the mean.

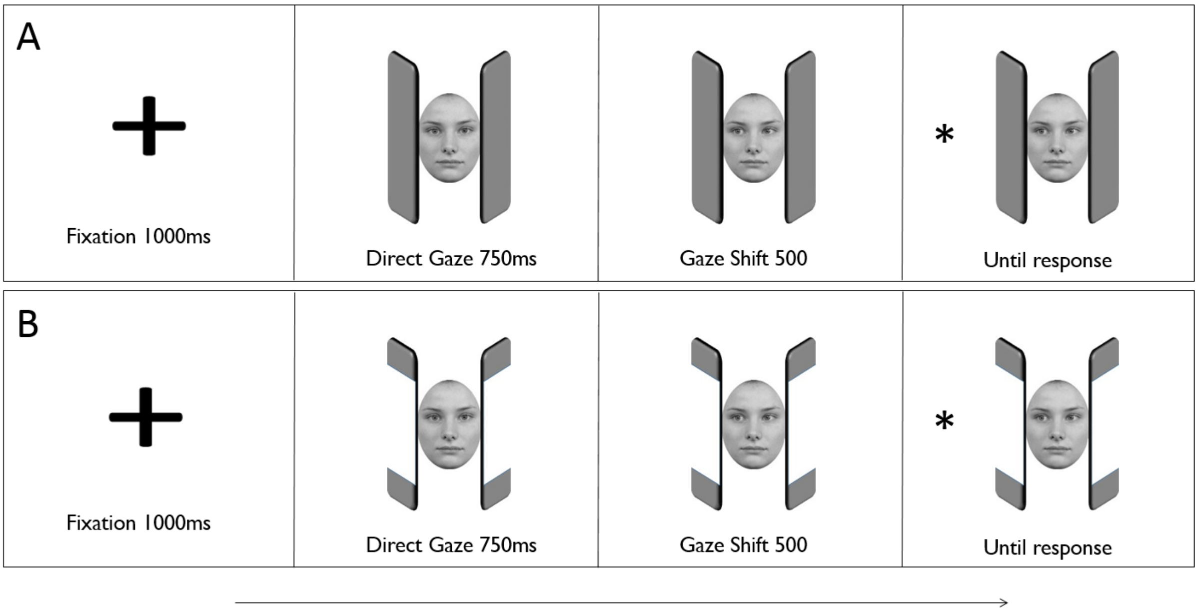

Figure 4. Illustration of the localisation task trial procedure used in Experiment 2, showing the closed barrier without a window (A), and the open barrier with a window (B). Both show the valid condition.

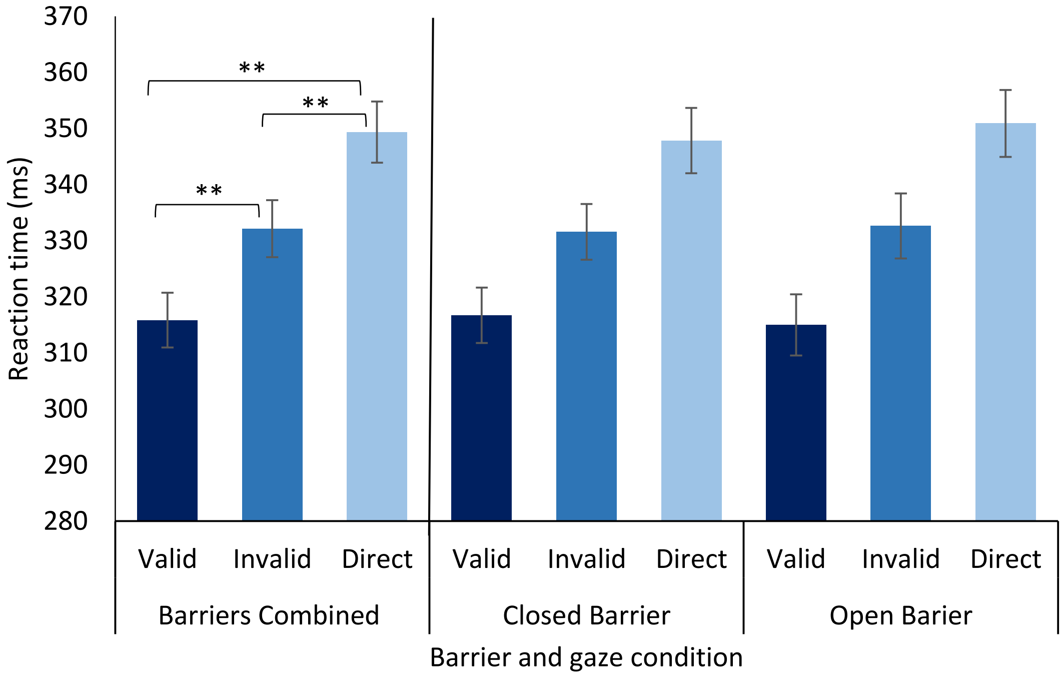

Figure 5. Results from Experiment 2, target localisation task. Reactions times to locate a target are plotted as a function of barrier condition and cue validity. Bars for the gaze conditions separated by barrier are shown for illustrative purposes, note that there was a significant cuing effect (valid vs invalid difference) in both the open and closed barrier conditions. Error bars represent 1 standard error above and below the mean.

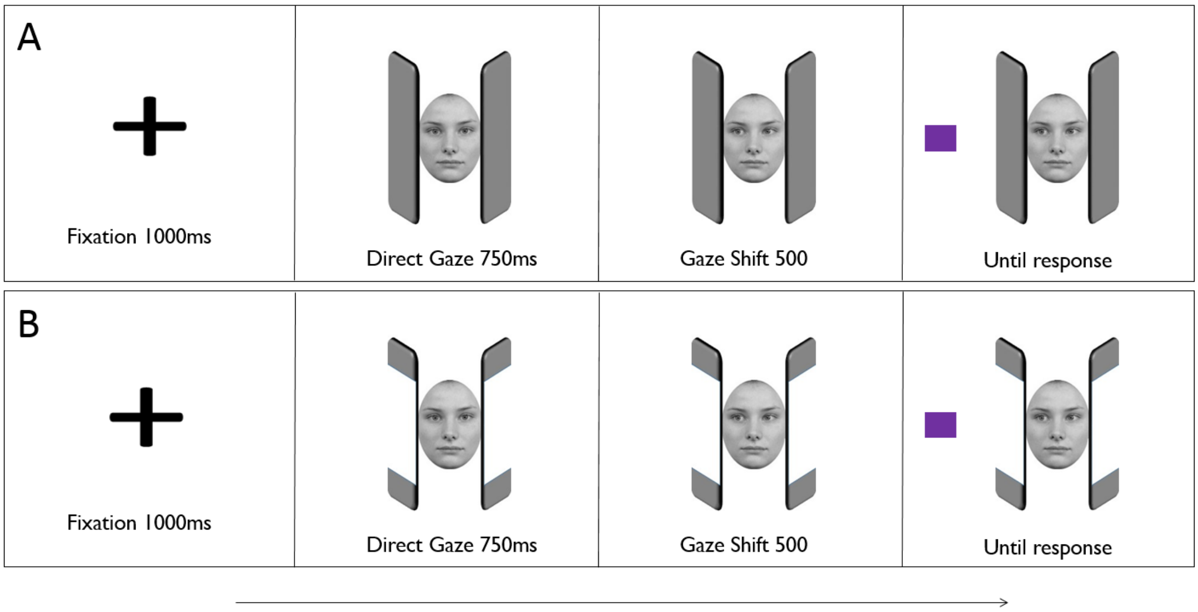

Figure 6. Illustration of the discrimination task trial procedure, showing the closed barrier (A), and the open barrier (B). Both show the valid condition.

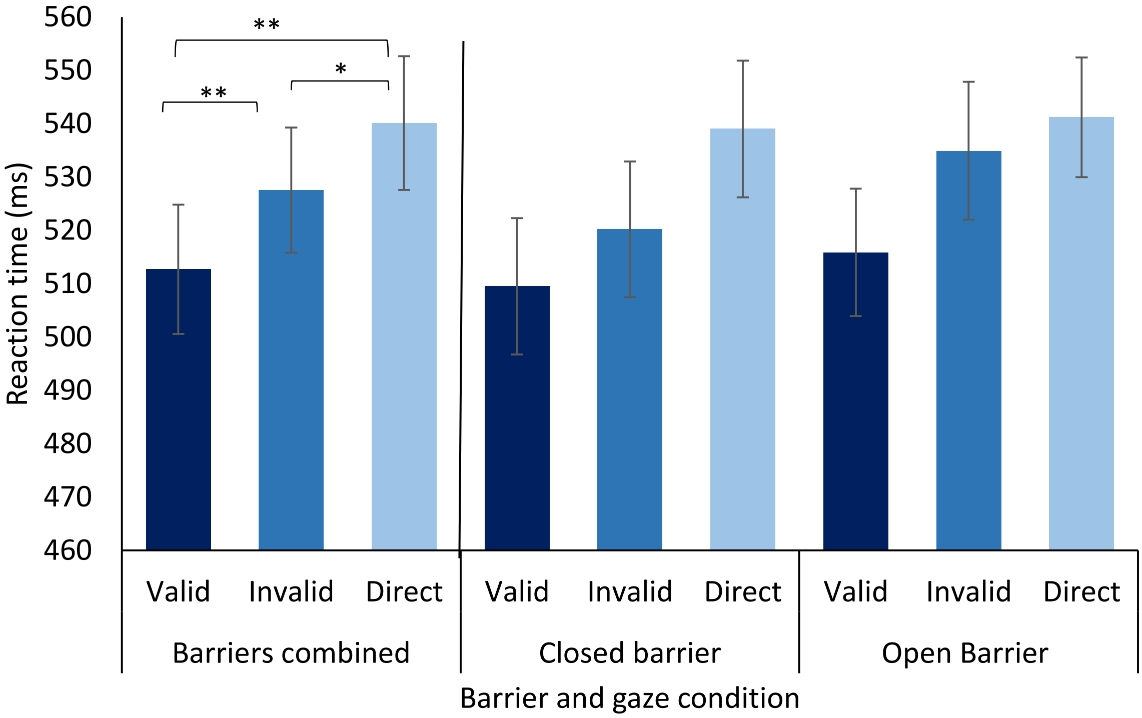

Figure 7. Results from Experiment 3. Reactions times to discriminate a coloured target as blue versus purple are plotted as a function of barrier condition and cue validity. Bars for the gaze conditions separated by barrier are shown for illustrative purposes, note that there was a significant cuing effect (valid vs invalid difference) in both the open and closed barrier conditions. Error bars represent 1 standard error above and below the mean.

Table 1
Mean and standard error (in parenthesis) for hits (%), false alarms (%), d', and reaction times (RT; ms).

	Open Barrier			Closed Barrier		
Data	**Valid**	**Invalid**	**Direct**	**Valid**	**Invalid**	**Direct**
Hits(%)	68.5(1.4)	67.5(1.4)	68.1(1.4)	67.9(1.4)	67.7(1.5)	66.6(1.5)
FA (%)	31.3(1.8)	35.2(2.0)	32.6(1.9)	31.0(1.8)	28.9(1.7)	30.6(1.6)
d'	1.053(0.067)	0.896(0.069)	1.002(0.052)	1.053(0.060)	1.101(0.065)	1.012(0.059)
RT(ms)	784(24)	782(24)	776(24)	799(23)	790(24)	795(25)