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CORRECTION

Correction: When the eyes break the (naturalistic) scene: investigation on the eye-gaze following mechanisms in complex scenarios

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Correction to: Motivation and Emotion
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The original version of this article contained a mistake. The given names and surnames of the first and second authors have been inverted in the publication. The correct author name format: Name: Bianca, Surname: Monachesi; Name: Anna, Surname: Pecchinenda. Now, it is corrected.

The original article has been corrected.

The original article can be found online at https://doi.org/10.1007/s11031-025-10162-w.

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ORIGINAL PAPER

When the eyes break the (naturalistic) scene: investigation on the eye-gaze following mechanisms in complex scenarios

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Abstract

Processing eye-gaze and aligning one's own attention with the gaze direction of others (gaze following) is a crucial ability and it underpins several cognitive and affective mechanisms. However, we know little about how this gaze following operates in realistic scenarios in adults. The present study addresses this gap by presenting naturalistic scenes, in which models were portrayed centrally or peripherally (7°), with their *eye* gaze directed straight ahead, averted towards an object (valid cue) or away from it (invalid cue), while maintaining a straight head position. Eye movements were recorded while participants ($N=60$) performed two tasks: a free viewing task to assess spontaneous gaze following, and a visual search task, to assess attentional shifts based on the observed gaze direction. Findings from the free viewing task showed that participants spontaneously looked faster at validly cued objects (i.e., gaze cueing effect) and they looked longer at the cued objects independently of whether the face was present centrally or peripherally. Importantly, in the visual search task, the cueing effects were also present when face cues were presented peripherally and in absence of overt attentional orienting. This finding provides new evidence on the spontaneity of gaze following in ecological contexts and offers theoretical insights on this important social cognitive ability.

Keywords Gaze following · Peripheral cue · Naturalistic scenes · Social cognition · Eye-tracking

Introduction

People often rely on information from others' gaze direction to infer the focus of attention or intentions of those around them (Baron-Cohen, 2014). Gaze following refers to a set of mental processes that allow us to attend towards locations and objects that are looked at by others (Driver et al., 1999; Frischen et al., 2007), and it is a process that is central to many aspects of social cognition (Kampis & Southgate, 2020; Shepherd, 2010). For example, gaze following is involved in our ability to coordinate attention, establish joint attention (Friesen & Kingstone, 1998), and communicate effectively (Macdonald & Tatler, 2013). Some authors (Hayward et al., 2017) highlighted that the patterns of gaze following observed in the typical laboratory settings may not consistently align with those observed in real-world scenarios (Laidlaw et al., 2011) Despite such inconsistencies, most of the existing literature on gaze following is still largely confined to relatively contrived contexts (Fan et al., 2021; Frischen et al., 2007). We know relatively little about how people prioritize others' gaze direction within more naturalistic scenes and the extent to which this attentional orienting occurs spontaneously, or even automatically. There also remain many unanswered questions about how gaze cues interact with other biological directional signals (e.g., the head). The present study sought to fill this gap by investigating eye-gaze following in naturalistic scenarios, and the extent to which the physical positioning of the task-irrelevant agent (agent presented centrally vs. peripherally) affects this form of attentional orienting. These findings will provide new insights into how people process social cues among the richness of their surroundings, and the nature of this social cognitive mechanism (Klein et al., 2009).

In adults, most scientific evidence on gaze following comes from studies using the gaze cueing task (e.g., Friesen

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& Kingstone, 1998), a social version of the Posner's cueing paradigm (Posner, 1980). Here, a non-predictive face-cue gazing left, or right is briefly presented centrally, and participants respond as quickly as possible to a peripheral target appearing shortly after the central cue. Participants typically respond faster to targets presented at the looked at location (i.e., valid cue) comparted to when the target appears at the opposite spatial location (i.e., invalid cue). This so-called "gaze cueing effect" is taken to index that individuals rely on the gaze direction to shift their attention to the looked-at location (Frischen et al., 2007; McKay et al., 2021 for reviews).

While much of the previous research investigated gaze following behaviour by presenting simplistic, cropped face or eyes in monochrome backgrounds, recently researchers argue for assessing how gaze biases observer's attention when embedded in more natural and realistic scenes (e.g., Borji et al., 2014; Castelhano et al., 2007; Fernandes et al., 2024; Fletcher-Watson et al., 2009; Freebody & Kuhn, 2018; Großekathöfer et al., 2020; Zwickel & Vo, 2010). In these studies, participants are invited to view pictures in which an actor is depicted within a natural image, and the actor either looks towards or away from a designated target object. The use of eye tracking allows us to overtly measure where people spontaneously look and the extent to which such eye movements occur automatically within a more natural context (Cole et al., 2016; Emery, 2000). In complex scenes, the gaze must be detected and selected among other possible inputs before it can affect attentional orienting. Research to date shows that when participants freely view images of complex scenes, they rapidly look at the social component in the picture, (i.e., an individual) and they look at it for longer (Birmingham et al., 2009; Rösler et al., 2017), prioritizing the eyes, the head, and finally the whole body depending on size and richness of individual's details (Birmingham et al., 2008, 2009). Interestingly, the same free-viewing procedure revealed that people prioritize the gaze cue as well as the areas that are being gazed at (Fernandes et al., 2024; Freebody & Kuhn, 2018; Großekathöfer et al., 2020; Zwickel & Vo, 2010).

More specifically, eye-tracking studies in which participants look freely at complex scenes for several seconds (e.g., 5 s, Freebody & Kuhn, 2018; 10 s Großekathöfer et al., 2020; 7 s, Zwickel & Vò, 2010) found that objects in the scenes that are gazed at by models are fixated faster and longer than objects not gazed at, providing new evidence of spontaneous gaze following. However, in these studies, gaze following has been mostly assessed when gaze was expressed by *head* (e.g., Freebody & Kuhn, 2018; Großekathöfer et al., 2020) or by *whole-body* orientation (e.g., Zwickel & Vò, 2010) leaving unexplored when it is expressed directly by *eyes*.

The high contrast between the iris and the sclera attracts attention, while the elongated shape of the eyes makes it easier to detect eye movements —together, these perceptual features offer useful cues for inferring where others are looking (Kobayashi & Kohshima, 2001; Ricciardelli et al., 2002).There is indeed evidence from a single face presented at fixation, that processing the directional information from eyes overrides (interferes with) that of head orientation when the two signals are incongruent (e.g., Itier et al., 2007). However, studies using cropped faces presented peripherally reveal that people prioritize head-related over eyes-related gaze direction (e.g., Hermens et al., 2017), suggesting that the peripheral presentation reduces the visibility of face details, which is common in naturalistic scenes (Großekathöfer et al., 2020; Zwickel & Vo, 2010). Consequently, the extent to which *eye*-related gaze direction influences where people look within a complex scene, especially when the model appears peripherally is unclear. When faces are presented peripherally, participants may struggle to discern eye direction among various visual elements, which may reduce the propensity by which people spontaneously (as previously reported in free viewing procedure) or automatically (as reported using the gaze cueing task) orient attention in response to the gaze direction. Therefore, understanding the mechanism underlying this main source of directional social signal becomes crucial, especially in more real-world settings.

Some studies in which cropped faces are presented in isolation suggest that gaze following shares characteristics of automatic-like responses (e.g., (Driver et al., 1999; Friesen & Kingstone, 1998; Frischen et al., 2007; Rösler et al., 2017). Attentional orienting to a non-predictive, centrally presented face-cue occurs rapidly (i.e., at short SOAs, Friesen & Kingstone, 1998) and it is difficult to suppress even when eyes-gaze direction gives the opposite information (i.e., counter-predictive). These characteristics are true for manual responses (Driver et al., 1999) and eye movements (Kuhn & Kingstone, 2009; Ricciardelli et al., 2002). Eye-gaze cueing effects are observed when the central single face cue is subliminally presented (e.g., Bailey et al., 2014; Sato et al., 2007), and participants are unable to report its gaze direction (Mitsuda & Masaki, 2018), suggesting that gaze following relies on highly efficient mechanisms (Salera et al., 2023). However, studies investigating gaze following where cropped faces are presented peripherally challenge this account (Burton et al., 2009; Nummenmaa & Hietanen, 2009; Palanica & Itier, 2017; Yokoyama & Takeda, 2019). For instance, Burton and colleagues (2009) asked participants to judge the gaze direction of centrally presented faces or the pointing direction of fingers, while flanked above or below by congruent or incongruent directional face- or hand-distractors. Results showed that the gaze direction of the distractor-face did not affect participants' judgement, whereas the pointing direction of distractor-hand did (i.e., slower RTs in incongruent than in congruent condition). Nummenmaa and Hietanen (2009) used a cueing task in which two cue types, arrows and eyes were simultaneously presented so that one cue appeared at central fixation and the other cue appeared below or above fixation and acted as a distractor. Participants responded to a laterally presented target and were instructed to attend only to the central cue, which could be non-predictive (Exp. 3 and 6), or 100% predictive (Exp. 5). Results showed similar interference on participants' responses from both arrow and gaze distractors (Exp. 3), but this effect disappeared for eye-gaze when the attended cue was 100% predictive (i.e., task-relevant) or when realistic eyes rather than schematic eyes were used. These findings suggest that for peripheral gaze in realistic stimuli, directional information is either not processed or voluntarily ignored when it is not useful to successfully perform the task at hand. In contrast to these findings, more recent studies (Palanica & Itier, 2017; Yokoyama et al., 2014) show that when an isolated face stimulus is presented away from central fixation, observers rapidly process and differentiate between straight gaze (toward the observer) and averted gaze (not directed toward the observer). Yokoyama and Takeda (2019) investigated the gaze cueing effect in peripheral vision by presenting participants with schematic facial stimuli positioned at different angles above or below the centre, and requiring them to detect targets presented to the left or to the right of the display. Results showed significant gaze cueing effects up to within 5.0° of visual angle, providing evidence that gaze following also occurs for gaze cues presented in peripheral vision (see Palanica & Itier, 2011 for similar conclusion).

In summary, there is evidence that *eye*-gaze direction alone (i.e., without congruent information from head and body orientation) orients attention in a classic gaze cueing task, resembling an automatic response. However, the automaticity hypothesis is challenged when eye-gaze information is not presented at fixation. On the other side, spontaneous gaze following is reported using more naturalistic scenes, although whether this holds true for eyes directional signal has never been investigated, and it may be constrained by peripheral eye cue presentation. Further, the extent to which the gaze direction of the face depicted in a naturalistic scene can still spontaneously orient observer's attention has not been investigated when the cue is task-irrelevant and rapidly presented. The present study aimed to investigate whether eye-gaze cues spontaneously orient attention when the cues are embedded within a more natural context. Eye movements were recorded while participants were presented with complex scenes, in which a model was depicted at a central or peripheral location, while looking at the observer (direct gaze condition), at an object (cued condition) or at the location opposite to the object (uncued condition). The model's head orientation was always straight and kept constant across conditions. Participants performed two tasks which allowed us to measure two different attentional processes: a free viewing task, followed by a visual search task. In the free viewing task, participants received no specific instructions, and they freely looked at the pictures for 5s. This task was used to assess whether *eye*-gaze direction spontaneously orients attention (gaze following) in the naturalistic scenes and whether it does so when presented peripherally or only when presented centrally. In the visual search task, participants had to look for a green rectangle (i.e., the target) which appeared after 200ms, and report its orientation (vertical/horizontal). The target either appeared on an object that was looked at by the model or in the opposite location. Depending on the gaze direction, the target could be looked at (cued condition) or not (uncued condition) by the model in the scene. This task was used to explore the extent of spontaneity of the eye-gaze following in naturalistic scenarios. Indeed, the gaze direction was non-predictive of the target location (i.e., task-irrelevant) and the brief image presentation before the target appearance prevented visual exploration of the scene (Rösler et al., 2017). If eye-gaze cues affect attention in the free viewing task, we expect greater dwell time on and faster fixations to the object/target when it is cued by the model, regardless of whether the model is presented centrally or peripherally. In addition, if gaze following is spontaneous and resembles an automatic mechanism, a similar pattern of results should occur even when the stimulus is task-irrelevant and presentation is 200ms as during the visual search task.

Method

Participants

A total of 60 students (31 females and 29 males, age M = 25, SD = 6) were recruited from Goldsmith University to complete the experiment. Using G*Power (Faul et al., 2009), a sample size of 54 was estimated as being sufficient to obtain a medium effect size (f = 0.25, Großekathöfer et al., 2020) with a power of 0.90 ($\alpha = 0.05$) in the main analyses. We opted for 6 additional participants to mitigate potential outliers. The sample size was in line with a study using the same procedure and similar stimuli (i.e., Kuhn et al., 2018). All participants had normal or corrected-to-normal vision and reported no previous neurological or psychiatric diseases. All gave informed written consent before participating in the study. The study was approved by the Goldsmith University Ethics Committee. This study was not preregistered.

Material and apparatus

Stimuli (frame size: 1024 × 768px, 28.3° x 21.2°) consisted of 12 models (6 female, 6 male, M_{age} = 29.5, SD_{age} = 2.5) individually depicted in common outdoor or indoor scenario (e.g., sitting on a sofa, or on a bench) while inactively looking (i) at an object (e.g., a laptop, a candle, a radio, etc…), (ii) away from it, or (iii) towards the observer, while keeping the direction of the head facing straight ahead. For each of these three gaze conditions – averted valid gaze (Cued), averted invalid gaze (Uncued), and direct gaze, respectively, the model was located centrally, or 7° left/right from the centre of the frame (peripheral face). A set of six pictures was taken for each of the 12 models for a total of 72 stimuli (12 scene x 3 gaze direction x 2 face location) (stimuli are available upon request to the corresponding author).

The left/right peripheral location of the model was balanced for male and female models. The object could be located at the bottom-left or bottom-right side of the scenes, and when the model was in the peripheral location, the object was always positioned contralateral to the model. The central face cue, the left/right peripheral face cue and the left/right object appeared approximately at the same position in the frame across all the 6 set of pictures. That is, the distance between the central face cue and the object or between the peripheral face cue and the object was constant among the 12 scenes. All pictures within each of the 12 scenes were balanced for colour (RGB value) luminance and contrast using Photoshop CS6.

For the visual search task, two additional versions of pictures were created by editing the 72 original images. Using Photoshop CS6, a small green rectangle (40 × 22px, 0.61° x 1.05°) horizontally or vertically oriented was superimposed on the object and served as target (see Kuhn et al., 2018, for similar procedure). The target appeared 10° left/right from the centre and 15° from the top side of the photos. This resulted in the final set of stimuli for this task of 144 pictures (72 with the target horizontally oriented and 72 with the target vertically oriented).

All stimuli were presented on a black background of a Pentium IV computer via a 21.5" Dell P2210H (Analog) monitor (1600 × 900 px, 60 Hz). The free-viewing task and the visual search task were presented using Experiment Builder 2.1.140 presentation software (SR-Research) for Windows 8.1 Pro, which also recorded participants' key press responses. Responses were entered using a standard USB-keyboard. Eye-movements were recorded using an Eyelink Portable Duo eye tracker (monocularly right eye) using a sampling rate of 1000 Hz.

Procedure

Participants performed the free viewing task followed by the visual search task. A chinrest was used to reduce head movements (viewing distance = 57 cm), and we used a 9-points calibration (maximum average error = 0.5°). The experimenter was present in the room throughout the experiment to check the calibration and to start each trial.

For the free-viewing task, six lists of twelve original pictures (without the green rectangle) were created by the factorial combination of 2 face positions (central, peripheral), 3 gaze directions (direct gaze, cued, and uncued condition), and 2 genders (female, male). Using a Latin Square design (see Freebody & Kuhn, 2018, for this procedure), we ensured that each scene/model was presented once in each list and each picture was presented once across all the 6 lists. Participants were verbally instructed to freely look at the twelve pictures presented one by one on the screen for 5s. They were provided with no other instructions.

Upon completion of the free viewing task, participants were instructed to perform the visual search task, which was preceded by 6 practice trials, followed by 288 experimental trials that were divided into 2 blocks of 144 trials. In each block, trials had equally probable factorial combination of scene (12), gaze direction (3: direct gaze, cued, and uncued condition), face location (2: central and peripheral), and target orientation (2: horizontal and vertical).

Each trial started by the experimenter pressing the space bar once participants fixated the central fixation point. The original picture was presented for 200ms after which the search target appeared and remained on the screen until the participants responded or a maximum of 5000 ms had elapsed (Fig. 1).

Participants were required to firstly fixate the target (to stress ocular responses) and report the rectangle orientation as quickly and accurately as possible by pressing one of two designated keys on the keyboard (m or z keys). Key assignment was counterbalanced between-participants. Participants were also informed that gaze direction was not predictive of the target location.

Measures and data analyses

Behavioural measures, consisting of mean RTs and response accuracy (i.e., proportion of correct responses), were computed only for the visual search task as a function of gaze directions and face locations. Trials in which an error was made (3% of trials) and with RTs were faster than 120 ms or 3 SD above the mean (1.7% of trials) were excluded.

Eye-movement data were computed for both the free viewing and the visual search task using Data Viewer (SR-Research, https://www.sr-research.com/data-viewer/). As

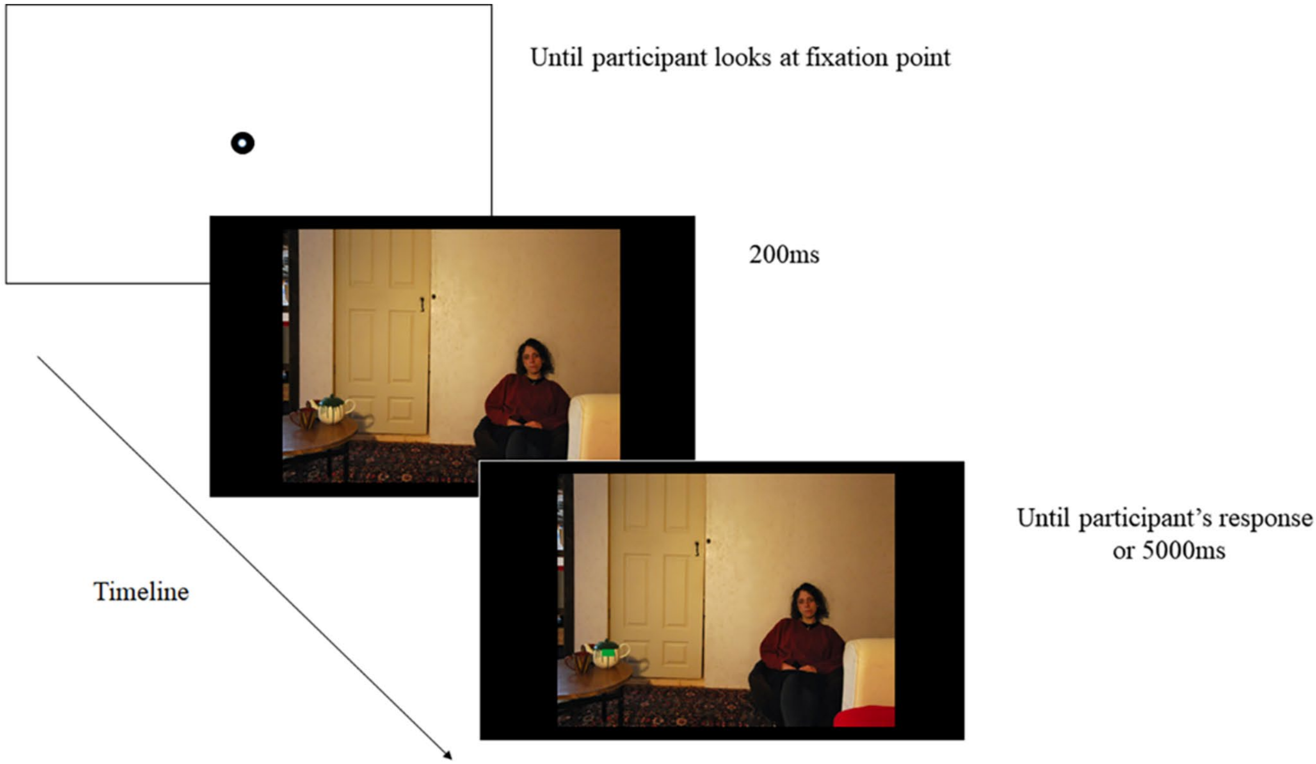


Fig. 1 Example of experimental timeline for the visual search task: peripheral female cue with straight gaze and target horizontal oriented on the left side (on the tea pot)

the target overlapped with the object, the Regions of Interest (ROI) for the object (Object ROI) in the free viewing task was the same of ROI for the target (Target ROI) in the visual search task. Its area was 9010px (1.1% relative to the whole scene) and it was identical for all scenes and conditions (see Figure S1 in the Supplementary material for an example of the ROIs).

For the free viewing task, the two commonly reported eye movement measures were computed (e.g., Fernandes et al., 2021; Freebody & Kuhn, 2018; Großekathöfer et al., 2020; Zwickel & Vo, 2010): (i) the time to first fixate the Object-ROI (FFT-Object), that is, the time between image onset and the first fixation on the ROI, and (ii) the Dwell Time on Object ROI (DT-Object), that is, the proportion of time spent fixating a particular ROI, as a function of the entire trial. Values above 3 SD from the mean were excluded from the analysis (1.3% of trials for the DT-Object, and 0% of trials for FFT-Object) (see Fernandes et al., 2021 and Zwickel & Vo, 2010 for similar criteria).

For the visual search task, we exclusively computed the time taken to fixate on the Target-ROI for the first time (FFT-Target) across all conditions. Eye movements values above 3 SD from the mean were excluded from the analysis (3% of trials). Both for the free-viewing task and the visual search task, eye movements and behavioural data were analysed by repeated measures ANOVAs with a 3 (Gaze direction: direct gaze, cued, and uncued condition) x 2 (Face location: Central, Peripheral) within-subject factors. All analyses were performed using the IBM SPSS Statistics for Windows (version 25). The a priori significance level was set to $\alpha = 0.05$. For statistically significant main effects or interactions, partial eta-square (*partial* η^2) value is reported as effect size. Raw behavioural and eye-tracking data are available online at the link https://osf.io/ujncp/.

Results

Free viewing task

Time to fixate object-ROI. Participants fixated the target object on 80% of trials. Missing data were randomly distributed across conditions, $X^2(2, N=142)=1.71$, $p=.42$, and they were estimated on the basis of the multiple imputation (Pigott, 2001) using R software, package *mice* (Buuren & Groothuis-Oudshoorn, 2011). An ANOVA showed no significant main effect of Face location, $F(1, 59)<1$, $p>.05$, but the main effect of Gaze direction was significant, $F(2, 118)=3.30$, $p=.040$, *partial* $\eta^2 = 0.053$. Pairwise comparisons showed that the time to fixate the object in the Cued condition ($M=1922$, $SE=82.18$) was faster than in the Uncued ($M=2136$, $SE=96.01$), $t(59)=2.23$, $p=.030$, and Direct gaze condition (M=2154, SE=92.95), t(59)=2.16, p=.035 (see Fig. 2). There were no differences between Uncued and Direct gaze condition, $t<1$, p=.85, indicating an orienting (i.e., facilitation effect) towards cued object, regardless of where the cue appeared in the scene (Fig. 2). The interaction was not statistically significant, F(2, 118)=0.39, p=.68. For sake of completeness, Figure S2 in the supplementary material shows the mean times to fixate Object-ROI as function of Face location and Gaze direction.

Dwell time on Object-ROI. Figure S3 in the supplementary material shows the mean Dwell times on Object-ROI as function of Face location and Gaze direction. An ANOVA showed no significant main effect of Face location, F(1, 59)=0.47, p=.49, and a main effect of Gaze direction, F(2, 118)=5.48, p=.005, *partial* η^2 = 0.09. Pairwise comparison showed that the time spent looking at the target was longer in Cued (M=0.12, SE=0.11) than in the Uncued (M=0.99, SE=0.006), t(59)=2.25, p=.028, and in the Direct gaze condition (M=0.09, SE=0.006), t(59)=3.11, p=.003 (see Fig. 3) indicating that participants looked for longer at targets that were looked at by the face in the scene. There was no difference between the Direct gaze and the Uncued condition, p>.43. The interaction was not statistically significant, F(2, 118)=0.87, p=.42.

Visual search task

Mean RTs. Figure 4 shows the mean RTs for each condition. An ANOVA found a non-significant main effect of Face Location, F (1, 59)=0.81, p=.37, but a significant main effect of Gaze Direction, F (2, 118)=3.74, p=.027, *partial* η^2 = 0.06. Pairwise comparisons showed that RTs in the Uncued condition (M=626, SE=10.65) were slower than in the Direct gaze condition (M=618, SE=10.42), t(59)=2.65, p=.010. There was no difference between Cued (M=621, SE=9.44) and Uncued, or between Cued and Direct gaze condition ($t<1$, p>.1). The interaction was not statistically significant, F (2, 118)=0.58, p=.56.

Accuracy No significant main effects or interactions were significant, all $Fs<1.69$, all $ps>0.2$ (see Table S1 for descriptive statistics).

Time to fixate target. ANOVA results for the First Fixation Time on Target-ROI (FFT-target) showed no significant main effect of Face Location, F(1, 59)=0.15, p=.70. The main effect of Gaze Direction was significant, F(2, 118)=3.27, p=.042, *partial* η^2 = 0.05. Pairwise comparisons revealed that participants were slower to fixate the target in the Uncued condition (M=351, SE=4.73), than in the the Cued condition (M=346, SE=4.36), t(59)=2.41, p=.019. The differences between the Direct gaze (M=347, SE=4.13) and the Cued or the Uncued condition were not statistically reliable, (t<2, p>.12), nor it was the interaction, F(2, 118)=0.09, p=.92 (see Fig. 5). The cueing effect occurred regardless of whether the face was presented at fixation, or peripherally and it was mainly due to the cost of following the invalid gaze-cue.

Note, it is reasonable to expect participants to fixate the target faster on valid trials when the face is presented centrally, than when it is presented peripherally. This delay would reflect the time needed to initially look at the peripheral face and then shift attention to the target, especially considering that the target and peripheral face appeared on opposite sides of the scene; for example, if the face was on the left, the target appeared on the right. The lack of a significant main effect of face location or interaction suggests that participants' attention has been *covertly* influenced by gaze direction when the face was presented laterally. To test this hypothesis, we defined a Regions of Interest (ROI) for the face. The size of this face-ROI was identical within each scene and slightly different between the 12 scenes (ROI area: M=11631px, SD=3642px, 1.4% relative to the whole scene). We computed the percentage of trials in which participants executed a fixation on the face ROI before to execute the first fixation on the target ROI. In the peripheral condition, this accounted for only 4% of the trials, which means that in 96% of the peripheral trials, participants did not overtly look at the face cue, yet their eye movements were still influenced by the gaze direction of the face cue.

Discussion

This study investigated gaze following behaviour when faces were embedded within realistic scenarios and the directional signal was expressed *exclusively* by the eyes. Across two tasks, we investigated firstly the spontaneity of following eye gaze when face stimuli are presented not at the fixation point, by using a free viewing task, and then whether such a spontaneity holds also when cues were task-irrelevant and rapidly presented by using a visual search task.

Findings from the free viewing task showed that when the object was validly cued, participants looked at it faster and longer than when it was invalidly cued, confirming a gaze following behaviour. This finding is in keep with previous research (Fletcher-Watson et al., 2009; Freebody & Kuhn, 2018; Kuhn et al., 2018 exp. 1; Zwickel & Vo, 2010) and suggests that when individuals explore a complex scene, they spontaneously orient attention based on the observed gaze direction of the face-cue. Importantly, our finding extends previous ones in two directions: (i) by providing direct evidence that gaze following is also elicited by the less perceptible direction of *eyes*, whereas in previous research using complex scenes the direction of gaze was conveyed by more

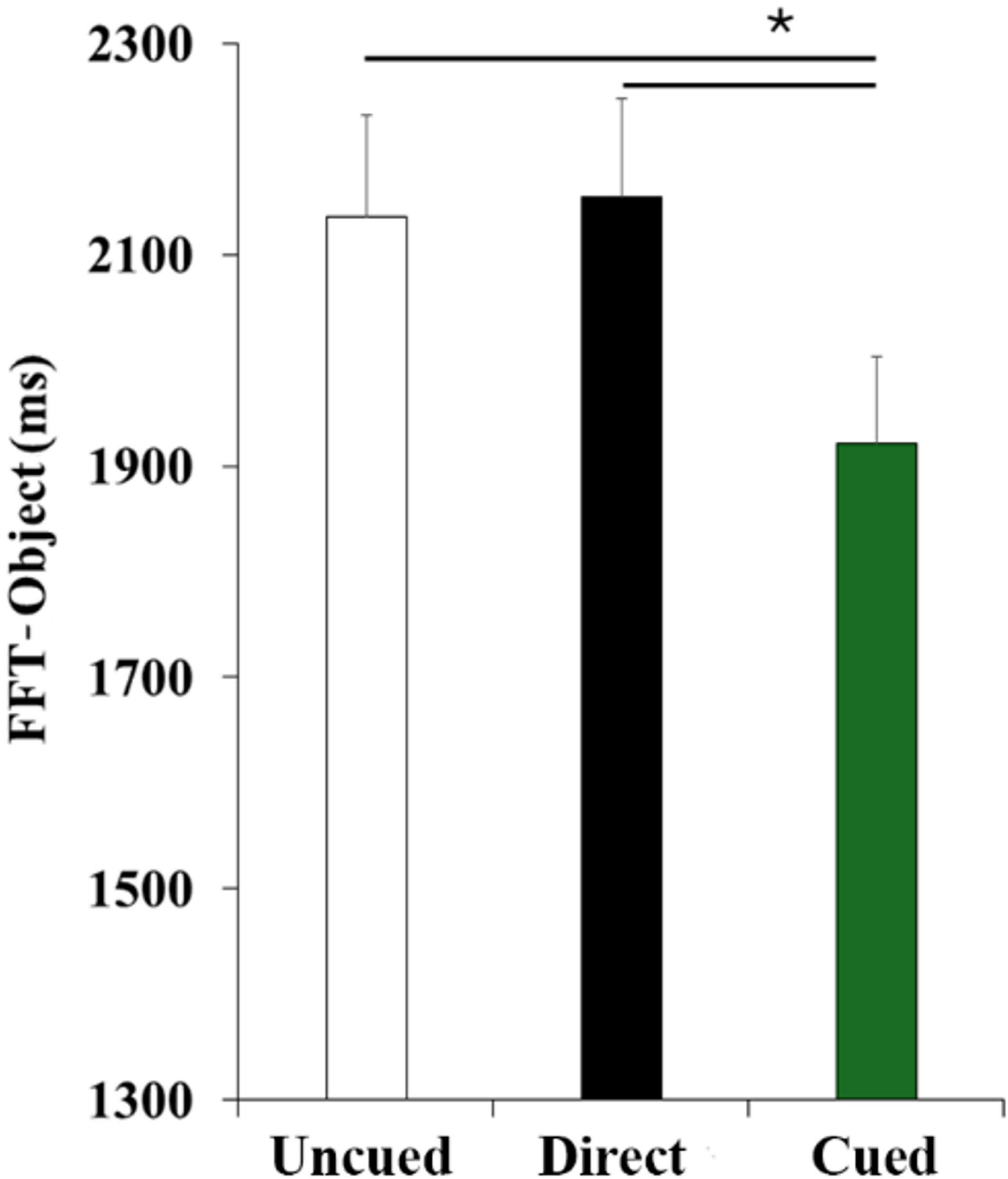


Fig. 2 First Fixation Time (FFT-Object) on Object-ROI as function of Gaze direction (Uncued, Direct gaze and Cued condition). Bars denote Standard Errors of the means

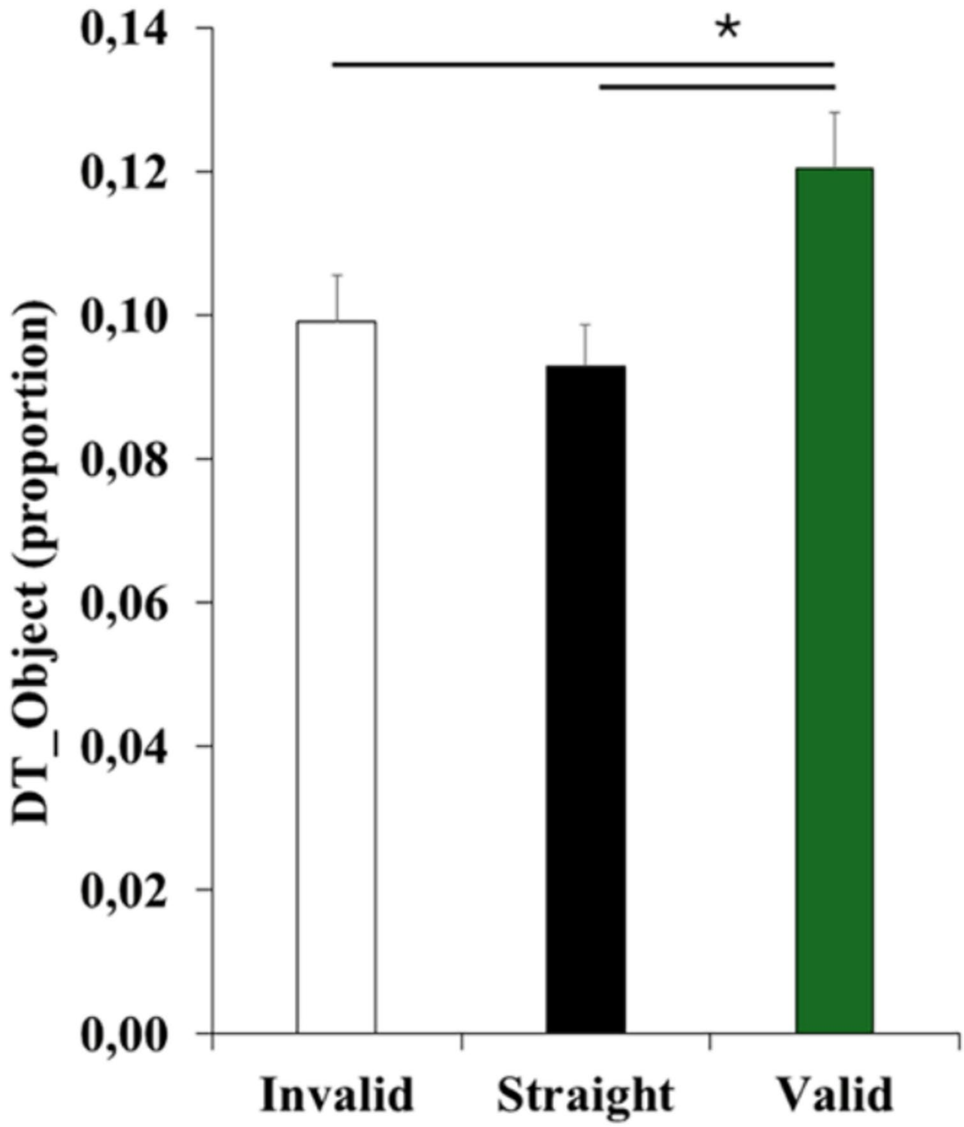


Fig. 3 Dwell Time (DT-Object) on Object-ROI as function of Gaze direction (Uncued, Direct gaze and Cued condition). Bars denote Standard Errors of the means

visible head or body orientation. Crucially, (ii) by showing that eyes prioritize attention also when presented not at fixation, as such *eye*-gaze following occurred regardless of face location (central or peripheral). Although one could argue that our result is due to participants having sufficient time to process the gaze, findings from the visual search task, in which participants had only 200ms before looking at the target, argue against such an account.

Eye-tracking results from the visual search task mirror the classical gaze cueing effect typically observed in the gaze cueing variant (Friesen & Kingstone, 1998) of the Posner task (Posner, 1980), for which the time to look at the validly cued target is shorter than the time to look at the invalidly cued target (Frischen et al., 2007). Again, this effect occurred regardless of face location and – most importantly, without an overt attentional shift towards the peripheral face, suggesting that the gaze-cueing effect arose even *covertly*, when eyes direction was processed peripherally (Hermens et al., 2017). While previous studies have investigated gaze following in naturalistic scenes (Großekathöfer et al., 2020; Zwickel & Vo, 2010), they did not specifically manipulate the presentation of faces at fovea or in the peripheral visual field, thought it was a randomly controlled aspect. Consequently, it was still unclear whether focused attention was necessary for gaze following to occur in these experimental settings. Using naturalistic stimuli and the visual search task, our results not only provides evidence that gaze following behaviour arises for task-irrelevant *eye* directional signals but also that it occurs rapidly, without focused attention, supporting its automatic-like nature (Driver et al., 1999; Friesen & Kingstone, 1998; Ricciardelli et al., 2002).

That gaze direction is processed when presented not at fixation conflicts with previous studies investigating the

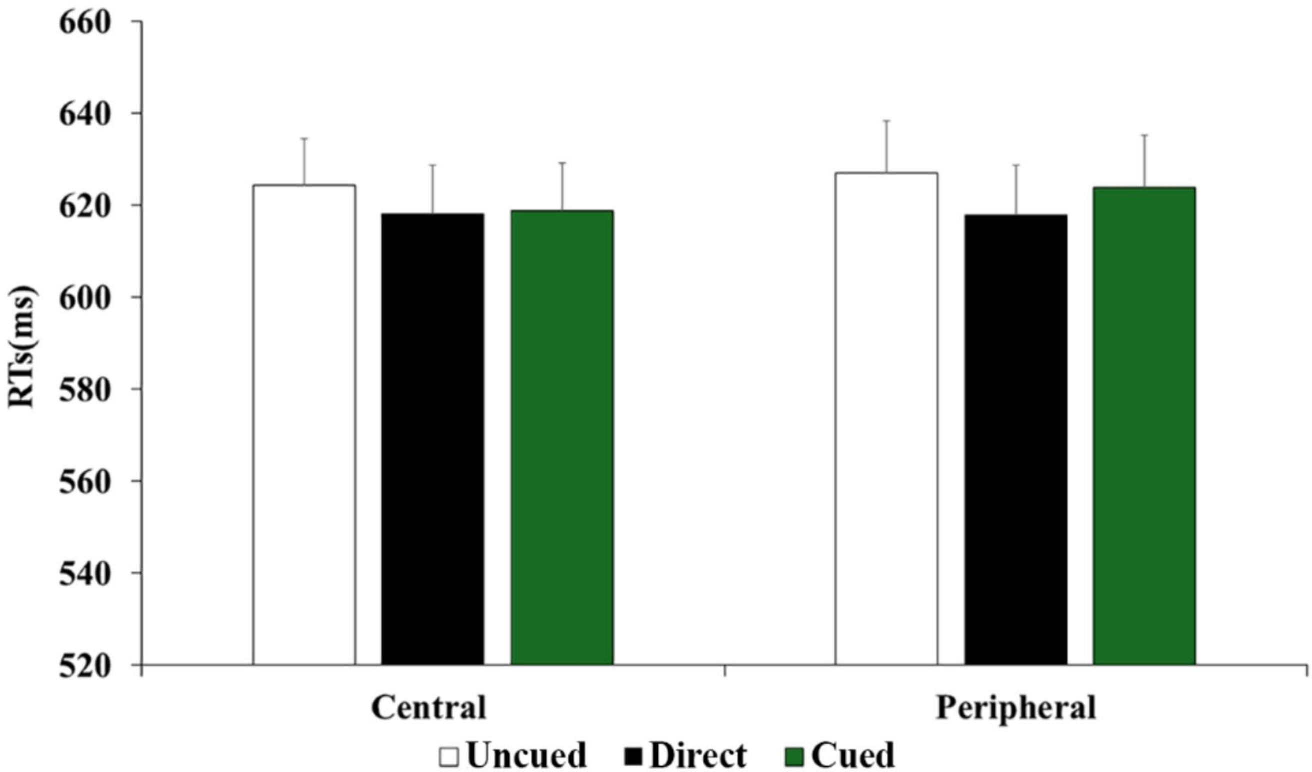
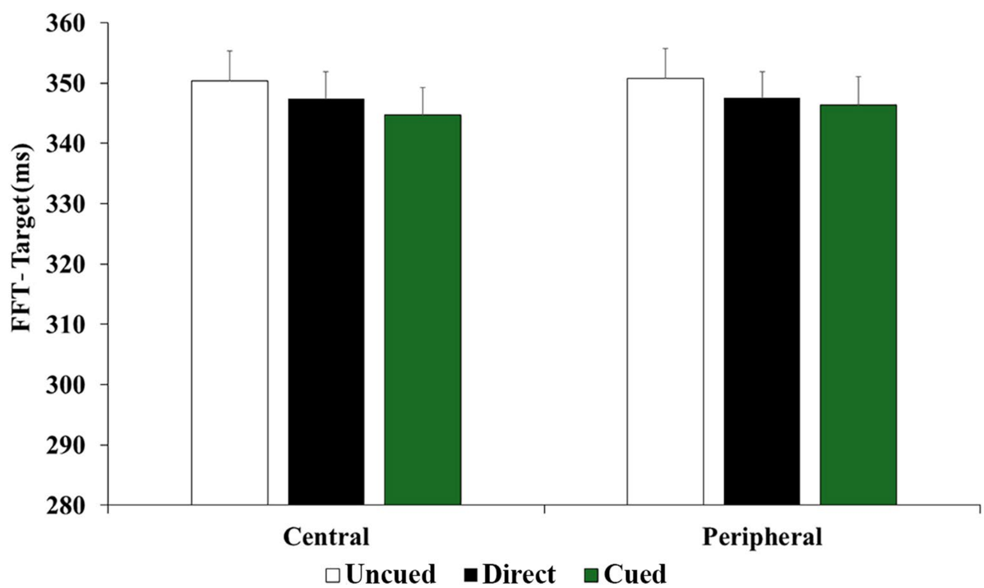


Fig. 4 RTs as function of Cue Location and Gaze direction (Uncued, Direct gaze and Cued condition). Bars denote Standard Errors of the means

Fig. 5 First Fixation Time on Target-ROI (FFT-Target) as function of Cue Location and Gaze direction (Uncued, Direct gaze and Cued condition). Bars denote Standard Errors of the means



effect of interference by peripheral gaze direction on directional decision to centrally-presented cues (Burton et al., 2009) or on peripheral target detection (Nummenmaa & Hietanen, 2009). It is important to point out that these studies considered only behavioural measures (i.e., RTs), which may differ from the explicit attentional orienting measured by eye-movement (Cole et al., 2016; Ozga & Zapała, 2023). Likewise in our study, behavioural results were only partially in line with a gaze following behaviour since no advantage on manual response time was observed when the target was validly cued by gaze direction. While considering that this null result might be due to the instructions stressing the importance of ocular responses instead of manual responses, we acknowledge that a previous study using complex scene and head-gaze direction (Kuhn et al., 2018, exp. 2) found a gaze cueing effect in manual responses. However, in Kuhn et al., 2018, exp. 2, the gaze direction was expressed by the direction of the whole head and not only by that of the eyes, which is a more subtle signal. Further investigation on eye-gaze following in naturalistic scenes will be important to replicate our results at behavioural level.

Moreover, prior studies have demonstrated that determining the gaze direction of a non-foveally presented face is easier when the eyes are looking towards the center of the scene (e.g., Marotta et al., 2018). This finding has been interpreted as a human tendency to mistakenly perceive ambiguous gaze signals as if they were directed at oneself (eye-contact) (Cañadas & Lupiáñez, 2012). Our results, particularly in the scenarios where models were presented at the periphery and their gaze was directed towards the "center" of the scene, might have been interpreted according to this misattributed eye-contact effect: that is, gaze following occurred by increased covert attention towards valid gaze, mistakenly perceived as direct gaze. However, recent evidence challenges this interpretation, suggesting instead that the facilitation in judging gaze direction towards the center of the scene is specifically due to the establishment of joint attention, especially when the gaze is directed toward a realistic object (Edwards et al., 2020). This study dovetails our interpretation in that efficient gaze following occurs rapidly and covertly as well as independently from potential eye-contact effect. This behaviour is necessary because gaze following helps us to navigate the social environment effectively. Gaze following is crucial in comprehending different social situations, especially when involving individuals' communicative intents (Macdonald & Tatler, 2013) and actions (Nummenmaa et al., 2009). According to this relevance, neuroscientific research suggests that gaze direction processing is associated with a specific neurocognitive system (Callejas et al., 2014; Salera et al., 2023), which slightly differ when processing occurs with and without conscious awareness (Sato et al., 2016) or when it leads to the establishment of joint attention (Stephenson et al., 2020). A similar neuropsychological mechanism is put forward for the processing of emotion expressions, a social signals that is just as crucial for interpersonal communication (Monachesi & Pecchinenda, 2022; Pecchinenda et al., 2020; Pourtois et al., 2013; Vuilleumier, 2005). More generally, during free viewing of natural scenes, some authors (Klein et al., 2009; Mackay et al., 2012) hypothesize a mechanism, likely involving subcortical circuits and providing a fast, automatic way to prioritize (i.e., by early saccades) known salient information, especially faces, without needing to cortically analyse each new retinal image.

To conclude, the present study showed that the direction of *eye*-gaze spontaneously engenders gaze following responses in the observer facing complex scenes, even when eyes information is task irrelevant, and it is not at the focus of attention. These findings carry both methodological and theoretical implications. From a methodological viewpoint, our study contributes to the necessity of increasing ecological validity and realistic experimental settings in psychological research, particularly when investigating cognitive processes that take place in social environments. By using naturalistic stimuli, we have shown that gaze following can be accurately replicated and compared to responses observed in more controlled experimental settings. Furthermore, our study contributes to the ongoing debate regarding the extent of spontaneity of gaze following behaviour, providing additional evidence in support of the automaticity hypothesis.

Author contributions BM: Conceptualization, Data curation, Formal analysis, Investigation, Project administration, Visualization, Writing – original draft, Writing – review & editing.
AP: Conceptualization, Project administration, Supervision, Writing – review & editing.
GK: Resources, Methodoloy, Writing – review & editing.

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Data availability Raw behavioural and eye-tracking data are available online at the link https://osf.io/ujncp/.

Declarations

Conflict of interest The authors have no known conflict of interest to disclose.

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