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Keeping the eyes on a fixation point modulates how a symbolic cue orients covert attention

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Abstract

Studies on covert attention usually monitor participants' eye movements in order to prevent participants from moving their eyes away from a central fixation point. However, given our frequently dynamic attention behavior, keeping the gaze on a fixation point may be effortful and require attentional resources. If so, then trying to maintain fixation should interfere with *covert* attention orienting because both maintaining fixation and attention orienting require attentional resources. Here we present two eye tracking experiments showing that the amount of attentional resources involved in maintaining fixation affects how an arrow orients covert attention.

Keywords: visual attention; covert attention; spatial cueing; eye movements

Introduction

It is an interesting fact about visual attention that people can shift their attention covertly while overtly fixating a central point (Posner, Snyder, & Davidson, 1980). Studies on covert attention shifts often instruct participants to fixate a cross in the middle of the screen while they are engaged in another task requiring them to shift their attention covertly away from the cross. However, keeping the eye on a fixation point goes against the natural tendency to explore the environment with the eyes (Hermens & Walker, 2010; Munoz, 2002; Rolfs, 2009). This suggests that maintaining fixation may involve attentional effort (Dauwels, Vialatte & Cichocki, 2010). Despite these observations, we so far do not know whether maintaining fixation does indeed require attentional resources and how it affects other attentional processes such as covert attention shifts.

Attentional-based interference

It is well known that attention has limited processing capacity (Kahneman, 1973) and when engaged in two concurrent activities (both requiring attentional resources), interference is observed (Pashler, 1994). Accordingly, keeping the eye on the fixation cross should interfere with any attention-demanding task performed simultaneously.

The spatial cuing paradigm is a good example of such a situation. Introduced by Posner (1980), it has become an established paradigm in the investigation of covert attention shifts. In Posner's classical study, as in more recent variants of the paradigm, participants are asked to keep their eye gaze on a (typically centrally-presented) fixation cross while they are asked to respond behaviorally to a peripheral target stimulus to which attention is either cued (e.g., by an arrow pointing in its direction) or not. Maintaining fixation ensures that the paradigm elicits covert (rather than overt[1]) attention shifts to the peripheral target stimulus. Overall, results from this paradigm have shown that an attentionally cued relative to an uncued non-central target stimulus elicits faster covert attention shifts and response latencies (e.g., in a binary target discrimination task). We use the spatial cuing paradigm to investigate the extent to which maintaining fixation interferes with covert shifts of attention.

Following the idea of limited resources (Kahneman, 1973), performance in covert orienting should be impaired if participants are engaged in a concurrent resource-taxing fixation task. This is in line with the studies on covert attention showing that a central-monitoring task affects the property of a peripheral cue to attract attention at a short SOA (Santangelo, Olivetti Belardinelli, & Spence, 2007; Santangelo, Botta, Lupianez & Spence, 2011).

Despite this evidence, a positive cueing effect (the latency difference between responding to a target at a cued location versus an uncued location) emerged even when participants maintained fixation (e.g., Downing; 1988; Eimer, 1994; Hawkins, Hillyard, Luck, Mouloua, Downing & Woodward, 1990). One possible explanation is that in these studies, participants did not receive any feedback on their fixation behavior during the experiment. In the absence of feedback, participants may not have been aware of their performance and they may thus have allocated few resources to maintaining fixation and instead focused on shifting covert attention to the cued location, eliciting a cueing effect.

To the extent that this reasoning holds, post-trial feedback every time participants move their eyes away from the fixation cross should make fixating more attention-demanding. Then, according to the limited resources view, we should observe interference in the cueing task, that is a reduced cuing effect. On the other hand, if keeping the eyes

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[1] Overt attention shifts are accompanied by an eye movement while 'covert' attention shifts are shifts of the attention focus without a corresponding overt eye movement.

on the fixation dot does not require attention, or if it does not interfere with other covert attentional processes, then the cueing effect in covert attention should be insensitive to the instruction of maintaining fixation.

We conducted two spatial cueing experiments to investigate this hypothesis. The spatial cueing paradigm is well established for investigating covert attention (Müller & Findley, 1988), and a central arrow robustly orients covert attention (Gibson & Bryant, 2005; Hommel, Pratt, Colzato & Godiji, 2001; Ristic, Friesen & Kingstone, 2002; Ristic & Kingstone, 2006). In the first experiment, participants had to discriminate a peripheral target as fast as possible while fixating a central dot for the entire duration of the experiment. The control on eye movements was obtained by setting an area of interest (AoI) around the fixation point; the eye tracker was then programmed to present a feedback message after each trial in which participants' eyes had left that AoI. Given that we made maintaining fixation on the central dot obligatory via the post-trial feedback, we should observe a decrease in the cueing of covert attention shifts by an arrow (to the extent that maintaining fixation interferes with covert shifts in attention).

A second experiment was identical but adopted a larger AoI around the central fixation dot, thus relaxing fixation control. This modification ensured that participants did not move their eyes to the target while reducing the amount of attentional resources necessary to keep the eye on the fixation dot (see Kingstone & Klein, 1993). According to the limited capacity view, this should free attentional resources which could, in principle, be allocated to covert attention shifts cued by an arrow.

Experiment 1

The first experiment aims to investigate whether keeping the eye on a fixation point interferes with the property of an arrow to covertly orient attention toward a cued location.

Method

Participants 24 participants (6 male and 18 female; age range = 22-33 years, mean age = 28.7 years) received 6 euro for participating in the experiment. All had normal or corrected-to-normal vision and were unfamiliar with the purpose of the study. All gave informed consent.

Apparatus and Stimuli An the Eyelink 1000 (SR research Ltd. Ontario, Canada) monitored eye gaze at a frequency of 1000 Hz. The experiment was presented via the Experiment Builder program (SR research Ltd. Ontario, Canada). A 22', 120Hz, 1680 x 1050 pixel resolution Samsung monitor was used to show the stimuli. This monitor and its high frequency guaranteed a reliable and accurate presentation time (Wang & Nikolic, 2011). Participants sat approximately 85 cm from the screen and their head rested on a chin rest. Responses were collected via a Cedrus RB-834 response box, providing an accuracy of +- 1 msec.

A simple arrow subtending 2.6° served as a central cue. The target was an "E" or a mirror "E" (see Schneider & Deubel, 1995) subtending 0.7° x 0.7° area. The target letter could appear in the four cardinal locations around a circle that subtended 8.8°. The target was presented at 4.6° from the fixation point. The distractors were the numbers 2, 5 and 9 all subtending the same area as the target. The target and distractors were pre-masked by an 8-like shape (0.7° x 0.7°). After removing parts of the 8-like shape, the pre-mask could become either a number (e.g. 2, 5 or 9) or the target. Neutral trials presented a circle (subtending 2.6°) instead of an arrow. All stimuli were black on a white background. The fixation point (a red cross subtending 0.7° visual degree) was presented at center display, superimposed to the cue.

Design The combination of two cue types (arrow vs. neutral circle), cue direction (0°, 90°, 180°, and 270°), and target location (0°, 90°, 180°, and 270°), yielded a trial factor with the levels neutral, valid, and invalid. Valid trials showed the arrow pointing to the target, invalid trials showed the arrow pointing to one of the remaining three locations and neutral trials used a circle as the cue (see Figure 1).

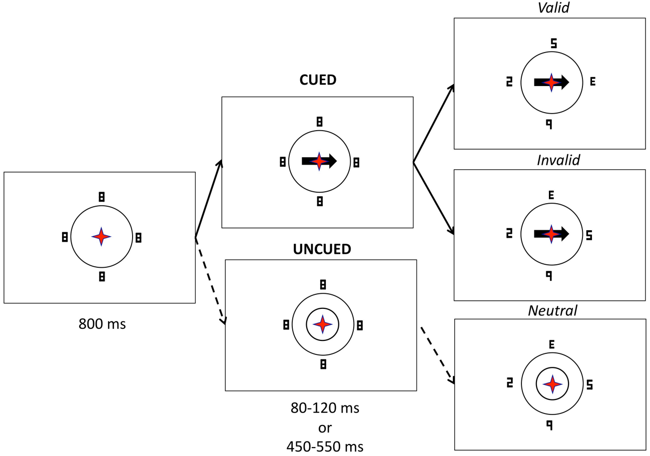

Figure 1: This schema illustrates the experimental trial sequence. First a fixation cross was displayed for 800 ms. Next a "cued" trial or an "uncued" trial could begin. Cued trials (solid lines) showed an arrow as a cue while trials showing a circle were encoded as neutral trials (dotted lines). If the arrow indicates the direction where the target appears, the trial is 'valid'. For invalid trials, the arrow indicates a location where the target does not appear. The target remained on-screen until a response was recorded or for a maximum of 3000 ms. Stimuli are not to scale.

A second factor was stimulus onset asynchrony (SOA) with two levels (short vs. long; short = random duration between 80 and 120 ms vs. long = between 450 and 550 ms). We used these times according to the evidence that stronger cueing effect is reached around 600 ms and the worst at about 100 ms SOA (e.g., Ristic & Kingstone, 2006 but c.f. Müller & Rabbitt, 1989; see also Chica, Lupianez & Bartolomeo, 2006). Finally we included block as a factor to verify that there is no learning effect (i.e., an increase of the cueing effect across blocks).

Participants saw each trial four times, totaling 512 trials per participant (64 valid, 192 invalid and 256 neutral). The percentage of valid trials was 25% (so that the arrow cue was not predictive given that invalid trials covered the remaining 75% of all cued trials). The number of neutral trials (uncued) was balanced with the number of cued trials. Participants were not informed about cue validity. It has been argued that an arrow orients attention automatically (Galfano, Dalmaso, Marzoli, Pavan, Coricelli & Castelli, 2012; Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003; Kuhn & Kingstone, 2009; Peterson & Gibson, 2011; Pratt, Radulescu, Guo & Hommel, 2010; Ristic, Friesen & Kingstone, 2002; Tipples, 2002), meaning that how often it points to the target should not modulate the cueing effect.

Procedure All participants signed an informed consent form and received instructions about the experiment. Then the eye tracker was calibrated via a 9-point calibration procedure. Before the experiment began, participants received 16 practice trials. Figure 1 illustrates the sequence of events. All trials began with a fixation point inside a circle and 4 masks. After 800 ms, either an uncued trial (with a circle) or a cued trial (with an arrow) was presented. The cue remained on the screen for a variable time depending on the SOA (short or long). Afterwards the masks were modified revealing one target and 3 distractors. The target was displayed for a maximum of 3000 ms or until the participant pressed a response button. Latencies were measured from target onset.

The inter-trial interval lasted 1200 ms. An AoI of 3.5° x 3.5° was set around the fixation cross. Its size was big enough to include the arrow cue. When an eye movement was detected outside the AoI, a message was displayed ("The eye tracker has detected that you moved your eyes away from the fixation point. Please try to always fixate the central red cross") and the trial was interrupted. The full experiment lasted about 45-50 minutes including 10 short breaks. Participants were re-calibrated after each break.

Analysis and Results

Reaction time analysis Three participants were excluded from the analysis because they failed to keep their eyes on the fixation point in more than 20% of the trials. For the remaining 21 participants, trials with latencies below 200 ms (14 = 0.13%), trials where participant moved their eyes (729 = 6.8%), and trials for which an incorrect response was given (305 = 2.8%) were excluded. In order to eliminate outliers (460 trials = 5% eliminated), we filtered the reaction times by 2 SD (calculated for each condition and for each participant). The cleaned data was analyzed using a repeated-measures ANOVA with three factors: 2 (SOAs) x 3 (trial type) x block (1-4). The latter factor was included to verify changes in the cueing effect across blocks (see Methods). Trial type levels were valid, invalid and neutral, and SOA levels were short vs. long (see Figure 1).

The 3-way ANOVA, F(2,40) = 6.66, $p < .01$, revealed a main effect of trial type that came from faster responses in neutral trials (M = 744 ms; SD = 28 ms than in valid trials (M = 764 ms; SD = 31 difference = 20.6 ms, see Figure 2), and descriptively valid trials were responded to faster than invalid trials ($p > 0.4$). The interaction between cue type and SOA was marginally significant, F(2,40) = 2.6, $p = .087$) but the post-hoc tests revealed no difference between valid and invalid trials in the two SOA types. A significant main effect of block also emerged, F(3,60) = 23.51, $p < .0001$, with slower responses in the first than fourth block (129 ms). No other effects were significant (*p*s > .4).

Table 1: Means reaction times and relative standard deviations for the main effects in Experiment 1 and 2.

Experiment 1		RT	SD
Block	1	827	40
	2	771	34
	3	738	26
	4	698	23
SOA	Short	758	31
	Long	755	29
Trial Type	Valid	764	31
	Invalid	755	34
	Neutral	744	28
Experiment 2			
Block	1	791	45
	2	749	35
	3	682	26
	4	671	22
SOA	Short	723	33
	Long	725	30
Trial Type	Valid	710	28
	Invalid	740	38
	Neutral	719	24

Discussion

The analyses for Experiment 1 converged in showing that the arrow did not automatically orient participants' attention towards the target location. Thus, making the fixation task demanding (by applying a tight control on eye movements and providing post-trial feedback on fixation performance), eliminated the cueing benefit reported in literature (c.f. Ristic, Friesen, & Kingstone, 2002). Indeed, if anything invalid trials were responded to faster than valid trials although this comparison was not reliable. Neutral trials elicited reliably faster responses than valid trials, but this can be explained in terms of cue validity. It is possible that participants used neutral trials efficiently because the circles distributed attention to all the potential target locations.

The fact that three participants failed to maintain fixation within the small area around the fixation dot for more than 20% of the trials, suggests that the task was difficult. This between-subject variation further suggests that keeping the eye on a central fixation dot requires attentional effort (Neuman, 1984, but c.f. Logan 1998). The remaining participants failed to maintain fixation on about 7% of the trials (c.f. Galfano et al. 2012).

The main effect of block replicated previous results showing a decrease in response times over the course of the experiment. The lack of a significant interaction between block and trial type again suggested that practice did not affect the effect of trial type. The marginal interaction of trial type and SOA seems to stem from a decrease in reaction time at the long (vs. short) SOA within invalid trials. At the short SOA, the target appeared after 80-120 ms after cue onset, a point at which participants' attention may still have been focused on the (cued but often incorrect) location, thus slowing target-onset time-locked response times. With the long SOA, participants had around 400 ms extra between cue and target onset to attend to all four locations, arguably speeding up their target discrimination time once the target appeared.

In summary, a tight control on eye movements prevents participants from using the arrow to automatically guide attention. If maintaining fixation takes away attention resources necessary for the positive cueing effect to emerge, then the cueing effect should reappear if we make the fixation task less demanding. Experiment 2 investigated this hypothesis by using a looser fixation control.

Experiment 2

In Experiment 1, a strict control on eye movements and feedback on fixation errors during a spatial cueing experiment prevented people from using the arrow to direct their attention to a cued location. This eliminated the advantage for valid over invalid trials. In Experiment 2, we loosened the control on fixation. If the amount of attention demanded by the tight control on fixation interfered with the cueing effect, then participants should be able to use the arrow and therefore we should see faster responses for valid than invalid trials in Experiment 2. Alternatively, if other properties of the stimuli or paradigm eliminated the cueing effect, then we should fail to replicate it.

Method

Participants 19 further native German speakers (6 male and 13 female; age range = 20-29 years, mean age = 23 years) with normal or corrected-to-normal vision participated in this study. All participants were naïve to the purpose of the study and gave informed consent in accordance with the declaration of Helsinki. Each participant was paid 6 euro for participation.

Material, Design and Procedure This experiment used the same materials, design and procedure as Experiment 1. The only difference concerns the use of a looser control on the eye movements. This was obtained by using a larger AoI (9° x 9°) compared to the one used in Experiment 1 (3.5° x 3.5°). The dimension of this area allowed eye movements along the entire length of the cue (arrow or circle, about 2.7°) but triggered feedback if the eyes moved to the target (which was located at 4.6° from the fixation point).

Analysis and Results

Reaction time analysis As for Experiment 1, we eliminated trials with latencies below 200 ms (59 = 1%), trials with eye movements (865 = 8.9%) and trials with an incorrect response (318 = 3.3%). In order to exclude outliers, reaction times were filtered (2 SD for each participant by condition) eliminating 430 trials (5%).

As for Experiment 1 we conducted an ANOVA including block, SOA and cue type as factors. The 3-way ANOVA revealed a significant main effect of trial type, F(2,36) = 3.44, $p < .05$. Crucially and unlike in Experiment 1, follow up analyses (Scheffé) showed a significant advantage for valid trials (M = 710 ms; SD = 28 ms) compared to invalid (M = 740 ms; SD = 37 ms) trials (see Figure 2). No other comparisons were significant (all remaining *p*s > .1). We also replicated the significant main effect of block, F(3,54) = 11.03, $p < .0001$, with slower responses for the first (M = 791 ms; SD = 45 ms) than the last (M= 671; SD = 22 ms) block. The analysis also found a significant interaction, between block and trial type, F(6,108) = 2.23, $p < .05$, with a significant advantage for valid trials compared to invalid trials in block 1 ($p < .0001$) and block 2 ($p < .05$), but not in block 3 and 4.

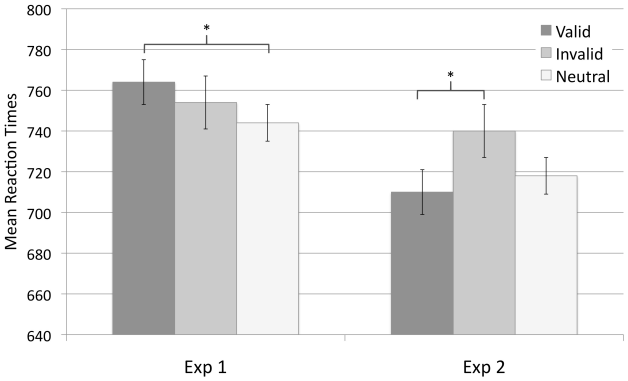

Figure 2: This graph summarizes the main effect of trial type found across the two experiments. Asterisks indicate significant comparisons. Bars represent standard errors.

The principal difference between Experiment 1 and Experiment 2 consisted in using a larger AoI to monitor the eye movements in Experiment 2. In doing this, it was then possible that people moved their eyes closer to the target (but still not on the target). This would have brought a visual advantage. In order to exclude this interpretation, we ran a new analysis excluding (post-hoc) trials in which people moved their eye away from the fixation point (detected by setting a new 0.7° x 0.7° area which was just about the same size as the fixation cross) but still within the monitored perimeter (9° x 9°). This analysis found that people moved their eyes outside this small area on 9.4% of the trials but an ANOVA including only trials where people did not move their eyes out of this small area revealed main effect of trial type, F(2,36) = 4.55, $p < .05$, replicating the advantage for valid (M = 703 ms; SD = 28 ms) over invalid (M = 739 ms; SD = 37 ms) trials.

Discussion

We investigated whether reducing the attentional effort involved in fixating the fixation cross would reproduce the response time advantage for valid over invalid trials. The results corroborate our hypothesis in that with a looser control on eye movements, the responses to valid trials were significantly faster than the responses to invalid trials.

As in Experiment 1, the block effect suggested that participants improved with practice. The interaction between block and trial type indicated that such improvement concerns only the first two blocks, which likely reflects that spatial orienting in target discrimination (while maintaining fixation) is modulated by practice.

General Discussion

The distinction between covert and overt attention lies in the role of eye movements: While covert attention shifts occur without eye movements, an overt attention shift is accompanied by an eye movement. In studies on covert attention participants have been asked to keep their eyes on a central fixation dot, ensuring that covert attention was tested. But keeping the eyes on a specific point is not a natural behavior, and it has been suggested that fixation control requires attention. If so, then the limited capacity hypothesis predicts that fewer attentional resources should be available for covert attention shifts to a non-central target when people are instructed to maintain central fixation.

The results from Experiment 1 revealed similar response times for valid (i.e., cued) and invalid trials when participants maintained fixation (a) under a tight spatial control on eye movements (a narrow perimeter) and (b) when online feedback alerted them if they moved their eye outside the perimeter. By contrast, in Experiment 2, when a laxer fixation control meant that fixating the central dot required less attentional resources, we did observe an advantage for valid over invalid trials.

We believe these findings are relevant for anyone interested in covert attention, given that often in such paradigms a spatial cueing task is associated with the instruction to maintain central fixation. However, these two experiments do not clarify whether the attentional resources engaged in keeping the eye on the fixation dot affected only reflexive shifts in covert attention or also voluntary shifts. We are currently testing this hypothesis by running a study where we keep a tight control on eye movements but increase the cue validity from 25% to 75%. We expect this manipulation will make the direction of the cue predictive, providing participants with an incentive to voluntarily shift attention in the cued direction (Jonides, 1981; Posner, 1980). If keeping the eye on the fixation affects only reflexive covert attention shifts, a positive cueing effect should emerge when cue validity is high and fixation control is strict. Another follow-up study using peripheral cues (abrupt onset) would provide insight into whether maintaining the eyes on the fixation dot affects also exogenous attention.

More broadly, the results from Experiments 1 and 2 are interesting in relation to the so-called gap effect (Braun & Breitmeyer, 1988; Fischer & Boch, 1983; Fischer & Ramsperger, 1984). According to the attentional pre-disengagement theory (APT, Fischer & Breitmeyer, 1987), removing the fixation dot disengages attention, facilitating attentional shifts elsewhere (Kingstone & Klein, 1993). In our experiments the fixation dot was never removed, ensuring that people attended to it. However, in Experiment 2, fixation control was lax, meaning less attentional resources were engaged at the dot, and more were available for covert shifts to the target. It will be interesting to see whether removing the fixation dot during a trial would elicit the same pattern as the overall laxer fixation control in Experiment 2. Another possible avenue for future research is to compare attention allocation and the cueing effect in a task which - unlike the fixation-task - does not engage spatial attention (e.g., mental arithmetic).

While these are exciting research possibilities, what we have shown here is that the attentional resources involved in maintaining fixation affect the property of a non-predictive cue to orient covert attention. Experiment 1 has provided evidence that when central fixation control was (spatially) strict, an arrow to a peripheral did not elicit a cueing effect. However, when maintaining fixation required less attentional resources (using a laxer spatial control on eye movements) the non-predictive arrow elicited a cuing effect.

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