Cognition 158 (2017) 215–223

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Original Articles

The functional consequences of social distraction: Attention and memory for complex scenes

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ARTICLE INFO

Article history:
Received 13 November 2015
Revised 12 October 2016
Accepted 26 October 2016
Available online 12 November 2016

Keywords:
Social distraction
Visual attention
Memory
Social anxiety

ABSTRACT

Cognitive scientists have long proposed that social stimuli attract visual attention even when task irrelevant, but the consequences of this privileged status for memory are unknown. To address this, we combined computational approaches, eye-tracking methodology, and individual-differences measures. Participants searched for targets in scenes containing social or non-social distractors equated for low-level visual salience. Subsequent memory precision for target locations was tested. Individual differences in autistic traits and social anxiety were also measured. Eye-tracking revealed significantly more attentional capture to social compared to non-social distractors. Critically, memory precision for target locations was poorer for social scenes. This effect was moderated by social anxiety, with anxious individuals remembering target locations better under conditions of social distraction. These findings shed further light onto the privileged attentional status of social stimuli and its functional consequences on memory across individuals.

1. Introduction

Decades of research have suggested that faces and social stimuli hold a privileged processing status in human cognition. Studies have shown increased perceptual sensitivity to faces in newborn babies, which led to the proposal that infants are born with an innate structural representation of faces (Morton & Johnson, 1991). Neuroimaging has extended these findings to show brain areas (e.g. Puce, Allison, Asgari, Gore, & McCarthy, 1996) as well as single cells (e.g. Perrett, Hietanen, Oram, & Benson, 1992) specialized for processing faces (although see Gauthier & Tarr, 1997 for evidence of perceptual sensitivity to non-faces after extensive training). In addition to perceptual sensitivity, faces also show a special role in selective attention (Vuilleumier, 2000; Vuilleumier, Armony, Driver, & Dolan, 2001), including in change-detection tasks (Ro, Russell, & Lavie, 2001) and cueing tasks (Langton & Bruce, 1999).

A less commonly used alternative to investigate how social stimuli affect selective attention is the case of social *distraction* when people are *not* the targets of attention. Distractor faces show interference effects in visual search even under high perceptual load, suggesting mandatory processing (Lavie, Ro, & Russell, 2003). Additionally, neurotypical adults and children take longer to detect a target in a simple search paradigm with a face as a distractor than when there is no face distractor (Langton, Law, Burton, & Schweinberger, 2008; Riby, Brown, Jones, & Hanley, 2012). Interestingly, this effect does not extend to autistic children (Riby et al., 2012), whose reduced attention to faces and people is thought to demonstrate the absence of a privileged status for social stimuli (Klin, Jones, Schultz, & Volkmar, 2003).

Surprisingly, and critically, the effects of such distraction have not been investigated beyond selective attention within perceptual tasks. Social distraction is likely to have downstream consequences, influencing how well individuals remember information encountered during visual search. Studies showing poorer memory due to general distraction at encoding are numerous, spanning both working memory (e.g. Awh & Vogel, 2008) and long-term memory (e.g. Foerde, Knowlton, & Poldrack, 2006). However, no studies have investigated the effect of *social distraction* on longer-term memory (see de Fockert, Rees, Frith, & Lavie, 2001; Mano et al., 2013 for working memory examples with distraction during maintenance), nor have they used search in naturalistic scenes instead of simple visual search. The current study addresses this important gap in the literature by investigating the consequences of social distraction during visual search in naturalistic scenes on the quality of subsequent memories.

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http://dx.doi.org/10.1016/j.cognition.2016.10.015
0010-0277/

We developed a task using natural scenes, which enabled us to contrast distraction caused by social stimuli vs. other, well-controlled stimuli that were matched for low-level visual properties. People are salient not just in terms of their social valence, but also with regards to low-level visual properties, including color and contrast. Although researchers often utilize scrambled or inverted faces, these control stimuli are less naturalistic and may pop out in natural scenes. The current study takes a novel approach to these problems, by using a graph-based visual saliency algorithm (Harel, Koch, & Perona, 2006) to ensure that the physical salience of social vs. non-social distractor items embedded within scenes is matched.

Finally, if social distraction does indeed have functional consequences, an individual's degree of bias towards social stimuli may play a moderating role. A large literature suggests a relationship between general anxiety and attentional bias towards threatening stimuli (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Bishop, Duncan, Brett, & Lawrence, 2004), and this relationship has been shown specifically for social anxiety and emotional faces in both clinical and typical populations. (e.g. Bradley, Mogg, White, Groom, & de Bono, 1999). In contrast to highly socially anxious individuals, as mentioned above, there is ample evidence that autistic individuals are less engaged by social stimuli in general, and more specifically do not demonstrate social distraction in simple visual search. We took advantage of these well-characterized individual differences, by including scales that tap into hypersensitivity to social stimuli (social anxiety) versus insensitivity to social stimuli and social distraction (autistic traits) [however, please see Senju & Johnson, 2009 for competing theories of hypo- versus hyper-arousal to social stimuli in autism spectrum disorders (ASD)].

In order to understand the consequences of social distraction for attention and subsequent memory, we posed three complementary questions: (1) Will the previously documented social distraction effect extend to visual search in natural scenes and when compared to distraction from items that are matched for visual salience? (2) Will social distraction influence later memory performance, such that memory will be poorer for social scenes? (3) Will these relationships be moderated by individual differences in social anxiety or autistic traits?

2. Materials and methods

2.1. Participants

This research was approved by the University of Oxford Central University Research Ethics Committee (CUREC). Thirty-seven healthy adult volunteers participated (aged 19–33, 21 female). All had normal or corrected-to-normal vision. Six other participants were tested but excluded—four due to age outside of our range of interest (18–35), one due to eye-tracker malfunction, and one due to lack of English proficiency to understand task instruction. Sample size was determined by the desire to at least double the size of previous studies, which had sample sizes of 16 (Patai, Doallo, & Nobre, 2012; e.g. Stokes, Atherton, Patai, & Nobre, 2012), in order to detect individual differences. Our stopping rule was to stop testing when our sample size was a multiple of four, due to the number of counterbalanced groups (see below). All participants provided written informed consent and were paid for their participation or received course credit.

2.2. Stimulus design and visual salience computation

Eighty natural indoor and outdoor scenes were prepared from photographs taken by the experimenter or acquired from the Internet with permission (1000×750 pixel resolution in 32-bit color, under the experimental conditions spanning 37.05 by 22.34 degrees of visual angle). Target objects were photographs of objects including tools, toys, fruits, etc., sized to approximately 1.09 by 1.09 degrees of visual angle. Social distractor stimuli were prepared from photographs of people standing upright taken by the experimenter (BD). Non-Social distractors were objects chosen to be similar to social distractors in terms of color and contrast (e.g. deck umbrella, ornamental plant, coat stand, etc.). They were also chosen to fit naturally into the scene such that they did not appear odd. All distractors were 9.03 degrees of visual angle in height.

Matching 'social' and 'non-social' versions of each scene were created using GIMP 2.8.10 image manipulation software with: (1) a social distractor (person) edited into a natural location or (2) a non-social distractor edited into the same location. Every scene had a unique target object placed within it. Target objects were superimposed on scenes during the visual search task through the stimulus presentation program.

Presentation of social and non-social scenes was counterbalanced across participants, so that half saw the same 40 scenes as social and the other 40 scenes as non-social, while the other half of the participants saw the reverse. In addition, each scene had two target locations that were counterbalanced across participants: one on the same side and the other on the opposite side of the distractor. These locations were balanced such that any one participant saw equal numbers of targets in the four visual quadrants. Finally, distractor position and gender of social distractors were also balanced (Fig. 1). Target location and distractor counterbalancing resulted in four participant groups: distractor group 1 location 1, distractor group 1 location 2, distractor group 2 location 1, distractor group 2 location 2.

To ensure that social and non-social distractors were equally salient with regards to low-level visual properties (color, contrast, etc.), salience values were calculated using a bottom-up visual saliency algorithm based off of the original Itti and Koch algorithm (Harel et al., 2006). For both target locations, paired samples t-tests comparing social and non-social versions of all scenes revealed no significant differences in salience between: (1) social/non-social distractors identified with hand-drawn AOIs ($p > 0.250$), (2) social/non-social scenes overall ($p > 0.250$), and (3) social/non-social scene target objects in the target locations identified with circular AOIs ($p > 0.250$) (Fig. 2).

2.3. Procedure

2.3.1. Visual search

Participants sat 75 cm away from a 1680 by 1050 resolution monitor (spanning 37.05 by 22.34 degrees of visual angle) with their chin on a chin rest. They were directed to look for target objects in 80 scenes over three blocks (Fig. 2). During search, gaze position was recorded from both eyes at 500 Hz using an Eyelink 1000 infrared camera following a 9-point calibration and validation. For each trial, participants saw: (1) a fixation square for 1000–1500 ms, (2) the object alone (1.61 by 1.61 degrees of visual angle) for 3000 ms, (3) the scene and embedded object, and (4) feedback for 1000 ms ("Object not found" or "Object found" on blank screen). 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. They were instructed to press the spacebar when they found the object to reveal the cursor and then click on the object (Fig. 2). Accuracy in locating the target was defined as clicking on the object within a 0.54 degrees of visual angle buffer.

<table>
<tr><td>Distractor type</td><td colspan="8">40 social</td><td colspan="4">40 non-social</td></tr>
<tr><td>Distractor location</td><td colspan="4">20 left</td><td colspan="4">20 right</td><td colspan="2">20 left</td><td colspan="2">20 right</td></tr>
<tr><td>Target location</td><td colspan="2">10 same</td><td colspan="2">10 opposite</td><td colspan="2">10 same</td><td colspan="2">10 opposite</td><td>10 same</td><td>10 opposite</td><td>10 same</td><td>10 opposite</td></tr>
<tr><td>Distractor gender</td><td>5F</td><td>5M</td><td>5F</td><td>5M</td><td>5F</td><td>5M</td><td>5F</td><td>5M</td><td colspan="4">Not applicable</td></tr>
</table>

Fig. 1. Scenes balanced for distractor type, distractor location, target location, and distractor gender. Distractor location refers to screen hemifield. Target location is with respect to the distractor: same or opposite side of the distractor. Distractor gender (F: female, M: male) is only applicable to social scenes.

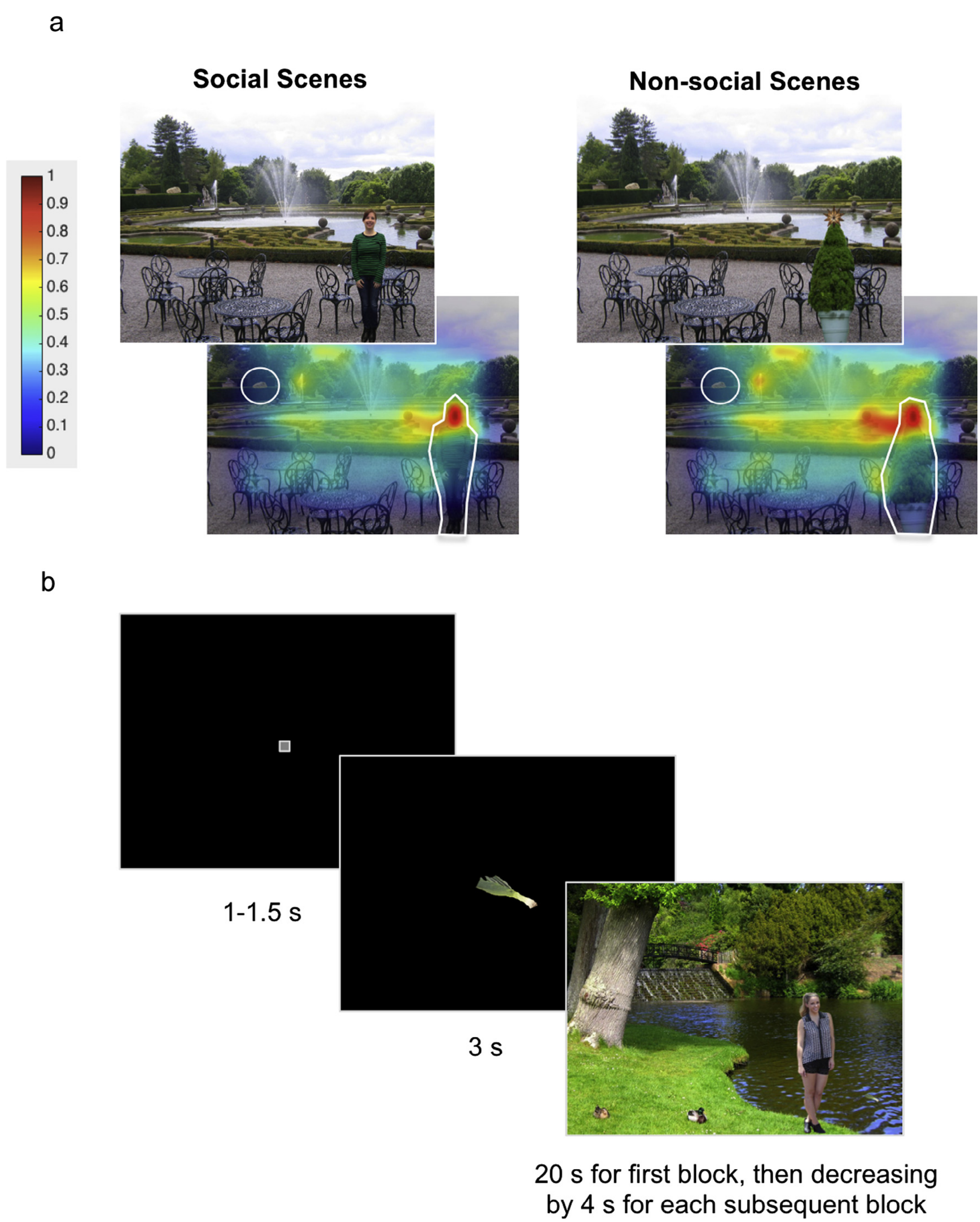

Fig. 2. Scene salience and visual search procedure. (A) Social and non-social scenes equated for salience. Salience values showed no significant differences in low-level visual properties (red indicates high salience values and blue indicates low values). Target and distractor AOIs (shown in white) were drawn using a circle, or freeform respectively. (B) Visual search trial timeline. Each trial was followed by feedback ("Object not found" or "Object found" on a blank screen for 1 s). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.3.2. Memory phase

After a short break (on average 4 min), explicit memory for target locations was probed. Participants saw each scene with its accompanying social/non-social distractor in a random order. The target appeared in the center of each scene and participants could move it around the scene with the mouse, indicating the remembered location with a mouse click.

2.3.3. Questionnaires

After the memory test, the participants filled out the autism-spectrum quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001)—a questionnaire designed to be sensitive to individual differences in the general population—and the Liebowitz social anxiety scale (SAS) (Liebowitz, 1987).

2.4. Statistical analysis

2.4.1. Visual search

For accurate trials, two measures were extracted: search time and first look. Search time was calculated as the time from scene onset to click on target. First look indicated whether the first saccade and associated fixation after scene onset was to the distractor (see supplementary material for details about eye-tracking data processing). First look was chosen in accordance with the previous literature, which suggested that fixations on distractors during visual search relate to incidental memory of distractors (Olejarczyk, Luke, & Henderson, 2014; Williams, Henderson, & Zacks, 2005), as well as increase search time (e.g. Boot, Kramer, & Peterson, 2005; Irwin, Colcombe, Kramer, & Hahn, 2000), and first fixations in particular indicate attentional capture in complex scenes (Becker, Pashler, & Lubin, 2007) as well as to faces specifically (Crouzet, Kirchner, & Thorpe, 2010).

2.4.2. Memory phase

Memory precision was evaluated as the distance in pixels from the accurate target location for trials in which participants accurately found the target object at least once in the visual search task.

For each dependent measure, two methods of statistical analysis were employed. The first was an information-theoretic (IT) approach using Akaike's information criterion (AIC) modeling (Burnham & Anderson, 2002). In this approach, a global linear mixed-effects model was created using all fixed predictor variables of interest, with participant and scene as random variables to account for the non-independence across trials within participants and across blocks of the visual search task within scenes. The AIC modeling approach was used for four reasons: (1) to include all trials in the analyses as opposed to averaging over trials, which allows for incorporating the variance within participants into the model, (2) to account for the variance between scenes, which more appropriately determines the strength of effects of the distractor on behavior over and above variability across scenes, also known in the literature as "controlling for item effects" (Baayen, Davidson, & Bates, 2008; Judd, Westfall, & Kenny, 2012), (3) to analyze proportion data 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), and (4) to determine a priori if covariates should be included into further analyses. These additional analyses employed traditional repeated-measures ANOVAs/ANCOVAs. This two-step method allowed us to investigate the direction of statistical relationships found in the AIC modeling approach. If any interaction term with the AQ or SAS were found to be significantly greater than zero using the AIC modeling approach, the AQ or SAS were included as covariates. In addition, G-power 3.1.9.2 (Faul, Erdfelder, Lang, & Buchner, 2007) was employed to calculate statistical power for these traditional ANOVAs/ANCOVAs. Compromise power analyses (beta/alpha ratio = 4) showed that with N = 37, we achieved adequate power (71.5%) to detect a large (f = 0.40) sized main effect for a two-level within subject variable (e.g., distractor) or covariate (SAS or AQ), but less adequate power for three-level within-subject variables (e.g., block) (power = 64.5%) or power to detect medium (48.9%) sized effects.

3. Results[1]

3.1. Visual search

Manual and eye-tracking measures provided converging evidence for social stimuli being more distracting than non-social stimuli, with the effects interacting with learning over successive blocks (see Table 1 for descriptives).

3.1.1. Manual search time (s)

We first investigated whether participants learned target locations across blocks, and whether distractor type affected this learning. Decreasing search time over blocks indicated learning and there was a moderating effect of distractor on learning slopes. AIC model averaging with manual response times during the visual search task revealed that the coefficient estimates for block as well as the distractor-by-block interaction term were significantly different from zero, indicating they had significant effects on the model (Table 2). A repeated-measures ANOVA with two within-subject factors (distractor: social, non-social; block: one, two, three), revealed a main effect of block, $F(1.47,52.89) = 395.23$, $p = < 0.001$, $\eta^2 = 0.92$, driven by decreasing search time across blocks. There was no main effect of distractor on search time, $F(1,36) = 0.38$, $p > 0.250$, $\eta^2 = 0.01$, but there was a significant distractor-by-block interaction, $F(1.94,69.98) = 3.78$, $p = 0.029$, $\eta^2 = 0.10$. Although Bonferroni-adjusted post hoc tests revealed no significant differences in search time between social and non-social scenes in each block separately (block one: $p = 0.218$, block two: $p = 0.215$, block three: $p = 0.135$), and highly significant differences between blocks for both social and non-social scenes separately ($p < 0.001$), there was a significant interaction between distractor and block in the linear contrasts, $F(1,36) = 5.13$, $p = 0.030$, $\eta^2 = 0.13$, suggesting a difference in slope across blocks between social and non-social scenes. Extracting the regression slopes for each participant for social and non-social scenes separately showed steeper negative slopes for non-social scenes ($M = -0.34$ ln(s), $SD = 0.10$ ln(s)) compared to social scenes ($M = -0.31$ ln(s), $SD = 0.08$ ln(s)) (Fig. 3).

3.1.2. First look (yes/no)

Next, to analyze whether distractor type predicted gaze behavior, we tested if the first saccade and subsequent fixation landed on the distractor (first look). There were more first looks to social distractors, indicating greater attentional capture, which decreased over blocks with a more negative slope for social scenes. In addition, overall attentional capture by both social and non-social distractors showed a negative relationship with the AQ. For this analysis, logit mixed-effects models (Generalized Linear Mixed Effects Models for binomially distributed outcomes) were used in AIC modeling. Distractor, block, AQ, and the distractor-by-block interaction term had significant effects on the model (Table 2). The main effect of the AQ reflected the finding of a negative relationship with overall first looks with fewer first looks to both social and non-social distractors for individuals with high

[1] As we had four counterbalanced groups, we first ran analyses excluding one participant to allow for even numbers in each group. There were no differences in the results between this smaller sample and the full sample described below.

Table 1
Visual search descriptive statistics.

Distractor	Block	RT (s)	Accuracy (%)	First looks (%)
Social	1	4.85 (0.11)	97.09 (0.45)	26.49 (1.81)
	2	3.32 (0.06)	97.97 (0.34)	21.51 (1.39)
	3	2.60 (0.06)	98.31 (0.32)	18.60 (1.12)
Non-social	1	5.00 (0.11)	95.95 (0.64)	16.97 (1.27)
	2	3.45 (0.07)	98.04 (0.33)	15.52 (1.23)
	3	2.53 (0.07)	98.12 (0.34)	14.11 (1.17)

Average values with standard errors in parentheses.

Table 2
Model averaging with parameters related to the visual search task dependent measures.

Predictor	Search time				First look			
	RI	θ	95% CI		RI	θ	95% CI	
(Intercept)		1.461***	1.396	1.525		−1.908***	−2.207	−1.608
Distractor	0.79	−0.021	−0.056	0.013	1	0.535***	0.229	0.840
Block	1	−0.619***	−0.655	−0.583	1	−0.330*	−0.582	−0.079
AQ	0.5	−0.024	−0.076	0.027	0.89	−0.159*	−0.300	−0.015
SAS	0.55	−0.031	−0.082	0.020	0.67	0.100	−0.028	0.227
Distractor × Block	0.68	0.054*	0.013	0.096	0.57	−0.301*	−0.599	−0.002
Distractor × AQ	0.13	0.008	−0.016	0.030	0.44	0.155	−0.079	0.388
Distractor × SAS	0.13	−0.004	−0.027	0.018	0.23	−0.094	−0.338	0.145
Block × AQ	0.12	−0.012	−0.032	0.010	0.26	0.094	−0.060	0.242
Block × SAS	0.13	0.013	−0.009	0.033	0.11	−0.030	−0.161	0.119
Distractor × Block × AQ	0.01	−0.027	−0.068	0.015	0.03	0.207	−0.086	0.497
Distractor × Block × SAS	<0.01	−0.015	−0.056	0.027	<0.01	−0.123	−0.407	0.161

For each parameter and dependent measure, this table presents the relative influence (RI) (based on Aikaike weights), the averaged coefficient estimates (θs), and the 95% confidence intervals (CI) based on estimated unconditional variance (see Supplementary Online Materials). Estimates with '***' differed statistically from zero based on 95% CIs with $p < 0.001$, '**' with $p < 0.01$, and '*' with $p < 0.05$. For both search time and first look, block had a significant effect, as would be predicted if learning took place. Distractor had a significant effect for first look, with more first looks to social distractors, as we would predict if social distractors in particular captured attention during search, even with distractors equated for salience. Furthermore, block-by-distractor interactions for both measures suggests differential distractor effects across blocks.

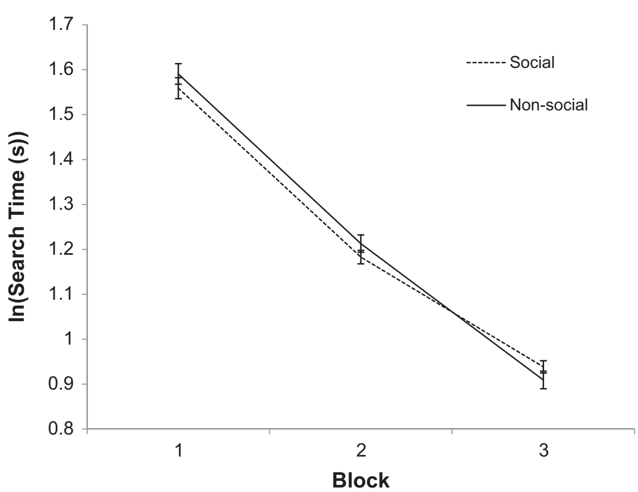

Fig. 3. Interaction between block and distractor for visual search time. Although there were no significant differences between social and non-social scenes for each block separately, and there were highly significant differences between blocks for both social and non-social scenes separately, there was a significantly steeper slope across blocks for non-social compared to social scenes. Dotted line represents social trials and solid line represents non-social trials. Error bars are standard errors.

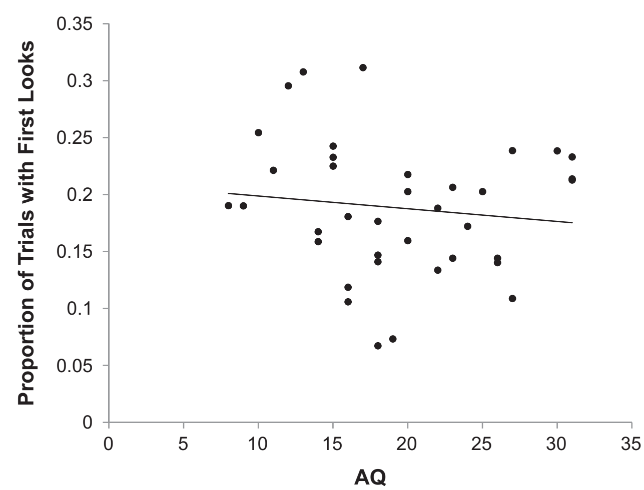

Fig. 4. Depiction of the significant relationship between the AQ and first looks to distractors, with increasing scores on the AQ related to fewer first looks to distractors overall, regardless of whether the distractor was social or non-social. Dots are average proportion of trials with first looks for individual participants.

autistic traits (Fig. 4). A repeated-measures ANOVA with two within-subject factors (distractor: social, non-social; block: one, two, three), with proportion of trials with first looks as the dependent measure revealed a significant main effect of block, $F(1.77,63.61) = 11.65$, $p < 0.001$, $\eta^2 = 0.24$, with first looks generally decreasing over blocks, a significant main effect of distractor, $F(1,36) = 14.17$, $p < 0.001$, $\eta^2 = 0.28$, with more first looks to social distractors (Fig. 5), and a marginal distractor-by-block interaction, $F(1.77,63.64) = 2.78$, $p = 0.068$, $\eta^2 = 0.08$. Although the interaction was only marginally significant, in light of the significant interaction term using the higher-powered AIC modeling approach, this interaction was followed up with post hoc analyses. Bonferroni-corrected post hoc tests revealed significant differences in first looks between social and non-social scenes for each block separately (block one: $p = 0.001$, block two: $p = 0.009$, block three: $p = 0.018$), but there was a significant interaction between distractor and block in the linear contrasts, $F(1,36) = 4.55$,

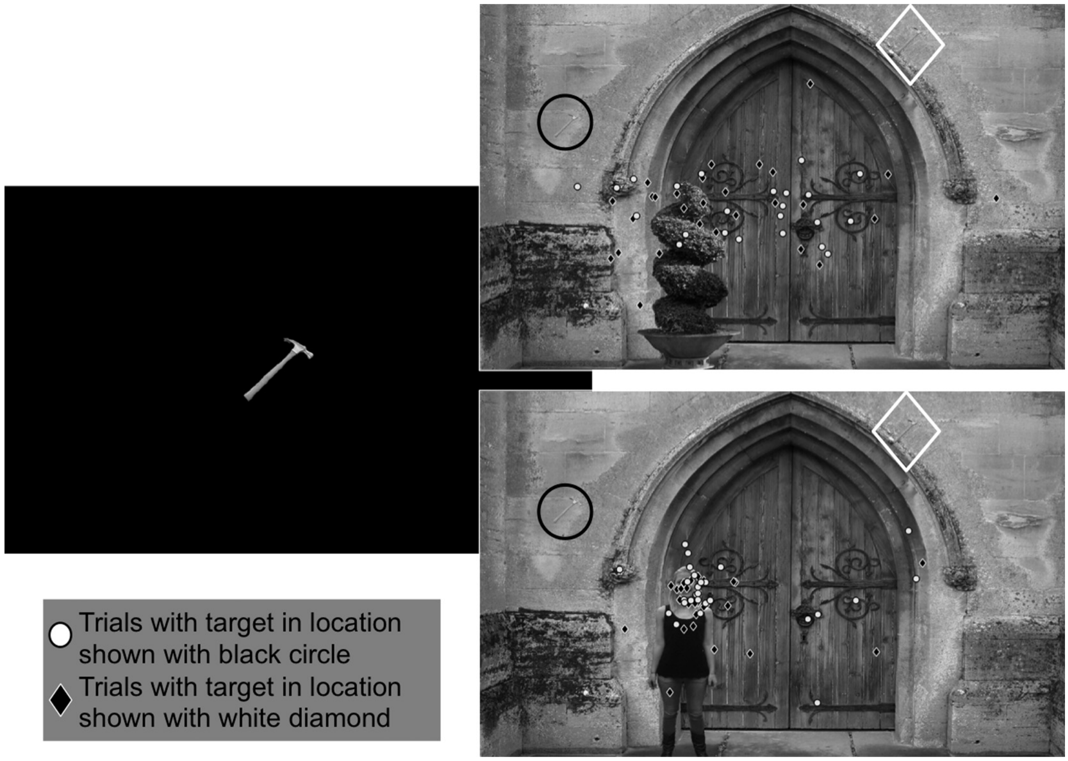

Fig. 5. First looks during visual search for a representative scene. This figure depicts the between-subjects first looks across all three blocks. For half of participants, the target appeared at the location marked with a black circle, and for other half at the location marked with a white diamond. Regardless of the specific target location, participants looked at the social distractor more than the non-social distractor in the same scene, despite the fact that the two stimuli were equally salient with regards to low-level visual properties.

$p = 0.040$, $\eta^2 = 0.11$, suggesting a difference in slope in first looks across blocks between social and non-social scenes. Extracting the regression slopes for each participant for social and non-social scenes separately showed steeper negative slopes for social scenes ($M = -3.94\%$, $SD = 6.09\%$) compared to non-social scenes ($M = -1.43\%$, $SD = 3.94\%$).

3.2. Memory phase

Next, to investigate the effects of learning on memory performance, memory precision (distance in pixels from recalled location to correct location) was analyzed. Participants showed poorer precision for social compared to non-social scenes, and importantly this effect was moderated by the SAS with anxious individuals remembering target locations better under conditions of social distraction. AIC modeling revealed that the fixed-effects distractor and the distractor-by-SAS interaction term had significant effects on the model (Table 3). In light of the significant interaction with the SAS, the SAS was included as a covariate in a repeated measures ANCOVA with one within-subject measure (distractor: social, non-social). There was a significant difference in memory precision for target locations, $F(1,35) = 15.00$, $p < 0.001$, $\eta^2 = 0.30$, with lower precision for social compared to non-social scenes (Social: $M = 179.60$, $SE = 7.10$; Non-social: $M = 158.62$, $SE = 7.10$). There was also a distractor-by-SAS interaction, $F(1,35) = 10.04$, $p = 0.003$, $\eta^2 = 0.22$. Splitting the group by median SAS score shows this relationship to be driven by a significant difference in memory between social and non-social scenes for low SAS ($p = 0.005$) with lower precision for social scenes, but no difference for high SAS ($p > 0.250$) (Fig. 6).

To determine if we had sufficient power to detect this interaction with the SAS using mixed effects modeling, the *R* package *simr* (Green & MacLeod, 2016) was used, which calculates power for mixed effects models by simulation. An observed power analysis revealed 82.6% power based on 1000 simulations (CI: 80.11, 84.90).

4. Discussion

This study aimed to investigate the functional consequences of social distraction on attention and memory, using complementary methodologies in cognitive science. First, using a novel task with greater ecological validity, our findings replicated the strong effects of social distraction on attention (Langton et al., 2008; Lavie et al., 2003; Riby et al., 2012), but critically, in our case, even when compared to distraction from items with similar low-level salience indexed by a computational algorithm (Harel et al., 2006). Eye-tracking showed greater attentional capture by social stimuli during visual search, consistent with previous findings (Crouzet et al., 2010). This effect was moderated by block, consistent with increasing control over attentional capture for social distractors, more so than for non-social distractors. Manual search time for targets also indicated that learning over blocks was moderated by distractor type, with a shallower learning slope for social scenes. Second, and to our knowledge for the first time, we showed that the effects of social distraction were not isolated to visual search, or even learning over time, but extended to subsequent memory for target locations with poorer memory precision for social scenes. Finally, social anxiety modulated memory precision, with better memory performance under social distraction for high-anxiety participants. In contrast, autistic traits did not moderate performance, but rather individuals with higher autistic traits demonstrated generally reduced attentional capture for both social and non-social distractors.

Table 3
Model averaging with parameters related to memory precision (pixels) during the memory phase.

Predictor	RI	θ	95% CI	
(Intercept)		158.529***	123.088	194.419
Distractor	0.98	20.537*	0.860	40.219
AQ	0.39	−8.521	−43.085	26.075
SAS	0.99	32.932	−2.191	66.564
Distractor × AQ	0.15	−11.015	−30.313	10.968
Distractor × SAS	0.9	−27.798**	−47.680	−7.915

Note: For each parameter, this table presents the relative influence (RI) (based on Aikaike weights), the averaged coefficient estimates (θs), and the 95% confidence intervals (CI) based on estimated unconditional variance (see Supplementary Online Materials). Estimates with '***' differed statistically from zero based on 95% CIs with $p < 0.001$, '**' with $p < 0.01$, and '*' with $p < 0.05$.

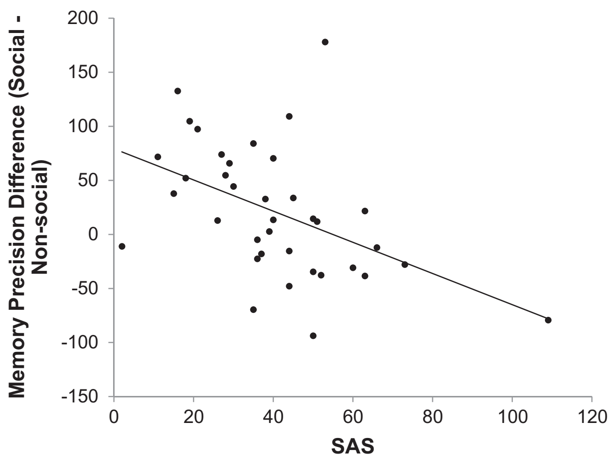

Fig. 6. SAS vs. memory precision. Difference score between the average memory precision (pixels away from target) for all social trials minus non-social trials during the memory phase versus SAS scores. Dots are individual participants. This graph depicts the significant distractor-by-SAS interaction, $F(1,35) = 10.04$, $p = 0.003$, $\eta^2 = 0.22$. This relationship holds without the extreme SAS score, $F(1,34) = 6.39$, $p = 0.016$, $\eta^2 = 0.16$. Splitting by median SAS score shows this relationship to be driven by a significant difference in memory between social and non-social scenes for low SAS (p = 0.005) with lower precision for social scenes, but no difference for high SAS (p > 0.250).

One exciting implication of this work is the extension of salience algorithms beyond predicting gaze behavior to investigating the functional consequences of visual salience. Salience algorithms are often used to predict eye movements, but only recently have these algorithms been used to predict memory performance, suggesting that target memory is correlated with target saliency (Fine & Minnery, 2009; Santangelo & Macaluso, 2013). The current study extends this work by looking at the salience of *distracting* items in order to control for their potential effects on attention and memory, a needed and too infrequently used control, particularly for natural scenes.

Furthermore, this extended learning and memory paradigm allows us to go beyond visual search alone in testing the consequences of social distraction. Our findings support a relationship between distraction at encoding and poorer memory performance (Awh & Vogel, 2008; Foerde et al., 2006), but crucially demonstrate this effect in a novel way by utilizing attentional biases towards social stimuli often discussed in the literature (Langton & Bruce, 1999; Ro et al., 2001; Vuilleumier, 2000; Vuilleumier et al., 2001). Moreover, additional analyses reveal relationships among the dependent measures that suggest a possible mechanism of social distraction. Gaze behavior during visual search (i.e., proportion of first looks towards distractors, which we found to differ between social and non-social scenes, indicative of social distraction) predicted search speed in locating targets over blocks. In turn, shallower search slopes during the visual search task (i.e., smaller improvements in speed to locate the target over blocks), predicted poorer memory performance (see SOM). Importantly, we found shallower search slopes for social compared to non-social scenes. Although these analyses do not equate to a full mediation analysis, an association between gaze behavior during search and search speed on the one hand, and an association between search speed and memory performance on the other, with a lack of a direct relationship between gaze behavior and memory performance suggests that search speed mediates the association between gaze behavior and memory precision.

The most novel findings are perhaps the effects of individual differences on social distraction. The finding that anxious individuals remember target locations better under conditions of social distraction may be surprising, as one might expect higher social anxiety to cause more distraction in social scenes and therefore poorer performance. Hypervigilance-avoidance in social anxiety accounts for these findings: social anxiety may be first characterized by hypervigilance to social stimuli, followed by avoidance (Vassilopoulos, 2005). Such avoidance may actually be advantageous in the current study, as people are distractors and not the targets of attention, and therefore may lead to better performance. The comparatively long presentation of social stimuli in our task compared to dot-probe tasks is likely to mean that participants will be in the avoidance phase, and manipulating length of scene duration in the current study may validate the hypervigilance-avoidance hypothesis and reveal it to be a general as opposed to a spatially specific effect. Additionally, in clinical populations high social anxiety leads to poorer encoding of faces (Holsen, Dalton, Johnstone, & Davidson, 2008). Individuals with high anxiety in this study may therefore not encode as much distracting information about the people, which in turn might allow for better memory for target locations in social scenes. Importantly, our current sample was only adequately powered to detect large sized effects of either individual differences in social anxiety or autism traits (see below) and therefore requires further investigation. We have now replicated these findings by collecting data from an additional sample of 20 participants for a follow-up study, replicating the statistically significant interaction between distractor type and social anxiety (data not shown). We urge further replication by scientists investigating the functional consequences of atypical attention in individuals with social anxiety.

In addition, although we did not observe an interaction with autism traits as we had expected, a main effect of AQ for first looks is important in the context of the autism literature. Although many studies conclude that autistic individuals show less attentional capture to social stimuli, these studies do not often directly compare attention to social stimuli to attention to well-controlled non-social stimuli. Aside from social impairments, autistic individuals demonstrate low-level perceptual differences with regards to color and contrast (Bertone, 2005; Franklin et al., 2010; Wang et al., 2015). It is possible that, compared to non-social objects equated for visual salience, autistic individuals do prefer social stimuli, but demonstrate reduced attention to salient stimuli in general driven by perceptual differences. This may explain discrepancies between some studies that find differences in social attention and others that do not (Fischer, Koldewyn, Jiang, & Kanwisher, 2013), as these studies often do not control for the saliency characteristics of natural stimuli. Our results are consistent with this hypothesis, and emphasize the need for well-controlled comparison stimuli for making appropriate conclusions when investigating social attention biases. However, caution is warranted not only because of the aforementioned statistical power consideration, but also because we investigated individual variation in a neurotypical population and not individuals with a full autism spectrum diagnosis. In addition, although SAS and AQ scores did not correlate in our sample, social anxiety and ASD are highly co-morbid in clinical samples (Bellini, 2006) and therefore determining the contributions of one independent of the other may be more difficult to do with diagnosed autistic individuals. This again complicates inferring directionality in the context of ASD, leaving the debate on hypersensitivity to social stimuli in social anxiety versus hyposensitivity in ASD open to further investigation (Senju & Johnson, 2009).

5. Conclusions

This work builds on the previous attentional bias literature. Our study suggests that encounters with distracting social stimuli affect not just the here and now, but the subsequent memories built from perceptual/learning interactions. More importantly, this effect is modulated by individual differences in sensitivity to social stimuli. Attentional biases therefore not only operate in a selective attention domain, but also have functional consequences on memory, which may in turn reinforce these biases. This idea has far-reaching implications in psychopathology, from anxiety to depression to autism. Attentional biases are often implicated in these disorders, yet until now the functional consequences of such biases on other aspects of cognition have not been investigated. This study provides new insights into the role of attentional biases in general, and the privileged status of social stimuli in particular, for memory.

Author contributions

B. Doherty, A. C. Nobre and G. Scerif developed the study concept. B. Doherty, Z. Patai, A. C. Nobre and G. Scerif contributed to study design. B. Doherty developed the stimuli, programmed the task, and collected the data. B. Doherty performed the data analysis under the supervision of G. Scerif, while M. Duta contributed significantly to the eye-tracking analyses. B. Doherty drafted the manuscript, and all other authors provided critical revisions. All authors approved the final version of the manuscript for submission.

Acknowledgements

We would like to thank Kathryn Atherton for her help in deciding the particulars of task structure and Michael Noonan for statistical advice. This research was supported by a Understanding Human Cognition James S. McDonnell Foundation Scholar Award to G. Scerif and by a Rhodes Scholarship to B. Doherty.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2016.10.015.

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