The influence of social working memory on allocation of social attention: Now you see it, now you don't.

Todd A. Vogel, B.Sc.

Department of Psychology

McGill University, Montreal

December 2016

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Master of Science.

Table of Contents

Abstract

The cognitive processes of attention and working memory routinely influence one other. Likewise, the two systems also appear to be specialized for processing of social information, like faces and eyes. A large body of existing research indicates that social cues, such as eye gaze, preferentially engage human attention. Likewise, recent studies in the working memory domain also suggest that the working memory system may be specialized for maintenance and manipulation of social information. Previous research investigating the links between attention and working memory however has mostly been conducted using manipulations of nonsocial information, such as geometric shapes, colors, and symbols. Extending this work, the main goal of this thesis was to explore the relationship between attention and working memory as it relates to their seeming specializations for manipulating social information. In two experiments, we investigated whether information held in social and canonical working memory influenced subsequent shifts of social attention. Both experiments employed a similar design, whereby participants were asked to hold information (i.e., a face) in working memory while performing a standard social attention orienting task. In Experiment 1, participants were asked to remember a single face, and in order to understand the content of the working memory were probed at the end of the trial about the face's gaze direction, identity, or both gaze direction and identity. The results indicated that when participants held eye gaze direction in working memory, subsequent shifts of social attention in the direction of remembered gaze were inhibited. This finding would suggest that social working memory and social attention interact. In Experiment 2, instead of allowing participants to choose the information to commit to working memory, we instructed them to maintain various parts of the face and a control nonsocial stimulus in working memory. Now, the data indicated that when participants held eye gaze information that was relevant to the

attention task, subsequent shifts of social attention in the direction of the remembered gaze were facilitated. Taken together, the results from these two studies show that social working memory may facilitate social attention when the contents of the working memory are relevant to the current task, but when this is not the case, social attention appears to be inhibited by the information held in social working memory.

Résumé

Les processus cognitives de l'attention et de la mémoire de travail s'entre-influencent régulièrement. De même, les deux systèmes semblent également se spécialiser dans le traitement de l'information sociale, comme le visage et les yeux. Alors qu'un grand nombre d'études indiquent que les indices sociaux, tels que le regard, engagent préférentiellement l'attention humaine, des récentes études dans le domaine de la mémoire de travail suggèrent également que ce système se spécialise dans l'entretien et la manipulation de l'information sociale. À jour, les enquêtes sur les liens entre l'attention et la mémoire de travail ont été effectués principalement à l'aide de manipulations d'informations non sociales telles que les formes géométriques, les couleurs et les symbols. Le principal objectif du travail présenté dans cette thèse est d'explorer l'interaction entre ces deux systèmes «sociaux» et leur rôle spécialisé proposé dans la manipulation de l'information sociale. Dans le cadre de deux expérimentations, nous avions examiné l'influence de l'information contenue dans la mémoire de travail social et canonique sur l'attention sociale. Les deux expérimentations ont utilisé une schème similaire, dans laquelle les participants sont demandés de détenir l'information (par exemple, un visage) en mémoire de travail tout en effectuant une tâche d'orientation d'attention sociale. Dans la première expérimentation, les participants sont invités à retenir un visage et sont par la suite questionnés sur la direction du regard, l'identité du visage, ou les deux dans le but de comprendre le contenu de leur mémoire de travail. Les résultats indiquent que lorsque les participants retiennent la direction du regard dans la mémoire de travail, les changements subséquents de l'attention sociale dans le sens du regard souvenu sont inhibés. Ce résultat suggère la présence d'une intéraction entre la mémoire de travail sociale et l'attention sociale. Dans la deuxième expérimentation, au lieu de permettre aux participants de choisir les informations à engager dans

la mémoire de travail, ces derniers sont demandés de maintenir différentes parties du visage et un stimulus contrôle nonsocial dans la mémoire de travail. À présent, les données indiquent que lorsque les participants retiennent de l'information du regard pertinent à la tâche de l'attention, les changements de l'attention sociale dans le sens du regard souvenu sont facilités. En somme, les résultats de ces deux expérimentations démontrent que la mémoire de travail sociale peut faciliter l'attention sociale lorsque le contenu de la mémoire de travail est pertinent à la tâche en cours. Dans le cas contraire, lorsque le contenu de la mémoire de travail n'est pas pertinent à la tâche, l'attention sociale semble être inhibée par l'information détenue dans la mémoire de travail social.

Acknowledgements

Firstly, I would first like to thank my supervisor Dr. Jelena Ristic for her feedback, support, and guidance throughout my Master's degree. Your assistance and mentorship have built a strong foundation for my career as a researcher and strengthened my skills and abilities as a scientist. This thesis would not have been possible without your generous patience, feedback, and support.

Thank you also to Drs. Thad Meeks, Betsy Meinz, and Jon Pettibone for their seminal work and feedback on earlier versions of the present study as well as David Grybinas, Josh Prince, and Dr. Paul Rose for their continued support, guidance, and friendship throughout the years. Without all of you, I would not be where I am today.

A big thank you to Dr. Dana Hayward and Effie Pereira for their wisdom, encouragement, and counsel throughout my graduate studies. Thank you for your thoughts and feedback on my thesis work throughout. Additionally, thank you Dr. Chris Blair, Dr. Francesca Capozzi, and Can Fenerci for making the lab a fun and lighthearted environment. I could not have asked for a better group of people to work alongside.

Thank you to the external reviewer for taking the time to review and evaluate my thesis. I appreciate you taking the time to comment and share your experience with me.

Finally, I would like to thank my friends and family who have supported me throughout the years and during my time as a graduate student. Notably, thank you to Matteo Bernabo, Kayleigh Clegg, Stephanie Gumuchian, and Lauri Gurguryan for always being there by my side. I cannot thank you enough.

Introduction

The processes of attention and working memory play a large role in the control of behavior. Attention is often conceptualized as a filter that allows processing of relevant sensory information. Working memory, on the other hand, involves online maintenance and manipulation of that information. A large number of studies suggest that although the processes of attention and working memory serve different functions, the two mechanisms are often intertwined in daily behavior, influencing one another at both the behavioral and neural levels (e.g., Anderson, Mannan, Rees, Sumner, & Kennard, 2010; see also Gazzaley & Nobre, 2012). Highlighting their joint involvement in behavior for example, attention has been found to be facilitated when attended stimuli are both similar and dissimilar to the current contents of working memory (e.g., Downing, 2000; Olivers, Peters, Houtkamp, & Roelfsema, 2011). Downing (2000) showed that attention was facilitated toward the targets that matched the item held in working memory while Soto and colleagues reported facilitated attention when working memory content matched the task-irrelevant object signifying target location (Soto, Heinke, Humphreys, & Blanco, 2005). However, attention and working memory may interfere as well. For example, several studies have shown slowed down visual search performance when task irrelevant spatial locations are concurrently held in working memory (e.g., Oh & Kim, 2004; Woodman & Luck, 2004). In the present thesis, we investigated whether similar links between working memory and attention existed when social instead of simple geometric stimuli were manipulated.

Meyer and Lieberman (2012) recently proposed that in addition to the well-known canonical working memory system (Linden, 2007; Rottschy et al., 2012; Wager & Smith, 2003), humans also possess a working memory system that is specialized for manipulating social information. Like the canonical working memory system, the social working memory system also allows for the maintenance and manipulation of information. Unlike the canonical working memory system, however, the social working memory system is uniquely specialized for manipulating social information, such as others people's traits and/or their mental states (Meyer, Taylor, & Lieberman, 2015). Thus, according to this account, social working memory would be taxed in situations when we think about relationships between our friends, our fit within a group of people, or when we mentally compare others on some personality characteristic. Consistent with this notion, in the first demonstration of the social working memory system, Meyer, Spunt, Berkman, Taylor, and Lieberman (2012) asked participants to rank a group of close friends on 96 personality traits, such as, funny, witty, and caring. Two weeks later, participants returned to the laboratory where they performed a working memory task while their brain's metabolic activity was recorded using fMRI. In the working memory task, participants were presented with 2, 3, or 4 friends' names and were asked to mentally rank them on one of the 96 personality traits. After 6 seconds, a probe appeared asking participants to answer a true/false question regarding the mental rank. These responses were compared against participants' prior ratings to arrive at an accuracy score. Behaviorally, the data indicated decreased accuracy and increased response times with increases in social load (i.e., 2, 3, or 4 names; see also Meyer et al., 2015). Neurally, distinct activity in regions associated with social processing, including the dorsomedial prefrontal cortex (dmPFC), medial prefrontal cortex (mPFC), precuneus/posterior cingulate cortex (PC/PCC), and tempoparietal junction (TPJ) were observed in concert with the activity in the brain regions commonly associated with the canonical working memory system, i.e., the dorsolateral prefrontal cortex (dlPFC), superior parietal lobule (SPL), and the supplementary motor area (SMA). The authors interpreted these results as indicating that humans possess a specialized, domain-specific working memory network that is responsible for holding and manipulating social information (see Meyer & Lieberman, 2012).

In a similar vein, research into attentional processes also suggests that humans preferentially and spontaneously attend to social cues, such as faces or gaze direction. In one of the first studies that demonstrated the so-called social attention, Friesen and Kingstone (1998) employed a modified version of a standard cueing task (Posner, 1980). The authors presented participants with an image of a schematic face looking either left or right, and asked them to detect targets that appeared on either the left or right side of the face. The results indicated that participants were always faster to respond to targets that appeared at the gazed-at relative to not gazed-at locations, despite the fact that gaze direction was fully uninformative about the location of the target, and as such task-irrelevant. Furthermore, they found that social attention facilitation emerged quickly by 100ms after the presentation of the cue and persisted for about 700ms. Friesen and Kingstone (1998) interpreted these data as indicating that attention is spontaneously and preferentially biased by social cues.

In addition to robustly replicating this basic finding numerous times (Driver et al., 1999; Friesen & Kingstone, 2003; Greene, Mooshagian, Kaplan, Zaidel, & Iacoboni, 2009), subsequent studies have also indicated that social information appears to engage attention uniquely (Bayliss, Bartlett, Naughtin, & Kritikos, 2011; Downing, Dodds, & Bray, 2004; Friesen, Ristic, & Kingstone, 2004; Langton, Watt, & Bruce, 2000; Ristic, Wright, & Kingstone, 2007). This is because the behavioral performance profile associated with social attention does not conform to performance profiles associated with either of the two well-known general modes of attentional orienting: exogenous, or reflexive (Posner & Cohen, 1984), and endogenous (Jonides, 1981), or voluntary, attention.

Exogenous attention involves the automatic, reflexive shift of attention elicited by a simple sensory stimulus, such as a flash of light. Such cues summon attention quickly by 100ms but do not ‘hold’ attention for a long period of time (Posner, 1980). After about 300ms, attention becomes inhibited for previously attended locations, revealing an effect called the Inhibition of Return (IOR; Posner & Cohen, 1984). In contrast, endogenous attention involves voluntarily shifting attention from location to location. Usually, in these tasks participants are presented with a cue (e.g., an arrow) that provides some reliable information about the target (e.g., its location). Since endogenous attention reflects an effortful process, attentional effects do not emerge until about 300ms after the cue but continue to develop until about 1000ms without IOR (Jonides, 1981). In contrast to exogenous and endogenous attention, the performance profile associated with social attention shows quick attentional effects emerging by 100ms with prolonged performance facilitation for gazed-at targets, dissipating between 700–1000ms. No inhibition is typically observed.

Recently, McDonnell and Dodd (2013) investigated whether such social attention shifts required online perception of the gaze cue or if the same behavior could also be guided by the working memory representation of gaze direction. To test this idea, the authors asked participants to maintain information about a face in working memory while performing a typical social cueing task (e.g., Friesen & Kingstone, 1998). In McDonnell and Dodd’s procedure, participants were shown an image of a face with the eyes looking to the left or right for 500–1250ms and were asked to remember it for a subsequent memory test. Following this encoding time, the face was extinguished, and a central fixation along with a response target (i.e., a circle) appeared either on the left or right side of fixation. Participants’ Response Times (RTs) to detect the target were measured. The location of the target was either congruent or incongruent with the face's gaze direction. The direction of gaze shown by the to-be-remembered face was not spatially informative about the location of an upcoming target, and the target occurred equally often on the left and right side of fixation. A memory test followed each target response. A display showing a side-by-side presentation of a new face and the old face prompted participants to identify the original face. Each face pair differed only in face identity and always displayed the same gaze direction as the old face.

The results of this experiment were surprising. Participants were found to be consistently faster to detect not gazed-at compared to gazed-at targets, demonstrating inhibition rather than the expected facilitation for gazed-at targets. This finding contrasts sharply with the results from past investigations in which the face cue is perceived online, which robustly show response facilitation and no inhibition for gazed-at targets (Driver et al., 1999; Friesen & Kingstone, 1998; Friesen et al., 2004; Langton & Bruce, 1999). It is important to note here that it is unlikely that McDonnell and Dodd's procedure simply failed to replicate the basic social attention effect. The removal of the memory component in their Experiment 3 resulted in somewhat typical social orienting with facilitation for gazed-at targets appearing within 500ms after the presentation of the cue (McDonnell & Dodd, 2013, Experiment 3). McDonnell and Dodd interpreted their results as indicating that holding social and/or biological stimuli, such as a gaze direction, in working memory interfered with subsequent social orienting in the direction of that cue.

While overall these data suggest potential interactions between the social working memory and social attention systems, at present they should be interpreted with caution for two key reasons. First, the cueing task parameters that were used to elicit social orienting departed significantly from those that are typically used to elicit social attention. That is, long encoding times for the faces (500–1250ms) coupled with long delays between the cue and the target (500–

1250ms) created cue–target onset intervals that ranged between 1000 and 2500ms. This time course is inconsistent with a typical time course of social orienting, in which facilitory attentional effects appear within 100ms after the cue presentation and persists for about 700–1000ms (Downing et al., 2004; Driver et al., 1999; Friesen & Kingstone, 1998; Friesen et al., 2004; Langton & Bruce, 1999). Reinforcing this concern, McDonnell and Dodd's Experiment 3, in which no working memory component was present, produced results that were consistent with this time course of social orienting. Thus, given the extended trial lengths, the task sequence in McDonnell and Dodd's study may have not allowed for social orienting to be elicited during the working memory manipulation.

Second, it is also unclear if the working memory task required participants to remember gaze direction information. This is because the memory test at the end of each trial required participants to make a discrimination response based on changes in face identity rather than based on changes in gaze direction. That is, the old and the new probe face images differed in face identity but displayed the same gaze direction, which always matched the original image. As such, participants' correct responses necessitated choosing an image based on the face identity of the old face rather than gaze direction. Thus, given these task requirements, participants may have held face identity rather than gaze information in working memory during the trials.

To address these methodological concerns, in the present thesis we re-examined the relationship between working memory and social attention. We did so when the cueing task parameters conformed to the established procedures (Experiment 1) and when the content of the working memory was controlled and directly measured (Experiments 1 and 2). The data from both studies converged onto the result showing that maintaining response-relevant gaze direction, but not face identity, in working memory facilitated rather than inhibited social orienting.

Experiment 1

In Experiment 1, we adjusted the cueing task parameters to capture the typical time course of social orienting and manipulated the working memory probe to better understand the type of information held in working memory on each trial.

First, to capture the typical time course of social orienting (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Friesen et al., 2004) our task included short, intermediate, and long cue–target time delays of 150, 500, 1500, and 2500ms. This change, however, necessitated decreasing the face encoding time from 1250ms to 150ms. Although control experiments carried out by McDonnell and Dodd (2013) suggested that participants performed at chance when encoding time was shorter than 750ms, we reasoned that longer encoding time in their study was necessary for remembering face identity but possibly not for remembering gaze information.

Second, the cueing task in McDonnell and Dodd's original study contained a response target on every trial. In detection tasks, this practice may lead to response bias, whereby participants respond to every trial but not to the target specifically. To guard against this, in our experiment we included about 6% of no-target trials in the cueing task sequence (Doneva & De Fockert, 2014; Helton, 2009; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). This was accomplished by making the cueing task a go/no-go procedure in which the response target was always accompanied by a distractor presented at an opposing location in 93.75% of trials. In the remaining 6.25% of trials, two distractors were presented, and participants were required to withhold their responses. Thus, rather than simply responding on each trial, as in McDonnell and

Dodd's study, in our procedure participants discriminated between the target and the distractor and responded to target stimuli only.

Third, to gain an understanding of the content of participants' working memory on each trial, we modified the memory probe part. First, instead of presenting participants with two face images, our probe screen presented a single face image. Critically, this face could be identical to the original face or differ from it in gaze direction, face identity, or both gaze direction and face identity. As such, and as illustrated in Figure 1, the probe images could present Same gaze and Same identity as the original face (Figure 1A), Same gaze but Different identity from the original face (Figure 1B), Different gaze and Same identity as the original face (Figure 1C), and Different gaze and Different identity from the original face (Figure 1D).

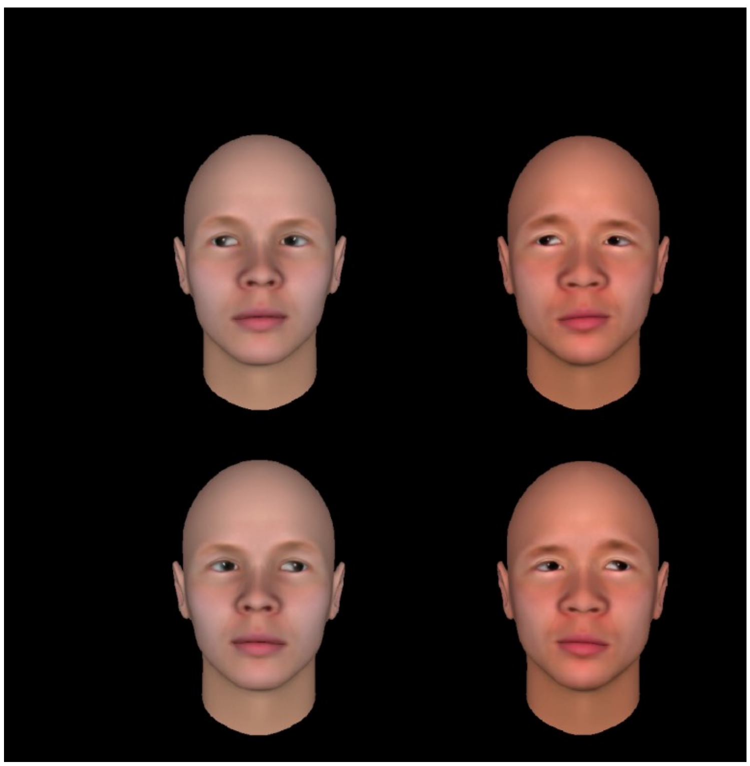

Figure 1. Memory probe conditions. A 2 x 2 matrix shows the possible combinations between the working memory content (i.e., Face Identity/ Eye gaze information) and possible responses.

Finally, and in addition to providing a better insight into the content of the working memory for each trial, this manipulation also allowed us to explore the effects of working memory load. Drawing from the work on canonical working memory in which increases in working memory load are induced by increasing the number of to-be-remembered items (Awh, Barton, & Vogel, 2007; Braver et al., 1997; Jensen & Tesche, 2002; Luck & Vogel, 1997) and/or their complexity (Alvarez & Cavanagh, 2004; Druzgal & D'Esposito, 2001; Eng, Chen, & Jiang, 2005; Morgan, Klein, Boehm, Shapiro, & Linden, 2008), here we reasoned that working memory load could be conceived as low on trials in which gaze direction alone was remembered, intermediate when face identity was remembered, and high when both gaze information and face identity were remembered. This is because face identity information is more complex than eye gaze information and in that vein remembering gaze direction could be conceived as low, face identity as intermediate, and the combination of the two as high working memory load.

Methods

Participants

Fifteen naïve undergraduate students participated in the experiment (14 females; mean age 19.8 years, SD 1.5 years) after providing written informed consent. They were compensated with course credits. All participants reported normal or corrected-to-normal vision.

Apparatus & Stimuli

Figure 2 illustrates the stimuli and the example task presentation sequence, both of which closely mirrored McDonnell and Dodd's (2013) design. The experimental sequence was controlled by SR Research Experiment Builder software and was presented on a 16-inch CRT monitor against a black background. Participants viewed the task sequence from an approximate distance of 57 cm. Face images (7.1° x 11.1°) were shown in color and positioned at central fixation. The face stimuli were identical to those used in McDonnell and Dodd's study. A total of twenty-four different face identities were used. Twelve pairs had their identity adjusted to 70% similarity using the FaceGen modeler software. Each face displayed both left and right deviated gaze.

The stimuli for the cueing task included a 1° white fixation cross as well as white circle and square targets, each measuring 2° in diameter. Each target/distractor appeared with 12° eccentricity from central fixation along the horizontal axis.

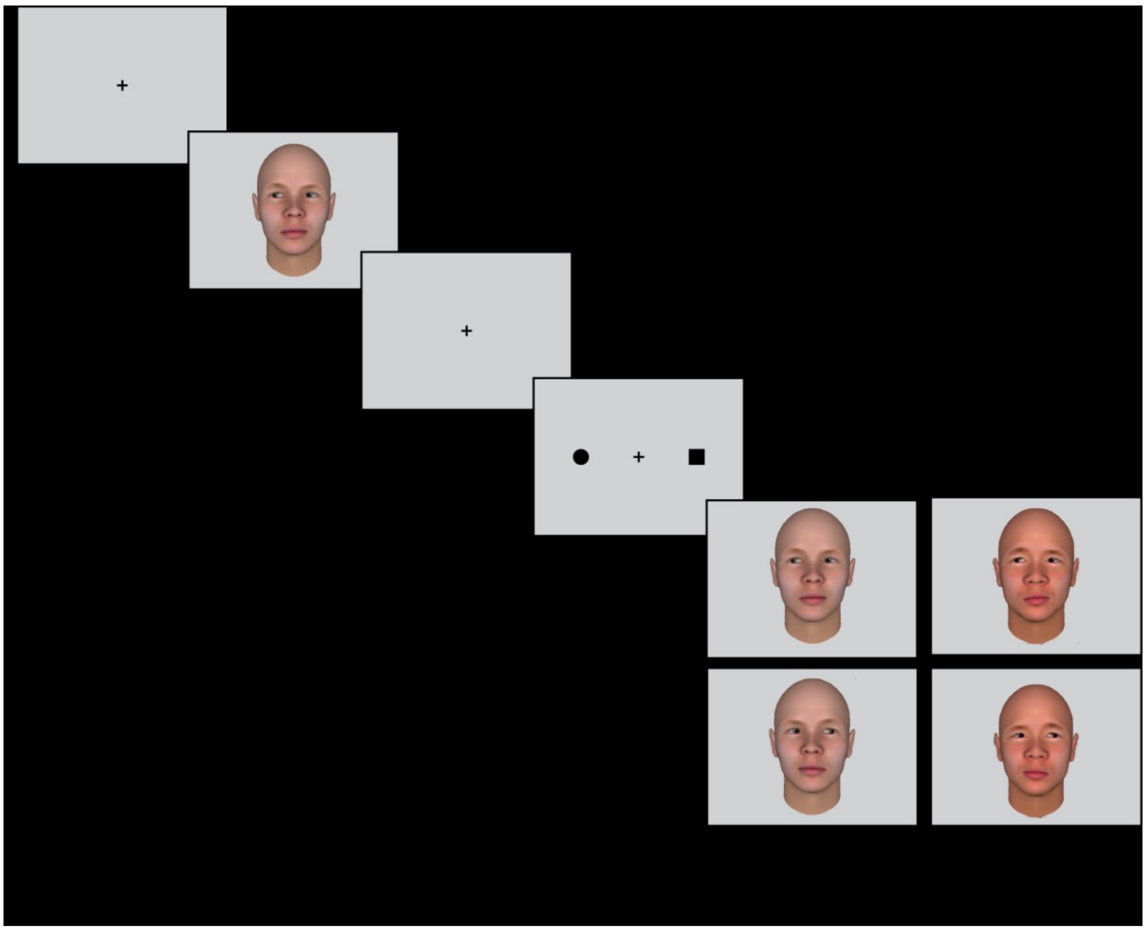

Figure 2. Experiment 1 stimuli and example task sequence. After the initial fixation screen, in duration of 1000ms, participants were presented with an image of a to-be-remembered face for 150ms. After 0, 350, 1350, or 2350ms a target display was presented. After participants' response, one of the four possible memory probes was presented, and participants were asked to indicate whether this image was the 'same' or 'different' as the original face. Note: Stimuli are not drawn to scale and were presented against a black background in the experiment.

Design

The experiment was a within subjects design with Memory condition (Same gaze/Same identity; Same gaze/Different identity; Different gaze/Same identity; Different gaze/Different identity), Cue validity (gazed-at; not gazed-at), and Cue–target interval (150ms; 500ms; 1500ms; 2500ms) included as variables. All variables were intermixed throughout the experiment and presented in pseudorandom order.

Memory condition reflected the match between the to-be-remembered face shown at the start of the trial and participants response for the memory probe face shown at the end of the trial. There were four possible Memory conditions, as illustrated in Figure 1: *(i) Same gaze/Same identity*, which displayed the same gaze direction and face identity as the original cue face; *(ii) Same gaze/Different identity*, which displayed the same gaze direction but different face identity from the original face; *(iii) Different gaze/Same identity*, which displayed different gaze direction but the same face identity as the original face; and *(iv) Different Gaze/Different identity*, which displayed different gaze direction and different face identity from the original face.

To assess working memory content, participants made ‘same/different’ judgments for each probe image. A ‘same’ response in condition *(i)* and a ‘different’ response in condition *(iv)* indicated that participants held both gaze and identity information in working memory. Conditions *(ii)* and *(iii)* measured working memory for gaze and face identity. A ‘same’ response in condition *(ii)*, indicated that participants held gaze direction information whereas a ‘same’ response in condition *(iii)* indicated that participants held face identity information in working memory. Each face image was equally likely to be used as the to-be-remembered face and a probe image. Each to-be-remembered image was equally likely to be probed by any of the four possible probe images, resulting in 96 distinct to-be-remembered – memory probe combinations.

Cue validity indicated the spatial congruency between the gaze direction displayed by the face held in working memory and the spatial location of the target during the cueing task. Gazed-at or valid trials were those in which the target appeared at the location congruent with the gaze direction of the face held in working memory. Not gazed-at or invalid trials were those in which the target appeared at the opposite location of the gaze direction of the face held in working memory. Each face displayed left and right gaze equally often. The target was equally likely to occur at either the left or right spatial location. Thus, the eye gaze was fully uninformative with respect to target location.

One half of the participants were asked to respond to the circle targets while the other half were asked to respond to the square targets. For each group, approximately 6% of trials contained no target (i.e., two squares or two circles). The cue–target onset intervals varied equally and randomly between 150, 500, 1500, and 2500ms, and were manipulated to understand the time course of social orienting.

Procedure

Each trial began with a presentation of a fixation screen for 1000ms. Then, a to-be-remembered face was shown for 150ms, after which the display reverted to a fixation screen for a variable time of 0, 350, 1350, or 2350ms (i.e., corresponding to cue–target onset intervals of 150, 500, 1500, and 2500ms). After this time, the cueing target display was presented until participants responded or until 1500ms had elapsed. The memory probe screen was shown after the response and remained present on the screen for a maximum of 7 seconds.

Participants were instructed to remember the face shown at the start of the trial for a later memory test. They were told that their task was to detect a peripheral target as fast and as accurately as possible by pressing the spacebar and to withhold responses when the target was not present. Participants were instructed that gaze information displayed by the face was irrelevant for the target detection task. They were also instructed to indicate whether the probe image was the ‘same’ or ‘different’ from the original image during the memory test by pressing either the ‘c’ or ‘,’ keys on the keyboard. The response-key assignment was counterbalanced between participants. A total of 544 test trials divided equally across eight blocks were run. Ten practice trials were run at the start. RT was measured from target onset.

Results

Working memory accuracy and RTs for the cueing task were analyzed. Working memory accuracy indexed the efficacy of the memory manipulation. RT results indexed shifts of attention toward the external target as a function of the working memory content.

Working Memory Performance

Overall accuracy in the working memory task was 70%. To examine whether this performance varied by memory condition, we calculated accuracy scores for each Memory condition separately. A ‘same’ response for matching images was coded as a correct response, except for the Different gaze/Different identity condition in which a ‘different’ response indicated a correct response. Interparticipant mean accuracy performance as a function of Memory condition was examined using a one-way repeated measures ANOVA. Figure 3B shows these means. The analysis returned a main effect of Memory condition, $F(3,42) = 20.69$, $p < .001$ with the highest overall accuracy in the Same gaze/Same identity condition (condition *(i)*, 92.4%) followed by the Different gaze/Same identity condition (condition *(iii)*, 77.7%). Performance for both of these memory trial types was significantly above chance, i.e., 50%, $t(14) = 24.78$, $p < .001$ and $t(14) = 5.54$, $p < .001$, respectively. In contrast, memory for the Same gaze/Different identity condition (condition *(ii)*, 54.3%) as well as for the Different gaze/Different identity condition (condition *(iv)*, 57%) trailed reliably behind and did not significantly differ from chance, $t(14) = 1.29$, $p = .22$ and $t(14) = 1.88$, $p = .08$, respectively. Follow up two-tailed paired t-tests further indicated that memory accuracy in the Same gaze/Same identity condition differed significantly from memory accuracy in the Same gaze/Different identity condition (Conditions *(i)* vs. *(ii)*, $t(14) = 11.75$, $p < .001$), Different gaze/Same identity condition (Conditions *(i)* vs. *(iii)*, $t(14) = 3.83$, $p = .002$), and Different gaze/Different identity condition (Conditions *(i)* vs. *(iv)*, $t(14) = 7.05$, $p < .001$).

These results suggest two main findings. First, they indicate that encoding time of 150ms was sufficient to retain basic face identity in working memory. This is because high working memory accuracy was observed for both types of trials in which face identity did not change (i.e., Same gaze/Same identity and Different gaze/Same identity). Second, they also indicate that working memory was better for trials in which participants remembered the overall holistic aspects of the face (i.e., Same gaze/Same identity; Different gaze/Same identity) relative to trials in which participants remembered isolated face parts (i.e., Same gaze/Different identity). This suggests that when faces are remembered, working memory load is lower when participants remember a face holistically rather than when they remember its parts, highlighting possible links between the specialized face processing mechanisms in the human brain and social working memory system (Druzgal & D'Esposito, 2001; Lepsien & Nobre, 2007; Morgan et al., 2008; Richler, Cheung, & Gauthier, 2011; Tanaka & Farah, 1993). We return to this point in the Discussion and the General Discussion.

Social Attention Performance

RT data collected during the cueing task were inspected for errors, which were defined as false alarms (i.e., responding on a no-target trial; 6.5%), anticipations (RTs < 100ms; 0.03%), and timed out responses (RTs > 1000ms; 6%). All errors were removed from analyses.

Interparticipant mean correct RTs were examined for each Memory condition separately (Same gaze/Same identity; Same gaze/Different identity; Different gaze/Same identity; Different gaze/Different identity) using repeated measures ANOVAs run as a function of Cue validity (gazed-at; not gazed-at) and Cue–target interval (150ms; 500ms; 1500ms; 2500ms). Figure 3A illustrates these RTs as a function of Cue validity and Cue–target interval.

All ANOVAs returned reliable main effects of Cue–target interval (all Fs > 51, ps < .001), indicating robust foreperiod effects (Bertelson, 1967), which reflect overall facilitated responses with lengthening of cue–target time. A main effect of Cue validity was not reliable in any analysis (all Fs < 2, ps > .22); however a sole significant interaction between Cue validity and Cue–target interval emerged in the Same gaze/Different identity case (condition (*ii*), $F(3,42) = 2.94$, $p = .04$). All other effects Fs < 3, ps > .10). This suggests that when the memory probe displayed same gaze but different identity from the original face, participants responded slower to gazed-at relative to not gazed-at targets in the cueing task. This inhibitory effect was reliably observed at the shortest cue–target interval of 150ms, $t(14) = 2.34$, $p = .03$, but also approached significance at a longer delay of 500ms, $t(14) = 1.85$, $p = .08$. There were no reliable RT differences between gazed-at and not-gazed at targets for either 1500ms or 2500ms cue–target interval, $t(14) = 0.63$, $p = .54$ and $t(14) = 1.03$, $p = .32$, respectively.

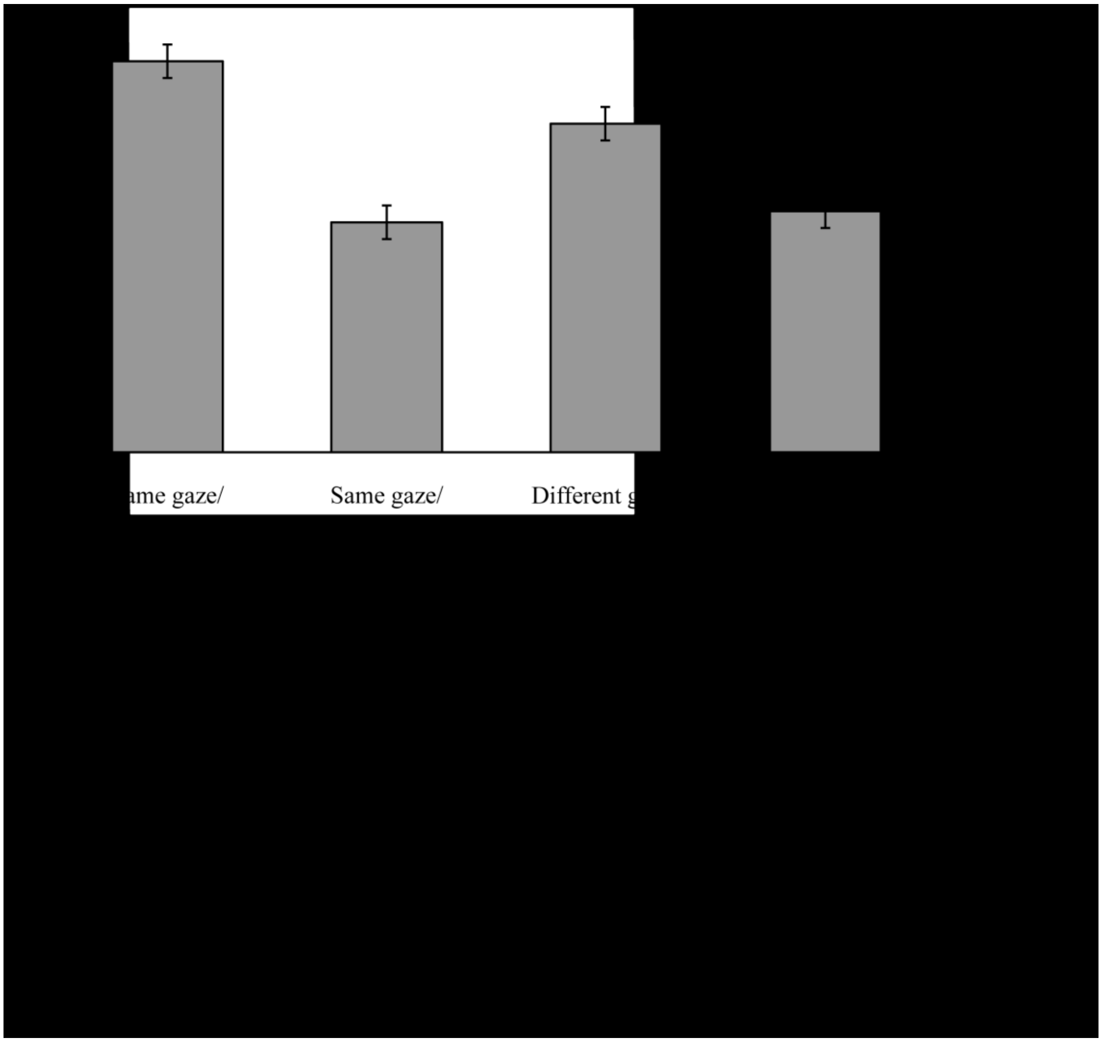

Figure 3. Experiment 1 results. *Figure 3A*. Working memory performance accuracy for each Memory condition. Error bars indicate standard error between the difference of the means. *Figure 3B*. Mean interparticipant RTs as a function of Memory Condition, Cue Validity, and Cue–target interval. Error bars indicate standard error between the difference of the means.

Discussion

The data from Experiment 1 both replicate and extend the original McDonnell and Dodd (2013) report. Like McDonnell and Dodd, our data revealed that under similar conditions (i.e., Same gaze/Different identity), social orienting toward externally presented targets was inhibited. In our study however, this effect emerged at the shortest cue target interval of 150ms and persisted until 500ms, despite a modified task sequence and substantially decreased memory encoding time.

Our results also revealed two additional insights about the interplay between social working memory and social attention. First, they suggest that inhibitory effects on social attention occur when representations of face identity rather than gaze direction differ (i.e., Same gaze/Different identity vs. Same gaze/Same Identity). However, as memory performance in this critical *Same gaze/Different identity* condition was at chance, it is at present difficult to discern if the inhibitory effects originated from holding gaze direction in working memory. Indeed, recognition of face parts has been shown to increase when faces are processed holistically relative to when face components are presented in isolation (Tanaka & Farah, 1993; see also Rossion et al., 2000). Specifically, for the *Same gaze/Different identity* condition, the 'same' response may indicate that in addition to discerning no change in gaze direction, participants may have been able make that discrimination based on the change in face identity. Taking this into account, our data showing inhibition of social orienting in the *Same gaze/Different identity* condition may reflect interactions between social orienting and social working memory for representations of face identity in addition to representations of gaze direction. Experiment 2 was designed to further pursue this question.

Second, looking at overall working memory performance, our data also suggest that participants were better able to hold overall face information in working memory relative to gaze direction information alone. This stands in contrast to the results from the canonical working memory studies indicating higher working memory load with increased number of items and/or their complexity (Alvarez & Cavanagh, 2004; Awh et al., 2007; Braver et al., 1997; Druzgal & D'Esposito, 2001; Eng et al., 2005; Jensen & Tesche, 2002; Luck & Vogel, 1997; Morgan et al., 2008). This result however dovetails with a wealth of data from the face processing literature indicating that faces are typically encoded in a holistic, rather than piecemeal fashion (Freire, Lee, & Symons, 2000; Hoffman & Haxby, 2000; Leder & Bruce, 2000; Tanaka & Farah, 1993; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998; Tanaka & Sengco, 1997).

Experiment 2

Experiment 1 thus suggested that when participants remembered gaze direction along with a change in face identity, social orienting was inhibited rather than facilitated. However, due to the nature of this manipulation, this result reflects post-hoc inference of the working memory content rather than its direct manipulation. To address this, in Experiment 2, we manipulated working memory content directly, by instructing participants to remember particular information conveyed by the display on each trial.

Furthermore, to gain additional insights into whether the interference between working memory and social orienting occurs only when social content is being remembered, in Experiment 2, we also manipulated nonsocial working memory using background color configurations. In Experiment 4, McDonnell and Dodd (2013) used a similar manipulation by instructing participants to remember a nonsocial colored arrow while performing a cueing task. In contrast to social working memory load, their Experiment 4 indicated facilitated performance for targets congruent with a memory representation of an arrow cue. Likewise, previous studies that manipulated canonical working memory load also indicate that social orienting is not affected by nonsocial canonical working memory load (Hayward & Ristic, 2013; Law, Langton, & Logie, 2010). Thus, if the interference between social working memory and social attention is specific to the condition in which participants hold social information in working memory, no interference effects should be observed when participants are asked to hold a nonsocial item in working memory.

Methods

Participants

Thirty new participants, with normal or corrected-to-normal vision, completed the experiment (23 females; mean age 22.7 years, SD 3.4 years). They provided written informed consent and were compensated with course credits.

Apparatus, Stimuli, Design, & Procedure

All aspects of the study were identical to Experiment 1, except that: (1) To manipulate nonsocial working memory load, a 4-rectangle color matrix (each rectangle measuring 6.25° x 8°, with the full array subtending 13° x 16°) was included behind each face (see Figure 4). Each rectangle displayed orange, cyan, pink, and violet color. On half the trials the spatial layout of the background colors remained the same throughout the trial. On the other half of trials, the spatial layout of the background colors changed according to a random sequence; (2) An instruction screen was added at the beginning of each trial, asking participants to remember one particular aspect of the display, namely, Eye gaze, face Identity, the full Face, or Background; (3) After the memory probe display at the end of the trial, participants were presented with four questions, in which they were asked to make 'same/different' judgments about each memory component. Specifically, they were asked to judge if each Eye gaze, Identity, full Face, or Background was the same or different from the original image; (4) The cueing task did not contain an irrelevant distractor. However, circle and square stimuli continued to serve as targets, with the target assignment counterbalanced between participants; (5) The longest cue–target interval of 2500ms was omitted, given that the data in Experiment 1 did not diverge at this long cue–target time.

Figure 4 illustrates the stimuli and an example trial sequence for Experiment 2. Participants were first presented with an instruction screen for 800ms. Fixation was then shown for 250ms. Then, a to-be-remembered face was shown for 150ms, after which the display reverted to a fixation screen for a variable time of 0, 350, or 1350ms (i.e., corresponding to cue–target onset intervals of 150, 500, and 1500ms). After this time, the target display was presented until participants responded or 1200ms had elapsed. Following response, a memory probe screen showing one of the face images against the original or a changed background color layout was shown for 1250ms. Finally, memory probe questions appeared one after another asking participants to judge whether Eye gaze, Identity, Face, or Background were the 'same' or 'different' from the original face using the 'c' and ',' keyboard keys (counterbalanced between participants). Each question remained on the screen until response or until 1750ms had elapsed. A total of 624 test trials divided equally across eight blocks were run. As in Experiment 1, ten practice trials were run at the start. RT was measured from target onset.

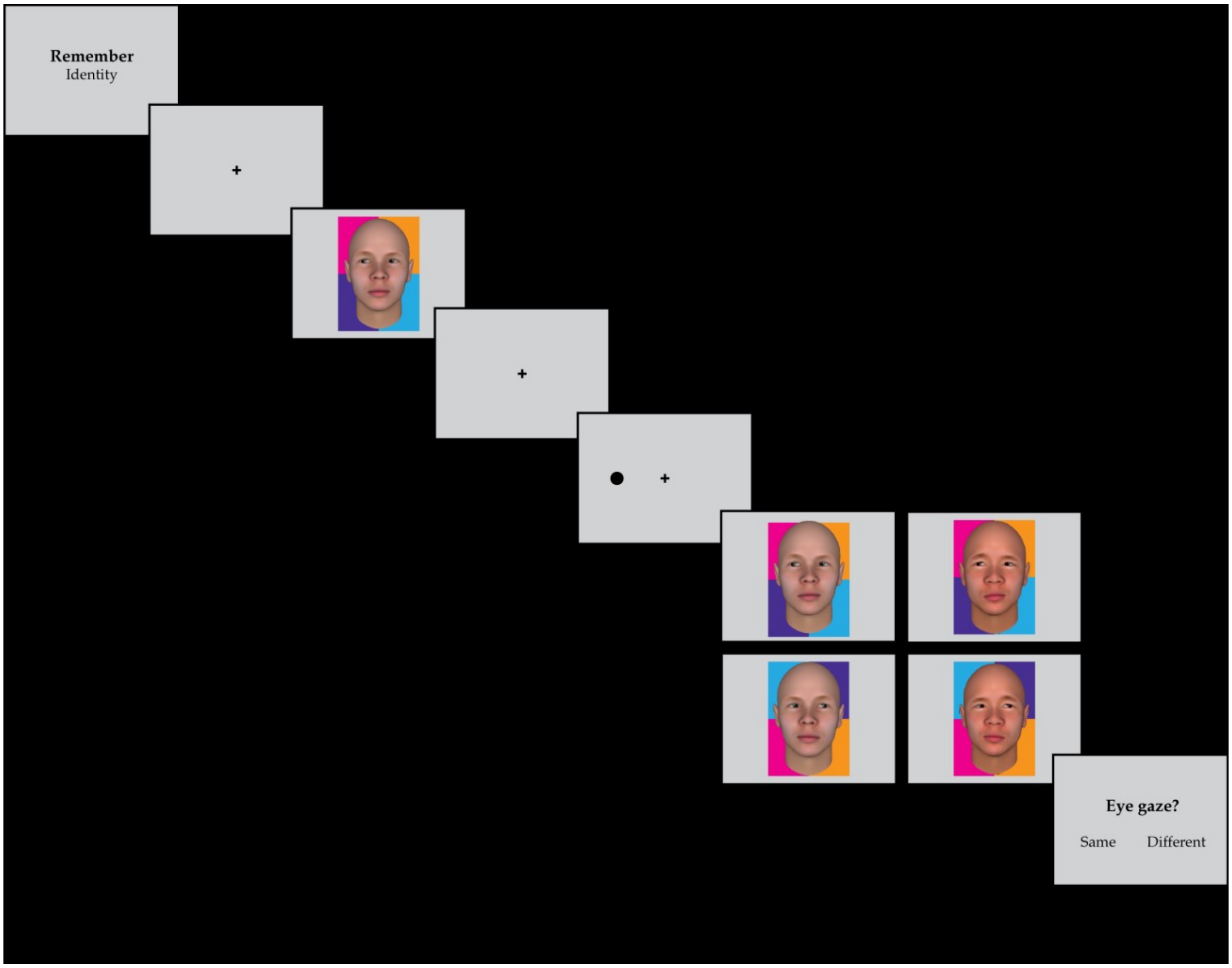

Figure 4. Experiment 2 Stimuli and Procedure. At first, participants received a memory instruction in a duration of 800ms. Then, a fixation screen was presented for 250ms, which was followed by the presentation of to-be-remembered item for 150ms. After 0, 350, or 1350ms, a target display was presented for 1200ms or until response. Memory probe screen included the presentation of one of the four possible memory face probes, which were shown either against the old or new background for 1250ms. Finally, participants were asked to make 'same/different' judgments about each face component. Note: As in Experiment 1, the stimuli were presented against a black background.

The design mirrored Experiment 1, with an addition of the initial Instruction (Eye gaze, Identity, full Face, Background) variable. As before, all variables were intermixed and presented equally often using a pseudorandom sequence. Each face image was equally likely used as the to-be-remembered face and as a probe image. Each to-be-remembered image was equally likely to be probed by any of the four possible probe types. Each face displayed left and right gaze direction equally often. The response target occurred equally often on either the left or right peripheral location. There were 24 possible background color arrays, which were manipulated independently from the face variables.

Results

As in Experiment 1, working memory accuracy as well as participants RTs for the cueing task were examined.

Working Memory Performance

Overall working memory accuracy was 79%. As before, we examined memory performance for each memory condition/instruction separately. Correct trials were dependent on the instruction message and participants' response to the respective question. For example, if the instruction was to hold Background in working memory, memory performance reflected the responses for the Background question only. A 'same' response for when the background color matrix did not change and a 'different' response when the background color matrix did change indexed correct responses. Similarly, when the instruction was to hold Eye gaze, Identity, or full Face, correct performance was indexed by a 'same' response for the corresponding probe question during trials with its corresponding memory condition (conditions *(ii)*, *(iii)*, and *(i)*, respectively).

Accuracy was analyzed using a repeated-measures ANOVA as a function of Memory condition (Eye gaze; Face identity; full Face; Background). Figure 5A shows these means. The analysis returned a main effect of Memory condition, $F(3,87) = 6.19$, $p < .001$, with the highest working memory accuracy for the full Face ($M = 82.4\%$) and face Identity ($M = 81.7\%$) followed by Eye gaze ($M = 79.2\%$) and Background ($M = 72.5\%$). Memory performance for all memory conditions was significantly above chance (all ts > 10, ps < .001). Pairwise two-tailed t-tests confirmed that working memory accuracy for Background was reliably lower than working memory accuracy for Eye gaze ($t(29) = 2.57$, $p = .02$), Face identity ($t(29) = 4.53$, $p < .001$), and full Face ($t(29) = 4.19$, $p < .001$). Performance for Eye gaze, face Identity and full Face was equivalent (ts < 2, ps $> .29$). Thus, when instructed to do so, participants were able to accurately maintain both social and nonsocial information in working memory. However, it appears that they were better able to hold social (Eye gaze, Identity, and full Face) relative to nonsocial information (Background).

Social Attention Performance

RTs were inspected for errors. False alarms (4.03%), response anticipations (0.34%), and response time-outs (5.92%) were excluded from analyses.

Interparticipant mean correct RTs were examined for each Memory condition separately (Eye gaze, Face Identity, full Face, and Background) using repeated measures ANOVAs run as a function of Cue validity (gazed-at; not gazed-at) and Cue–target interval (150ms; 500ms; 1500ms). All ANOVAs returned reliable main effects of cue–target interval (all Fs > 19, all ps $< .001$). A main effect of cue validity approached significance in the Eye gaze instruction condition, $F(1,58) = 3.41$, $p = .08$, now suggesting facilitation for gazed-at relative to not gazed-at targets, as illustrated in Figure 5B. No other effects or interactions were reliable (all Fs < 2, ps $> .30$).

Figure 5. Experiment 2 results. *Figure 5A*. Working memory performance accuracy for each Memory instruction condition. Error bars indicate standard error between the difference of the means. *Figure 5B*. Mean interparticipant RTs as a function of Memory instruction, Cue Validity, and Cue–target interval. Error bars indicate standard error between the difference of the means.

Thus, when participants were asked to hold eye gaze in working memory and when it was verified that they have successfully done so, the memory representation nearly facilitated subsequent social orienting. That is, the data suggest that working memory content may affect social orienting when the memory representation is directly relevant for the subsequent task.

Alternative Data Coding

Although this response-coding scheme parallels the coding implemented in Experiment 1, it does not allow one to examine whether working memory accuracy suffered when the participants were asked to identify the change in Gaze direction or face Identity from memory. To address this, we conducted additional analyses, which were based on an alternative response-coding scheme. To capture the performance for both change and no change in gaze direction representation, we analyzed responses from Question #1 asking about the eye gaze information, and considered the following responses as correct: *(i)* a 'same' response for Same Gaze/Same Identity and Same Gaze/ Different Identity (No Change condition) and *(ii)* a 'different' response for Different Gaze/Same Identity and Different Gaze/Different Identity (Change condition) probes. Likewise, to capture the working memory performance for encoding working memory representation change and no change in face identity, we analyzed responses from Question #2 asking about the face identity information, and considered the following responses as correct: *(iii)* a 'same' response for Same Identity/Different Gaze, and Same Identity/Same Gaze (No Change condition), and *(iv)* a 'different' response for Different Identity/Same Gaze and Different Identity/Different Gaze (Change condition) probes.

Eye Gaze.

Working Memory Performance. Responses from Question #1 showed performance for the Same gaze/Same identity (M = 81.9%, $t(29) = 14.69$, $p < .001$) and Same gaze/Different identity (M = 75.0%, $t(29) = 9.73$, $p < .001$) conditions to be above chance. Pairwise two-tailed t-tests indicated that accuracy for the Same gaze/Different identity condition was significantly lower than accuracy in the Same Gaze/Same Identity condition, $t(29) = 6.33$, $p < .001$, in which neither gaze direction nor identity changed. Thus, memory performance for gaze information appears to be affected when face identity changes.

Social Attention. To examine if holding information about eye gaze in working memory affected subsequent social orienting, we analyzed mean correct RTs for trials in which participants were instructed to remember eye gaze information as a function of Cue validity and Cue–target interval. A main effect of Cue–target interval, $F(2,29) = 50.51$, $p < .001$ showed faster RTs as cue–target time increased. Although there was a trend for gazed-at trials to have faster RTs than not gazed-at trials ($F(1,29) = 1.60$, $p = .22$), no effects reached statistical significance (all other *F*s < 1, *p*s > .58). Memory accuracy and RT data are shown in Figure 6.

Figure 6. Experiment 2 results for Eye Gaze alternative coding scheme. *Figure 6A*. Working memory performance accuracy for each Memory condition. Error bars indicate standard error between the difference of the means. *Figure 6B*. Mean interparticipant RTs as a function of Memory instruction, Cue Validity, and Cue–target interval. Error bars indicate standard error between the difference of the means.

Face Identity.

Working Memory Performance. Accuracy for conditions in which face identity did not change was above chance (Same gaze/Same identity: $M = 82.4\%$, $t(29) = 19.53$, $p < .001$; Different gaze/Same identity: $M = 79.9\%$, $t(29) = 13.06$, $p < .001$) while response accuracy for conditions in which face identity did change was below chance (Same gaze/Different identity: *M*

= 39.4%, $t(29) = 4.73$, $p < .001$; Different gaze/Different identity: $M = 37.6\%$, $t(29) = 6.91$, $p < .001$). Figure 7A shows these accuracy means. Pairwise two-tailed t-tests indicated that mean accuracy for trials in which face Identity changed (i.e., *(ii)* Same gaze/Different identity and *(iv)* Different gaze/Different identity) was reliably lower than accuracy for trials in which identity remained the same (i.e., Same gaze/Same identity and Different gaze/Same identity; *(ii)* vs. *(i)*: $t(29) = 13.30$, $p < .001$, *(ii)* vs. *(iii)*: $t(29) = 11.11$, $p < .001$, *(iv)* vs. *(i)*: $t(29) = 15.18$, $p < .001$, *(iv)* vs. *(iii)*: $t(29) = 11.51$, $p < .001$). Thus, participants were better able to remember face identity when its representation did not change.

Social Attention. Mean correct interparticipant RTs were examined for the condition in which participants were instructed to remember face identity using a repeated measures ANOVA with Cue validity and Cue–target interval included as factors. Aside from the reliable Cue–target interval main effect ($F(2,29) = 48.67$, $p < .001$) no effects reached significance (Fs < 1, ps > .70). This suggests that specifically holding face identity in working memory does not affect orienting of attention.

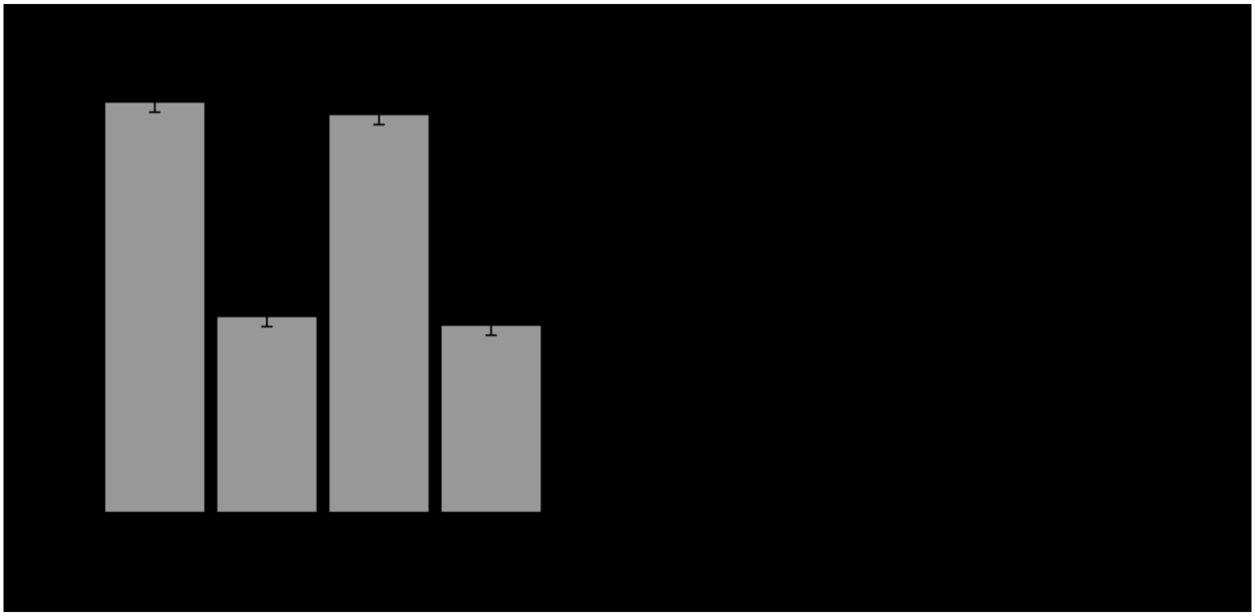

Figure 7. Experiment 2 results for Face Identity alternative coding scheme. *Figure 7A*. Working memory performance accuracy for each Memory instruction condition. Error bars indicate standard error between the difference of the means. *Figure 7B*. Mean interparticipant RTs as a function of Memory instruction, Cue Validity, and Cue–target interval. Error bars indicate standard error between the difference of the means.

Finally, we analyzed whether the representation change in the gaze direction or in face identity had a more pronounced effect on social orienting. To do so, we compared RTs in the conditions in which there was no change and those in which there was change in the working memory representation for gaze direction (Same gaze, conditions (*i*) and (*ii*) vs. Different gaze, conditions (*iii*) and (*iv*)) as a function of Cue validity and Cue-target intervals. The same analysis was repeated for changes in face identity (Same identity, conditions (*i*) and (*iii*) vs. Different identity, conditions (*ii*) and (*iv*)).

Both ANOVA analyses returned reliable main effects of Cue–target interval, Fs > 34, ps < .001. A near significant interaction between changes in gaze direction and cue validity when participants correctly held gaze information in working memory emerged, $F(1,29) = 3.76$, $p = .06$. In other words, trials in which gaze direction did not change had faster RTs to gazed-at targets relative to not gazed-at targets. No other effects reached significance, all *F*s < 3.8, *p*s > .13. Thus, it appears that social orienting is affected by the representation of gaze direction when participants are instructed to remember gaze information and when they are not required to identify a change in that representation. This again indicates that social attention is influenced when contents of working memory are relevant to the task.

Discussion

To understand the specific influences of eye gaze vs. face identity information in working memory, in Experiment 2 we manipulated the content of working memory directly. In contrast to Experiment 1, here we found that when participants held gaze information in working memory they showed expected social orienting effects, in that they showed trends toward faster responding to gazed-at relative to not-gazed-at external targets. This suggests that holding face identity in working memory in Experiment 1 may have played a role in inhibiting social orienting. However, when participants were specifically instructed to remember face identity in Experiment 2, and we have verified that they have successfully done so, no effects on social orienting were observed. When participants were instructed to remember eye gaze and we have verified that they have done so, we observed marginal attentional facilitation for gazed-at targets.

Importantly however, this effect was modulated by the nature of the working memory representation. That is, facilitory effects of working memory on social attention were found only when participants were specifically instructed to remember eye gaze information, and when working memory representation did not require a ‘different’ response at the probe screen. Thus, it appears that a working memory representation of gaze direction may affect social attention only when the remembered gaze direction is relevant for the task. Since face identity was never relevant for the cueing task performance, no effects on social orienting were observed.

General Discussion

In this thesis we re-examined the putatively inhibitory relationship between social working memory and social attention. We did so by modifying the original McDonnell and Dodd (2013) paradigm in which participants were asked to hold social information about a face in working memory while completing a social cueing task.

Our data indicated that overall effects of working memory on social attention were fleeting. In Experiment 1, we observed inhibition of social orienting only when the representation of gaze direction remained unchanged but face identity differed. Thus, it appears that holding gaze direction in working memory inhibits social attention when the contents of working memory are not directly relevant to the task. In Experiment 2, we instructed participants to remember a particular part of the face. Within a given trial, they were instructed to hold gaze information, identity information, the whole face, or the configuration of the nonsocial background color matrix in working memory.

The data indicated that overall working memory performance for all conditions was above chance, with participants generally performing the working memory task well. In terms of social orienting, in Experiment 2, participants were faster to respond to gazed-at targets when they were instructed to specifically hold gaze information in working memory. However, this result was dependent upon gaze direction representation remaining unchanged from the encoding to the probe screen. When participants were instructed to hold face identity in working memory, no effects on social attention were observed. Thus, the results from Experiment 2 indicated that holding gaze direction and not face identity in working memory appears to facilitate social attention. Three conclusions that follow from these results are discussed next.

The reliability of the inhibitory effect of social working memory on social attention

The first conclusion relates to the fragility of the inhibitory effect of working memory on social orienting. Across two experiments, we repeatedly observed little influence of the working memory representation on social attention. Furthermore, modifying McDonnell and Dodd's original task parameters had little effect on the general performance and the outcome of the original inhibitory effect. Despite a severely reduced initial working memory encoding time, participants were able to accurately encode the face cue. Information within the face relevant to the cueing task was encoded quickly and subsequently led to orienting effects similar to studies with longer cue encoding times (e.g., McDonnell & Dodd, 2013).

Due to the intertwined nature of gaze and identity information within face stimuli, isolating the contribution of each factor within the working memory representation remains a challenge. Our manipulations attempted to address this issue. However, across two experiments we found opposing results. In Experiment 1, when participants appeared to be holding gaze information in working memory, social orienting was inhibited. However, working memory performance in this case was at chance, and furthermore participants also appeared to be holding at least some face identity information in memory. In Experiment 2, when we specifically instructed participants to hold gaze information in working memory, we found hints of facilitation in social orienting. In other words, when participants were not specifically instructed to remember eye gaze information, social orienting was also inhibited. However, when they were instructed to remember eye gaze, social orienting appeared to be facilitated.

Thus, it appears that holding response-relevant information in working memory enhances attention. That is, when eye gaze information is held in working memory, attention is facilitated. This parallels previous studies of working memory and attention which showed enhancements in attention when working memory representations were relevant, such as enhanced visual search when targets matched items held in working memory (e.g., Downing, 2000; Soto et al., 2005). In the present study, the relevant information reflected the correspondence between gaze direction and target location, i.e., the match between the directionality provided by eye gaze information and the target's location.

To illustrate, Downing (2000) presented participants with an image of a face and instructed them to remember this image for a subsequent memory test. This image was shown for 1 second and was followed by a 1.5 second delay. After the delay, two faces simultaneously appeared side-by-side for about 200ms. One of these faces was the same face being held in memory, while the other was a novel face. Shortly after the offset of the faces, a target appeared in one of the two locations previously occupied by the faces. Participants responded as quickly as possible to the orientation of the target ("up" or "down") using a key press. The data showed that participants were faster to respond to targets that appeared in the location that matched the face held in working memory. In other words, when the location of the target was the same as the location of the working memory representation, attention was facilitated toward that area. To test for memory accuracy, at the end of each trial participants were shown a face and asked to indicate whether this face was the same as the one held in working memory or not. Across all experiments, participants showed high accuracy (> 80%) for remembering the correct face image.

With this design, the face as a whole is deemed relevant. Holistic information is sufficient to match the face held in working memory with one of the two presented faces. Once identified, attention is shifted toward the location of the matching face. Thus, location provides relevant directional information used in the allocation of attention. In our Experiment 2 participants were also instructed to hold an image of a face in working memory. However, in our study participants were instructed that the faces (specifically eye gaze direction) gave no indication as to the location of the subsequent target's appearance. We found significant effects on attention only when participants appeared to be holding relevant directional information via eye gaze in working memory. In other words, gaze information provided the necessary directional information to shift attention only when eye gaze specifically was held in working memory and not any other aspect of the face.

Soto et al. (2005) also directed attention using task-irrelevant stimuli. In their study, participants were shown an array of colored shapes, each containing a line. The task was to detect the slanted line amongst vertical lines. Prior to the onset of the array, participants were cued with a colored shape that matched the shape surrounding the target, matched a non-target, or matched nothing. Their results showed that participants were faster to detect the slanted line target when the shape surrounding it matched the shape cued at the beginning of the trial. Thus, similar to the work by Downing (2000), matching the cued shape to the one in the array gave directional information and shifted attention toward the location. Importantly, when the cued shape did not match the target's shape, RTs to identify the target were slowed.

The present study adds to this body of literature showing interactions between working memory and attention. Similar to the relationship between canonical working memory and attention, our results show that social working memory is also able to influence social attention. An important caveat is that only social working memory, and not canonical working memory, appears to influence social attention (see Hayward & Ristic, 2013; Law et al., 2010). Furthermore, the effect of social working memory on social attention seems to be dependent on the specific content being held in memory.

Of note here is also the time course of effects in our study vs. McDonnell and Dodd (2013). Our data suggest that the influence of working memory on social orienting appears to be mediated by encoding time as well as the time delay between the cue and the target. Orienting effects observed in the present study did not extend past the 500ms cue–target interval. That is, a short encoding time of 150ms produced effects up to 350ms after the offset of the cue. With longer encoding times and cue–target delays, as manipulated in McDonnell and Dodd, the inhibitory effect persisted up to 2500ms (see Experiments 1 & 2, McDonnell & Dodd, 2013). This suggests that longer and perhaps more in-depth encoding of faces leads to longer lasting and more robust inhibitory effects. Future studies may shed light on this question by investigating the effects of a range of working memory encoding times.

The relationship between working memory, social working memory, and social attention

The second conclusion relates to the relationship between working memory, social working memory, and social attention. In line with past studies (e.g., Hayward & Ristic, 2013; Law et al., 2010), in Experiment 2 we found no interactions between the canonical working memory load and social attention. That is, when participants were instructed to remember the nonsocial background color matrix, their response times to gazed-at targets were unaffected. This would suggest that a nonsocial working memory load did not interfere with social orienting. Past research shows that general mechanisms of attention and working memory often share resources and neural mechanisms (e.g., Anderson et al., 2010; Downing, 2000; Gazzaley & Nobre, 2012; Oh & Kim, 2004; Soto et al., 2005; for a review, see Awh, Vogel, & Oh, 2006). However, the relationship between social attention and canonical working memory is less clear. The present results, along with past research (Hayward & Ristic, 2013; Law et al., 2010) suggest no interference effects between social attention and the canonical working memory system. This dovetails with Hayward & Ristic's (2013) study in which the authors embedded a gaze cueing task within a verbal working memory task and, similarly to our Experiment 2, found that social orienting was unaffected by the concurrent working memory load. Thus, it appears that the cognitive resources that are shared between attention and the canonical working memory system are not utilized when attention is engaged by social cues. However, recent work by Bobak and Langton (2015) found that social attention was disrupted and almost inhibited under verbal working memory load, when task difficulty was increased. Specifically, in the high load condition, participants were asked to generate a random string of numbers (using numbers 1–9) while performing a gaze cueing task. The results showed that social attention was spared under low load (reciting 1–9 in order), but disrupted under high load (i.e., no difference between cued and uncued trials). As such, this suggests that the difficulty of the working memory task may modulate the relationship between the canonical working memory system and social attention.

Along with the canonical working memory system, the present results suggest that social attention is affected by the *social* working memory system, which taken together with our previous point, suggests differences between the canonical and social working memory systems. In the present study, social attention was both inhibited and facilitated depending on the type of information held in social working memory. In contrast, social attention remained unaffected by the canonical working memory manipulation. Under social working memory load, the directionality of the gaze information representation (e.g., face looking left or right) was related to the "directionality" of the target detection task (i.e., targets appear left or right). Thus, even when working memory cues were nonpredictive, participants' attention was influenced by the direction of working memory representation of eye gaze. This is presumably due to the working memory gaze representation falling along the same response-relevant dimension. Face identity information, on the other hand, does not embody any task-relevant directional information, and as such was insufficient to facilitate social orienting.

Thus, working memory for social information appears to operate similarly, but separately, from the canonical working memory for nonsocial information. When the contents of social working memory are relevant to the task (e.g., gaze information), social attention appears to be facilitated toward relevant information (cf. Downing, 2000). If the contents of working memory are irrelevant to the task (e.g., identity information), social attention is either unaffected or inhibited (cf. Oh & Kim, 2004; also Woodman & Luck, 2004). Thus, social working memory and social attention appear to be influenced by social information separately from the canonical working memory.

This leads to two interesting questions (1) is social information processed uniquely by domain-specific systems, and (2) is social information able to uniquely influence domain-specific systems, such as social working memory and social attention? Meyer et al. (2012) recently reported that in addition to brain areas associated with canonical working memory (Linden, 2007; Rottschy et al., 2012; Wager & Smith, 2003), areas of the mentalizing network associated with social cognition (Lieberman, 2010; Van Overwalle, 2009; see also Frith & Frith, 2003) were concurrently activated when participants mentally ranked close friends based on various personality traits. Based on those data, Meyer and Lieberman (2012) suggested that the social working memory is uniquely specialized for maintenance and manipulation of social information such as traits, relationships, and mental states.

However, it remains to be resolved if this finding reflects the manipulation of social information specifically or the maintenance of relational information between items more generally. In their study, Meyer et al. (2012) asked participants to manipulate and maintain social information such as others' traits and relationships but did not contrast that performance with a task in which participants would be asked to manipulate and maintain nonsocial cognitive information (although see Meyer et al., 2015). For this reason, it is possible that participants held the relational information rather than *social* information in their working memory. Thus in the present study, faces may not represent a social working memory load, *per se*. Holding face identity, which is arguably an important social aspect of a face, showed no facilitation of attention, similar in line to past studies using canonical working memory manipulation (Hayward & Ristic, 2013; Law et al., 2010). However, when participants held gaze information in working memory, facilitory effects on social attention were observed. This may be due, not to gaze information being social by nature, but due to the relationship between gaze direction and directionality of the target's location (see also Thornton & Conway, 2013).

Social working memory load

Finally, our experiments revealed that contrary to our initial predictions, social working memory load appeared to be the lowest when participants remembered whole faces rather than isolated face parts. This stands in contrast to the canonical working memory work, which typically indicates that increasing the number of items and/or their complexity results in higher working memory loads (e.g., Druzgal & D'Esposito, 2001; Jensen & Tesche, 2002; Luck & Vogel, 1997; Morgan et al., 2008). This general observation of increasing load with the amount of information also appears to hold within the social working memory as well. Increases in the amount of remembered social information, operationalized as the amount of information related to familiar individuals, have also been found to lead to increases in social working memory load (for review, see Meyer & Lieberman, 2012). One possibility for why we have observed different results is because we used faces as working memory stimuli. Many studies point to the uniqueness of face perception and analysis, both in behavior (Farah, Wilson, Maxwell Drain, & Tanaka, 1995; Young, Hellawell, & Hay, 2013; Yovel & Kanwisher, 2004) and in underlying neural processes (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Haxby, Hoffman, & Gobbini, 2000; Kanwisher, McDermott, & Chun, 1997). Faces also appear to engage working memory resources differently from non-face stimuli.

For example, work by Curby and Gauthier (2007) showed higher visual short term memory capacity for faces as compared to other complex objects given sufficient encoding time. In their task, participants were briefly shown a circular array of faces, and, after a delay, were asked to identify one of the faces as same or different from the original display. The authors found an advantage for upright faces compared to inverted faces and non-face complex objects with sufficient encoding time. That is, the advantage for upright faces relative to inverted/non-face objects increases as encoding time lengthens. Conversely, visual short-term memory capacity for upright faces was lowest for short, insufficient encoding times. Based on these results, the authors argued that holistic face processing—the ability to recognize the object as a face—occurs early, but that short encoding times are not sufficient to consolidate, or fully encode, the face identity information (see Eng et al., 2005).

These results suggest that the holistic processing of faces may be so efficient that it requires less resources from working memory. Our results showing lowest working memory load for whole faces dovetails with this result. Overall, we observed that memory performance was highest when no changes in face configuration (i.e., face identity) occurred. This suggests that holistic processing occurs early, but that an encoding time of 150ms may not be sufficient for the face part configuration consolidation (i.e., ability to detect changes in identity). However, such effects may not be specific to faces and may extend to other stimuli for which humans have developed perceptual expertise, as increased perceptual expertise for complex nonsocial objects have also been found to lead to increased visual short term memory capacity (Curby, Glazek, & Gauthier, 2009).

Future Directions

Even though the present investigation did not reveal large modulations of social attention by social working memory, two general future directions may be useful in further characterizing this relationship.

First, one could utilize eye movement recordings to better understand what participants attend to when encoding and remembering faces. To do so, one could present participants with whole faces or isolated face parts and observe eye movement patterns during encoding. Based on the results from the present investigation, one would expect to find subsequent attentional modulations only when eyes specifically were remembered. That is, presenting eyes in isolation should have the same effects as when participants were explicitly instructed to remember eyes only.

Observing eye movement patterns of looking at eyes exclusively when encoding the faces would support the hypothesis that gaze information plays a key role in social attention. Additionally, this hypothesis would be supported if the data indicated that participants looking at other aspects of the face produced no additional attentional effects. However, if attentional effects occurred when participants did not look at eyes at encoding it would suggest that attention during encoding does not affect the quality of working memory representation and/or subsequent attentional orienting.

Eye tracking would also allow one to examine how encoding time and instructions may modulate encoding strategies and later attention performance. Manipulating encoding times to include both long and short presentation times could highlight potentially different encoding strategies. As evidenced by the results of McDonnell & Dodd (2013, see Experiments 1 and 2), longer encoding times may lead to longer inhibitory effects. Collecting eye movement data could highlight different encoding approaches based on encoding time. Prior research suggests that short encoding times may not be sufficient for configuration consolidation (Curby & Gauthier, 2007). If this were true, one would expect to observe differences in attentional orienting as well as encoding strategies for long vs. short encoding times.

In conjunction with manipulating length of encoding, instructions may also affect encoding strategies. First, and perhaps most importantly, eye tracking could verify if participants change their encoding behavior based on instructions. Second, manipulating instructions in conjunction with encoding time could reveal the impact that the two variables have on encoding behavior. For example, are participants more likely to look at eyes first at short compared to long encoding times? Does this pattern vary with different instructions? Collecting eye movement patterns in these various conditions would shed more light on the strategies that are used when encoding faces into working memory. This information, in conjunction with performance RT data, would provide additional evidence on the processes involved in social working memory and social attention.

Second, once could also utilize neuroimaging methods to better understand the underlying brain mechanisms that are engaged when social working memory and social attention are engaged simultaneously. Work by Meyer et al. (2012) showed activity in social working memory areas including dmPFC, mPFC, PC/PCC, and TPJ as well as activity in canonical working memory areas including dlPFC, SPL, and SMA when participants were maintaining and manipulating traits and relationships between close friends. The present study used faces as a social working memory load. Future studies could test various types of social working memory load and contrast each to gain a better understand of how the brain processes and maintains social information.

To examine overlap in brain activity between social attention and social working memory, areas involved in social attention—including the fusiform gyrus, superior temporal sulcus (STS), SPL, frontal eye fields (FEF), amygdala, and mPFC (for review, see Nummenmaa & Calder, 2009) would need to be activated concurrently with social working memory areas. If the present design does this successfully, one would expect to see higher activation in the areas of overlap (mPFC and SPL) when performing the task. Importantly, observing the activity in these areas would allow one to see if and how social working memory modulates activity in social attention areas.

If social working memory and social attention recruit similar brain areas, it would suggest shared resources between the two systems. Again, manipulating encoding time and instructions would allow one to see how the type and depth of encoded social working memory load modulates social attention.

Finally, it is important to note the potential influence of the ratio of female to male participants in our samples (i.e., 1 male in Experiment 1 and 7 males in Experiment 2). While participant gender may be an important variable to study in the future, available evidence does not suggest that this sample composition may have influenced the present outcome. Namely, recent work by Feng and colleagues suggests women allocate more attentional resources during a visual spatial attention task (Feng et al., 2011) while Bayliss, Pellegrino, and Tipper (2005) have found stronger gaze cueing effects in women compared to men. Despite these potential advantages for social cognitive processes in females over males and our predominantly female sample, we still did not observe reliable gaze cueing effects across the two experiments.

Conclusions

Building upon the work of others, here we investigated the relationship between social working memory and social attention. Across two experiments we found that social working memory load, and not canonical working memory load, influenced social attention but only when its contents were relevant to current task goals. This research extends to present work on the relationship between attention and working memory and offers some further support for the uniqueness of the social working memory system.

References

Alvarez, G. A., & Cavanagh, P. (2004). The capacity of visual short-term memory is set both by visual information load and by number of objects. *Psychological Science*, *15*(2), 106-111. doi:10.1111/j.0963-7214.2004.01502006.x

Anderson, E. J., Mannan, S. K., Rees, G., Sumner, P., & Kennard, C. (2010). Overlapping functional anatomy for working memory and visual search. *Experimental Brain Research*, *200*(1), 91-107. doi:10.1007/s00221-009-2000-5

Awh, E., Barton, B., & Vogel, E. K. (2007). Visual working memory represents a fixed number of items regardless of complexity. *Psychological Science*, *18*(7), 622-628. doi:10.1111/j.1467-9280.2007.01949.x

Awh, E., Vogel, E. K., & Oh, S. H. (2006). Interactions between attention and working memory. *Neuroscience*, *139*(1), 201-208. doi:http://dx.doi.org/10.1016/j.neuroscience.2005.08.023

Bayliss, A. P., Bartlett, J., Naughtin, C. K., & Kritikos, A. (2011). A direct link between gaze perception and social attention. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(3), 634-644. doi:10.1037/a0020559

Bayliss, A. P., Pellegrino, G. d., & Tipper, S. P. (2005). Sex differences in eye gaze and symbolic cueing of attention. *The Quarterly Journal of Experimental Psychology Section A*, *58*(4), 631-650. doi:10.1080/02724980443000124

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience*, *8*(6), 551-565. doi:10.1162/jocn.1996.8.6.551

Bertelson, P. (1967). The time course of preparation. *Quarterly Journal of Experimental Psychology*, *19*(3), 272-279. doi:10.1080/14640746708400102

Bobak, A. K., & Langton, S. R. H. (2015). Working memory load disrupts gaze-cued orienting of attention. *Frontiers in psychology*, *6*, 1258. doi:10.3389/fpsyg.2015.01258

Braver, T. S., Cohen, J. D., Nystrom, L. E., Jonides, J., Smith, E. E., & Noll, D. C. (1997). A parametric study of prefrontal cortex involvement in human working memory. *NeuroImage*, *5*(1), 49-62. doi:http://dx.doi.org/10.1006/nimg.1996.0247

Curby, K. M., & Gauthier, I. (2007). A visual short-term memory advantage for faces. *Psychonomic Bulletin & Review*, *14*(4), 620-628. doi:10.3758/bf03196811

Curby, K. M., Glazek, K., & Gauthier, I. (2009). A visual short-term memory advantage for objects of expertise. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(1), 94-107. doi:10.1037/0096-1523.35.1.94

Doneva, S. P., & De Fockert, J. W. (2014). More conservative go/no-go response criterion under high working memory load. *Journal of Cognitive Psychology*, *26*(1), 110-117. doi:10.1080/20445911.2013.855780

Downing, P. E. (2000). Interactions between visual working memory and selective attention. *Psychological Science*, *11*(6), 467-473. doi:10.1111/1467-9280.00290

Downing, P. E., Dodds, C. M., & Bray, D. (2004). Why does the gaze of others direct visual attention? *Visual Cognition*, *11*(1), 71 - 79.

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

Druzgal, T. J., & D'Esposito, M. (2001). Activity in fusiform face area modulated as a function of working memory load. *Cognitive Brain Research*, *10*(3), 355-364. doi:http://dx.doi.org/10.1016/S0926-6410(00)00056-2

Eng, H. Y., Chen, D., & Jiang, Y. (2005). Visual working memory for simple and complex visual stimuli. *Psychonomic Bulletin & Review*, *12*(6), 1127-1133. doi:10.3758/bf03206454

Farah, M. J., Wilson, K. D., Maxwell Drain, H., & Tanaka, J. R. (1995). The inverted face inversion effect in prosopagnosia: Evidence for mandatory, face-specific perceptual mechanisms. *Vision Research*, *35*(14), 2089-2093. doi:http://dx.doi.org/10.1016/0042-6989(94)00273-O

Feng, Q., Zheng, Y., Zhang, X., Song, Y., Luo, Y.-j., Li, Y., & Talhelm, T. (2011). Gender differences in visual reflexive attention shifting: Evidence from an erp study. *Brain Research*, *1401*, 59-65. doi:http://dx.doi.org/10.1016/j.brainres.2011.05.041

Freire, A., Lee, K., & Symons, L. A. (2000). The face-inversion effect as a deficit in the encoding of configural information: Direct evidence. *Perception*, *29*(2), 159-170. doi:10.1068/p3012

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

Friesen, C. K., & Kingstone, A. (2003). Abrupt onsets and gaze direction cues trigger independent reflexive attentional effects. *Cognition*, *87*(1), B1-B10. doi:http://dx.doi.org/10.1016/S0010-0277(02)00181-6

Friesen, C. K., Ristic, J., & Kingstone, A. (2004). Attentional effects of counterpredictive gaze and arrow cues. *Journal of Experimental Psychology: Human Perception and Performance*, *30*(2), 319-329.

Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *358*(1431), 459-473. doi:10.1098/rstb.2002.1218

Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: Bridging selective attention and working memory. *Trends in Cognitive Sciences*, *16*(2), 129-135. doi:http://dx.doi.org/10.1016/j.tics.2011.11.014

Greene, D. J., Mooshagian, E., Kaplan, J. T., Zaidel, E., & Iacoboni, M. (2009). The neural correlates of social attention: Automatic orienting to social and nonsocial cues. *Psychological Research*, *73*(4), 499-511. doi:10.1007/s00426-009-0233-3

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*(6), 223-233.

Hayward, D. A., & Ristic, J. (2013). The uniqueness of social attention revisited: Working memory load interferes with endogenous but not social orienting. *Experimental Brain Research*, *231*(4), 405-414. doi:10.1007/s00221-013-3705-z

Helton, W. S. (2009). Impulsive responding and the sustained attention to response task. *Journal of Clinical and Experimental Neuropsychology*, *31*(1), 39-47. doi:10.1080/13803390801978856

Hoffman, E. A., & Haxby, J. V. (2000). Distinct representations of eye gaze and identity in the distributed human neural system for face perception. *Nature Neuroscience*, *3*(1), 80-84.

Jensen, O., & Tesche, C. D. (2002). Frontal theta activity in humans increases with memory load in a working memory task. *European Journal of Neuroscience*, *15*(8), 1395-1399. doi:10.1046/j.1460-9568.2002.01975.x

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. *Attention and performance IX*, *9*, 187-203.

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *The Journal of neuroscience*, *17*(11), 4302-4311.

Langton, S. R. H., & Bruce, V. (1999). Reflexive visual orienting in response to the social attention of others. *Visual Cognition*, *6*(5), 541 - 567.

Langton, S. R. H., Watt, R. J., & Bruce, V. (2000). Do the eyes have it? Cues to the direction of social attention. *Trends in Cognitive Sciences*, *4*(2), 50-59. doi:http://dx.doi.org/10.1016/S1364-6613(99)01436-9

Law, A. S., Langton, S. R. H., & Logie, R. H. (2010). Assessing the impact of verbal and visuospatial working memory load on eye-gaze cueing. *Visual Cognition*, *18*(10), 1420-1438. doi:10.1080/13506285.2010.496579

Leder, H., & Bruce, V. (2000). When inverted faces are recognized: The role of configural information in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *53*(2), 513-536. doi:10.1080/713755889

Lepsien, J., & Nobre, A. C. (2007). Attentional modulation of object representations in working memory. *Cerebral Cortex*, *17*(9), 2072-2083. doi:10.1093/cercor/bhl116

Lieberman, M. D. (2010). Social cognitive neuroscience *Handbook of social psychology*: John Wiley & Sons, Inc.

Linden, D. E. J. (2007). The working memory networks of the human brain. *The Neuroscientist*, *13*(3), 257-267. doi:10.1177/1073858406298480

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279-281.

McDonnell, G. P., & Dodd, M. D. (2013). Examining the influence of a spatially irrelevant working memory load on attentional allocation. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(4), 933-940. doi:10.1037/a0032111

Meyer, M. L., & Lieberman, M. D. (2012). Social working memory: Neurocognitive networks and directions for future research. *Frontiers in Psychology*, *3*(571), 2-26.

Meyer, M. L., Spunt, R. P., Berkman, E. T., Taylor, S. E., & Lieberman, M. D. (2012). Evidence for social working memory from a parametric functional mri study. *Proceedings of the National Academy of Sciences*, *109*(6), 1883-1888. doi:10.1073/pnas.1121077109

Meyer, M. L., Taylor, S. E., & Lieberman, M. D. (2015). Social working memory and its distinctive link to social cognitive ability: An fmri study. *Social Cognitive & Affective Neuroscience*, *10*(10), 1338-1347. doi:10.1093/scan/nsv065

Morgan, H. M., Klein, C., Boehm, S. G., Shapiro, K. L., & Linden, D. E. J. (2008). Working memory load for faces modulates p300, n170, and n250r. *Journal of Cognitive Neuroscience*, *20*(6), 989-1002. doi:10.1162/jocn.2008.20072

Nummenmaa, L., & Calder, A. J. (2009). Neural mechanisms of social attention. *Trends in Cognitive Sciences*, *13*(3), 135-143. doi:http://dx.doi.org/10.1016/j.tics.2008.12.006

Oh, S., & Kim, M. (2004). The role of spatial working memory in visual search efficiency. *Psychonomic Bulletin & Review*, *11*(2), 275-281. doi:10.3758/bf03196570

Olivers, C. N. L., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in Cognitive Sciences*, *15*(7), 327-334. doi:http://dx.doi.org/10.1016/j.tics.2011.05.004

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*(1), 3-25.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance x: Control of language processes* (Vol. Attention & Performance, pp. 531-566). Hillsdale, NJ: Erlbaum.

Richler, J. J., Cheung, O. S., & Gauthier, I. (2011). Holistic processing predicts face recognition. *Psychological Science*, *22*(4), 464-471. doi:10.1177/0956797611401753

Ristic, J., Wright, A., & Kingstone, A. (2007). Attentional control and reflexive orienting to gaze and arrow cues. *Psychonomic Bulletin & Review*, *14*(5), 964-969.

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). 'Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia*, *35*(6), 747-758. doi:http://dx.doi.org/10.1016/S0028-3932(97)00015-8

Rossion, B., Dricot, L., Devolder, A., Bodart, J., Crommelinck, M., de Gelder, B., & Zoontjes, R. (2000). Hemispheric asymmetries for whole-based and part-based face processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience*, *12*(5), 793-802. doi:10.1162/089892900562606

Rottschy, C., Langner, R., Dogan, I., Reetz, K., Laird, A. R., Schulz, J. B., . . . Eickhoff, S. B. (2012). Modelling neural correlates of working memory: A coordinate-based meta-analysis. *NeuroImage*, *60*(1), 830-846. doi:http://dx.doi.org/10.1016/j.neuroimage.2011.11.050

Soto, D., Heinke, D., Humphreys, G. W., & Blanco, M. J. (2005). Early, involuntary top-down guidance of attention from working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(2), 248-261. doi:10.1037/0096-1523.31.2.248

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *46*(2), 225-245. doi:10.1080/14640749308401045

Tanaka, J. W., Kay, J. B., Grinnell, E., Stansfield, B., & Szechter, L. (1998). Face recognition in young children: When the whole is greater than the sum of its parts. *Visual Cognition*, *5*(4), 479-496. doi:10.1080/713756795

Tanaka, J. W., & Sengco, J. A. (1997). Features and their configuration in face recognition. *Memory & Cognition*, *25*(5), 583-592. doi:10.3758/bf03211301

Thornton, M. A., & Conway, A. R. A. (2013). Working memory for social information: Chunking or domain-specific buffer? *NeuroImage*, *70*, 233-239. doi:http://dx.doi.org/10.1016/j.neuroimage.2012.12.063

Van Overwalle, F. (2009). Social cognition and the brain: A meta-analysis. *Human Brain Mapping*, *30*(3), 829-858. doi:10.1002/hbm.20547

Wager, T. D., & Smith, E. E. (2003). Neuroimaging studies of working memory. *Cognitive, Affective, & Behavioral Neuroscience*, *3*(4), 255-274. doi:10.3758/cabn.3.4.255

Woodman, G. F., & Luck, S. J. (2004). Visual search is slowed when visuospatial working memory is occupied. *Psychonomic Bulletin & Review*, *11*(2), 269-274. doi:10.3758/bf03196569

Young, A. W., Hellawell, D., & Hay, D. C. (2013). Configurational information in face perception. *Perception*, *42*(11), 1166-1178. doi:10.1068/p160747n

Yovel, G., & Kanwisher, N. (2004). Face perception: Domain specific, not process specific. *Neuron*, *44*(5), 889-898. doi:10.1016/j.neuron.2004.11.018