The interpretation attributed to observed gaze shifts affects their social-cueing effect

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Abstract

In an environment busy with abundant stimulation, individuals must rely on attentional cues to select the most relevant targets. As social creatures, a crucial strategy involves monitoring where others are focusing their attention and following them, assuming that locations attended by others are more likely to yield benefits than other locations. Given that gaze shifts represent a visible shift in attention, mirroring the gaze shifts of others can serve as an effective, social-attentional strategy. Indeed, research demonstrates that observing others redirect their gaze results in a reflexive shift of attention, reflected by improved perceptual performance for objects located at the gazed-at positions. This phenomenon is known as the *gaze cueing effect* (GCE). However, gaze shifts may not always align with the direction of attention. Individuals often avert their gaze while they are engaged in demanding cognitive tasks. Such gaze shifts signify internal focus rather than shifting attention outward. Here we hypothesize that the response to a gaze-shift cue is not reflexive but is contingent upon social context. In two pre-registered experiments, participants viewed videos of gaze shifts and engaged in a perceptual task, with one group primed to perceive the gaze shifts as reflecting cognitive processing rather than overt attentional shifts. Results indicated that GCE was suppressed in this group, suggesting that GCE is influenced by contextual cues framing the nature of the gaze shifts. These findings suggest that social attention is flexible and depends on the specific interpretation of the social context.

Introduction

In a crowded and sensory-overloaded environment, spatial attention allows humans and animals to selectively process information through the prioritizing of specific locations in their perceptual field. A central challenge of the cognitive system is to correctly and efficiently choose its attentional goals based to priorities. Attentional goals may be selected exogenously, triggered by external stimuli that attract attention, such as a sudden bright light prompting a swift attentional shift, or endogenously, prompted by cues to direct attention, for example, an arrow indicating the location where a target is most likely to appear. In laboratory settings, abstract cues can be easily provided to guide participants on where to focus their attention. However, in natural environments, such cues

are typically absent. Conversely, one of the most effective cues for determining where to focus attention is the attention of other individuals. For social beings like humans, utilizing the attentional prioritization of others can enhance the likelihood of making accurate choices. As eye movements mirror the overt orientation of attention, a practical method for tracking another person's focus is to monitor their eye movements.

Observing another person's gaze shift was demonstrated to prompt a shift of attention in the observer, leading to faster reaction times (RTs) when responding to a target aligned with the observed gaze trajectory (Friesen & Kingstone, 1998). This phenomenon, known as the *gaze cueing effect* (GCE), highlights the social dimension of spatial attention, showing that individuals tend to shift their attention according to where others are presumed to be looking (Frischen, Bayliss & Tipper, 2007). The impact of this effect extends beyond interactions with physically present individuals, as it also manifests in response to images of people (Dalmaso, Galfano & Castelli, 2015; Lachat et al., 2012) and even to schematic depictions of eyes (e.g., Friesen & Kingstone, 1998). This robust effect of gaze cueing is considered to be reflexive, as it emerges rapidly in the neural timecourse (Friesen, Moore, & Kingstone, 2005) and may occur unconsciously (Sato, Okada & Toichi, 2007; and see Frischen, Bayliss, et al., 2007; McKay et al., 2021) for more detailed overviews). It was also shown to be affected by top-down factors, including the observer's characteristics like gender or age, perceived social status, emotional expressions, racial group, mental states attribution and familiarity between the observer and the cuing faces (Bayliss, Di Pellegrino & Tipper, 2005; Bayliss, Schuch & Tipper, 2010; Dalmaso et al., 2014; Dalmaso et al., 2015; Frischen & Tipper, 2006; Slessor et al., 2016; Teufel, et al., 2010; for a review see Dalmaso, Castelli & Galfano, 2020).

The evolutionary perspective on the GCE suggests that following someone else's gaze enhances survival prospects by directing attention to potentially crucial information, assuming that another person's gaze shift signifies their priority selection. But is this an accurate assumption? Do gaze shifts invariably correspond to attentional shifts and prioritization? The answer to this question is no. Despite the common correlation between eye movements and attention shifts, there are instances where gaze may be directed to non-informative or irrelevant locations. For example, the 'looking at nothing' effect illustrates how participants who are recalling memorized items, shift their gaze to locations where these items were previously located, even if they are no longer there (Brandt & Stark, 1997; Johansson & Johansson, 2014; Taub & Yuval-Greenberg, 2023). Moreover, during cognitively demanding tasks, like formulating a response to a question, individuals tend to avert their gaze away from the conversational partner (Glenberg, Schroeder & Robertson, 1998; Doherty-Sneddon, 2002). These gaze aversions (GAs) constitute large eye movements away from

the center of the visual field, where the interlocutor is typically located, and to the far periphery. GAs were hypothesized to assist in reducing external distractions during internal cognitive processing (Doherty-Sneddon & Phelps, 2005; Glenberg et al., 1998; Abeles & Yuval-Greenberg, 2017, 2021).

Research across diverse fields has explored the social implications of GAs during conversations. In one of the earlier exploratory studies, Kendon (1967) suggested that GAs serve as signals in conversation dynamics, indicating an impending conversational turn, or as a way of saying "I'm about to talk". This was supported by Ho, Foulsham & Kingstone (2015) who linked GAs to the beginning and end of speaking turns during turn-taking activities. This alignment is evident not only in human-human interactions but also in human-robot exchanges. In one study, a robot's head aversions that were synchronized with its speaking turn decreased the likelihood of the robot being interrupted by a human in a conversation (Andrist et al., 2014). Overall, these findings suggest that the use of GAs facilitates seamless communication, by signaling that the performer is occupied by internal mental processing and aiding in turn-taking without interruptions. Importantly, unlike gaze cues, GAs do not reflect spatial attention orientation, with their target locations being non-informative for external observers, and therefore following them is not beneficial.

In summary, social interactions involve two key aspects of eye movements: the GCE, reflecting *outward* attentional orienting, and GAs, indicating *internal* attentional focus. While the GCE prompts observers to orient their attention outward, GAs suggest a focus on internal processing, potentially inhibiting an external orienting response. On one hand, there is abundant research showing that looking at someone else's gaze causes attentional shifts towards that location. On the other hand, since gaze shifts do not always reflect attentional orienting, it may not always be a good strategy to attend to the targets of other people's gaze shifts. An intriguing question is what causes certain eye movements to serve as spatial gaze cues, and in what situations are eye movements perceived as attentionally uninformative gaze aversions.

One possible answer is that observers differentiate between different types of eye movements according to their kinematics, such as their direction, eccentricity, or velocity. It may be the case that an eye movement of certain characteristics would elicit a cueing effect and another, with different characteristics would not. Evidence relating the direction of gaze shifts to their attributed attentional role is ambivalent. Some evidence suggests that people who were asked to interpret still images of an averted gaze were associating the direction of the gaze with the type of attention that it reflects: an upward gaze was associated with internal attention (i.e. GA) and central or horizontal gaze shifts were associated with external attention orientation (i.e. GCE; Servais, Hurter & Barbeau,

2022). However, other evidence suggests that the GCE exists for both horizontal and vertical gaze shifts, regardless of their direction (Friesen, Ristic & Kingstone, 2004).

Here we hypothesize that, while GA and GCE are kinetically identical, they lead to different interpretations by observers and consequently to different attentional effects. According to this hypothesis, the GCE depends on the interpretation of the type of eye movement, which, in turn, depends on the presented context. We suggest that the same eye movement, with the same kinematic attributes, could signal either spatial orienting of attention or internal processing, depending solely on the cognitive state attributed to their performer. The way we perceive someone's eye movement may be influenced by the cognitive state we attribute to them.

In two pre-registered experiments, participants were presented with a video of a person gazing sideways, followed by a peripheral letter discrimination task. In each experiment, participants were assigned randomly to one of two groups. One group (Thinking group) was led to believe that the gazing person is thinking effortfully (solving an arithmetic question). The other group (Attention group) was not provided with any meaningful context. With this paradigm, we were able to utilize a gaze cueing task in which the viewed eye movements were identical in both experimental conditions, but their social interpretation differed between the groups. Finding that the GCE of the Thinking group is lower than the Attention group would provide support to our hypothesis and indicate that the interpretation of an eye movement determines its role as an attentional cue.

Methods

Participants

A total of 122 healthy individuals participated in this study. Participants were randomly assigned to one of the two groups ("Thinking" or "Attention"). We applied two pre-registered exclusion criteria. First, participants were excluded from the study if they reported understanding that the goal of the thinking manipulation was to modulate the way the cueing face is interpreted or if they reported understanding any other crucial aspect of the manipulation. A total of three participants were excluded due to this reason from **Experiment 1** and one was excluded from **Experiment 2**. In addition, since this was an easy task, participants who performed the task with less than 80% accuracy were assumed to have not been engaged in the task and were excluded from the analysis. This has led to the exclusion of seven participants in **Experiment 1** and one in **Experiment 2**). The remaining participants included **50** in **Experiment 1** – 25 in the Attention group (14 females, 2 left-handed, mean age 23.7 ± 1.9 SD) and 25 in the Thinking group (17 females, 5 left-handed, mean age 24.0 ± 3.0 SD); and **60** in **Experiment 2** – 30 in the Attention group (23 females, 2 left-handed, mean age 23.4 ± 2.6 SD) and 30 in the Thinking group (27 females, all right-handed, mean age 23.1

± 2.3 SD). All participants reported having normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. Participants received payment or course credit for their participation. All participants signed a consent form before participating. The experiment has been approved by the ethical committees of Tel-Aviv University and the School of Psychological Sciences at Tel-Aviv University.

Stimuli

All stimuli were displayed on a gray background (RGB: [0.75,0.75,0.75]). The fixation point was a white cross, measuring 1.3° wide and 1.3° high, positioned 3.4° below the center of the screen (degree symbols ° represent visual degrees). The cue display consisted of a brief video of an individual shifting his gaze, in parallel with an auditory stimulus. The filmed individual (male, age 31) was positioned on the screen such that the fixation point was located between his eyes (approximately 0.3° from each eye). The auditory stimulus was numbers or an arithmetic question read-out in Hebrew by a male speaker. The target stimulus was a black capital letter L or T, measuring 0.8° wide and 1.3° high. In **Experiment 1**, the target was located 10.7° from fixation (3.4° on the vertical axis, and 10.1° on the horizontal axis to the right or left according to target position). Since some of the participants in **Experiment 1** reported perceiving the cuing gaze as directed above the target rather than at the target, we have shifted the target's location in **Experiment 2** to be slightly upward from the horizontal midline. Therefore, the target was located at an eccentricity of 12.6° from the center of the screen, 7.6° on the vertical axis, and 10.1° on the horizontal axis.

Experimental Design

Participants were seated in a dimly lit room, with a computer monitor placed 100 cm in front of them (24-inch LCD ASUS VG248QE, 1920×1080 pixels resolution, 60 Hz refresh rate). During the experiment, participants rested their heads on a chinrest. The monitor was adjusted such that the participants' eyes were positioned at the same height as the fixation point. The experimental design and stimuli were generated using PsychoPy software (Peirce et al., 2019).

Each trial began with a fixation display presented for 500ms. Then a video ("cueing video") depicting an individual was played for approximately 3.5 seconds, in parallel with an auditory recording. The depicted individual was gazing straight ahead at the camera until slightly before the end of the video (approximately 100ms), when he either continued looking straight (neutral trial, 33% of the trials) or shifted his gaze up-left or up-right (valid and invalid trials, each 33% of the trials). Participants of the "Thinking" group listened to a recording of an arithmetic question that was played simultaneously with the video. This recording consisted of a two-digit number, an

operator (–, +, or ×), and a second two-digit number (e.g., “54+91”). The purpose was that the presentation of an arithmetic question in parallel to the video would lead the participants to interpret the situation as an arithmetic question being read-out to the filmed person, which will then think about the answer. Participants of the “Attention” group listened to a recording of a sequence of three numbers: a two-digit number, a single-digit number, and another two-digit number (e.g., “54,1,91”), also played simultaneously to the video. Thus, this group was not led to believe that the situation is of a person thinking of an answer.

At the beginning of the experiment, participants received instructions. In **Experiment 1**, participants of the “Thinking” group were told that in each trial they would see a person listening to arithmetic problems and attempting to solve them and that the targets would appear as soon as the person begins to think of the solution. Participants of the “Attention” group were told that they would see a person and hear a sequence of numbers. In **Experiment 2**, none of the groups received these instructions. In addition, in both experiments and for both groups participants were told that the video was task-irrelevant and were asked to ignore it.

In **Experiment 1**, the video froze at its end for an additional fixed 500ms (an interval which served as a *stimulus onset asynchrony*; SOA) depicting the individual gazing upward left or right, or looking straight, in different trials. In **Experiment 2**, this SOA was modified to be jittered such that the same frame froze for 500±100ms (400-600ms, 10 randomized steps with a step size of 20ms) instead of a fixed interval. This modification was intended to prevent anticipatory responses.

Following the cuing video, the target letter (T or L) was presented at 12.6° up-right or up-left of fixation. Third of the trials were ‘valid’ trials, in which the target was presented on the same side as the direction of the gaze shift. Another third of the trials were ‘invalid’ trials in which the target was presented on the opposite side. The remaining third of the trials were ‘neutral’ trials, where the gazing individual kept looking straight, without any gaze-cue. The target remained on screen until response, but no longer than two seconds. Trials in which no response was detected within two seconds were considered incorrect. Participants were requested to indicate the identity of the target letter by pressing one of two keys labeled “L” or “T”. These labels were applied to the keys “z” (positioned left) and “/” (positioned right) with colored stickers and were counterbalanced between participants. For participants in the “Attention” group, this was the end of the trial and the next trial began immediately after. Participants of the “Thinking” group were presented with another video lasting 1-4 seconds, in which the depicted individual shifted his gaze back to the center and then announced the correct solution for the arithmetic question. Then the trial ended, and the next trial began. The trial procedure is depicted in Figure 1.

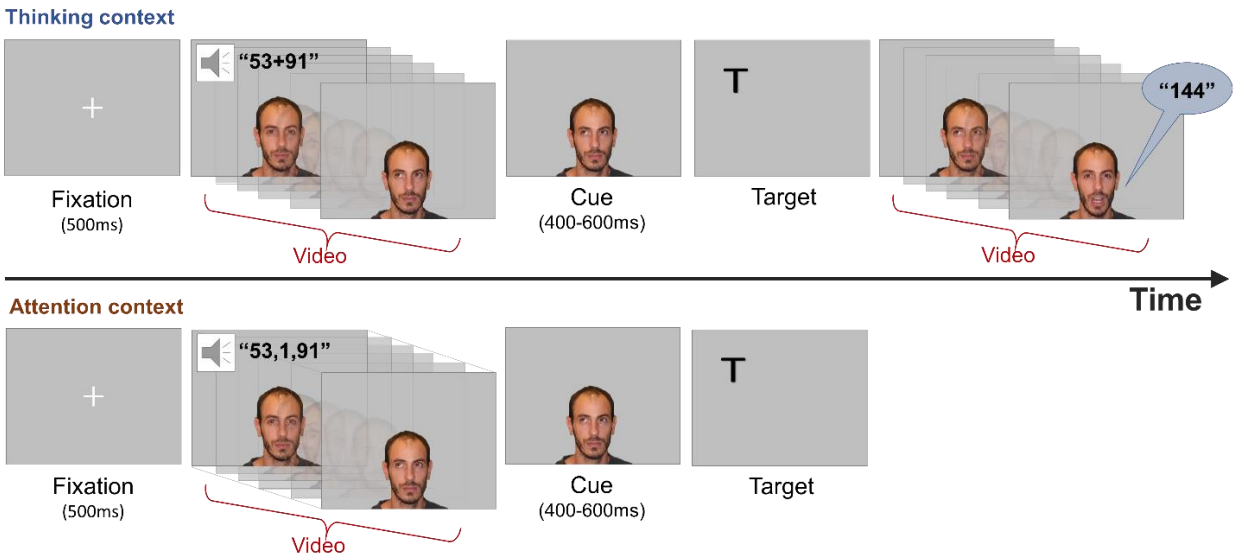

Figure 1. *Trial procedure in each condition.* Each trial began with a fixation display for 500ms. Then a video depicting an individual (the first author) was played for 3.5s, in parallel with the auditory recording. The depicted individual was gazing straight until the end of the video, when he either continued looking straight (neutral trial) or shift his gaze up-left or up-right (valid and invalid trials). The film froze at its end for an additional 500ms (in **Experiment 1**) or 500±100ms (in **Experiment 2**) depicting the gaze cue. Following this, a target letter was presented right or left of fixation. Participants were requested to indicate the identity of the target letter by pressing one of two designated keys. Following target-offset the next trial began, only for participants in the "Attention" group. Participants of the "Thinking" group were then presented with another video, in which the depicted individual shifted his gaze back to the center and then read-out the correct solution for the arithmetic question

For both groups, the experiment consisted of 270 trials in total, with 45 different auditory stimuli, repeating size times each. These included 45 arithmetic questions and their answers in the "Thinking" group and 45 sequences of numbers in the "Attention" group. Cue-validity (valid/invalid/neutral), Gaze direction (left/right/center), Target location (left/right) and Target identity (L/T) were selected at equal probabilities and in pseudo random order.

At the end of each experimental session, participants were debriefed by completing a questionnaire in which they were asked what they assumed to be the purpose of the experiment. Participants of the "Thinking" group were additionally asked to rate the filmed person's concentration in solving the questions (from 1 to 5), and the percentage of his correct answers (0%, 25%, 50%, 75% or 100%), in their estimation. Participants of the "Attention" group were asked about the task of the filmed person and the reason for playing the sequences of numbers. This questionnaire was used to validate the thinking manipulation.

Statistical analysis

Analysis followed our pre-registered plan. Trials with incorrect or no response (error trials) or with RT below 150ms, considered unlikely to represent a genuine target-related response (e.g., Keele &

Posner, 1968), were discarded from the analysis (3.7% of all trials, range 0–16.3% of trials per participant).

The single-trial RTs of the remaining trials were modeled using a generalized linear mixed model (GLMM), assuming a gamma family of responses with an identity link (Lo & Andrews, 2015). Particularly, this analysis assumes that the RTs follow a gamma distribution, and that the predictors are linearly related to the predicted RT, thus an identity link was used (i.e., no transformation was made on the value produced by the predictors; Lo & Andrews, 2015). The fixed effects were modeled as follows: (1) cue-validity (valid/invalid/neutral) as a within-subject term, to model the GCE; (2) context-group ("Thinking" / "Attention") as a between-subject term, to model the effect of the manipulation; (3) the interaction terms between group and cue-validity to model the effect of the context on the GCE. Statistical significance for main effects and interaction was determined via a likelihood ratio (LR) test against a reduced nested model, excluding the fixed term. Statistical significance for the parameter coefficients was determined according to the Wald Z test (Fox, 2016).

In addition to the fixed effects, we considered the z-scaled current trial number (i.e., the running trial identifier for the given session) as a covariate to capture the effects of fatigue and training during the experiment (Baayen & Milin, 2010). Since the different experimental groups may have experienced different fatigue or training effects, we additionally considered the interaction between group and trial number. In addition, RTs may be affected by the congruency between the target location (T/L in left or right) and the order of the key positions (T/L in left or right), a phenomenon known as the "Simon effect" (Simon, 1990), therefore we considered the interaction between the target location and the key position.

The random effect structure of the model followed a procedure suggested by Bates et al. (2015). We started with the simplest model, a random intercept-by-subject-only model, and then added a random slope for the within-subject factor cue-validity. We examined whether the new model converges, and then used the likelihood ratio test (using $\alpha = .05$) between the new and the simple model, to examine whether there is an improved fit over the previous model and avoid overfitting. Next, we tested whether the model supports random slopes for the current trial covariate. The full model selection process is described in the R markdown file in the project OSF repository (see below, Data availability).

For simplicity and consistency with existing research (e.g., McKay et al., 2021), we performed an additional analysis. Mean RTs for correct responses in each of the groups were subjected to a separate one-way repeated-measures ANOVA with cue-validity (valid, invalid, and neutral) as a

within-participant factor. Follow-up planned contrasts between valid and invalid levels were applied to measure the effect size of the GCE for each group. The p-values were corrected for multiple comparisons, using a false-discovery-rate (FDR) correction (Benjamini & Hochberg, 1995). To examine whether the results of each ANOVA provide support for null hypothesis (H_0; i.e., no GCE) compared to the alternative hypothesis (H_1; i.e., a GCE), we performed a Bayesian analysis for each ANOVA, with an ultrawide Cauchy distribution (scale of effect r = 1). We considered $BF_{10}>3$ and $BF_{10}< 0.33$ to provide conclusive evidence against or in favor H_0, respectively, and $0.33<BF_{10}<3$ as inconclusive (Dienes & Mclatchie, 2018; with a BF_{10} between 3 and 10, 10 and 30, 30 and 100 and > 100 providing moderate, strong, very strong, and extreme evidence, respectively, for H_1; Jeffreys, 1961; Wagenmakers et al., 2018). The calculated effect sizes are Cohen's d standardized repeated-measures mean differences with Hedges's g corrections (Lakens, 2013). To allow comparison between effect sizes, a 95% bootstrapped confidence interval (CI) with 2000 iterations was computed for each effect size. Analyses were performed in R version 4.3.2 using RStudio (https://www.r-project.org). GLMM modeling was performed using the lme4 (Bates et al., 2015) package, Bayesian modeling was performed using the BayesFactor package (Morey & Rouder, 2015).

Data Availability

The datasets generated by this study and an R markdown file that reproduces all the reported modeling, statistical analyses, and graphs in the article as well as the pre-registered plan, are uploaded to the Open Science Foundation repository and are available at https://osf.io/EGFK7.

Results

Experiment 1

RTs were modeled using a GLMM with Context-group (Attention/Thinking) as a between-subject fixed term, Cue-validity (valid/invalid/neutral) as a within-subject fixed term, and their interaction as a fixed term. Trial number and the interaction between the target location and key position were added as covariates, and we allowed for a random intercept by participant. We found an unpredicted significant main effect for group ($\chi^2(3) = 8.0$, $p = 0.04$), originating from shorter RTs in the Attention relative to the Thinking group ($\beta = -0.09$, $t = -2.38$, $p = 0.017$). As expected, we found a significant main effect for cue-validity ($\chi^2(4) = 32.4$, $p < 0.001$), reflected by faster RTs towards validly cued targets, compared to neutral ($\beta = 0.01$, $t = 2.14$, $p = 0.03$) and invalidly cued ones ($\beta = 0.01$, $t = 2.4$, $p = 0.02$), consistent with the GCE. Despite finding no significant interaction between group and cue-validity ($\chi^2(2) = 3.17$, $p = 0.21$), follow-up simplified ANOVA conducted within each group separately revealed a GCE only in the Attention group ($F(2,6460)=8.73$, $p < 0.001$) but

not in the Thinking group ($F(2,6496)=1.41$, $p = 0.24$). These findings were supported by a Bayesian analysis suggesting strong evidence for a GCE in the Attention group ($BF_{10}=10.84$) and extreme evidence for no GCE in the Thinking group ($BF_{10}=0.007$). More specifically, In the Attention group, RTs in valid trials were found to be significantly shorter compared to invalid ($M_{\Delta} = 16.6$ms, $SE = 5.76$, $t(6460) = 2.87$, $p = 0.006$, Hedges's $g = 0.09$; 95% CI for the effect size = [0.03, 0.15]) and compared to neutral trails ($M_{\Delta} = 23.3$ms, $SE = 5.74$, $t(6460) = 4.06$, $p < 0.001$, Hedges's $g = 0.12$; 95% CI for the effect size = [0.06, 0.18]). However, in the Thinking group, no significant difference was found between valid and invalid trails ($p = 0.28$, Hedges's $g = 0.05$; 95% CI for the effect size = [-0.01, 0.11])) nor between valid and neutral trails ($p = 0.49$, Hedges's $g = 0.02$; 95% CI for the effect size = [-0.04, 0.08])).

Experiment 2

RTs were modeled similarly to **Experiment 1**, except that the model also allowed for adding the interaction between Trial number and Group as an additional covariate. As in **Experiment 1**, we found a significant main effect for group ($\chi^2(4) = 17.8$, $p = 0.001$), resulting from shorter RTs in the Attention group relative to the Thinking group ($\beta = -0.09$, $t = -2.52$, $p = 0.012$). We also found a significant main effect for cue-validity ($\chi^2(4) = 38.98$, $p < 0.001$), reflected by faster RTs towards validly cued targets, compared to neutral ($\beta = 0.01$, $t = 3.14$, $p = 0.001$), but not compared to invalidly cued targets ($\beta = 0.004$, $t = 1.14$, $p = 0.25$). Confirming our hypothesis, we found a significant interaction between group and cue-validity ($\chi^2(2) = 9.40$, $p = 0.009$), reflected by a GCE (the difference in RT between valid and invalid trials) in the Attention group ($\beta = 0.01$, $t = 2.69$, $p = 0.007$). These results were consistent with the follow-up one-way ANOVAs conducted within each group separately. Consistently with our hypothesis, this analysis revealed a GCE only in the Attention group ($F(2,7874)=10.46$, $p < 0.001$) but not in the Thinking group ($F(2,7807)=1.24$, $p = 0.29$). These findings were supported by a Bayesian analysis suggesting very strong evidence for a GCE in the Attention group ($BF_{10}=49.93$) and extreme evidence for no GCE in the Thinking group ($BF_{10}=0.005$). More specifically, In the Attention group, RTs in valid trials were found to be significantly faster compared to invalid ($M_{\Delta} = 20.4$ms, $SE = 4.63$, $t(7874) = 4.41$, $p < 0.001$, Hedges's $g = 0.12$; 95% CI for the effect size = [0.07, 0.18]) and compared to neutral trails ($M_{\Delta} = 15.0$ms, $SE = 4.63$, $t(7874) = 3.25$, $p = 0.002$, Hedges's $g = 0.09$; 95% CI for the effect size = [0.04, 0.14]). However, in the Thinking group, no significant difference was found between valid and invalid trails ($p = 0.47$, Hedges's $g = 0.02$; 95% CI for the effect size = [-0.08, 0.03]) nor between valid and neutral trails ($p = 0.35$, Hedges's $g = 0.04$; 95% CI for the effect size = [-0.01, 0.10]). Notably, adding SOA as a covariate to the model in **Experiment 2** did not improve the model fit ($p=0.73$), nor the interaction of SOA with cue-validity ($p=0.57$).

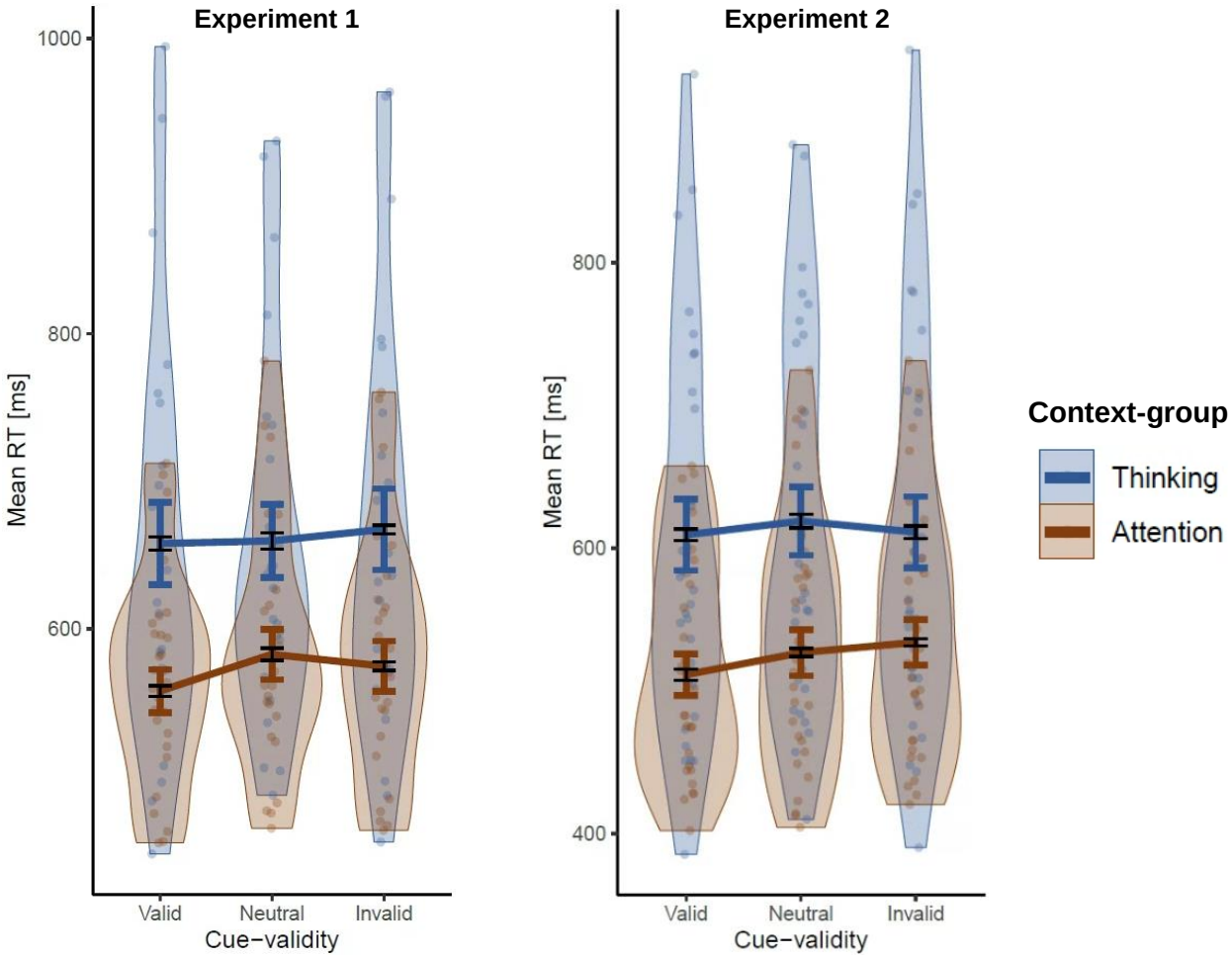

Figure 2. *RTs as function of cue-validity for each context group,* in **Experiment 1** (left; N=50) and **Experiment 2** (right; N=60). Mean RT for the Attention context (orange) and the Thinking context (blue) in thick lines. Colored violin areas and dots represent the dispersion of the RT means of each cue-validity within each context. Colored thick error bars indicate ±1 SE of the group mean, for a between-groups comparison. Black thin error bars indicate ±1 SE of the group mean, corrected to within-subject variability (Cousineau & O'Brien, 2014), for within-group comparisons.

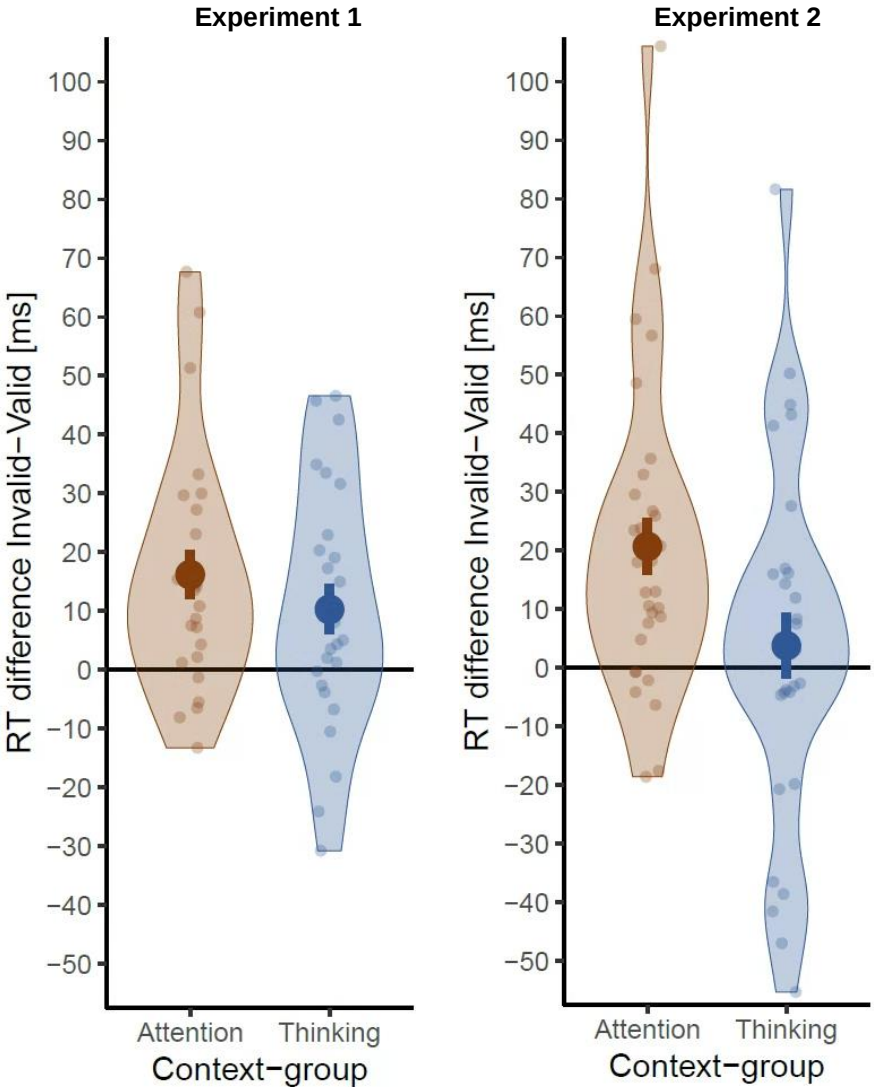

Figure 3. *GCE in each context-group*, in **Experiment 1** (left; N=50) and **Experiment 2** (right; N=60), presented as the mean RT difference. Individual RT differences were computed by subtracting the mean RT in valid trials from the mean RT in invalid trials, for each participant. Colored violin areas and dots represent the dispersion of individual GCEs within each context. Error bars indicate ±1 SE of the GCEs' group mean.

Discussion

The findings of two pre-registered experiments revealed that the interpretation of another person's eye movements is intricately tied to the context in which they are perceived. Our findings showed that the well-established Gaze Cueing effect (GCE) is abolished when participants are led to believe that the individual conducting the gaze shift is presently engaged in cognitive processing. This occurs as a consequence of participants interpreting the other person's eye movements as indicative of processing-related gaze aversions, rather than attentional orienting gaze shifts. The implication is that when individuals are perceived as engaged in intensive cognitive activities, their eye movements lose their significance as spatial cues for attention.

The effect of kinematics on the interpretation of eye movements

These findings highlight the essential role of context in interpreting non-verbal social cues. The GCE is a robust attentional phenomenon; so robust that it can be triggered by a wide array of gaze images, including schematic, photographed or real-person gaze. Despite its robust nature, our findings indicate that minor contextual manipulations can alter the interpretation of the eye movement, leading to a reduction in their attentional effect as spatial cues. These findings challenge the hypothesis that the kinematics of GAs, particularly their predominantly upward direction, serve as a social cue for cognitive processing (Servais et al., 2022). In our study, both groups observed the same eye movements but arrived at different interpretations based solely on the provided social context.

While our findings illustrate the impact of context on interpreting eye movement, it is important to note the potential role of kinematics in supporting specific interpretations. The GAs used in our study were directed upward diagonally (left/right), to align with reported characteristics of this type of eye movement in existing literature (McCarthy et al., 2008; Previc, Declerck & de Brabander, 2005). Different directions of eye movements, such as downward shifts, may lead to different interpretations: such as a weaker association with effortful thinking and a stronger association with the shifting of spatial attention. Further investigation with GAs in various directions could provide invaluable insights into the influence of kinematics on interpretation.

Gaze aversions as a social cue for cognitive processing

While people are engaged in cognitive processing, they often avert their gaze. However, the precise purpose behind these gaze aversions remains not fully understood. While it is acknowledged that GAs may carry a social function, numerous studies have focused primarily on their role in perception and attention, aiming to avoid distraction and preserve cognitive resources for demanding tasks (Doherty-Sneddon & Phelps, 2005). In two previous studies we have supported this view by demonstrating that during a cognitively demanding task in a non-social setting, gaze tends to shift away from salient stimuli (Abeles & Yuval-Greenberg, 2017, 2021).

Previous research on GAs has investigated this behavior by manipulating its perceptual, attentional, and social contexts, investigating how these manipulations influence its occurrences. These studies have focused on the individual exhibiting the GAs (performer), studying the triggers for these aversions, their amplification, and suppression. None of these studies have delved into how GAs impact observers – those who witness these behaviors in others and ascribe meaning to them. The current discovery that observers' interpretations of GAs influence attentional cues represents a groundbreaking insight into the social impact of these behaviors. While evidence suggests a social

dimension to GAs alongside their attentional and perceptual roles (Andrist et al., 2014; Doherty-Sneddon et al., 2005; Ho et al., 2015; McCarthy et al., 2008), the present finding that observers' interpretations of GAs influence attention cues represents a novel insight into the social impact of these behavior.

We hypothesize that a primary function of GAs is to signify ongoing cognitive processing, allowing others to recognize when an individual is engaged in such tasks. According to this view, GAs signals to reduce, slow down or pause conversational input until cognitive processing is completed. This hypothesis is supported by differences observed in the sizes of GAs performed within social versus non-social settings. In non-social contexts, GAs are typically subtle with minimal amplitude, around 1° (Abeles & Yuval-Greenberg, 2021), making them inconspicuous to external observers (Gibson & Pick, 1963). However, within social environments, GAs become more pronounced and noticeable (unpublished data). This could be attributed to the influence of social dynamics on the expression of gaze aversions in terms of direction or amplitude. Future investigations could manipulate both social and cognitive variables and analyze how each factor influences various measures of GAs.

Top-down effects on spatial attention

Our findings revealed how high-level processes, such as interpreting the cognitive states of others, can influence reflexive mechanisms like spatial orienting. A few studies have previously examined whether the GCE can be manipulated by cue interpretation (Cole, Smith & Atkinson, 2015; Kingstone et al., 2019; Morgan et al., 2018; Nuku & Bekkering, 2008; Teufel et al., 2010). Particularly, they explored whether inducing participants to believe that the cueing face could see the target would impact the GCE. Existing findings on this matter are inconclusive: some studies reported stronger GCEs when participants thought the cueing face could see the target (Morgan et al., 2018; Nuku & Bekkering, 2008; Teufel et al., 2010), while others found a robust GCE, irrespective of whether the cueing face could see the target or not (Cole et al., 2015; Kingstone et al., 2019). Notably, the methods used to manipulate cue interpretation varied among these studies. For instance, Teufel et al. (2010) and Morgan et al. (2018) altered participants' interpretations through the initial instructions – the cueing face was depicted wearing glasses of different colors, with participants informed that one pair was opaque and the other transparent. In contrast, Cole et al. (2015) manipulated mental state attribution by altering stimulus properties, such as adding or removing an occluding barrier between the gaze cue and the target. Therefore, one explanation for the inconsistent findings is that top-down manipulations like instructions could diminish the GCE, while the visual characteristics of the gaze cue might not have a stronger impact on mental state attribution than the reflexive cueing effect itself (Cole et al., 2015). Our results align with this

perspective. The observed attentional effect in our study was solely driven by a top-down manipulation of context. In our experimental design, the visual attributes of the stimuli were identical across groups, and therefore no low-level visual manipulation was performed.

Main effect of context

Aside from the anticipated effect of context on attention, the findings also revealed an unpredicted main effect of context. This effect manifested as longer overall response time (RT) in the "Thinking" group compared to the "Attention" group. This effect is evident in certain individuals in the "Thinking" group displaying relatively long RTs (see Figure 2). One possible rationale for this effect is that, despite being instructed to disregard the math question, some participants in the "Thinking" group may have inadvertently or deliberately engaged with the calculations. Consequently, this cognitive activity could have delayed their response across all attentional conditions. Another potential explanation could be attributed to the slightly longer duration of the experimental sessions in the "Thinking" group (owing to each trial ending with the additional answering video), potentially resulting in greater fatigue among participants, leading to longer RTs during the late part of their session. This explanation was dismissed as there was no observed modulation of this effect with trial number (data provided in Supplementary Material S1). It is paramount to emphasize that regardless of the reasoning behind the context effect, it does not introduce any confounding variables to the key findings, as it merely introduces a constant factor across all three attentional conditions that are compared in the main analysis.

Comparing the two experiments

Although our hypothesis was statistically supported by data of both experiments, the anticipated interaction between cue-validity and context-group was only evident in Experiment 2. One possible explanation for this inconsistency could be the variation in statistical power, due to the different sample sizes in the two experiments (50 participants in **Experiment 1** versus 60 in **Experiment 2**). Another factor to consider is the difference in temporal predictability of the cue across the experiments; the SOA was fixed in **Experiment 1** but jittered in **Experiment 2**. It is conceivable that in situations where the timing of target onset is highly predictable, attention can be oriented to its location regardless of the cue, resulting in a diminished cueing effect. Beyond predictability, there was also a difference in SOAs durations between the two experiments (400-600ms in **Experiment 2**, versus a fixed 500ms in **Experiment 1**). It is plausible that certain attentional effects interact with the duration of SOAs. It is worth noting that while the SOA was not directly examined here as an independent variable, integrating it as a covariate to the model in **Experiment 2** failed to enhance either the model fit or the interaction between SOA and cue validity.

Conclusion

This study shows that the well-known Gaze Cueing effect (GCE) can be attenuated when people believe that the gaze shifts are related to cognitive processing rather than attentional orienting. This shows that the interpretation of eye movements as social and attentional cues is heavily influenced by the context in which they are perceived, demonstrating the vital role of contextual framing in shaping the understanding and utilization of non-verbal social cues. Furthermore, the findings demonstrate that a primary social-cognitive effect such as the GCE can be altered top-down by changing the individual's perspective. By revealing how seemingly subtle contextual manipulations can override attentional mechanisms associated with gaze cues, these findings offer a novel perspective on the interplay between social perception and attention.

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References

Andrist, S., Tan, X. Z., Gleicher, M., & Mutlu, B. (2014, March). Conversational gaze aversion for humanlike robots. In *Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction* (pp. 25-32).

Baayen, R. H., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research, 3(*2), 12-28.

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). *Parsimonious mixed models. arXiv preprint arXiv:1506.04967*.

Bayliss, A. P., Di Pellegrino, G., & Tipper, S. P. (2005). Sex differences in eye gaze and symbolic cueing of attention. *The Quarterly Journal of Experimental Psychology Section A*, *58*(4), 631-650.

Bayliss, A. P., Schuch, S., & Tipper, S. P. (2010). Gaze cueing elicited by emotional faces is influenced by affective context. *Visual Cognition*, *18*(8), 1214-1232.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal statistical society: series B (Methodological)*, *57*(1), 289-300.

Brandt, S. A., & Stark, L. W. (1997). Spontaneous eye movements during visual imagery reflect the content of the visual scene. *Journal of cognitive neuroscience*, *9*(1), 27-38.

Cousineau, D., & O'Brien, F. (2014). Error bars in within-subject designs: a comment on Baguley (2012). *Behavior Research Methods*, *46*, 1149-1151.

Dalmaso, M., Castelli, L., & Galfano, G. (2020). Social modulators of gaze-mediated orienting of attention: A review. *Psychonomic Bulletin and Review*, *27*(5), 833–855.

Dalmaso, M., Galfano, G., & Castelli, L. (2015). The impact of same-and other-race gaze distractors on the control of saccadic eye movements. *Perception*, *44*(8-9), 1020-1028.

Dalmaso, M., Galfano, G., Coricelli, C., & Castelli, L. (2014). Temporal dynamics underlying the modulation of social status on social attention. *PloS One*, *9*(3), e93139.

Dienes, Z., & Mclatchie, N. (2018). Four reasons to prefer Bayesian analyses over significance testing. *Psychonomic bulletin & review*, *25*, 207-218.

Doherty-Sneddon, G., Bruce, V., Bonner, L., Longbotham, S., & Doyle, C. (2002). Development of gaze aversion as disengagement from visual information. *Developmental psychology*, *38*(3), 438.

Doherty-Sneddon, G., & Phelps, F. G. (2005). Gaze aversion: A response to cognitive or social difficulty?. *Memory & cognition*, *33*(4), 727-733.

Driver IV, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze perception triggers reflexive visuospatial orienting. *Visual cognition*, *6*(5), 509-540.

Fox, J. (2016). Applied regression analysis and generalized linear models. Sage Publications.

Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic bulletin & review*, *5*(3), 490-495.

Friesen, C. K., Moore, C., & Kingstone, A. (2005). Does gaze direction really trigger a reflexive shift of spatial attention?. *Brain and cognition*, *57*(1), 66-69.

Friesen, C. K., Ristic, J., & Kingstone, A. (2004). Attentional effects of counterpredictive gaze and arrow cues. *Journal of Experimental Psychology: Human Perception and Performance*, *30*(2), 319.

Frischen, A., Bayliss, A. P., & Tipper, S. P. (2007). Gaze cueing of attention: visual attention, social cognition, and individual differences. *Psychological bulletin*, *133*(4), 694.

Frischen, A., & Tipper, S. P. (2006). Long-term gaze cueing effects: Evidence for retrieval of prior states of attention from memory. *Visual Cognition*, *14*(3), 351-364.

Gelman, A., Simpson, D., & Betancourt, M. (2017). The prior can often only be understood in the context of the likelihood. *Entropy*, *19*(10), 555.

Gibson, J. J., & Pick, A. D. (1963). Perception of another person's looking behavior. *The American journal of psychology*, *76*(3), 386-394.

Glenberg, A. M., Schroeder, J. L., & Robertson, D. A. (1998). Averting the gaze disengages the environment and facilitates remembering. *Memory & cognition*, *26*(4), 651-658.

Gronau, Q. F., Sarafoglou, A., Matzke, D., Ly, A., Boehm, U., Marsman, M., Leslie, D.S., Forster, J.J., Wagenmakers, E.J. & Steingroever, H. (2017). A tutorial on bridge sampling. *Journal of mathematical psychology*, *81*, 80-97.

Ho, S., Foulsham, T., & Kingstone, A. (2015). Speaking and listening with the eyes: Gaze signaling during dyadic interactions. *PloS one*, *10*(8), e0136905.

Jeffreys H. (1961). *Theory of probability* (3rd ed.). New York, NY: Oxford University Press.

Johansson, R., & Johansson, M. (2014). Look here, eye movements play a functional role in memory retrieval. *Psychological science*, *25*(1), 236-242.

Keele, S. W., & Posner, M. I. (1968). Processing of visual feedback in rapid movements. *Journal of experimental psychology*, *77*(1), 155.

Kendon, A. (1967). Some functions of gaze-direction in social interaction. *Acta psychologica*, *26*, 22-63.

Kingstone, A., Kachkovski, G., Vasilyev, D., Kuk, M., & Welsh, T. N. (2019). Mental attribution is not sufficient or necessary to trigger attentional orienting to gaze. *Cognition*, *189*, 35-40.

Lachat, F., Conty, L., Hugueville, L., & George, N. (2012). Gaze cueing effect in a face-to-face situation. *Journal of Nonverbal Behavior*, *36*, 177-190.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in psychology*, *4*, 863.

Lo, S., & Andrews, S. (2015). To transform or not to transform: Using generalized linear mixed models to analyse reaction time data. *Frontiers in psychology*, *6*, 1171.

McCarthy, A., Lee, K., Itakura, S., & Muir, D. W. (2006). Cultural display rules drive eye gaze during thinking. *Journal of cross-cultural psychology*, *37*(6), 717-722.

McKay, K. T., Grainger, S. A., Coundouris, S. P., Skorich, D. P., Phillips, L. H., & Henry, J. D. (2021). Visual attentional orienting by eye gaze: A meta-analytic review of the gaze-cueing effect. *Psychological Bulletin*, *147*(12), 1269.

Morey, R. D., & Rouder, J. N. (2015). BayesFactor 0.9. 11-1. *Comprehensive R Archive Network*, *82*(87), 126.

Morgan, E. J., Freeth, M., & Smith, D. T. (2018). Mental state attributions mediate the gaze cueing effect. *Vision*, *2*(1), 11.

Nuku, P., & Bekkering, H. (2008). Joint attention: Inferring what others perceive (and don't perceive). *Consciousness and Cognition*, *17*(1), 339-349.

Peirce, J. W., Gray, J. R., Simpson, S., MacAskill, M. R., Höchenberger, R., Sogo, H., Kastman, E., Lindeløv, J. (2019). PsychoPy2: experiments in behavior made easy. *Behavior Research Methods*. 10.3758/s13428-018-01193-y

Posner, M. I. (1980). Orienting of attention. *Quarterly journal of experimental psychology*, *32*(1), 3-25.

Previc, F. H., Declerck, C., & de Brabander, B. (2005). Why your "head is in the clouds" during thinking: The relationship between cognition and upper space. *Acta psychologica*, *118*(1-2), 7-24.

Sato, W., Okada, T., & Toichi, M. (2007). Attentional shift by gaze is triggered without awareness. *Experimental Brain Research*, *183*, 87-94.

Servais, A., Hurter, C., & Barbeau, E. J. (2022). Gaze direction as a facial cue of memory retrieval state. *Frontiers in Psychology*, *13*, 1063228.

Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In *Advances in psychology* (Vol. 65, pp. 31-86). North-Holland.

Slessor, G., Venturini, C., Bonny, E. J., Insch, P. M., Rokaszewicz, A., & Finnerty, A. N. (2016). Specificity of age-related differences in eye-gaze following: Evidence from social and nonsocial stimuli. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *71*(1), 11-22.

Taub, K., & Yuval-Greenberg, S. (2023). The contribution of eye movements to memory retrieval depends on the visual input. *bioRxiv*, 2023-02.

Teufel, C., Alexis, D. M., Clayton, N. S., & Davis, G. (2010). Mental-state attribution drives rapid, reflexive gaze following. *Attention, Perception, & Psychophysics*, *72*(3), 695-705.

Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., ... & Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic bulletin & review*, *25*, 58-76.