Assessing the impact of verbal and visuo-spatial working memory load on eye-gaze cueing

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Abstract

Observers tend to respond more quickly to peripheral stimuli that are being gazed at by a centrally presented face, than to stimuli that are not being gazed at. While this gaze-cueing effect was initially seen as reflexive, there have also been some indications that top-down control processes may be involved. Therefore, the present investigation employed a dual-task paradigm to attempt to disrupt the putative control processes involved in gaze-cueing. Two experiments examined the impact of working memory load on gaze-cueing. In Experiment 1, participants were required to hold a set of digits in working memory during each gaze trial. In Experiment 2, the gaze task was combined with an auditory task that required the manipulation and maintenance of visuo-spatial information. Gaze-cueing effects were observed, but they were not modulated by dual-task load in either experiment. These results are consistent with traditional accounts of gaze-cueing as a highly reflexive process.

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Introduction

If a face is presented in the centre of a computer screen with its gaze averted, it will produce a shift in the spatial attention of the observer. This is evidenced by faster reaction time (RT) responses to targets appearing at the gazed-at location compared to other locations on the screen. This form of attentional orienting has come to be known as gaze-cueing (for a detailed review of the literature see Frischen, Bayliss, & Tipper, 2007). In the research reported here, we investigated the nature of attentional control processes at work in gaze-cueing using dual-task methodology.

To put the gaze-cueing effect in its wider context, studies of spatial cueing of attention have traditionally made a distinction between two types of effect. The first type, labelled “exogenous”, “reflexive” or “stimulus-driven”, occurs when a cue stimulus such as a luminance onset (usually presented in peripheral vision) causes facilitation in RTs to targets appearing in the same location, even when there is an equal likelihood that the target will appear somewhere else. The second type, labelled “endogenous”, “voluntary” or “goal-driven”, occurs when a centrally-presented symbolic cue stimulus, such as a word, causes facilitation in RTs to targets appearing in the location indicated by the cue, but only when the target *is* actually more likely to appear there than elsewhere. In order to remain consistent with the majority of previous gaze-cueing papers, the terms “reflexive” and “voluntary” will be used here to refer to the two different types of cueing. Gaze-cueing was initially thought to be a special case where a centrally presented stimulus (e.g., a face with laterally averted gaze) could produce reflexive attentional orienting. Evidence for this came from studies demonstrating that observers responded more quickly to targets appearing at gazed-at (cued) locations even when participants were truthfully informed that the cue did not predict the location of the target more often than chance (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). The implication of these findings was that eyes are stimuli of such biological and social importance, that they are capable of producing a reflexive shift in spatial attention from human observers. In support of this view, Driver et al. (1999) demonstrated that this shift could not be suppressed at short delays between the cue and the target, even when the gaze was made to be *counter*-predictive of the target location.

Nevertheless, some recent papers on the subject have suggested that there may be an element of top-down direction in the gaze-cueing effect. Ristic and Kingstone (2005) have argued that although gaze-cueing is a reflexive process engaged by biological stimuli, top-down control is required to “shift” the attentional system into this mode by first recognising the cueing stimulus as a face. When an ambiguous stimulus was perceived as a car, it did not produce cueing effects. Once the participants had been instructed that the stimulus was a gazing face, however, it seemed to be impossible for it to be viewed as anything else, and reflexive cueing effects were observed. Another study by Koval, Thomas and Everling (2005) found that observers were able to exert flexible control over their responses to eye-gaze cues. They presented a central face at fixation during pro- and anti-saccade tasks, and found that on cued trials (i.e. where the peripheral target appeared on the side indicated by the gaze) participants were quicker to look in that direction on pro-saccade trials (as was expected) but they were also quicker to look in the *opposite* direction on anti-saccade trials. This indicated that participants used the central cue differently depending on the nature of the task. When the task was to make a pro-saccade, they readied a response toward the gaze-congruent direction. When the task was to make an anti-saccade they prepared a response toward a direction that was incongruent with the gaze direction of the central face. Koval et al. argue that this is inconsistent with the notion that eye-gaze directs attention in a purely reflexive manner.

However, it is possible that they would have obtained different results if the gaze cue had remained on screen throughout the trial (Frischen et al., 2007), instead of disappearing before the target onset.

The strongest advocates of a voluntary account of gaze-cueing are Vecera and Rizzo (2004, 2006), who showed that a patient with frontal lobe damage (patient EVR) did not display the usual pattern of attentional orienting from centrally presented directional cues, including eye-gaze cues. Whether central word or gaze cues were predictive (75% valid) or non-predictive (50% valid) of the target location, they did not influence his responses. However, EVR did show normal reflexive orienting to peripheral (non-face) cues, showing that he was able to attend to peripheral locations. Vecera and Rizzo therefore argue that, like words, eye-gaze cues orient attention through a voluntary rather than a reflexive process, and this process is impaired in EVR. They point out that it would make sense for people to be able to adapt their responses to eye-gaze cues, because it is possible for the relationship between the gaze cue and the target location to be violated (e.g., by deception) and often it merely specifies a general direction rather than a precise spatial location. However, Frischen et al. (2007) question whether it is valid to generalise from single-case patient studies, given that not all healthy participants show the gaze-cueing effect. They state that “rather than a universal effect, it is simply a robust effect given an appropriately sized random sample” (page 711). It is not possible to know whether patient EVR would have shown gaze-cueing prior to acquiring his brain lesion.

If Vecera and Rizzo are correct, and top-down control is involved in gaze-cueing, what might be the nature of this control process? It is plausible to argue that during a gaze-cueing task, top-down control might be required to create and maintain an attentional set that prioritises processing of the eye stimuli and facilitates a shift in spatial attention to the cued location. Working memory (WM) is the system generally thought to be responsible for the temporary maintenance and manipulation of information relating to on-line cognitive processing, and there is increasing evidence of WM involvement in other visual selective attention tasks. Studies have demonstrated that specific content held in WM may influence what is attended to (e.g., Downing, 2000; Pratt & Hommel, 2003; Woodman, Luck, & Schall, 2007), that general WM load can modulate interference from visual distracters (e.g., Boot, Brockmole, & Simons, 2005; Lavie & de Fockert, 2005; Spinks, Zhang, Fox, Gao, & Tan, 2004), and that participants with low WM spans are less able to maintain control of attentional shifts in the anti-saccade task (Kane, Bleckley, Conway, & Engle, 2001). WM is therefore a strong candidate for the system through which "voluntary" control of attentional orienting to eye-gaze might operate. Our aim in the present study was to load participants' WM while they attempted a typical gaze-cueing task, and examine whether the gaze-cueing effect was modulated. Dual-task methodology is increasingly being employed to investigate the interaction between WM and visual attention, but has not, to our knowledge, previously been applied to gaze-cueing.

If gaze-cueing is modulated by WM load, in which direction would we expect such modulation to occur? Assuming that gaze-cueing arises from the adoption and maintenance of a specific attentional set, as implied by the arguments of Vecera and Rizzo and the lack of cueing shown by EVR, then one might predict a decrease in cueing with higher WM load. However, it is also possible to frame the opposite prediction. One theory with particular relevance here is Lavie's load theory of selective attention (e.g., Lavie, 2005; Lavie, Hirst, De Fockert, & Viding, 2004). Lavie's theory predicts that while an increase in perceptual load in a selective attention task will reduce interference from distracters (because fewer resources are available to “spill over” and process them), high WM load will *increase* interference from distracters. This is because WM resources are necessary to maintain processing priorities that exclude distracter stimuli and facilitate task-relevant stimuli. Under conditions of high WM load, observers will be less able to maintain these priorities. This argument could be extrapolated to the gaze-cueing task. Here the gaze cue is viewed as an irrelevant distracter, which nevertheless provokes a pre-potent attentional orienting response. Ordinarily WM attempts to maintain task goals (i.e., respond to the peripheral targets) by suppressing this response, although the observation of the gaze-cueing effect suggests that this is not entirely successful. Under conditions of high WM load, participants would be less able to suppress the influence of this distracter, and the degree of gaze-cueing would increase.

Experiment 1

In Experiment 1 we employed a standard gaze-cueing paradigm with the addition of a digit-rehearsal secondary task adopted from Lavie and de Fockert (2005). Variants of this task have already been shown to affect attention capture by colour singletons (Lavie & de Fockert, 2005) and interference by both famous (De Fockert, Rees, Frith, & Lavie, 2001) and emotional (Pecchinenda & Heil, 2007) faces during selective attention tasks. Participants attempted the gaze-cueing task under both single and dual-task conditions. If a modulation of the gaze-cueing effect were found with a high WM load compared to a low WM load, this would indicate that gaze-cueing draws upon high level processes that are also used in maintaining information in WM.

Method

Participants

Undergraduates and visitors (N = 52, 37 female, 15 male) were recruited at the campuses of Stirling University and Liverpool John Moores University. They participated for course credit or a small financial honorarium. They ranged in age from 18 to 44, with an average age of 24.04 years (SD = 6.36), and had normal or corrected-to-normal vision according to self-report.

Stimuli and Apparatus

Gaze-cueing task: To create the gaze stimuli a greyscale photographic image of a male face gazing to the left with a neutral expression was cropped into an oval shape to remove the external features and face outline. The eyes from a mirror-reversed version of the same photograph were then superimposed onto this image so that both face images were the same except for the direction of gaze. Faces subtended 5.7 by 4.8 degrees of visual angle and were presented on the screen so that eyes appeared in the centre (i.e. parallel with target stimulus). The target stimulus was a grey square that subtended 0.95° VA. The distance from the centre of the face between the eyes and the centre of the target was 6.25 cm (5.95° VA). Stimuli were presented against a white background on a 16 inch monitor running at a resolution of 1280 x 1024 pixels. Images were prepared in Adobe Photoshop 7.0. E-prime experiment generator software was used to present the images and record the responses.

Digit load task: The WM secondary task was adapted from Lavie and de Fockert (2005). The stimuli for the low-load version were the numbers 0, 1, 2 and 3, one of which was presented in the centre of the screen at the beginning of each trial. Each number appeared 30 times, so that there was a total of 120 trials. Participants were instructed to enter the next number in numerical sequence at the end of the trial, when they were prompted with a question mark. Therefore, if the memory load was a “2”, participants should enter a “3” at the prompt. In the high load version of the task, participants were presented with a set of five digits at the beginning of each trial. This digit set always began with a 0, followed by the numbers 1, 2, 3 and 4 in a varying order. Each of the 24 possible orderings of these four digits appeared five times (120 trials). At the end of the trial participants were prompted with one of the numbers from the sequence (but never the last number), and they were instructed to enter the number that had followed it. So, if “02341” appeared at the beginning of the trial, and participants were prompted with a “2”, the correct response would be “3”.

Design and Procedure

Half of the participants were allocated to a low load group (one digit WM load), and half to a high load group (five digit WM load). All participants received a block of single task trials (gaze-cueing localisation task only) and a block of dual-task trials (gaze-cueing + WM load). During the experiment participants were seated in a dimly lit laboratory and were instructed to keep their eyes focused on the centre of the screen at all times while performing the task. They were asked to respond to the target as quickly an accurately as possible, and were informed that the gaze was not predictive of the target location and should be ignored. They were also told that the attention task and the memory task were of equal importance, and that they should try to do them both as well as possible. Single and dual task trials were blocked, and the order in which participants attempted these blocks was counterbalanced. Each block contained 120 trials presented in a random order, with a break in the middle. Prior to attempting the experimental trials, participants were given a block of 24 single task practice trials and then a block of 24 dual task practice trials.

(Figure 1 about here please)

An illustration of the trial sequence is provided in Figure 1. All trials began with a fixation cross displayed on the screen for 1000 ms. In dual-task trials, the memory load digits then appeared for 1500 ms, followed by another fixation cross for 1000 ms. In both single and dual trials, the gaze cue was displayed for either 100 ms, 500 ms, or 1000 ms before the onset of the target stimulus (stimulus onset asynchrony, SOA). The gaze cue was non-predictive of the target location (i.e., 50% cued and 50% uncued trials). Both gaze cue and target remained on screen until the participant responded. They were instructed to press the leftmost button of a 4-button response box if the target appeared on the left, and the rightmost button if it appeared on the right, using the index fingers of each hand. Single task trials ended with this response, but in dual-task trials participants were prompted to recall the digit load. Participants in the low-load group saw a question mark and had to enter the next digit in numerical order after the one presented at the start of the trial. Participants in the high load group were presented with one digit from the sequence of five and had to enter the one that came next. The memory prompt stayed on screen for 3000 ms or until the participant responded. Feedback (Correct, Incorrect or No Response Detected) was then presented for 1000ms. In both memory tasks the correct answer was always 1, 2, 3 or 4; therefore participants were able to use the four buttons on the response box to respond on the memory task.

Results and Discussion

Gaze-cueing task: Trials with RTs of less than 150 ms or greater than 1500 ms were excluded from this analysis along with trials that contained an error on either the localisation task or the memory task. In total, this led to the exclusion of 3.17% of the data for the reaction time analysis. For the remaining trials, mean reaction times were calculated for each participant and these were combined to create the inter-participant mean reaction times, shown in Table 1 along with percentage error rates.

(Table 1 about here please)

A four factor mixed analysis of variance was conducted, with two levels of the between participants factor group (low load vs. high load), two levels of the within-participants factor demand (single task vs. dual task), three levels of the within-participants factor SOA (100 ms, 500 ms or 1000 ms) and two levels of the within-participants factor gaze cue-condition (cued vs. uncued). According to this analysis, there was no significant difference between the low and high load groups in terms of reaction time to the attentional probe, $F(1, 50) < 1$. There was a significant main effect of demand, $F(1, 50) = 61.00$, $MSE = 12508.27$, $p <.001$, reflecting the slowing of overall reaction times to the attentional probe under dual-task conditions relative to single-task conditions. There was also a significant main effect of SOA, $F(2, 100) = 217.19$, $MSE = 975.49$, $p < 0.001$, reflecting a typical fore-period effect where reaction times are faster at longer SOAs, as participants are able to use the cue as a warning signal and prepare their response. Importantly the main effect of gaze cue-condition was also statistically significant, $F(1, 50) = 10.49$, $MSE = 650.65$, $p < 0.01$, demonstrating that participants did respond more quickly to the probe when it was cued by the gaze. These main effects were qualified by a significant interaction between demand and SOA, $F(2, 100) = 13.54$, $MSE= 718.57$, $p <.001$, reflecting the tendency for the impact of the secondary task to be greatest at the shortest SOA (100ms). No other interactions approached significance (all *p*s > .2). In particular, there was no indication of an interaction between gaze cue-condition and either demand or group (in both cases, $F < 1$), which would have indicated some modulation of the gaze-cueing effect.

Memory Task: The percentages of errors made on the memory task for both low and high groups are shown in Table 2. A 2 x 3 x 2 mixed ANOVA was conducted with two levels of the between-participants factor group (low load vs. high load), three levels of the within-participants factor SOA and two levels of the within-participants factor gaze cue-condition (cued vs. uncued). This analysis revealed a highly significant main effect of group, $F(1, 50) = 27.97$, $MSE = 82.39$, $p < 0.001$, but no significant main effect of SOA, $F(2, 100) < 1$, or cue-condition, $F(1, 50) < 1$. Group did not significantly interact with SOA, $F(2, 100) < 1$, or cue-condition, $F(1, 50) < 1$. The interaction between SOA and cue-condition was also non-significant, $F(1, 50) = 1.67$, $MSE = 22.00$, $p > .1$, as was the 3-way interaction, $F(2, 100) < 1$. Therefore, while the high load group were (as expected) more likely to make errors than the low load group, the type of trial on the gaze-cueing task had no impact on accuracy on the memory task.

(Table 2 about here please)

Experiment 1 showed a clear effect (though small in magnitude) of gaze cue-condition, particularly at the two shorter SOAs. Participants responded more quickly when targets appeared at the cued than the un-cued location. However, this effect was not modulated by working memory load. Rehearsing a set of either one or five digits slowed overall RTs to the target, as evidenced by the main effect of dual-task demand, but the difference between cued and uncued trials was constant over both the single and dual task blocks.

The digit rehearsal task, although capable of disrupting performance in certain visual attention tasks (see above), requires only the maintenance, but not manipulation, of information. It may therefore place limited demands on executive control processes within WM, and it may be these processes that are involved in the control of attention to eye-gaze. Moreover, the information involved (digits) can be coded verbally, while the gaze-cueing task is visual and involves a shift in spatial attention. Therefore, a secondary task involving both maintenance and manipulation of visuo-spatial material might be more disruptive to the gaze-cueing effect. This hypothesis was tested in Experiment 2.

Experiment 2

As there was no evidence in Experiment 1 that a verbal WM task disrupted gaze-cueing to any significant extent, Experiment 2 combined gaze-cueing with a secondary task that required the manipulation of visuo-spatial information in WM. While completing each of a number of short blocks of gaze-cueing trials, participants were asked to listen to an auditory description of a matrix pattern and to use this description to build up a corresponding mental image. Once completed, they were asked to maintain this image in memory until prompted to make a verbal judgement about its identity at the end of the block of gaze-cueing trials. This secondary task was adapted from one used by Logie, Zucco and Baddeley (1990) and was selected primarily because it involves the manipulation as well as maintenance of visuo-spatial information. However, the nature of the task also discourages participants from verbally re-coding the visuo-spatial information, a problem that plagues secondary tasks where participants are presented with a to-be-remembered visual pattern prior to performing the primary task.

It was hypothesized that if top-down control is involved in orienting to gaze cues, gaze-cueing would be modulated on trials where participants had to perform this task concurrently relative to trials where they performed a gaze-cueing task alone. Some minor changes were made to the gaze-cueing task in order to increase the magnitude of the gaze-cueing effect. In particular, instead of the gaze cue being presented directly after the fixation cross, “placeholder” faces with straight gaze were used so that there was a smaller visual transient when the gaze cue appeared. Four different facial identities were used (instead of one), and to reduce the complexity of the design, there was only one SOA between the cue and the target.

Method

Participants

Undergraduates and postgraduates (N = 39, 31 female, 8 male) at the University of Edinburgh were recruited for this experiment. They received course credit or a small financial honorarium in return for participation. The data from one participant was lost due to computer failure, and another due to experimenter error, leaving 37 participants (29 female). The mean age was 19.95 years (SD = 4.01).

Stimuli and Apparatus:

The visual gaze-cueing task was conducted on a desktop PC running E-prime experiment generator software, while the auditory matrix task ran on a laptop using Superlab experiment generator software. The laptop was connected to speakers located on either side of the desktop PC monitor, so that sound was not localised to the left or right of the participant.

Gaze-cueing task: As in Experiment 1, participants were instructed to localise a peripheral target, which was cued by centrally presented face. The faces used in this experiment were 4 photographic greyscale faces from the Ekman and Friesen (1976) set (faces JJ, MO, PE & C), all with neutral facial expressions. Adobe Photoshop 7.0 was used to prepare the images, by cropping the faces of their external features (hair and ears) and altering the eye region to create the averted gaze cues. The stimuli were presented on a 17 inch monitor running at a resolution of 1280 x 1024 pixels. Participants viewed the stimuli from a distance of approximately 70cm. The centrally presented faces subtended a visual angle of approximately 5.7° by 4.8° and were placed so that the eyes were parallel with the target (i.e. in the centre of the screen). The target was a grey square which subtended 0.95° of VA, and appeared 6.1° from the centre of the face.

Matrix task: The stimuli were nine pre-recorded auditory descriptions of matrix patterns that represented different digits. A male voice was recorded speaking two words: “filled” and “unfilled”. These auditory clips each lasted about 1 second and were arranged in sequences of 15, describing a 3 x 5 matrix pattern starting with the top left square and working along each row in turn. Figure 2 shows a pictorial example of one of the digits used in the task, alongside the verbal description. There was 500 ms pause after every third word, i.e., at the end of a matrix row. The nine digits used were 0, 2, 3, 4, 5, 6, 7, 8, and 9. Only nine digits were required to fit in with the number of blocks in the gaze-cueing task, therefore the digit “1” was omitted.

(Figure 2 about here please)

Design and Procedure

The experiment had a 2 x 2 repeated measures design with two levels of the factor demand (single task, dual task) and two levels of the factor gaze cue-condition (cued, uncued). The single and dual task trials were organised in blocks as described below, but the cued/uncued gaze-cueing trials were presented in a different random order for each participant.

Participants were seated in a dimly lit laboratory in front of a desktop computer which displayed the stimuli for the gaze-cueing task. The auditory stimuli from the matrix task were presented via speakers on each side of the screen. The experimenter remained in the room with the participant and controlled presentation of the auditory matrix task via a laptop computer. At the start of the session participants were introduced to the concept of the auditory matrix task and given practice. In the first phase of this practice they were given a pen and a sheet of paper with nine blank 3 x 5 grids. The experimenter asked them to start at the top and work left to right, and to mark a cross in each square of the grid if they heard the word “filled” but to leave it blank if they heard the word “unfilled”. The experimenter then read aloud the sequence for each of the nine digits used. The participant was asked to identify each of the digits to make sure they were able to recognise what the patterns were meant to represent. It was then explained that the next time they heard the sequences they would have to use mental imagery to perform the task; that is, they would have to create a mental image of the grid and they should imagine it being filled in with black squares. They were then given the opportunity to practice this, using the pre-recorded sequences on the laptop. The nine digits were presented in a random order, and after each one the participant had to report which digit they had heard described. If they made a mistake the sequence was repeated until they had responded correctly to all of the digits.

(Figure 3 about here please)

After the practice of the matrix task they were given an opportunity to practice the gaze-cueing task. An illustration of the trial sequence in the gaze-cueing task is provided in Figure 3. For this task participants were instructed to keep their eyes focussed on the centre of the screen at all times, and to respond to the appearance of the target as quickly and accurately as possible. They were instructed to press the leftmost key on a stimulus response box it the target appeared on the left, and the rightmost key if it appeared on the right, as quickly and accurately as possible using the index fingers of both hands. They were also informed that the gaze did not predict where the target would appear and should be ignored. Before beginning the experimental trials, participants were instructed that the visual and auditory tasks were of equal importance, and that they should try to do both of them as well as possible.

The trials of the gaze-cueing task were organised into 36 blocks of 8 trials. Half of these blocks were performed single task and half were performed dual task (i.e., while listening to a matrix description). Single and dual task blocks were alternated, with half of the participants starting with a single task block and half starting with a dual task block. During each block, E-prime selected randomly (without replacement) from the total pool of either single or dual task trials. Therefore it was randomly determined how many of the trials within each block were cued or uncued (and how many required a “left” or a “right” response) but over the course of the experiment participants performed 72 trials in each cell of the experimental design.

For each dual-task block, the experimenter triggered the start of the auditory description at the same time as the participant triggered the start of the visual task. The imagery instructions took about 3 seconds longer than the block of gaze-cueing trials, to ensure that all cueing trials were performed dual-task. At the end of the auditory description, they gave a verbal response indicating which digit they had heard being described. The experimenter entered this response on the laptop. Following this, participants triggered the start of the next (single task) block of gaze-cueing trials.

For each gaze-cueing trial the face appeared at fixation with a straight-ahead gaze for 750 ms, and was then replaced by a picture of the same face with the gaze laterally averted. The gaze was averted left and right on an equal number of trials, and was completely non-predictive of the target location (i.e., 50% cued, 50% uncued). The target appeared on screen 300 ms after the gaze cue and remained there until the participant’s response. Between each trial a blank screen was presented for 150 ms.

Results and Discussion

Gaze-cueing task: Localisation errors and trials with RTs of less than 150 ms or greater than 1500 ms were excluded from this analysis (a total of 1.19% of trials). For the remaining trials, the mean RT was calculated for each participant, and combined to give overall means for each condition across participants (shown in Table 3 with error rates). Under single-task conditions, reaction times when the gaze cued the location of the target were quicker by 31 milliseconds than when the target was uncued. A similar pattern was evident for the dual-task trials, although the difference was somewhat smaller at 23 milliseconds. A 2 x 2 repeated-measures analysis of variance was conducted on these data, with two levels of demand (single task, dual task), and two levels of the within-participants factor gaze cue-condition (cued, uncued). This analysis revealed a significant main effect of demand, $F(1, 36) = 62.79$, $MSE = 3544.91$, $p < 0.001$, indicating that reaction times were slower under dual-task conditions, and a significant main effect of gaze cue-condition, $F(1, 36) = 103.74$, $MSE = 256.40$, $p < 0.001$, reflecting the facilitation of RTs when the gaze cued the target. However, the interaction between these two factors did not reach statistical significance, $F(1,36) = 2.32$, $MSE = 196.52$, $p > 0.1$.

(Table 3 about here please)

Matrix errors: Error rate on the matrix task ranged from 0% to 50%, with a mean of 18.77% ($SD = 12.10$). Given that each matrix trial was associated with eight randomly selected gaze-cueing trials, it is not possible to look directly at the influence of the primary task on performance of the secondary task. However, it is possible to exclude any gaze-cueing trials where participants made an error on the associated matrix trial – this was not done in the main analysis above as it results in the exclusion of 9.75% of the primary task data. But after these exclusions, it is clear that the mean RTs for dual task trials remain very similar to those reported in Table 3, at 366 ms ($SD = 77$) for cued trials and 389 ms ($SD = 72$) for uncued trials (single task trials are unaffected by the exclusions). A 2 x 2 repeated-measures analysis of variance confirmed that the reduced data set had the same pattern as the full data set, with significant main effects of demand, $F(1, 36) = 61.48$, $MSE = 3523.38$, $p < 0.001$, and cue-condition, $F(1, 36) = 91.25$, $MSE = 285.40$, $p < 0.001$, but no significant interaction, $F(1, 36) = 2.65$, $MSE = 200.11$, $p > 0.1$ between these factors.

Very clear gaze-cueing effects were observed in this experiment, but as in Experiment 1, the effect was not modulated by the secondary task. The difference between cued and uncued trials under single-task conditions was slightly larger than under dual-task conditions, but this effect was not significant. A number of changes were introduced to the primary task for Experiment 2. Some of these changes (e.g., the change to the block structure) were necessitated by the nature of the secondary task. Others (e.g., using fixation faces with straight gaze) were introduced in order to increase the size of the gaze-cueing effect. This was successful, as the magnitude of the gaze cueing effect in Experiment 2 was more than twice that shown in Experiment 1.

General Discussion

The two experiments reported here made a concerted attempt to disrupt gaze-cueing behaviour in a typical sample of participants, with the aid of two demanding secondary tasks. In Experiment 1, participants had to maintain information in verbal working memory, and in Experiment 2 they had to maintain and manipulate information in visuo-spatial working memory using mental imagery. However, gaze-cueing proved resistant to interference by either of these demands; it was not modulated by WM load. That is not to say that WM load had no effect on performance; indeed these tasks clearly had a big impact on performance in terms of overall reaction time, but this effect did not interact with the effect of gaze cue-condition. Gaze-cueing was initially argued to be a highly reflexive effect (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999), and the evidence presented here is more in line with this notion than with more recent accounts of gaze-cueing as a voluntary process (Vecera & Rizzo, 2004; 2006).

The digit-rehearsal secondary task used in Experiment 1 has already been shown to modulate the level of interference by other types of distracter in selective attention tasks (De Fockert et al., 2001; Lavie & de Fockert, 2005; Pecchinenda & Heil, 2007), which is why it was chosen for the current study. The studies by De Fockert et al. and Pecchinenda and Heil demonstrated greater interference under WM load in variations of a Flanker task where participants had to ignore incongruent distracter faces while categorising famous names or emotional labels. Lavie & de Fockert (2005) used the digit rehearsal task to demonstrate increased attention capture by irrelevant colour singletons during a visual search task. Therefore, there were many differences between these primary tasks and the gaze-cueing task employed here. Our results suggest that the processes involved in the digit rehearsal task – the simple maintenance of information in WM – did not interfere with the tendency for non-predictive gaze cues to produce a shift in spatial attention. This is in line with the null findings of two recent studies which have attempted to combine WM tasks with a different type of spatial cueing. Santangelo and Spence (2007) found that a verbal WM load did not affect reflexive orienting to spatially non-predictive peripheral cues, while Santangelo, Finoia, Raffone, Belardinelli and Spence (2008; Experiment 3) found that a visual WM load was also ineffective in modulating this type of cueing. These studies suggest that maintenance of information in WM does not affect spatial cueing by peripheral stimuli. Our results extend this conclusion to centrally presented, non-predictive gaze cues.

It was originally thought that gaze-cueing represented a special case where a centrally-presented cue could produce reflexive orienting, because of the social and biological importance of eyes. However, similar cueing effects were also demonstrated with centrally-presented, spatially-non predictive arrows (Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). Subtle differences between gaze and arrow cueing (for example, gaze continues to cue attention even when counter-predictive of the target but arrows do not) have led some authors to describe gaze-cueing as “more reflexive” than arrow cueing (Friesen, Ristic, & Kingstone, 2004; Ristic, Wright, & Kingstone, 2007). Frischen et al. (2007) suggest that, given the recent findings with gaze and arrows, it may no longer be useful to divide spatial cueing into reflexive and voluntary categories (see also Lambert, Roser, Wells, & Heffer, 2006); rather, one might think in terms of a continuum of automaticity in spatial cueing tasks.

Is it possible that a WM task with a greater level of executive demand would have an impact on gaze-cueing? In terms of the multiple-component model of WM (e.g., Baddeley, 2000), the digit rehearsal task used in Experiment 1 may have relied mainly on the phonological loop verbal slave system, with minimal involvement from central executive resources. However, if attentional control processes are involved in gaze-cueing (either through the adoption of an attentional set, or by suppressing the pre-potent tendency to follow eye-gaze), then we might expect greater disruption from a secondary task that engages central executive resources. The matrix task used in Experiment 2 did require the manipulation of (visuo-spatial) information in WM, but this task also failed to modulate the gaze-cueing effect. It remains an open question whether secondary tasks with different types of executive demand could have an impact. The central executive is now widely regarded to consist of a set of interconnected and yet separable processes (e.g., Miyake et al., 2000), and it is of course not possible to conclude, based on the null effects reported here, that a task drawing on a different aspect of executive functioning would not interact with attentional shifts provoked by eye gaze. For example, a secondary task requiring the inhibition of pre-potent responses might be predicted to increase gaze-cueing, as it could reduce the capacity of participants to ignore the irrelevant gaze cues which also require to be inhibited. Ultimately, this is an empirical question, and further studies will be required to demarcate the boundaries of our conclusion that WM load does not modulate the gaze-cueing effect.

To our knowledge, the work reported here is the first to examine the impact of secondary tasks on the gaze-cueing effect. The results can be summarised by stating that gaze-cueing in a standard paradigm was not modulated by secondary tasks loading both verbal and visuo-spatial working memory. Although overall reaction times were slowed under dual-task conditions, cued targets retained their advantage over uncued targets. These findings can be seen as supportive of traditional accounts of gaze-cueing as a process lying towards the reflexive end of a continuum of automaticity in spatial cueing tasks.

Table 1: Mean reaction times (in milliseconds) and errors (in percentages) for the gaze cueing task in Experiment 1 (standard deviations in parentheses)

		Low load group		High load group	
		Single task	Dual task	Single task	Dual task
100 ms SOA	Cued RT	375 (48)	470 (109)	394 (51)	467 (86)
	% Error	0.77 (1.84)	0.00 (0.00)	0.19 (0.98)	0.00 (0.00)
	Uncued RT	383 (51)	480 (124)	400 (57)	478 (92)
	% Error	0.19 (0.98)	0.38 (1.35)	0.19 (0.98)	0.00 (0.00)
500 ms SOA	Cued RT	337 (47)	408 (107)	361 (60)	410 (102)
	% Error	0.00 (0.00)	0.19 (0.98)	0.19 (0.98)	0.19 (0.98)
	Uncued RT	350 (42)	419 (114)	365 (54)	416 (97)
	% Error	0.58 (1.63)	0.38 (1.35)	0.38 (1.35)	0.38 (1.35)
1000 ms SOA	Cued RT	319 (43)	405 (109)	351 (71)	401 (104)
	% Error	0.77 (1.84)	0.19 (0.98)	0.77 (1.83)	0.00 (0.00)
	Uncued RT	329 (47)	393 (100)	353 (61)	411 (98)
	% Error	0.38 (1.96)	0.00 (0.00)	0.19 (0.98)	0.00 (0.00)

Table 2: Percentage of errors in Experiment 1 memory task (standard deviations in parentheses)

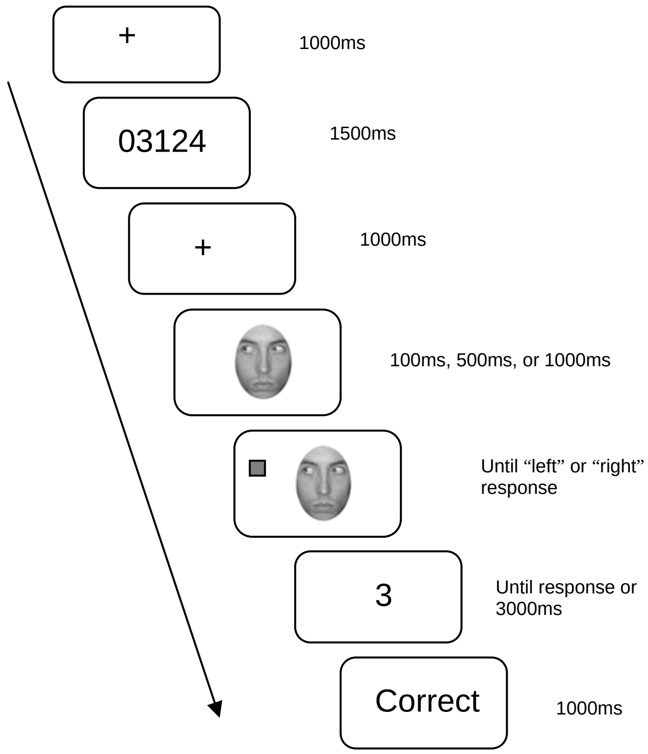
		Low Load Group	High Load Group
100 ms SOA	Cued	2.69 (4.30)	6.73 (5.09)
	Uncued	3.08 (4.91)	8.65 (8.07)
500ms SOA	Cued	1.92 (3.19)	8.08 (7.76)
	Uncued	2.92 (2.86)	7.88 (8.02)
1000ms SOA	Cued	3.12 (4.68)	9.81 (7.81)
	Uncued	2.69 (4.06)	7.88 (6.19)

Table 3: Mean reaction times (in milliseconds) and errors (in percentages) for the gaze cueing task in Experiment 2 (standard deviations in parentheses)

	Single Task	Dual Task
Cued RT	285 (29)	367 (77)
% Error	0.26 (0.55)	0.98 (1.50)
Uncued RT	316 (36)	390 (73)
% Error	1.35 (1.95)	2.18 (2.21)

Figure 1:

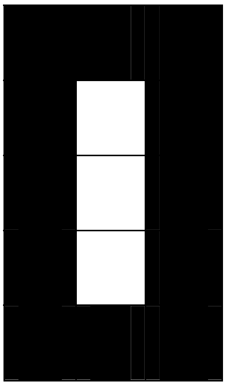
Example trial sequence from the high-load dual task condition of Experiment 1 (not drawn to scale)



+
1000ms
03124
1500ms
+
1000ms
100ms, 500ms, or 1000ms
Until “left” or “right” response
3
Until response or 3000ms
Correct
1000ms

Figure 2:

An example digit from the matrix task in Experiment 2



“filled, filled, filled

filled, unfilled, filled

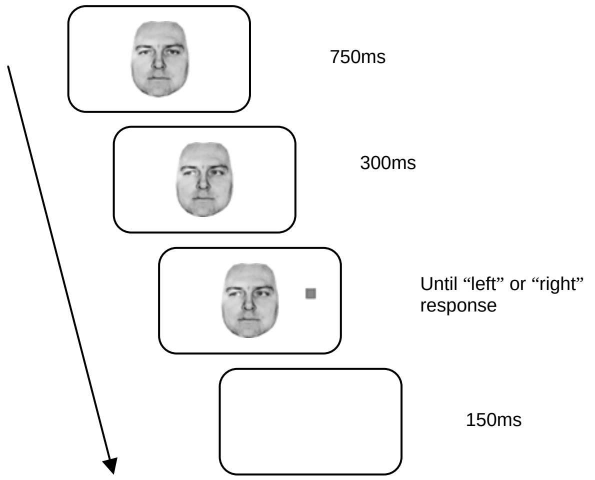
filled, unfilled, filled

filled, unfilled, filled

filled, filled, filled”

Figure 3:

Example trial sequence from Experiment 2 (not drawn to scale)



750ms
300ms
Until “left” or “right” response
150ms

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