

The functional consequences of social attention for memory-guided attention orienting and anticipatory neural dynamics.

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## **Abstract**

Social attention when viewing natural social (compared to non-social) images has functional consequences on contextual memory in healthy human adults. In addition to attention affecting memory performance, strong evidence suggests that memory in turn affects attentional orienting. Here we ask whether the effects of social processing on memory alter subsequent memory-guided attention orienting, and corresponding anticipatory dynamics of 8-12 Hz alpha-band oscillations as measured with EEG. Eighteen young adults searched for targets in scenes that contained either social or non-social distracters and their memory precision tested. Subsequently, reaction time was measured as participants oriented to targets appearing in those scenes at either valid (previously learned) locations or invalid (different) locations. Memory precision was poorer for target locations in social scenes. In addition, distractor type moderated the validity effect during memory-guided attentional orienting, with a larger cost in reaction time when targets appeared at invalid (different) locations within scenes with social distractors. The poorer memory performance was also marked by reduced anticipatory dynamics of spatially lateralized 8-12 Hz alpha-band oscillations for scenes with social distractors. The functional consequences of a social attention bias therefore extend from memory to memory-guided attention orienting, a bi-directional chain that may further reinforce attentional biases.

## Introduction

Previous literature suggests that there are functional consequences of social distraction on learning and spatial contextual memory (Doherty, Patai, Duta, Nobre, & Scerif, 2017). Both behavioral and gaze differences have been reported previously during visual search with naturalistic social and non-social scenes that were indicative of social distraction, and these behavioral differences were associated with subsequent poorer memory performance for target locations in scenes with social distractors. However, in addition to attention affecting memory performance, memory performance also affects attentional orienting, a bidirectional relationship that is well-documented for both short-term (Astle & Scerif, 2011; Griffin & Nobre, 2003; Kuhl & Chun, 2014) and longer-term memory (Chun & Turk-Browne, 2007; Goldfarb, Chun, & Phelps, 2016; Hutchinson & Turk-Browne, 2012; Rosen, Stern, Michalka, Devaney, & Somers, 2016). It is possible, therefore, that the effect of social distraction on learning and memory may in turn alter later orienting within natural scenes, completing this bidirectional chain. We investigated this novel memory-guided attentional orienting aspect, and also asked whether the presence of social distractors during learning alters anticipatory neural dynamics during subsequent attentional orienting using EEG.

There is ample evidence that learning and memory guides attentional orienting. For example, the contextual cueing literature suggests that implicit memories for simple visual search arrays that have been seen previously reduce visual search time compared to novel search arrays (Chun & Jiang, 1998). Other more recent work has built on these studies by reporting that spatial, contextual long-term memories for objects located within natural scenes also enhance perceptual sensitivity and response time during subsequent attention-orienting tasks (Patai, Buckley, & Nobre, 2013; Patai, Doallo, & Nobre, 2012; Stokes, Atherton, Patai, & Nobre, 2012; Summerfield, Lepsien, Gitelman, Mesulam, & Nobre, 2006; Summerfield, Rao, Garside, & Nobre, 2011). In these tasks, participants search for target objects in natural

scenes over several blocks, to form a memory for where the target is located in each scene. Memory precision for target location is also tested (similar to Doherty et al., 2017). After a break, participants engage in an attentional orienting task. In one version, participants must react to the onset of the target superimposed on a previously studied scene in either the learned location (valid trials) or in a different location (invalid trials) while fixating centrally (Salvato, Patai, & Nobre, 2016a; Salvato, Patai, McCloud, & Nobre, 2016b; Summerfield et al., 2006). This memory-based Posner-style cuing task leads to a validity effect, whereby reaction time (RT) for valid trials is significantly faster than for invalid trials. This additional orienting task therefore allows for investigating the effects of memory on attention orienting. Hence, it can be classified as a memory-guided orienting task akin to contextual cuing. As social distraction affects memory performance, is it possible that this memory difference will carry over to subsequently affect attentional orienting.

Additionally, can the effects of social distraction on memory-guided attention orienting be seen in neural activity? In the current study, we utilized natural social and non-social distractors embedded within scenes – human figures or objects with similar physical salience. Are there neural markers of memory-guided orienting of anticipatory attention that might be influenced by the nature of distractors within natural scenes? To address this question, we focused on anticipatory spatial lateralization of alpha-band oscillations, a neural marker of spatial attention that is well documented following both explicit symbolic cues (Haegens, Händel, & Jensen, 2011; Romei, Gross, & Thut, 2010; Thut, Nietzel, Brandt, & Pascual-Leone, 2006; van Ede, de Lange, Jensen, & Maris, 2011; Worden, Foxe, Wang, & Simpson, 2000; Wyart & Tallon-baudry, 2008) as well as mnemonic cues for memory-guided orienting in natural scenes (Stokes, Atherton, Patai, & Nobre, 2012; Summerfield et al., 2011). This phenomenon is generally thought to reflect relative up-regulation of neuronal excitability in task-relevant (contralateral) vs irrelevant (ipsilateral) neural populations ahead of anticipated

perceptual targets (Jensen & Mazaheri, 2010; Kelly, Lalor, Reilly, & Foxe, 2006; Stokes, Atherton, Patai, & Nobre, 2012), and is associated with improved perceptual performance (Romei et al., 2010; Thut et al., 2006; van Dijk, Schoffelen, Oostenveld, & Jensen, 2008; van Ede, de Lange, & Maris, 2012a; van Ede, Köster, & Maris, 2012b). However, this spatial lateralization of alpha-band oscillations has not, to our knowledge, been studied in the context of natural scenes containing salient social distractors.

The current study therefore addressed two aims. The first aim was to explore the functional consequences of social distraction during learning on behavioral markers of attention: will poorer explicit memory for target locations in social scenes after a visual search task affect memory-guided attention orienting in a Posner-like cueing task? The second aim of the current study was to identify a possible neural marker for the processing of natural scenes containing social distractors during memory-guided attention orienting. What are the neural consequences of social distraction on spatially lateralized memory-related alpha-band preparatory activity? Will poorer memory performance for social compared to non-social scenes also be reflected in attenuated preparatory alpha lateralization relative to the memorized location of anticipated perceptual target?

### **Methods and materials**

Task design, data processing, statistical analyses, and task measures are the same as those used in the previous study (Doherty et al., 2017), unless otherwise noted.

#### **Participants**

The University of Oxford Central University Research Ethics Committee (CUREC) approved this research. Twenty healthy adult volunteers participated. All had normal or corrected-to-normal vision. Two participants were excluded due to inability to record EEG (due to particularly thick hair styling). The final sample consisted of eighteen participants aged

19-21 of which 15 were female. Participants were recruited through a lab practical for undergraduate psychology students at the University of Oxford. All participants provided written informed consent and received course credit for their participation.

## **Stimuli**

Stimuli were social and non-social distracters in 80 natural scenes equated for low-level visual salience, as established using a bottom-up visual saliency algorithm based on the original Itti and Koch algorithm (Harel et al., 2006). These scenes included various indoor and outdoor scenes prepared from photographs. Target objects were also photographs, including tools, toys, fruits, etc. Every scene had a unique target object placed within it. Matching social and non-social versions of each scene were created by editing a photograph of a social distractor (person) or non-social distractor into the same location in the scene. Stimuli were counterbalanced across participants similar to the previous study (Doherty et al., 2017), such that half of the participants saw the same 40 scenes as social and the other 40 as non-social, while the other half of participants saw the reverse. Also, there were two target locations in each scene (on the same side and the opposite side of the distractor) that was counterbalanced across participants. In addition to utilizing this previous counterbalancing scheme, the validity of the scene during the orienting phase (described below) was also counterbalanced. While half of the participants saw the same 40 scenes as valid and the other 40 scenes as invalid, the other half saw the reverse. Within this counterbalancing, distractor location (left or right side) and gender of social distractors (male or female) were also balanced to the extent possible [see supplementary online material (SOM)]. Visual salience with regards to low-level visual properties (color, contrast, etc.) was investigated using a bottom-up visual saliency algorithm (Harel et al., 2006), which demonstrated no significant differences in salience between isolated

social and non-social distractors within scenes, as well as social and non-social scenes overall (see Doherty et al., 2017 for further details).

## **Procedure**

### ***Visual search / learning phase***

Participants sat 60 cm away from a 23” monitor with a 1920-by-1080 resolution and spanning approximately 46-by-27 degrees of visual angle. Participants were directed to look for target objects in 80 scenes over three blocks. For each trial, participants saw: 1) a fixation square for 1000-1500 ms, 2) the object alone for 3000 ms, 3) the scene and embedded object until they located the scene or the time expired, and 4) feedback for 1000 ms (“Great job!” or “Uh oh!”). Maximum search time was 20 s in the first block and decreased by 4 s each subsequent block. Participants observed all 80 scenes in random order during each of three blocks, and each scene had a unique target object.

Several small adjustments were introduced compared to a previous study (Doherty et al., 2017). Instead of pressing the spacebar to reveal the cursor once they located the target objects, participants pressed the mouse. Because a higher resolution monitor was used for this task, the targets and scenes were displayed centrally using the resolution of the previous study (central object: 2.01 by 2.01 degrees of visual angle; scenes: 45.45 by 26.73 degrees of visual angle; target in scene: 1.36 by 1.36 degrees of visual angle) with a grey (153, 153, 153) border surrounding. A practice phase was included before the task, consisting of twelve trials. The task was cartoon themed including images of characters during the feedback and instruction screens, a story for the task including the characters to make the task appear more like a game, and points acquired after each block. These points were random and increasing from block to block, to keep participants motivated and not discouraged in subsequent developmental experiments including child participants. When the targets were correctly located, they flashed

bigger and smaller for positive reinforcement. These last three alterations were included to make the task child-friendly for compatibility with subsequent developmental experiments.

The current study used a Tobii TX300 eye-tracker with gaze recorded from both eyes at 300 Hz following a 9-point calibration. Participants' eye gaze positions were calibrated before the start of each block.

### ***Memory phase***

After a short break, explicit memory for target locations was probed. This phase differed from the previous study (Doherty et al., 2017) by including a cartoon-themed introduction. Each of the studied scenes was presented in a random order with its accompanying social/non-social distracter. Participants moved the cursor shaped as the target for that scene and click when the target was in the location they remembered it to be in the scene.

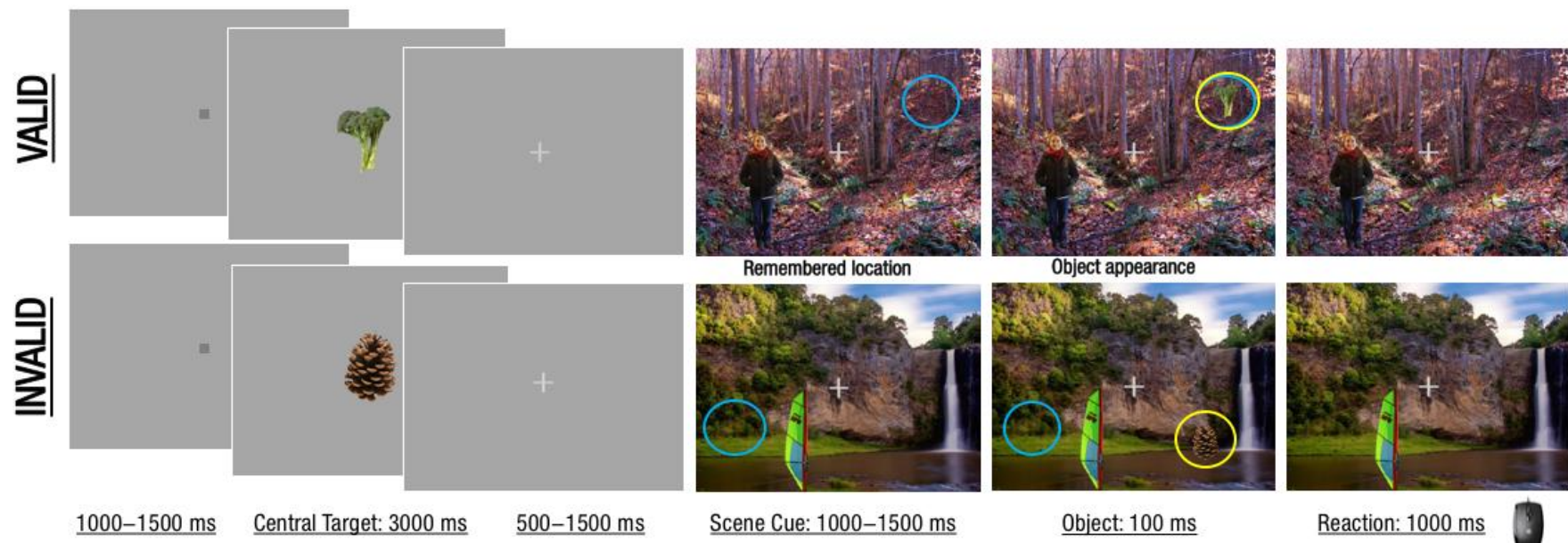
### ***Orienting phase***

After the memory phase, participants were capped for EEG, which lasted approximately 30 minutes. Participants then engaged in a memory-guided orienting task in which they reacted to the brief appearance of targets within their associated scenes while holding their gaze at a centrally located fixation cross present during the entire presentation of scenes.

Trials commenced with the presentation of the central target (2.16 by 2.16 degrees of visual angle) for 3000 ms (Figure 1). A fixation cross on a blank screen followed for 500-1500 ms, after which the associated scene appeared. The target object was presented superimposed on the scene for 100 ms after 1000-1500 ms. After target disappearance, the scene remained present for 1000 ms, providing a response window. A fixation point remained present throughout the trial. After each trial, a blank screen appeared for 1500 ms, during which



participants could blink, followed by the presentation of a fixation square lasting between 1000-1500 ms, which prompted participants to get ready for the next trial. Participants responded to the presentation of the target object by pressing the left mouse button if the target appeared on the left and the right mouse button if the target appeared on the right. Participants observed all 80 scenes in random order. Although previous studies often utilized a present/absent discrimination after entire scenes were presented briefly (200ms) (e.g. Patai et al., 2012), this version was chosen for being simpler for use with children in subsequent experiments. In half the scenes, the object appeared in the learned location (valid trials) and in the other half the object appeared in a new location in the opposite hemifield (invalid trials).



**Figure 1.** Trial sequence for the orienting phase. Participants viewed: 1) a fixation square, 2) the centrally presented target, 3) a warning cross, 4) the scene, 5) the target appearance, 6) reaction-time window. Blue circles are examples of the remembered location for the target and yellow circles are examples of the location of the target appearance during the orienting phase. These circles were not present during the task and are for illustrative purposes. Targets have been magnified for illustrative purposes.

At the start of EEG testing, participants were instructed to relax and move their heads a little as possible. In addition, they were asked to minimize blinking and to avoid making saccades during experimental trials. Participants were then allowed 12 practice trials to make sure they understood the task. To encourage fewer blinks during each trial, participants were instructed to blink during the blank screen that preceded the appearance of the fixation square. To reduce fatigue, participants had a short break every 16 trials. The entire orienting task, including practice trials, lasted approximately 15 minutes.

### **EEG acquisition and processing**

EEG activity was recorded using a 128-channel Hydrocel Geodesic Sensor Net connected to Net Amps 300 (Electrical Geodesics Inc., Eugene, OR, USA) using NetStation 4.5 software. EEG signal was referenced online to the vertex and was sampled at 250 Hz. Electrode impedances were kept below 5 k $\Omega$  as recommended by the manufacturer. Eye movements and eye blinks were monitored with six eye channels placed on the outer canthi of both eyes and above and below the eyes. EEG processing was conducted using Fieldtrip software (Oostenveld, Fries, Maris, & Schoffelen, 2011). EEG data were re-referenced the average reference, de-meanned, and segmented into three time epochs offline.

Three types of epochs were segmented from the continuous EEG stream, to analyze oscillatory activity induced by the central object cue (epoch indicated by Figure 1, panel 2), the scene (epoch indicated by Figure 1, panel 4), and the target appearance (epoch indicated by Figure 1, panel 5). The segments were as follows: 1) 500 ms before and 4000ms after central object presentation, 2) 2000 ms before and 2000 ms after scene presentation, and 3) 1000 ms before and 2000 ms after target presentation. Fieldtrip's fast ICA was used for removing the artefactual

independent components associated with ocular artefacts (blinks and eye-movements) from the data while keeping trials in the analyses. To find the noise components of interest, we correlated component time courses with the measured vertical and horizontal EOG signals. Trials with muscle artifacts were removed prior to ICA. This exclusion of trials resulted in an average of 38.94 non-social trials (SD = 1.51) and 39.11 social trials (SD = 1.23) included in the EEG analyses per person for the central object epoch. For the scene epoch, this resulted in an average of 39.11 non-social trials (SD = 1.13) and 38.78 social trials (SD = 1.17) per person. Finally, 39.33 non-social trials (SD = 0.84) and 39.37 social trials (SD = 0.92) were included in the target appearance EEG analyses. Bad channels, identified via visual inspection, were removed and replaced by interpolated values. To investigate transient neural dynamics following the brief target presentation, a time-frequency analysis was performed using a short-time Fourier transform in combination with a Hanning taper. We used a sliding time window of 500 ms that was advanced over the data in 25-ms steps. These data were primarily used to find the channels of interest that showed the maximal difference in the post-target alpha response following left vs. right visual targets. In contrast to this brief target response, we predicted the anticipatory modulation of oscillatory activity in response to the central object and the scene to be much more sustained, and therefore applied a sliding time window of 1000 ms (in steps of 50 ms) instead. To increase sensitivity further, this larger time window also enabled us to utilize multi-tapering of the data (Percival & Walden, 1993) to achieve  $\pm 3$  Hz smoothing, as this would be beneficial in averaging across participants with slightly different peak frequencies.

## **Eye-tracking**

Eye-tracking data from the left eye were processed and analyzed using custom MATLAB scripts. Gaze data were first pre-processed. Trials were determined invalid if 1000 ms of consecutive gaze points were invalid or if more than 40% of gaze points were invalid during the entire trial. Trials with invalid data were removed from the analysis. Periods of blink were replaced with the last good values. Fixations were calculated using a maximum velocity threshold of 75 degrees of visual angle/second, a dispersion threshold of 0.5 degrees of visual angle around the fixation centroid and a minimum duration threshold of 50 msec. Areas of Interest (AOIs) were hand drawn around distracters.

## **Statistical analysis**

### ***Visual search / learning phase***

Search time from scene onset to click on target (s) and first look (whether the first saccade and associated fixation after scene onset was to the distractor) were both calculated only for trials in which the target was accurately located. Accuracy was calculated as whether participants correctly clicked on the target within a buffer of 0.63 degrees of visual angle.

### ***Memory phase***

Memory error was measured as distance in pixels from the accurate target location to recalled location, for trials in which participants accurately found the target object at least once in the visual search task.

### ***Orienting phase***

Accuracy was calculated as trials in which participants correctly responded to the location of the target appearance (on the left or right hemisphere) with the left or right mouse button within the reaction-time window. Reaction time from target onset to mouse press was calculated for accurate trials. Trials included for reaction-time analyses were also limited to trials in which participants accurately found the target object at least once during the visual search task, and trials in which the reaction time was within two standard deviations of the mean for that condition for that participant.

### *AIC modeling*

For each dependent measure, model averaging was performed. An information-theoretic approach using Akaike's information criterion (AIC) modeling (Burnham & Anderson, 2002) was used for statistical analysis. In this approach, a global linear mixed-effects model was first created using all fixed predictor variables of interest, with subject and scene as random variables to account for the non-independence across trials within subjects and across blocks of the visual search task within scenes. Random slopes were included in the mixed-effects models according to the "best-path" method described in the literature (Barr, Levy, Scheepers, & Tily, 2013). Next, a subset of candidate models that contained all possible combinations of the fixed effects included in the global model was specified. Finally, Akaike weight-based averaging over all candidate models allowed for the derivation of mean estimates of the coefficients ( $\theta$ ) as well as 95% confidence intervals (CI), to be used for determining which coefficients were statistically significantly different from zero. This approach allowed us to include all trials in the analyses as opposed to averaging over trials, which incorporates the variance within subjects into the model. It also allowed us to analyze proportion data more appropriately by using logit linear mixed-effects

models (Generalized Linear Mixed Effects Models for binomially distributed outcomes) with the binary response variable first look (Jaeger, 2008). All models were checked for the assumptions of normality and homogeneity of variance using visual inspection in R. If data were not normally distributed, data were transformed with natural log (ln). The variable search time was the only variable transformed, and was done so due to positive skew.

### *EEG analyses*

Contrasts were created to investigate lateralized activity (contralateral – ipsilateral) to the learned target location (for central object and scene epochs) and the target presentation (target appearance epoch). To focus the analysis on the electrodes that were relevant to target processing, while also ensuring that data selection was independent of the analysis of interest, left and right channels of interest were selected on the basis of the post-target induced alpha response. These channels were then used to zoom in on the effect of interest in the pre-target anticipatory intervals (following central target cue and scene onsets). To deal with variability across frequencies (1/f) and participants, we normalized these contra-ipsi differences to a percentage change by dividing them by their sum and multiplying the resulting value by 100 (i.e.,  $([\text{contra-ipsi}]/[\text{contra+ipsi}]) * 100$ ). To deal with the multiple comparisons encountered along the time and frequency axes, we relied on cluster-based permutation tests (Maris & Oostenveld, 2007) as implemented in the Fieldtrip software. In essence, this approach circumvents the multiple-comparison problem by evaluating the full data space (time-frequency space) under a single permutation distribution of the largest cluster. In essence,  $([\text{contra-ipsi}]/[\text{contra+ipsi}]) * 100$  was compared against 0 in statistical tests, and this equates to  $((\text{contra} / (\text{contra+ipsi})) \text{ vs. } ((\text{ipsi} / (\text{contra+ipsi})))$ . For cluster-thresholding

we used the conventional univariate two-tailed alpha level of 0.05. To obtain cluster  $p$  values, we permuted the data 1000 times.

## Results

### Visual search / learning phase

#### *Accuracy (%)*

Accuracy was at ceiling, with no significant effects other than the intercept when using model averaging (results not shown) (social block 1:  $M = 97.88\%$ ,  $SD = 3.79\%$ ; social block 2:  $M = 98.31\%$ ,  $SD = 1.96\%$ ; social block 3:  $M = 98.75\%$ ,  $SD = 2.26\%$ ; non-social block 1:  $M = 97.78\%$ ,  $SD = 2.43\%$ ; non-social block 2:  $M = 98.06\%$ ,  $SD = 2.24\%$ ; non-social block 3:  $M = 98.19\%$ ,  $SD = 2.32\%$ ).

#### *First look (yes/no)*

Due to the binary nature of the dependent measure (participants either made a first look to the distracter in each trial or they did not), logit mixed-effects models (Generalized Linear Mixed Effects Models for binomially distributed outcomes) were used in AIC modeling. The only fixed-effect coefficient that was significantly different from zero was the interaction between distractor and block. Post-hoc analyses with subject-averaged data revealed this interaction to be driven by a significantly higher proportion of first looks to social compared to non-social distractors in block one ( $p = 0.047$ ), but no significant differences in blocks two and three ( $p > 0.250$ ) (Figure 2).

Table 1  
*Model averaging with parameters related to the dependent measures during visual search*

Predictor	Estimate	Search time (ln(s))			First look (yes/no)			
		l-95% CI	u-95% CI	$p$ -value	Estimate	l-95% CI	u-95% CI	$p$ -value
(Intercept)	1.206	1.094	1.321	<0.001	-1.818	-2.157	-1.475	<0.001
Block	<b>-0.538</b>	<b>-0.623</b>	<b>-0.459</b>	<b>&lt;0.001</b>	-0.195	-0.528	0.138	0.251

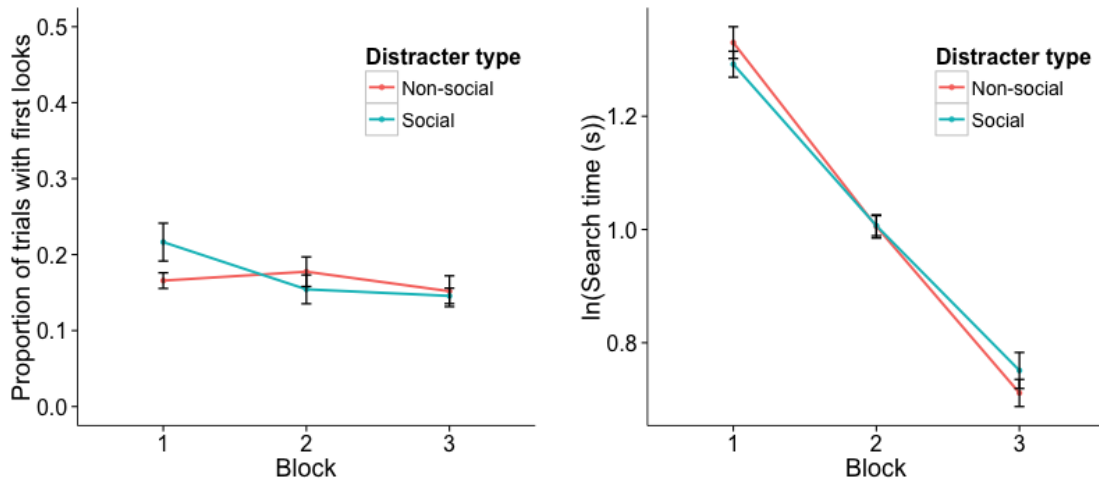


Distractor	-0.015	-0.061	0.012	0.495	0.26	-0.225	0.761	0.305
Distractor x Block	<b>0.063</b>	<b>0.011</b>	<b>0.115</b>	<b>0.017</b>	<b>-0.548</b>	<b>-0.972</b>	<b>-0.124</b>	<b>0.011</b>

For each parameter and dependent measure, this table presents the averaged coefficient estimates ( $\theta$ s), and the 95% confidence intervals (CI, l = lower, u = upper) based on estimated unconditional variance. Estimates in bold differed statistically from zero based on 95% CIs with  $p < 0.05$ .

### Search time (s)

AIC model averaging with search time during the visual search task revealed that the coefficient estimates for block as well as for the interaction between distractor and block were significantly different from zero, indicating their significant effects on the model (Table 1). The effect of block was driven by large reductions in search times as scene-target associations became learned over the course of the three blocks (see Figure 2). In light of the significant effect of the distractor-by-block interaction term in model averaging, investigating the slopes in a similar manner to the previous study (Doherty et al., 2017) revealed shallower search slopes for scenes with social distractors compared to non-social distractors (Figure 2).



**Figure 2.** Mean proportion of trials with first looks and search times for social and non-social scenes over three blocks during visual search. Error bars are standard error of the means (SEMs).

Participants made more first looks towards social distractors compared to non-social distractors in block one, but not in blocks two and three. Participants also had shallower search time slopes over three blocks for social scenes compared to non-social scenes.

To investigate whether gaze behavior towards distractors predicted search time during the visual-search task, first look, distractor, and block, as well as all possible interactions between these variables, were entered as predictors for search time in AIC model averaging. Apart from the effects described above, there was only a non-significant trend for the interaction between first look and distractor ( $p = 0.056$ ), and no other effects including first look ( $p > 0.250$ ) (results not shown here).

### **Memory phase**

In order to determine if social distraction during the learning phase translated into poorer subsequent memory for scenes social distractors (as in the previous study: Doherty et al., 2017), memory error (distance in pixels from recalled to correct location) was analyzed. AIC modeling revealed a significant effect of distractor type (estimate = 12.63,  $p = 0.028$ , no CIs due to only having one fixed effect: distractor), with poorer memory (larger error) for scenes with social distractors (social:  $M = 185.57$ ,  $SD = 26.18$ , non-social:  $M = 158.56$ ,  $SD = 26.18$ ), similar to the previous study (Doherty et al., 2017).

### **Orienting phase**

#### ***Accuracy (%)***

Accuracy was at ceiling, with no effects other than a significant coefficient for the intercept (results not shown) (social valid:  $M = 97.59\%$ ,  $SD = 1.96\%$ ; social invalid:  $M = 98.18\%$ ,  $SD = 2.37\%$ ; non-social valid:  $M = 98.57\%$ ,  $SD = 1.98\%$ ; non-social invalid:  $M = 98.85\%$ ,  $SD = 2.52\%$ ).

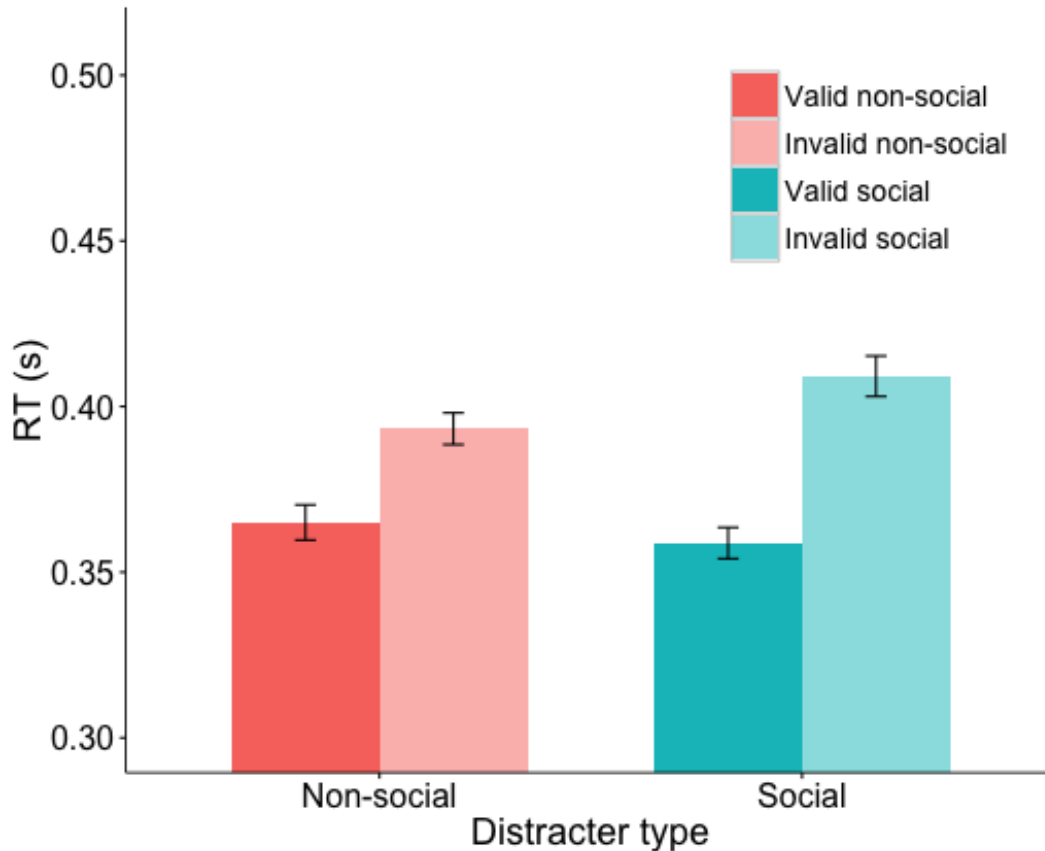
### ***RT (s)***

Model averaging using RT during the orienting phase showed a significant effect of all three fixed effects: distractor, validity, and the distractor-by-validity interaction (Table 2). The effect of validity was driven by longer RTs for invalid trials. The distractor-by-validity interaction was followed up with subject-averaged post-hoc analyses, which revealed this interaction to be driven by significantly longer RTs for invalid social trials compared to invalid non-social trials ( $p = 0.030$ ), but no difference between social and non-social scenes for valid trials ( $p > 0.250$ ) (Figure 3).

Table 2  
*Model averaging with parameters relevant for orienting phase RT (s)*

Predictor	Estimate	l-95% CI	u-95% CI	<i>p</i> -value
(Intercept)	0.394	0.37	0.418	<0.001
<b>Distractor</b>	<b>0.015</b>	<b>0.005</b>	<b>0.026</b>	<b>0.012</b>
<b>Validity</b>	<b>-0.03</b>	<b>-0.041</b>	<b>-0.018</b>	<b>&lt;0.001</b>
<b>Distractor x Validity</b>	<b>-0.021</b>	<b>-0.036</b>	<b>-0.006</b>	<b>0.006</b>

For each parameter, this table presents the averaged coefficient estimates ( $\theta$ s), and the 95% confidence intervals (CI, l = lower, u = upper) based on estimated unconditional variance. Estimates in bold differed statistically from zero based on 95% CIs with  $p < 0.05$ .



**Figure 3.** Mean RTs during the orienting phase demonstrate an overall validity effect for both social and non-social scenes, with slower RTs for invalid compared to valid trials, while also showing a moderating effect of distracter type with slower RTs for invalid social trials compared to invalid non-social trials. Error bars are SEMs.

### **Relationships among learning, memory, and attention**

To investigate whether gaze behavior or search slope during the visual search task predicted memory error during the memory phase, search-time slope (the regression slope of the search times across all three blocks for a particular scene), first-look proportion (the proportion of the blocks out of three in which the participant made a first look at the distractor for a particular scene), and distractor were entered as predictors for memory error in model averaging. In addition

to the effects seen in the above memory-phase analyses, there was a significant effect of search-time slope, with shallower slopes associated with poorer memory precision (higher error), similar to participants in the previous study (Doherty et al., 2017) (Table 3).

Table 3  
*Visual search measures (search-time slope and first-look proportion) as predictors for memory error during the memory phase*

Predictor	Estimate	l-95% CI	u-95% CI	p-value
(Intercept)	154.591	110.313	197.809	<0.001
<b>Search-time slope</b>	<b>25.654</b>	<b>4.098</b>	<b>46.798</b>	<b>0.019</b>
<b>Distractor</b>	<b>31.186</b>	<b>3.246</b>	<b>59.126</b>	<b>0.029</b>
Distractor x Search-time slope	23.717	-4.624	52.093	0.101
First-look proportion	12.339	-6.441	31.247	0.198
Distractor x First-look proportion	-17.81	-46.367	10.704	0.221
First-look proportion x Search-time slope	-2.743	-16.465	10.465	0.701
First-look proportion x Search-time slope x Distractor	-5.887	-32.927	21.153	0.67

For each parameter, this table presents the averaged coefficient estimates ( $\theta$ s), and the 95% confidence intervals (CI, l = lower, u = upper) based on estimated unconditional variance. Estimates in bold differed statistically from zero based on 95% CIs with  $p < 0.05$ .

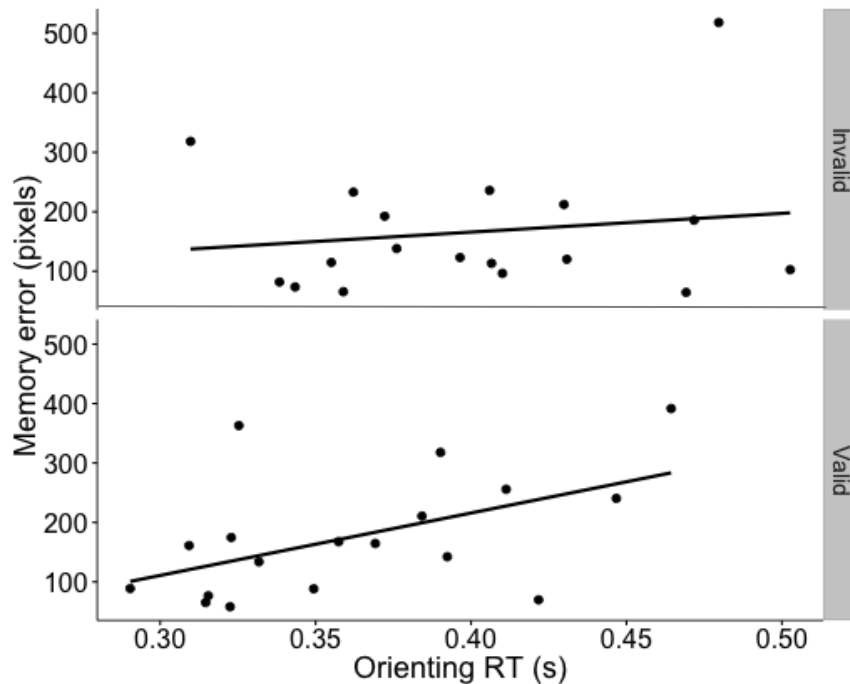
To investigate whether memory precision during the memory phase subsequently predicted RTs in the orienting phase, memory error, distractor, validity, and all interactions between these variables were entered as fixed effects in AIC model averaging. In addition to the effects described above, there was also a significant effect on the model of the interaction between memory error and validity (Table 4). Following up on this interaction, post-hoc analyses with subject averages revealed that there was a significant positive correlation between memory error and RT for valid trials during orienting ( $r = 0.52$ ,  $p = 0.027$ ), with worse memory precision related to longer RTs. In contrast, there was no significant correlation for invalid trials ( $r = 0.15$ ,  $p > 0.250$ ) (Figure 4).

Table 4  
*Memory error (pixels) during the memory phase as a predictor for orienting phase RT*

Predictor	Estimate	l-95% CI	u-95% CI	p-value
(Intercept)	0.395	0.371	0.418	<0.001

Memory error	-0.003	-0.011	0.005	0.538
<b>Distractor</b>	<b>0.016</b>	<b>0.005</b>	<b>0.027</b>	<b>0.01</b>
<b>Validity</b>	<b>-0.03</b>	<b>-0.041</b>	<b>-0.018</b>	<b>&lt;0.001</b>
Memory error x distractor	-0.007	-0.017	0.004	0.199
<b>Memory error x validity</b>	<b>0.015</b>	<b>0.004</b>	<b>0.025</b>	<b>0.006</b>
<b>Distractor x validity</b>	<b>-0.025</b>	<b>-0.042</b>	<b>-0.009</b>	<b>0.002</b>
Memory error x distractor x validity	-0.007	-0.024	0.01	0.426

For each parameter, this table presents the averaged coefficient estimates ( $\theta$ s), and the 95% confidence intervals (CI, l = lower, u = upper) based on estimated unconditional variance. Estimates in bold differed statistically from zero based on 95% CIs with  $p < 0.05$ .



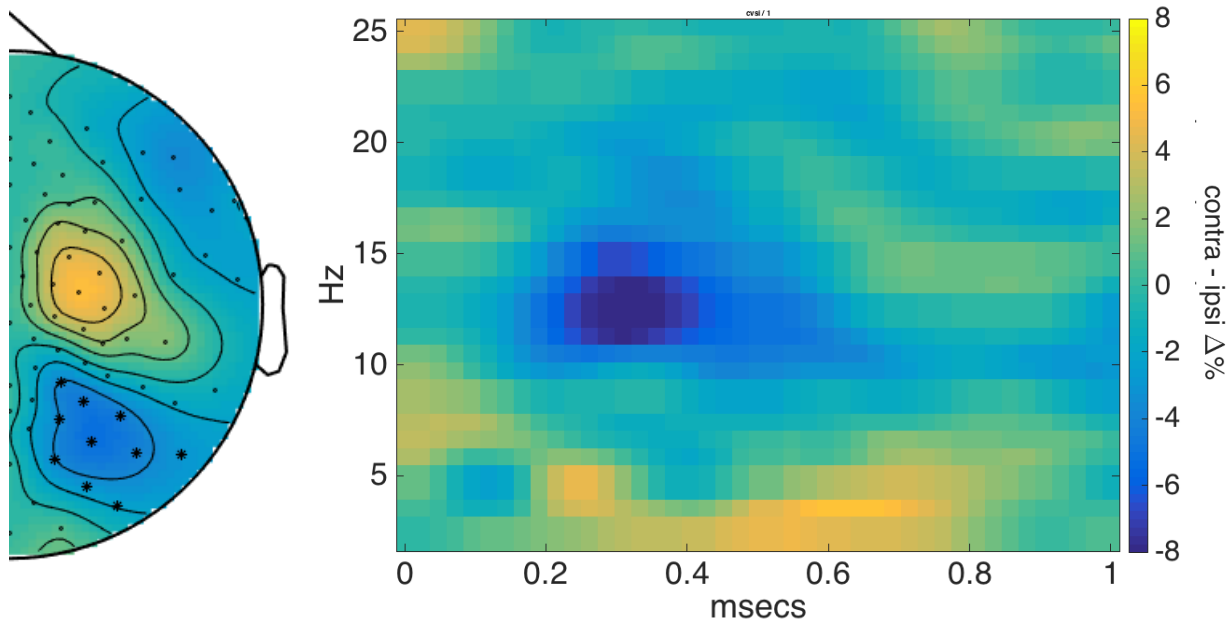
**Figure 4.** Depicts the significant relationship between memory error (pixels) during the memory phase and RT (s) during the orienting phase for subject averages for valid trials, but no significant relationship for invalid trials. Result still hold without the potential outlier in invalid trials.

## EEG analyses

### *Alpha desynchronization*

We used the alpha-band response induced by left and right targets to find the channels of interest, that could then subsequently be used to look at pre-target (anticipatory) modulations by

spatial orienting following central target cue and scene onsets. The topography for alpha activity (8-12 Hz) contralateral compared to ipsilateral to the target location was inspected from 100-600 ms post-stimulus. Alpha suppression (desynchronization) in contralateral (relative to ipsilateral) targets was most evident in the posterior channels highlighted in Figure 5. Inspecting the time-frequency plot for the contralateral – ipsilateral target contrast, averaged over these highlighted channels showed that this target response was most prominent between 200-400 ms post-target (Figure 5).



**Figure 5.** The topography for alpha activity (8-12 Hz) contralateral compared to ipsilateral to the location the target briefly appeared on the screen averaged from 100-600 ms post-stimulus, with posterior channels used for follow-up analyses highlighted (left); and time-frequency plot for contralateral – ipsilateral % power change averaged over these highlighted symmetrical channel pairs (right).

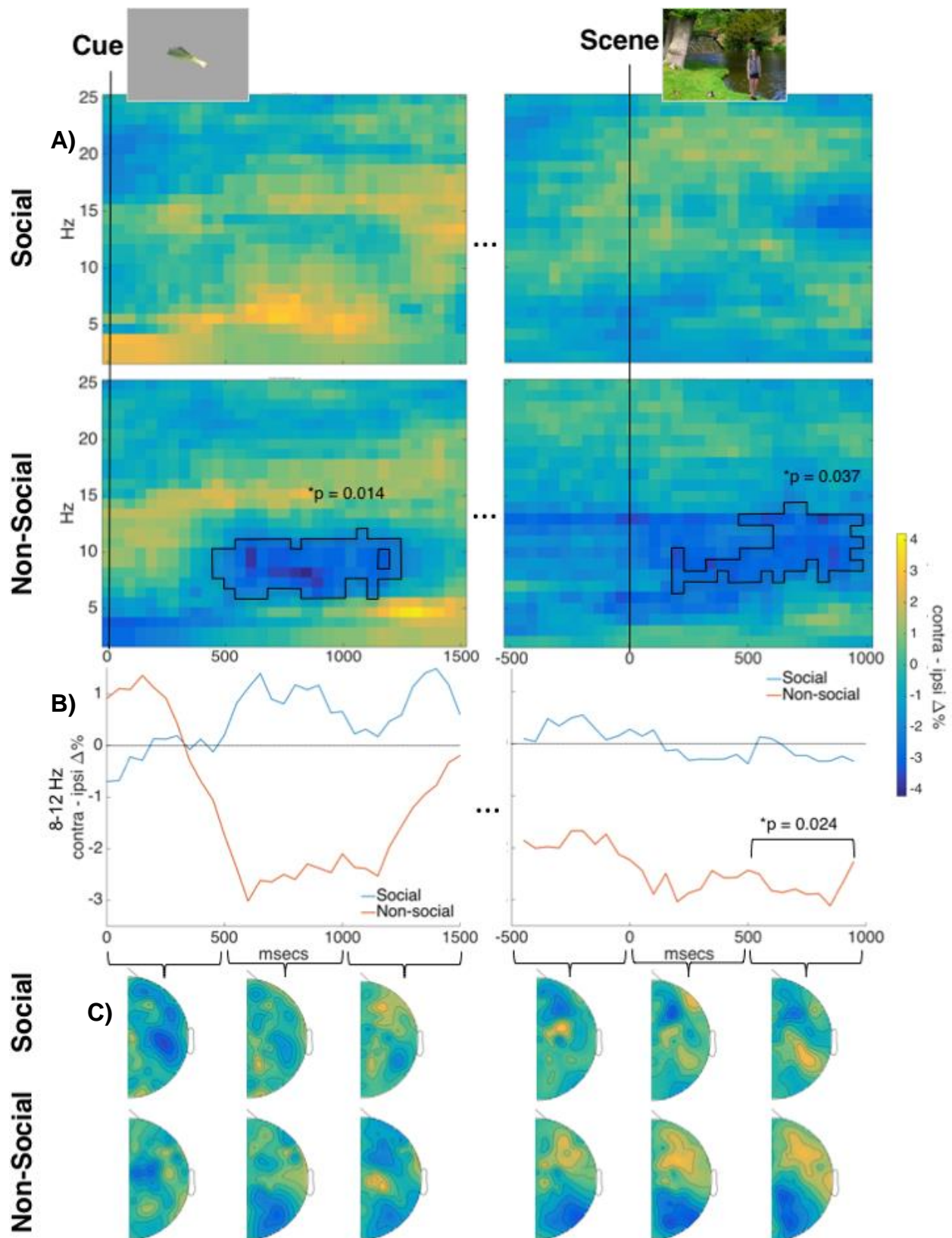
Contralateral – ipsilateral contrasts averaged over the highlighted posterior channels were then used to investigate preparatory alpha lateralization following the central object cue as well as the scene presentation. Associated time-frequency contrasts were then evaluated using cluster-based permutation tests.

As we expected given the prior literature on memory-guided preparatory attention, for centrally presented targets associated with scenes with non-social distractors, we found a significant cluster when comparing power contralateral compared to ipsilateral that encompassed the alpha range,  $p = 0.014$  (Figure 6). In contrast, there were no detectable significant differences in power contralateral compared to ipsilateral in response to centrally presented targets associated with scenes with social distractors. To follow up the significant cluster for centrally presented targets associated with non-social scenes, a cluster-based permutation test over time was conducted with contrasts averaged over the alpha range (8-12 Hz) specifically. Although there were no significant clusters in response to the presentation of central objects associated with scenes with either social or non-social distractors, there was a non-significant trend for non-social scenes ( $p = 0.050$ ). At face value, this contrasts with the cluster observed in the time-frequency evaluation. However, careful examination of the time-frequency plot suggests this may be due to the fact that this desynchronization cluster following object cues peaks in slightly lower frequencies than typically considered for alpha oscillations. Examining the topographies of the difference between contralateral and ipsilateral alpha power (8-12 Hz) over time confirmed a largely posterior localization of these results and is, again, most clearly evident in the non-social case (Figure 6). There were no significant differences when comparing contralateral – ipsilateral contrasts between scenes with social and non-social distractors directly ( $p = 0.11$ ).



For the scene presentation, we found a significant cluster when comparing power contralateral compared to ipsilateral that encompassed the alpha range in response to scenes with non-social distractors,  $p = 0.037$  (Figure 6). In contrast, there were no detectable significant differences in power contralateral compared to ipsilateral in response to the presentation of scenes with social distractors. To follow up the significant cluster for non-social scenes, a cluster-based permutation test over time was conducted with contrasts averaged over the alpha range (8-12 Hz) specifically. A significant negative cluster was detected in response to scene presentation for scenes associated with non-social targets from 500-1000 ms, indicating less power (desynchronization) contralateral compared to ipsilateral to the side of the remembered target location (Figure 6). Again, there were no significant differences when comparing contralateral – ipsilateral contrasts between scenes with social and non-social distractors directly ( $p > 0.250$ ).

As a very helpful reviewer noted, preparatory alpha-band lateralization for targets associated with non-social scenes and alpha modulation for non-social scenes themselves in the absence of a similar modulation for targets and social scenes provide converging, but weak, statistical evidence for an effect of social distraction on these neural markers. This is because the laterality effects in the non-social condition but not the social condition were not supported by the two corresponding statistically significant interaction effects of hemisphere (contralateral, ipsilateral) and scene (social, non-social). In turn, the absence of interaction effects is problematic (Nieuwenhuis, Forstmann, & Wagenmakers, 2011), as at best we can speak about absent lateralization in the social condition, not a difference between social and non-social conditions. While we believe that this is a very important issue, and one that points to the need to replicate our alpha-band findings, we would like to point to the qualitative absence of modulation for social scenes, as graphically shown in Figures 6(A) and 6(B).



**Figure 6.** Contralateral – ipsilateral % power change in oscillatory activity over time in response to the central object (left) and the scene presentation (right) for social and non-social associated targets and scenes, extracted from the posterior channels highlighted in Figure 5 (A). Contralateral – ipsilateral % power change in oscillatory activity over time for alpha power specifically (8-12 Hz), cluster outline indicates significant decrease for contralateral vs. ipsilateral for non-social during scene presentation (B). Topographies for contralateral – ipsilateral % power change in alpha (8-12 Hz) oscillations averaged over 500 ms time segments (C).

## Discussion

The current study built on the previous findings of the effects of social distraction on learning and subsequent memory for natural scenes (Doherty et al., 2017), to investigate the behavioral consequences of social distraction on subsequent memory-guided orienting of attention as well as on anticipatory neural dynamics during said memory-guided attentional orienting. Importantly, we replicated the effect of social distraction on subsequent memory, with poorer explicit memory for targets in scenes with social distractors. Interestingly, and contrary to our original hypothesis, this did not attenuate memory-based orienting. In contrast, memory-guided attention orienting, as measured by the magnitude of the validity effect, was boosted for scenes previously associated with social distractors, with a greater cost for invalid trials in particular. EEG measures revealed an effect of preparatory attention on lateralized alpha power, typically considered a marker of spatial attention, for targets associated with non-social scenes: significant alpha (8-12 Hz) lateralization occurred after presentation of central targets associated with scenes with non-social distractors and of the scenes themselves. This finding is consistent with prior work and suggestive of changes in excitability in posterior cortical regions in anticipation for targets

appearing at learned location, although likely reflects a mix of post-cue mnemonic retrieval and pre-target anticipatory dynamics. Alpha lateralization was absent for scenes containing social distractors. These neural findings require replication, as we did not find an interaction effect between laterality and scene type, but they converge with our behavioral data and they suggest a possible knock-on effect of an attention bias towards social stimuli. The presence of social stimuli in natural scenes, even when such stimuli are task irrelevant, results in poorer explicit contextual memory, which subsequently affects memory-guided attention orienting at both behavioral and possibly neural levels.

Important to note is the fact that the current study replicated the main results from the previous study (Doherty et al., 2017). First, we replicated here the difference in search time slopes between social and non-social scenes during the visual search task, with shallower slopes over three blocks for social scenes. This subtle difference was subsequently followed by a more pronounced difference in memory precision, with poorer memory for scenes containing social distractors, similar to the previous study. Finally, we replicated the cross-task relationship whereby search slope during visual search predicted memory precision in the memory phase, with shallower search slopes relating to poorer precision. With regards to first look, there was a subtle difference in the results between the two studies. Whereas participants in the previous study made more first looks to social distractors compared to non-social distractors across all three blocks, participants in the current study only made more first looks to social distractors in the first block. Given this discrepancy, it is possible that although participants may consistently demonstrate social distraction in their search times and memory precision in this task, there is more variability in the degree of overt attention capture as measured by gaze behavior.

One intriguing finding from the current study is the fact that although we show *poorer* explicit memory for scenes containing social compared to non-social distractors, we show a *greater* validity effect with a higher cost (slower RTs) for invalid social trials in particular. One explanation may lie in the cross-task analyses. We found that memory precision interacted with validity to predict RTs during the orienting phase, such that poorer memory precision related to longer RTs in valid trials; however, there was no such relationship for invalid trials. As the distractor effect at the orienting phase was driven by *invalid* trials, this cross-task analysis suggests that something other than explicit memory may be driving differential orienting effects between social and non-social scenes. One hypothesis is that while explicit memory for social scenes is poorer, implicit memory, which has also been implicated in the orienting phase in addition to explicit memory (see discussion in Summerfield et al., 2006), may be better. Indeed, other work with a similar paradigm and healthy ageing participants suggests that explicit contextual memory is not necessary for memory-guided attention to spatial locations in natural scenes, thus memory-guided orienting can de-correlate from explicit memory measures (Salvato, Patai, & Nobre, 2016a; Salvato, Patai, McCloud, & Nobre, 2016b). Further research is necessary to explore this hypothesis. Another possibility is that the orienting phase was overall more difficult in trials with social scenes compared to non-social scenes. Previous literature reports larger validity effects with increased task difficulty for endogenous cues (arrow cues) compared to exogenous cues (Berger, Henik, & Rafal, 2005). In light of this study, it is possible that while memory for target locations in scenes with social distractors is “good enough” to detect targets at valid locations, participants pay a larger re-orienting cost during invalid trials due to the difficulty of memory-guided orienting in the context of social distraction. Inclusion of neutral trials may help in exploring this hypothesis by determining if RTs are longer for neutral social compared to neutral non-social trials.

Crucially, investigating alpha desynchronization contralateral to learned target locations in response to centrally presented targets and scene cues during the orienting phase detected significant desynchronization in response to the presentation of central targets associated with non-social scenes, as well as the non-social scenes themselves. We had expected this finding, as alpha desynchronization of this kind has been previously reported in the context of memory-guided orienting to target locations in naturalistic scenes (Stokes et al., 2012). This was not the case for targets associated with social scenes or social scenes themselves, although this null lateralized alpha desynchronization needs to be caveated by the absence of an overall interaction effect of hemisphere and scene type. Importantly, the centrally presented targets were counterbalanced—while some participants saw a particular target and associated it with a social scene, other participants associated that same target with a non-social scene. It is unlikely, therefore, that differences arose due to the perceptual properties of the stimuli. These findings suggest that the effect of social distraction on explicit contextual memory extends to neural activity, and specifically to lateralized alpha oscillations that have previously been shown to occur in response to perceptual cues (Haegens et al., 2011; Romei et al., 2010; Thut et al., 2006; van Ede et al., 2011; Worden et al., 2000; Wyart & Tallon-baudry, 2008), as well as memory cues (Stokes, Atherton, Patai, & Nobre, 2012; Summerfield et al., 2011). While the previous literature found alpha desynchronization in response to the scene cue with similar memory-guided orienting tasks using natural scenes (Stokes, Atherton, Patai, & Nobre, 2012; Summerfield et al., 2011), in the current study we extend this by showing for the first time even earlier similar lateralization, already following the presentation of an object cue that predicts the upcoming non-social scene cue. Crucially, EEG-detected lateralization that has been seen previously in response to lateralized targets (e.g. Patai et al., 2012) we have shown can be induced by central targets associated with

lateralized locations, at least in the context of targets for which the memory trace had been laid down in non-social scenes.

Although we have interpreted these alpha modulations as an index of preparatory spatial attention for the upcoming target (in line with many other studies cited above), these modulations may also be associated with mnemonic retrieval operations alone (Hanslmayr et al., 2011). Although distinguishing between these alternatives remains an important target for future research, it is likely that both processes go hand in hand during memory-guided attentional orienting, provided that it is the mnemonic retrieval of the target location that steers the subsequent orienting of spatial attention. Additionally, it is intriguing that for scenes with social distractors we do not detect alpha lateralization, yet do see strong behavioral memory-guided orienting effects. One explanation is there may have been parallel alpha lateralization to remembered social distractors and to targets that may have had a cancelling out effect. Although this could not be tested in the current study due to limited number of trials, this could be tested in the future. Another explanation is that net alpha lateralization is not required to carry out the behavioral effects of memory-guided attention orienting. Finally, there may be additional markers of net attention that correlate with the behavioral findings, but were not investigated here.

Interestingly, moderation of the orienting validity effect by distractor type, as well as the finding of poorer explicit memory for social scenes, were still present when including longitudinal data following up participants approximately 1-3 weeks later (see SOM). These longitudinal results provide evidence against two possible hypotheses for the seemingly contrasting effects of distractor type between the memory phase and the orienting phase. One hypothesis is that while explicit memory may initially be poorer for social scenes, in the approximately 30 intervening minutes until the orienting phase memory degrades more rapidly for *non*-social scenes, such that

by the time participants engage in the task their memory has become poorer for non-social scenes. However, the longitudinal data provides evidence against this hypothesis, as poorer memory for social scenes appears to persist even 1-3 weeks later. Another hypothesis is that the distractor effect at the orienting phase is not due to distraction at encoding (during learning in the visual search phase), but rather distraction during retrieval (during the orienting phase) due to the presence of the social distractors within the scenes during the task. The longitudinal data again provides evidence against this hypothesis. In the longitudinal version of the orienting phase, the scenes and the distractors were not present when participants reacted to the target's appearance, which occurred on a gray screen (see SOM). The only cue they were given was the centrally presented target, yet still there was a robust validity effect that appears to be moderated by distractor type.

In summary, the current study extends the literature on memory-guided attention orienting, and in particular the literature utilizing memories of spatial locations within natural scenes, by demonstrating the moderating effect of social distraction. Here, we show that an attention bias towards social stimuli, even when such stimuli are task irrelevant, results in poorer explicit contextual memory, which subsequently affects memory-guided attention orienting. Moreover, there is preliminary evidence to suggest these effects are long lasting, present even several weeks after memory encoding (see SOM). Finally, anticipatory lateralization of 8-12 Hz alpha oscillations following mnemonic cues is absent for targets associated with social scenes.



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