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"Gaze Leading": Initiating Simulated Joint Attention Influences Eye Movements and Choice Behavior

Andrew P. Bayliss
University of East Anglia

Emily Murphy, Claire K. Naughtin, and Ada Kritikos
University of Queensland

Leonhard Schilbach
University Hospital of Cologne, Cologne, Germany, and Max-Planck Institute for Neurological Research, Cologne, Germany

Stefanie I. Becker
University of Queensland

Recent research in adults has made great use of the gaze cuing paradigm to understand the behavior of the follower in joint attention episodes. We implemented a gaze leading task to investigate the initiator—the other person in these triadic interactions. In a series of gaze-contingent eye-tracking studies, we show that fixation dwell time upon and reorienting toward a face are affected by whether that individual face shifts its eyes in a congruent or an incongruent direction in response to the participant's eye movement. Gaze leading also biased affective responses toward the faces and attended objects. These findings demonstrate that leading the eyes of other individuals alters how we explore and evaluate our social environment.

Keywords: joint attention, gaze perception, social cognition, eye tracking, preferences

Humans are unique in their mastery of the mind. Not only can we introspect and meditate upon our own experiences, we also naturally and intuitively grasp other humans' mental states. A developmental breakthrough in infancy is the emerging awareness that others have minds with mental states that may differ from one's own (e.g., Charman et al., 2000). For example, throwing food around the dining room might inspire joy in the playful toddler, but the mother may experience a rather different mental state. However, our mental states can also effortlessly align with those of an interactive partner in a shared experience (e.g., Decety & Sommerville, 2003).

Joint attention is one example of a shared experience between two minds (Argyle & Cook, 1976; Baron-Cohen, 1995; Kleinke, 1986, Mundy & Newell, 2007; Scaife & Bruner, 1975). This transient state can be achieved when Individual B perceives the direction of attention of Individual A. Individual B then orients her attention, usually by shifting her gaze, to the same object. Both A and B are now attending the same object due to A's original signal (Emery, 2000). Being able to follow joint attention signals has been shown to be important in social development (Corkum & Moore, 1995; Moore, 2008). For example, early language and theory of mind development are predicted by joint attention proficiency in infancy (Charman et al., 2000; Morales, Mundy, & Rojas, 1998). Further, the failure to appropriately engage in joint attention is associated with autism; missing out on the information yielded in these exchanges may explain some of the social difficulties faced by individuals with autism spectrum disorders (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998).

The link between gaze perception and the representation of the affective content of stimuli is also clear from very early in infancy. For example, Mumme and Fernald (2003) showed that infants' interactions with objects are modulated by the observation of directed gaze and emotional expression of a model. The overlap of activity associated with these two abilities in the brain supports the notion of integrated neural mechanisms for gaze perception and affective evaluations. For example, the amygdala is a key subcortical area for affective evaluation of environmental stimuli (e.g., Öhman, 2005) but is also associated with gaze perception (Whalen et al., 2004). In addition, structural development of the amygdala is positively associated with proficiency of joint attention between the ages of 2 and 4 years (Mosconi et al., 2009). Moreover, functional neuroimaging experiments have revealed overlap between brain areas associated with theory of mind and areas that are active when engaging in joint attention (Schilbach et al., 2010; Williams, Waiter, Perra, Perrett, & Whiten, 2005). Hence, the neural underpinnings of our ability to follow someone's eyes and following someone's internal mental states appear to be tightly linked. Joint attention, related states such as simple gaze following

Andrew P. Bayliss, School of Psychology, University of East Anglia, Norwich, United Kingdom; Emily Murphy, Claire K. Naughtin, and Ada Kritikos, School of Psychology, University of Queensland, St. Lucia, Queensland, Australia; Leonhard Schilbach, Department of Psychiatry, University Hospital of Cologne, Cologne, Germany, and Cortical Networks, Max-Planck Institute for Neurological Research, Cologne, Germany; Stefanie I. Becker, School of Psychology, University of Queensland.

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Correspondence concerning this article should be addressed to Andrew P. Bayliss, School of Psychology, University of East Anglia, Norwich NR4 7TJ, United Kingdom. E-mail: apbayliss@gmail.com

(which does not require the fixation of a common object), and higher level states such as shared attention (where both individuals are aware of one another's state Emery, 2000) all engage low-level visual processes, affective systems, and higher level social cognitive structures to fluently respond to the rapidly changing content and context of cues to other's attention (Frischen, Bayliss, & Tipper, 2007; Mathews, Fox, Yiend, & Calder, 2003; Teufel, Alexis, Clayton, & Davis, 2010).

Clearly, therefore, as a shared experience, joint attention is an exquisite example of the fluent reciprocity of human nonverbal communication. Determining the contribution of the three components of a joint attention scenario—the object, the initiator, and the follower—is critical to our understanding of human social interactions (Frischen et al., 2007; Schilbach, 2010). Gaze following and joint attention initiation may rely on very different cognitive processes (e.g., Mundy & Gomes, 1998), so a full picture of joint attention requires an understanding of the processes involved in both following and initiating joint attention, yet research has focused on the former. The present study implemented a computer-based gaze-contingent eye-tracking design to investigate the impact of observing a face follow one's own gaze. We examined whether interactions with photographs of faces that respond to our own behavior can reveal reliable behavioral effects, such as biases in fixation dwell time on the elements of the simulated, incidental joint attention scenario, and on affective biases as measured by preference decisions.

In essence, therefore, our intention is to study the initiator of a joint attention scenario under a similar framework as implemented in gaze cuing studies that have investigated attentional and affective biases in the "follower" (e.g., Bayliss & Tipper, 2006; see Frischen et al., 2007, for review). We therefore do not aim to directly mimic the naturalistic joint attention scenarios that are observed in real life or in child development laboratories. As much of the work on gaze-based interactions is conducted the field of developmental psychology, our conceptual and theoretical impetus does come from this perspective, in a similar way to how the original gaze cuing studies were conceived (Driver et al., 1999; Friesen & Kingstone, 1998). Therefore, in these terms, we consider below the two roles taken by the conscious agents in a joint attention scenario—the individual who initiates joint attention and the person who responds to joint attention (Mundy & Newell, 2007). Although our work may not directly investigate naturalistic joint attention, our paradigm places our participants as initiators of simulated and incidental joint attention with a computerized face that may or may not respond and establish simulated joint attention with the participant. The present study therefore focuses on the initiator of joint attention in order to explore the affective and behavioral consequences of incidentally causing someone else to follow one's own eyes.

Responding to Joint Attention

The information-sharing aspect of joint attention affords clear benefits for the follower. Individual A, for example, already knows that a particular object is worth attending. Individual B can, using joint attention, evaluate the object for herself—perhaps she will discover the presence of an important food source, conspecific, threat, or other object of interest of which she would not otherwise be aware. Beyond acquiring the advantage of gaining knowledge about the environment, the follower can use information gathered from the joint attention episode to peer "into the mind" of the individual whose gaze she just followed. She can discover the individual's current object of interest and, from the object's features, infer the mental state that precipitated the orienting of attention (Baron-Cohen, 1995). For example, if one is in a bar and a friend looks at his or her watch, then perhaps it is time to wrap things up and head home. Whereas if a friend is gazing over to the attractive member of bar staff, perhaps one might find it easy to convince him or her to get the next round of drinks. If one fails to follow one's friend's eyes in these cases, one will miss out on information that will help the estimate of the friend's mental state and therefore decrease the chances of a positive social outcome.

Initiating Joint Attention

What beneficial consequences might be conferred to the initiator of joint attention? What happens to our behavior when we detect that someone has followed our eyes, and do we gain anything from modifying our behavior when someone follows our own gaze shifts? We know much less about the initiating member of the joint attention triad than the follower because following, rather than gaze leading, has been the focus of the majority of joint attention research. However, some studies have highlighted the importance of initiating joint attention episodes (see Mundy & Newell, 2007, for review). A joint attention episode can emerge from intentional or automatic gaze following, and when an individual makes a manual pointing gesture at an object—encouraging another person to reorient his or her gaze to a particular locus. Indeed, pointing is a perfect example of the benefits of initiating joint attention, as it is often used to request an object (e.g., food, or a toy). Declarative pointing has been shown to be important for the development of efficient interpersonal communication, as it rapidly increases infants' sensitivity to social contexts (Franco, Perucchini, & March, 2009). Interestingly, although children with autism are able to point to request objects, they tend not to use this behavior to initiate a joint attention episode to point out an object of interest to their social partners (Mundy, 1995).

Although *communicative* joint attention states are common, it is important to note that in everyday life, joint attention states often emerge by accident, perhaps driven by primarily low-level visual processing and attention reorienting mechanisms (Frischen et al., 2007). Despite being based upon low-level visual cues, an incidentally emerging joint attention episode may nevertheless provide feedback regarding the quality of the current social interaction. In an fMRI experiment, Schilbach et al. (2010) studied incidental joint attention initiation by asking participants to make an eye movement to a particular part of a computer screen. In response to this, an avatar—representing the eye movements of a confederate outside the scanner—either looked at the same location or looked away from the participant's chosen location (see also Redcay et al., 2010, and Wilms et al., 2010, for similar approaches). Schilbach et al. found the ventral striatum preferentially activated during the self-initiated joint attention episodes, relative to episodes where joint attention failed to be achieved. The ventral striatum has been shown to activate to a wide variety of reward scenarios, supporting the idea that other people's gaze-following eye movement behavior is a form of social reinforcement. This evidence indicates that, even in highly controlled interactions with avatars, gaze-following behavior is registered automatically and interpreted as a successful initiation of a joint attention episode.

Developing a Gaze Leading Paradigm

We wanted to investigate the behavioral and affective consequences of engaging in noncommunicative, self-initiated simulated joint attention episodes, compared with a similar situation where simulated joint attention was not achieved. To do so, we developed a novel gaze-contingent computer-based task. We presented a centrally positioned face, and two pictures of different objects on the left and right side on the screen, and asked participants to decide which of the two objects they preferred. Participants were then asked to indicate their object preference by moving their eyes to their chosen object. In response to the eye movement, the face would move its eyes either in the same direction (gaze congruent) or in the opposite direction (gaze incongruent). In all experiments we used faces of different individuals that behaved consistently: Some faces always produced congruent gaze behavior, and other faces always produced incongruent gaze behavior. Participants were finally required to return their gaze to the face after this episode.

Although participants were instructed that the central face's gaze behavior was irrelevant to their task, we hypothesized that the face's eye movement would be registered and have reliable consequences for behavior on the present and subsequent trials. Because gaze-following behavior in real-world settings is commonly viewed as instantiating a joint attention episode, we expected that a gaze congruent eye movement of the face in our experiment would be interpreted as a simulacrum to a joint attention episode, allowing us to study the effects of joint attention on the participant's eye movement behavior and affect. Participants' eye movement behavior was analyzed over the course of the experiment to determine which variables are modulated by simulated joint attention episodes and to examine any potential learning effects that may emerge while interacting with faces that display consistent congruent or incongruent gaze behavior. In Experiments 1 and 4, we also asked participants to provide their preferences for the interactive faces and the objects in order to examine the impact of consistent gaze congruency behavior on affective evaluations. Finally, to gauge the ability of our new paradigm to simulate joint attention episodes, we asked participants to rate how realistic our simulated joint attention episodes appeared to them, compared to real-life social interactions (Experiments 2 and 3).

Gaze Bias

Preferential looking is a dominant paradigm in the infant development literature (e.g., Teller, 1979) and has been a particularly powerful tool for highlighting early preferences for social stimuli (e.g., Johnson, Dziurawiec, Ellis, & Morton, 1991). The use of highly accurate eye tracking in adults follows a similar logic, and it has been used to great effect in recent eye-tracking studies investigating social cognitive abilities through the assessment of gaze bias toward one stimulus over an alternate (e.g., behavioral markers of automatic belief processing; Schneider, Bayliss, Becker, & Dux, 2011; Schneider, Lam, Bayliss, & Dux, in press; Senju, Southgate, White, & Frith, 2009). Previous work has shown that the affective evaluation of a stimulus is both driven by and reflected in gaze fixation duration (Krajbich, Armel, & Rangel, 2010; Schotter, Berry, McKenzie, & Rayner, 2010; Shimojo, Simion, Shimojo, & Scheier, 2003). For example, if you were asked to decide which of two pictures you prefer when presented side by side, you would likely inspect both, making several eye movements between and within each item (e.g., Schotter et al., 2010). During this decision process, however, on average, you will tend to look longer at the object that you will eventually decide you prefer. Previous reports have used combinations of average fixation duration, duration of first fixation, average duration of all but first fixation, and number of fixations as measures (e.g., Schotter et al., 2010).

Here, we chose to use the total fixation dwell time (i.e., the sum of all fixations on a stimulus in a given trial) as an index of gaze bias and of information seeking to assess whether, in the initial decision phase, participants would spend longer looking at their (later) preferred object. We used total fixation dwell time rather than the average fixation duration or duration of the first fixation, because total dwell times offer the most straightforward operationalization of gaze bias as "looking longer at the preferred object" and are positively correlated with the alternate measures. During different stages of observing congruent or incongruent gaze responses to one's own eye movement, we predict, individuals will seek to gain information from a preferred source—and this will bias their gaze toward or away from an interactive partner and objects in a context-dependent manner.

Return-to-Face Saccade Latency

We were also interested in investigating the influence of initiated gaze congruency on the readiness to reengage the face stimulus. Our predictions were derived from another key component of social orienting, namely *social referencing*, which is a special case of refocusing attention on a social partner (see Feinman, Roberts, Hsieh, Sawyer, & Swanson, 1992, for a review). More broadly, infants regularly engage in "checking-back" behavior to see whether an adult is present or has indeed followed their gaze to an object (e.g., Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998). Given the importance of reorienting to an interactive partner in the developmental literature, we were interested in investigating whether our manipulation of initiated gaze congruency could modulate the readiness to refocus on the face in our gaze leading task.

Affective Evaluations

Finally, previous work on gaze cuing (i.e., gaze following) in adults shows that there are both attentional and affective aspects gaze perception that operate somewhat independently. Although participants follow the gaze of others automatically (Driver et al., 1999; Friesen & Kingstone, 1998), there is also a highly context-dependent affective component to social attention. Followers of gaze prefer faces that look toward the participant's target over faces that look away (Bayliss & Tipper, 2006), and participants also like objects that are looked at by faces compared with objects that are ignored (Bayliss, Paul, Cannon, & Tipper, 2006). Critically, these affective aspects of gaze cuing emerge most clearly when the faces are smiling (Bayliss, Frischen, Fenske, & Tipper, 2007; Bayliss, Griffiths, & Tipper, 2009; see also Bayliss, Schuch,

& Tipper, 2010). Thus, the positive affect expressed by the faces appears to encourage learning in these contexts. Moreover, in a joint attention episode, the object of attention is as important as the conscious agents in the scenario (see Frischen et al., 2007, for review). Hence, the experiments we report here take into account this previous work by presenting smiling faces as interactive partners and—in Experiments 1 and 4, by also examining the effects of gaze leading on preferences for both the faces and the objects used in the experiments.

In the gaze leading paradigm, we created a computer-based scenario in which the participants had to choose which one of two objects they preferred. This choice task was the sole task the participants were required to engage in. As far as the participants were concerned, their job was to simply decide their favorite of two objects. Making this task reasonably demanding means that any effects of engaging in incidental gaze leading are unlikely to be due to demand characteristics affecting overt strategy. The participants indicated their choice by looking at their preferred object. In response to this eye movement, a face on the screen also moved its eyes—either in the direction that the participant looked or in the opposite direction (see also Wilms et al., 2010). Our first question was, How does having one's eyes followed or not followed affect eye movement behavior? In particular, how much time does the participant spend gazing at faces that consistently follow the participant's eyes, relative to faces that look consistently in the opposite direction, and how readily do participants reorient back to the face in the two scenarios? This first question, explored in each of the four experiments, aims to assess whether there are behavioral markers that demonstrate that the cognitive system has detected that a face has executed a congruent/incongruent eye movement with respect to one's own. Our second principal question, addressed in Experiments 1 and 4, was whether gaze leading impacts preference formation and choice behavior—does gaze leading impact upon affective evaluations of interactive partners and the objects that are presented in the scenario? The following experiments report our exploration of these issues and reveal important features of the mechanisms underlying gaze-based interactions.

Experiment 1

Participants completed a forced-choice preference task, during which they chose their preferred object from a pair presented on either side of a computer screen. A face was also present at the center of the screen. During this decision-making period we measured how long the participants spent looking at the three components of the display (the face and the two objects) prior to making their preference decision, to test whether the dwell times would reflect the observer's preferred object prior to the observer explicitly indicating a choice. A corresponding standard gaze bias has often been reported in previous studies (e.g., Shimojo et al., 2003) and would indicate that our paradigm is sufficiently sensitive to reflect the link between explicit preferences and (implicit) eye movement behavior.

More important for our present purposes, however, is total dwell time on the face on the screen, as a function of whether the face is a consistent producer of congruent (eight individual faces) or incongruent (the remaining eight faces) eye movements. We predict that as the experiment progresses, with increasing exposures to different individuals who either always follow their eyes or always look in the other direction, participants will spend less time fixating the congruent faces relative to incongruently gazing faces. This pattern of data would be similar to the finding that the faces of cheaters are viewed longer than those of cooperators (Chiappe et al., 2004).

Once participants reached a decision, they were required to make a speeded saccade to their preferred object. By moving their eyes, a gaze leading scenario ensued, and—depending upon the experimental condition associated with that particular face—the eyes of the face then either followed the eyes of the participant to the left or right or looked the opposite way. Finally, participants were required, in their own time, to look back to the center of the screen where the face remained, still looking at the object at which it had looked. We expected the latencies of these return saccades to be longer with gaze incongruent faces than gaze congruent faces, for two possible reasons: First, participants may be inclined to reengage more rapidly with a positively responsive face and extend their fixation at the object following a rejected bid; in a similar way, infants spend longer pointing at an object when an adult fails to follow their finger (Moore & D'Entremont, 2001). In this case, the return to face latencies would be a correlate of the readiness for refocusing on the face. Alternatively, gaze incongruent episodes could prompt participants to inspect the chosen object at greater lengths (e.g., because the incongruent gaze behavior is interpreted as a rejection of the participants' chosen object, which prompts participants to reevaluate their choice by inspecting the chosen object in more detail). According to this possibility, the return to face latencies would not directly reflect the participants' readiness to reengage with the face but rather the time needed to validate their choice before they can execute the instructed saccade back to the face. The present experiment cannot distinguish between these two possibilities; however, both are plausible and would elongate return to face latencies in the gaze incongruent condition (we return to this issue directly in Experiment 2).

After participants had completed the gaze leading procedure, we asked them to rate the pleasantness of all the objects they had chosen between. Because each object pair was free to appear in either condition, these ratings could not be used to compare gaze congruency conditions directly and were principally used as an additional manipulation check. This aspect of the design preempts the more important role of objects in Experiment 4. Participants also made preference judgments about the faces they had interacted with. The prediction was that participants would prefer the faces that produced congruent gaze shifts in response to the participants' eye movements (after Bayliss et al., 2009; Bayliss & Tipper, 2006). These ratings allow us to bring to bear explicit measures of learning in our interpretation of our implicit measures of gaze latency and dwell time in evaluating our data as a whole. Finally, because we were interested in investigating the impact of gaze-sharing episodes that emerge in a task-irrelevant manner, we expected that participants would not be able to report after the experiment that the individual faces had been behaving consistently.

Method

Participants. Twenty-seven women participated (mean age = 18.5 years, *SD* = 4.7 years) in return for payment (AUD10) or course credit. All had normal or corrected-to-normal vision and gave informed consent.

Stimuli. Images of 18 smiling faces, subtending $12.5° \times 9.5°$, were taken from the NimStim face set (Tottenham et al., 2009). These were digitally edited to produce different versions with eyes looking left, right, or straight ahead. The faces were sorted into pairs that were matched for age, gender, ethnicity, and attractiveness (see Bayliss et al., 2009). One member from each pair was allocated to Face Group A and the other to Face Group B; each group had nine faces. Thirty-six images of everyday household objects (variable size, average $= 2.5° \times 3.0°$) from the set of kitchen and garage objects developed by Bayliss et al. (2006) were sorted into 18 pairs matched for pleasantness (from average ratings given by participants from a previous study; Bayliss et al., 2007, Experiment 1). Both objects from the 18 pairs were placed either into Object Group I (the kitchen objects) or into Object Group II (the garage objects), so that each group of objects comprised nine pairs. The face stimuli were presented in the center of the screen, and objects appeared approximately 13° to the left and right of the center. A fixation point was presented during the intertrial intervals, the position of which corresponded to the bridge of the nose of the faces. For the post-experiment object rating task, a horizontally oriented numerical scale was presented with numbers 1–9 printed underneath a centrally presented image of one of the objects.

Apparatus. A video-based (infrared) eye tracker (Eyelink 1000, SR Research, Ontario, Canada) recorded right eye position (spatial resolution of 0.1°, 500 Hz). Participants placed their head on a chinrest in front of a 15-in. monitor (resolution $= 1{,}024 \times 786$ pixels). Viewing distance was 57 cm. A standard keyboard collected manual responses.

Design. The experiment used a within-subjects design with two factors. First, gaze response congruency had two levels, congruent and incongruent. This corresponded to whether the eyes of the face on the screen would or would not follow the participant's eyes and look at the object that the participant chose to look at, respectively. The second factor, Block, was introduced to examine the time course of effects of gaze congruency and had six levels (Block 1–6). The dependent variables of primary interest were as follows: (a) time to decision, which was the time between stimulus onset and the participant hitting the spacebar to declare a decision had been reached; (b) face preview dwell time, prior to object choice; (c) gaze bias, for fixating the chosen object relative to rejected object; and (d) return-to-face latency, how quickly participants executed a saccade to refixate the face after object choice. Other measures, such as saccade latency during choice, object rating, and face preference, were also collected.

Procedure. In each experimental session, the eye tracker was calibrated to the participant to ensure accurate tracking. This involved the participant looking toward nine predefined points on the computer screen. This procedure was repeated at least five times through the experiment (during midsession breaks and whenever necessary). The participants were then introduced to the gaze leading experiment. Importantly, the only task that each participant was asked to perform was to choose which of the two objects they preferred. The face that appeared on the screen was incidental to their primary goal of object choice. The participants were not asked to take note of the face's behavior, and they were encouraged to simply complete the task efficiently in a manner that reflected their honest opinion about the relative aesthetic appeal of the two objects only.

An experimental trial began with a fixation point in the center of the screen. Once the participant had maintained stable fixation on this point (a boundary of 1.8°) for 500 ms, a smiling face, with direct gaze, appeared in the center of the screen. The face was flanked by two objects from a single object pair. The onset of these stimuli marked the start of the free-viewing period during which participants were asked to decide which object they preferred. The only constraint placed upon participants was that they must fixate each object at least once (eye movements were monitored online by the experimenter viewing a separate monitor showing eye position). There were no time limits. Participants were asked to demonstrate that they had reached a preference decision by (a) fixating the center of the face and then (b) pressing the spacebar. The trial then progressed to the "select object" phase. This began with a red fixation point in the center of the face, and following 500 ms of fixation on that point, a tone sounded (100 ms duration, 750 Hz), signaling that the participant was required to make a speeded saccade to the chosen object. After 300 ms, the eyes of the central face moved, either to look at the same object that the participant had chosen (congruent gaze response) or to look toward the other object (incongruent gaze response). The participants' instruction was to fixate the object and then "naturally return to the center of the face." Again, no time constraint was implied for this action. A trial ended, with the face's eyes still averted, once the participants had fixated the face for 500 ms after returning from the peripheral object. Next, a fixation cross appearing in the center of the screen, on which participants fixated for 1,000 ms to trigger the next trial. A failure to maintain adequate fixation during a trial (but prior to looking at the chosen object) would result in the trial restarting. See Figure 1 for an illustration of the important phases of an example trial.

Participants first completed a number of familiarization trials, in which a single novel face was presented without the eyes moving. This practice session was used principally to familiarize participants with the fixation controls and various phases of a trial and continued until the experimenter was satisfied the participant was comfortable with the task ($<$50 trials, typically $\sim$16). The experimenter gave ongoing feedback where participants failed to comply with a requirement during a trial. Then, participants completed 216 trials in the gaze leading procedure—108 congruent and 108 incongruent trials, over six experimental blocks. Each individual face appeared 12 times (i.e., twice in each block), and each object appeared alongside its pair mate in 12 trials (i.e., twice in each block). For a given participant, each face was presented in only one type of trial, either gaze congruent or gaze incongruent. Hence, the behavior of the face was contingent on the choice made by the participant—the object that the participant looked at determined the object at which face would look. The two groups of faces were counterbalanced across conditions across participants; hence, two versions of the procedure were alternately assigned to participants. The different object pairs were permitted to be presented in either gaze congruency condition in a random order; however, we ensured that objects from Object Group I (kitchen objects) and Object Group II (garage objects) were presented equally often in either condition.

Following the gaze leading task, participants completed two tasks in which they appraised the stimuli from the experiment.

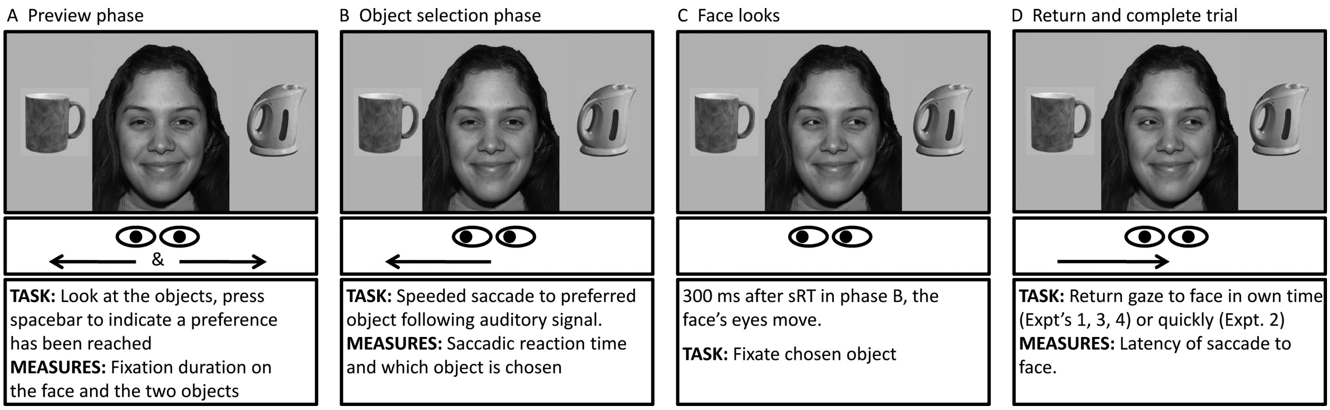

Figure 1. Illustration of the central phases of an experimental trial. In this example, the face on the screen is one of the gaze incongruent faces. The top panel shows the screen that the participant views during each phase (fixation crosses are presented before and after each trial). The middle panels illustrate the eye movement behavior of the participant during each phase, with arrows showing examples of eye movements. The lower panels explain the task for each phase and indicate which dependent measures we derive from each phase. From *NimStim Face Stimulus Set*, by the Research Network on Early Experience and Brain Development, 2002 (http://www.macbrain.org/resources.htm). Copyright 2002 by the Research Network on Early Experience and Brain Development. Development of the NimStim Face Stimulus Set, also known as the MacBrain Face Stimulus Set, was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham at tott0006@tc.umn.edu for more information concerning the stimulus set.

First, they were presented with each object in the center of the screen and were asked to rate it on a 1–9 pleasantness scale. Next, they were presented with the pairs of faces side by side. Each pair was composed of one face that had always shifted its gaze in the same direction as the participant and its matched counterpart, which had never followed the eyes of the participant throughout the experiment. For each pair, they were asked to select the face they deemed more pleasant.

Finally, the participants were debriefed. An informal, funneled set of questions was included to probe their awareness of the gaze congruency manipulation and of their behavior during the task.

Results

Eye movement measures. One participant was excluded from statistical analyses due to extreme (i.e., >2.5 *SD* from the mean) scores in the dwell time measures.[1] These extreme scores were mainly in the final block, suggesting the conscious employment of a strategy; henceforth, $n = 26$.

Time to decision. On average, participants spent 2,682 ms viewing the face and objects before hitting spacebar to declare that they had reached a decision about which object they preferred. A 2 (gaze congruency condition) × 6 (block) within-subjects analysis of variance (ANOVA) revealed no significant main effects or interaction, although there was a trend for decision time to reduce over the blocks (e.g., Block 1 = 2,891 ms; Block 6 = 2,479 ms), $F(5, 125) = 2.03$, $MSE = 509{,}367$, $p = .079$, $\eta_p^2 = .08$. However, the central manipulation of responsive gaze congruency did not influence the time to make a decision (other Fs < 1.2), which suggests that participants were not delaying their choice overall in one condition relative to another.

Face preview dwell time. While deciding which object they preferred, participants spent on average 1,346 ms looking at the task-irrelevant face. Again, this duration reduced over time, with the block main effect reaching significance, $F(5, 125) = 2.53$, $MSE = 117{,}134$, $p = .032$, $\eta_p^2 = .09$ (e.g., Block 1 = 1,430 ms; Block 6 = 1,228 ms). The main effect of gaze congruency did not approach significance, $F(1, 25) < 1$. The interaction was significant, $F(5, 125) = 2.85$, $MSE = 9{,}491$, $p = .018$, $\eta_p^2 = .10$, such that the duration of fixation on the faces that would—later in the trial—follow the participants' eyes reduced more quickly than fixation duration on the faces that would look in the opposite direction. The emergence of this effect over time was confirmed through a significant linear contrast of the interaction of gaze congruency condition and block, $F(1, 25) = 6.65$, $MSE = 7{,}714$, $p = .016$, $\eta_p^2 = .21$ (higher order contrasts were nonsignificant; see Figure 2).

Gaze bias. We calculated the time spent looking at the object that the participant eventually chose as a proportion of time spent

[1] Excluding this participant from the analysis of the eye-tracking data does not change the pattern of data markedly. However, the only statistical change of note is that the p value of the linear contrast of the face preview duration measure (Block × Responding Gaze Congruency) rises from .048 to .060. As this crosses the $\alpha = .05$ boundary, we ran a combined analysis with Experiments 1 and 4, with experiment as a between-subjects factor ($n = 63$) on the face preview duration measure. Now, the linear contrast interaction was significant, $F(1, 61) = 10.26$, $MSE = 11{,}218$, $p = .002$, $\eta_p^2 = .14$. Furthermore, we conducted Bonferroni-corrected ($\alpha = .0083$) post hoc contrasts to examine the effect of joint attention in each block, which showed that a significant effect of gaze congruency condition emerged only in the final block, $t(62) = 2.74$, $p = .008$, $d = 0.34$ (all other ps $> .11$). These additional analyses show that the growing effect of gaze congruency condition—though subtle—was solid over these two experiments as a whole. We thank an anonymous reviewer for suggesting these additional analyses.

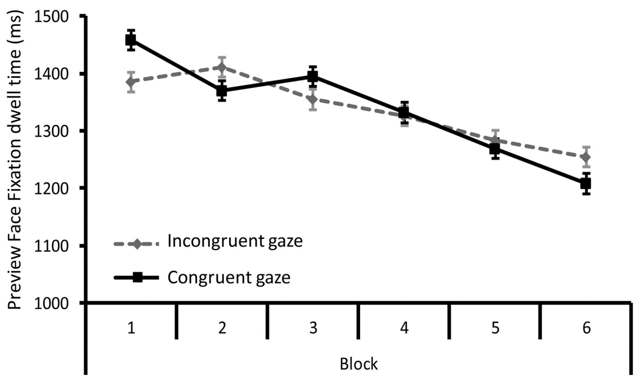

Figure 2. Graph of the average total fixation duration on the face for the two face type conditions and six experimental blocks in Experiment 1. Over the course of the experiment, participants spent progressively less time fixating the congruently gazing faces than the incongruently gazing faces. Error bars represent within-subjects standard error for the linear contrast interaction (Loftus & Mason, 1994).

fixating the two objects while deciding between them. Values above .5 indicate a bias in dwell time during the pre-choice period for looking longer at the object that the participant will choose than the object the participant will reject. In both the responding gaze congruent condition (M = .517) and the responding gaze incongruent condition (M = .514), a gaze bias favoring the chosen object was evident, one-sample ts(25) > 2.2, ps < .05. To investigate whether the gaze bias effect varied across conditions, we performed a 2 × 6 ANOVA, as above. It showed no significant effect of block or interaction of gaze bias with block (Fs < 1). Hence, the gaze bias effect was consistent across conditions and over the experiment.

Saccade latency during choice. To indicate their choice, participants were required to make a saccade toward their chosen object. The latency of this eye movement (M = 377 ms) after the tone sounded was analyzed in a 2 × 6 ANOVA. The analysis showed that although speeded saccadic reaction times (sRTs) decreased over the blocks, $F(5, 125) = 3.60$, MSE = 10,670, p = .004, $\eta_p^2 = .126$, neither the main effect of responding gaze congruency nor the interaction approached significance (Fs < 1). This null effect again shows that participants were not delaying one response over another as a function of gaze congruency. This suggests that participants were engaging with the task in the manner that we wished them to: to approach the task as one of object choice and to disregard the face while executing their choice behavior. It also suggests that any effect of gaze congruency found later in the episode is unlikely to be due to some form of carryover effect from this measure.

Return-to-face latency. After fixating the object, participants were instructed to return to the face. On average, this returning saccade was executed 1,879 ms after looking at the object. A 2 × 6 ANOVA revealed that this latency reduced over the course of the experiment, with a significant effect of Block, $F(5, 125) = 8.72$, MSE = 449,232, $p < .001$, $\eta_p^2 = .26$ (e.g., mean in Block 1 = 2,316 ms, mean in Block 6 = 1,602 ms). More important, participants returned to responding gaze congruent faces (M = 1,844 ms) more quickly than to responding gaze incongruent faces (M = 1,913 ms), $F(1, 25) = 10.2$, MSE = 37,223, p = .004, $\eta_p^2 = .29$. The interaction was nonsignificant, $F(5, 125) = 1.43$, MSE = 20,361, p = .22, $\eta_p^2 = .05$, indicating that this effect was present from early exposures to the faces and persisted throughout (see Figure 3).

Object ratings and face preference. As a manipulation check, the correlation coefficient between the pleasantness rating assigned to an object and the number of times that object was chosen during the main experiment was calculated. This is important, because if one assumes that the participant was expressing a true opinion about the objects in the experiment, then one would expect a positive correlation between the two measures. That is, an object that was seldom chosen during the experiment should receive a lower pleasantness rating than an object that was often chosen. Participants had, on average, correlations between their ratings and choice frequencies of more than zero (mean r = .33), as revealed by a one-sample t test, $t(25) = 4.28$, $p < .001$, d = 0.39.

Finally, in the face preference task, participants preferred the faces that produced congruent gaze shifts (59% of pairs), as revealed by a one-sample t test, $t(25) = 2.72$, p = .012, d = 0.53. This suggests that having one's eyes followed in this kind of paradigm leaves a positive affective trace that is linked in memory with the face that followed one's eyes.

Discussion

This experiment investigated participants' eye movement behavior following exposure to faces responding to participants' gaze shifts in a congruent manner (i.e., looking in the same direction that the participant looked) or an incongruent manner (i.e., looking in the opposite direction). The data suggest that online measures of fixation dwell time and saccade latency as well as explicit preference judgments are influenced by exposure to episodes in which simulated joint attention incidentally emerges compared with episodes in which the gaze of the face and participant does not align.

Evidence from the gaze bias and affective evaluation of the objects suggests that in general, participants did engage with the

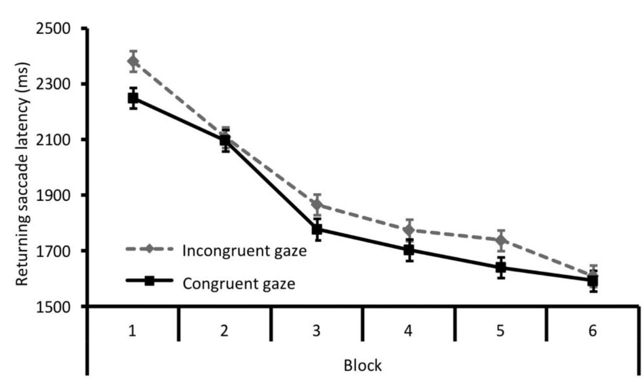

Figure 3. Graph illustrating the average latency of the self-paced saccade returning to the central face at the end of the trial, for Experiment 1. Over the experiment, participants returned more rapidly to faces that had produced congruent gaze shifts than to incongruently gazing faces. Error bars represent within-subjects standard error for the main effect of gaze congruency (Loftus & Mason, 1994).

task primarily as an object preference task. Furthermore, null effects in the time to decision and choice sRT measures show that general performance measures that do not directly refer to the interaction per se are unaffected by gaze congruency. Further, there was no evidence in the debriefing procedure that participants were in any way intentionally altering their behavior as a function of the congruency condition. Moreover, the participants were not aware that there was any contingency between their behavior and particular faces' responses. Therefore any effect of congruency over time is likely to be due to nonexplicit processing of the behavior of individual faces. These data are useful because although they do not bear heavily on our central hypotheses, they do provide a validation of the paradigm.

The clearest and most consistent behavioral effect noted in Experiment 1 was that participants were quicker to return to the central face at the end of the trial when that face had looked in the same direction that the participant had decided to look. To investigate the reliability of this return to face latency effect and to specify further the nature of the behavior, we briefly describe two experiments replicating the design of Experiment 1, but with analysis mainly focusing on this measure of interest.

Experiment 2

One question about the unspeeded return to face latency measure from Experiment 1 is whether participants are more readily refixating the central face on congruent trials or are instead fixating the chosen object for longer on incongruent trials. The measure as implemented in Experiment 1 cannot distinguish these object-based effects and face-based explanations. That is, it is possible that participants are motivated to reengage more quickly with reciprocating individuals and, analogously, with the gaze congruent faces than with gaze incongruent faces. Alternatively, it is possible that faces looking at the participant's nonpreferred object result in a time-consuming reevaluation of the participant's selected object, which prolongs return to face latencies on incongruent face trials.

In order to distinguish between these two possibilities, we compared directly two ways of presenting the objects to participants. During half the blocks, participants could see the objects throughout each episode, as in Experiment 1. During alternate blocks, both objects were replaced with a pattern mask immediately following choice declaration (when participants pressed the spacebar to indicate that they had chosen a preferred object) but prior to execution of choice and returning saccades. This visual mask comprised a dense array of randomly oriented black lines on a white background. If the return to face latencies toward incongruent gazing faces was elongated in Experiment 1 because of a time-consuming reevaluation of the chosen object (i.e., an *object-based* effect), this effect should be eliminated in the masked condition of the present experiment, where the critical stimulus was not available for viewing. If, however, the return to face latency effect is replicated even under these masked conditions, we could conclude that the effect is primarily a *face-based* effect, driven by differences in the readiness to reengage with reciprocating versus nonreciprocating faces.

A power analysis based on the observed effect size of the main effect of gaze congruency on the return to face latency measure in Experiment 1 suggested that a sample size of 12 would yield a high level of power (.98) to observe statistically reliable effect. Twelve participants (six women, six men, mean age = 21.3 years, SD = 1.9 years) volunteered for this experiment. Experiment 2 was identical to the eye movement task used in Experiment 1, with the sole difference that in alternating blocks, the objects were replaced with masks prior to the object-directed saccade (six blocks, beginning with mask or no mask for alternate participants). Our statistical analyses focused solely on eye movement measures that showed a statistically significant effect of gaze congruency in Experiment 1.

In line with Experiment 1, the results showed shorter return-to-face latencies on gaze congruent trials than gaze incongruent trials, both when the objects were masked (1,547 ms vs. 1,593 ms), $t(11) = 2.30$, $p = .042$, $d = 0.66$, and when they were not (1,424 ms vs. 1,496), $t(11) = 3.58$, $p = .004$, $d = 1.02$. The ANOVA revealed a significant effect only of gaze congruency, $F(1, 11) = 11.3$, $MSE = 3{,}776$, $p = .006$, $\eta_p^2 = .51$; the main effect of mask condition and the interaction were nonsignificant (Fs < 1.7, ps $>$ .2). That the return to face latency effect is significant even when the objects are masked prior to being foveated suggests that the faster saccades toward a gaze congruent face are driven mainly by face-based effects (i.e., facilitated looking back to a reciprocating face) rather than by object-based effects.

Although we were primarily interested in the return to face latency effect, we also investigated face dwell time on the congruent and incongruent faces prior to the object choice decision, as this measure had also revealed an effect of gaze congruency in Experiment 1. However we found no evidence for the steeper reduction in face dwell time over blocks in this experiment, $F(1, 11) < 1$. It is worthwhile speculating as to why this effect failed to replicate here, when the alteration to the design affected only half of the trials, concerned the objects rather than the face, and occurred after the face dwell time measure had already been taken for a given trial. However, considering that the effect—as it appeared in Experiment 1—was a learning effect, emerging over time, it is very likely that this learning can easily be disrupted through the manipulation of the stimuli. In contrast, however, the return to face latency effect does not appear to be a learning effect, because it is present throughout the experiment and appears to be due to the online processing of the individual trial. Hence, these two effects appear to be generated by different mechanisms, need not coexist, but yet depend on the specific demands of the task.

Experiment 3

In this experiment, we aimed to further specify the conditions under which the return to face latency effect could emerge. In Experiment 2, we showed that the effect was driven principally by the face rather than the object. Hence, participants return their eyes to faces more quickly when the faces' eyes are looking at the same object as the participant. However, because this effect was significant under unspeeded conditions in Experiments 1 and 2, it is not clear as to the relative contribution of low-level perceptual processing of the face and high-level motivational (or strategic) processing of the face as a social entity. From the gaze perception and gaze cuing literature, we know that low-level visual processing of the eyes underpins social attention to a great extent (see Bayliss et al., 2007, for review) but also that high-level factors such as theory of mind (e.g., Nuku & Bekkering, 2008) and shared attention

(Böckler, Knoblich, & Sebanz, 2011) can modulate gaze processing.

It is a plausible, yet to our knowledge untested, hypothesis that the pupils of a peripherally located face shifting toward the participant's current fixation location in the gaze congruent condition may be more salient than the eyes shifting away (gaze incongruent condition). One way to test whether the low-level difference between the congruent and incongruent conditions contributed strongly to the emergence of quicker returning saccades in Experiments 1 and 2 under unspeeded conditions is to repeat the experiment under speeded conditions and using the observed eye movement itself as the imperative stimulus. If the return to face latency effect emerges again, this would suggest that low-level stimulus factors contribute strongly to the effect, whereas if the effect fails to replicate under speeded conditions, this would imply the influence of higher level social cognitive and motivational factors. Hence, participants were asked to return their eyes as quickly as possible to the central face as soon as they detected the onset of the face's eye movement. Apart from this alteration of task instructions, Experiment 3 was the same as Experiment 1. Note that the reported sRTs in this experiment are timed from the onset of the eye movement of the central face.

Twelve participants (eight women, four men, mean age = 19.9 years, *SD* = 1.7 years) completed this experiment and showed no reliable advantage for sRT on congruent trials (765 ms) than on incongruent trials (786 ms), $t(11) = 1.22$, $p = .24$, $d = 0.35$. This null effect suggests that the return to face saccade latency effect observed in Experiment 1 is unlikely to be due solely to low-level stimulus differences between observing a face in the periphery look toward or away from one's current locus of regard; hence, higher level motivational factors may be involved in driving the effect. Further work is needed to fully examine the dynamics of the underlying mechanism and its possible relation to the reward system (see Schilbach et al., 2010).

We also analyzed the face dwell time data from the preview period, which in Experiment 1 showed a faster linear decline in dwell time on the congruent gaze faces than the incongruent gaze faces, but no such effect was observed in Experiment 2. Here, we discovered a statistical trend for the same linear contrast interaction term, in the same direction as in Experiment 1, $F(1, 11) = 4.06$, $MSE = 6{,}397$, $p = .069$, $\eta_p^2 = .27$, due to a general decline in dwell time spent on the congruent gaze faces relative to incongruent gaze faces as the experiment progressed (−56ms, −6ms, 14ms, −1ms, 96ms, −5ms, Blocks 1–6, respectively; positive values indicate blocks where fixation dwell time on incongruent faces exceeded dwell time on congruent faces). This trend suggests that the change in task instructions did not completely disrupt the learning effect, unlike in Experiment 2, where the disruption of the visual display on half the trials did appear to prevent the emergence of this learning effect. Although we may only be able to speculate at this stage and some of our conclusions are based on a statistical trend (though note that the effect size of this effect is numerically larger than in Experiment 1; η_p^2s = .27 and .21, respectively), it appears that these two effects are due to the operation of separate mechanisms. One mechanism utilizes an online processing of the scene that influences the return to face latency and is sensitive to task instructions. The other influences preview face dwell time over time and is based upon learning processes that are sensitive to the consistency of the visual presentation of the object stimuli.

Experiment 4

Having established in Experiments 2 and 3 some of the boundary conditions and contextual factors that appear to be important for the emergence of some of the effects we describe in Experiment 1, we now return to the task and visual presentation of stimuli that we introduced in Experiment 1. As well as replicating the effects shown in Experiment 1, the main aim in Experiment 4 was to investigate whether the gaze leading paradigm would also permit measuring effects of gaze congruency on participants' object preferences, if individual objects are consistently paired with gaze congruent versus gaze incongruent faces.

The fourth experiment is broadly a replication of the first; hence, we make the same predictions regarding the gaze behavior of participants under gaze congruent and gaze incongruent conditions. However, to build on the intriguing results from Experiment 1, we took a closer look at the object choice decisions participants were making during the task. As we noted in the introduction, our previous work has shown that affective evaluations of objects are modulated when others look at them (e.g., Bayliss et al., 2006). Here, we wanted to investigate the influence of observing a face produce a congruent eye movement in response to one's own gaze shift on preference decisions. To focus on this issue, we ensured that the object pairs, and not just faces (see Experiment 1), would appear in only one of the two gaze congruency conditions. Recall that in Experiment 1, we ensured only that each object category (kitchen or garage) would appear equally often across conditions. In Experiment 4, we further ensured that specific object pairs would consistently appear in a single gaze congruency condition; thus, we were able to inspect the effect of congruency condition on object choice *consistency* (i.e., the reliability of object choices over experimental blocks).

We predicted that engaging in a reciprocated gaze shifting episode would increase the consistency with which participants make their object choices within each object pair. On the other hand, interacting with a face that always looks away from the participants' chosen object would disrupt the decision-making process and therefore lead to participants' changing their mind more often with respect to which object they prefer, reducing choice consistency. Interacting with gaze incongruent faces, which always make the alternative choice to one's own choices, may also impact the expression of one's affective response to objects. As we anticipated these object choice effects to be subtle, and to also allow us to reexamine the gaze dwell and latency effects discussed in the previous three experiments, we recruited a larger sample than in the previous experiments.

Method

Participants. Forty women participated (mean age = 20.5 years, *SD* = 3.4 years) in return for payment (AUD10) or course credit. All had normal or corrected-to-normal vision and gave informed consent.

Stimuli and apparatus. We used the stimulus set from Experiment 1, except for one pair of faces and two pairs of objects that were discarded in order to allow us to retain a balanced design following the modification of the paradigm whereby the conditions in which different object pairs appear was controlled and manipulated as an experimental factor. That is, we needed to have four pairs of either object category (kitchen or garage) in either gaze congruency condition. The apparatus was identical to that used in Experiment 1.

Design and procedure. The design was identical to Experiment 1, except that additional control over the appearance of the objects was employed. Because the experiment now controlled the appearance of the objects as well as the faces, the object pair–gaze congruency condition mapping was counterbalanced. Hence, four versions of this experiment were used to counterbalance the face group and object subgroups (2 × 2). Statistical analyses were performed in the same manner as Experiment 1. An additional dependent measure was introduced to investigate the influence of gaze congruency condition on object choice consistency as a function of which congruency condition a given object pair appeared in over the session (see Results section). The procedure was identical to that in Experiment 1.

Results

Eye movement measures. Two participants' data were excluded from statistical analyses of eye movements due to extreme mean values (>2.5 *SD* away from the group mean) in one of the eye movement measures of interest (the return-to-face latency measure; one participant) and due to random object choice behavior (one participant; i.e., choice consistency measure was close to zero, suggesting that the participant was not expressing a true opinion about the objects as per task instructions). Henceforth, $n = 38$.

Time to decision. On average, participants spent 2,457 ms viewing the face and objects before hitting the spacebar to declare that they had reached a decision about which object they preferred. As in Experiment 1, this decision time reduced over the blocks (e.g., Block 1 = 2,956 ms; Block 6 = 2,066 ms), $F(5, 185) = 12.5$, $MSE = 534{,}332$, $p < .001$, $\eta_p^2 = .25$. Neither the main effect of gaze congruency nor the interaction was significant (*F*s < 1), again showing that the time needed to choose an object was unaffected by gaze congruency condition.

Face preview dwell time. Participants spent on average 1,283 ms looking at the face before hitting spacebar to declare they had decided upon a preferred object. This duration reduced over the blocks, $F(5, 185) = 7.36$, $MSE = 166{,}791$, $p < .001$, $\eta_p^2 = .17$ (e.g., Block 1 = 1,449 ms; Block 6 = 1,074 ms). Neither the main effect of gaze congruency nor the interaction reached significance, $F(1, 37) = 1.85$, $MSE = 11{,}238$, $p = .18$, $\eta_p^2 = .05$, and $F(5, 185) = 1.10$, $MSE = 11{,}789$, $p = .36$, $\eta_p^2 = .03$, respectively. However, the linear contrast of the gaze congruency and block interaction did reach significance, as in Experiment 1, $F(1, 37) = 4.18$, $MSE = 11{,}238$, $p = .048$, $\eta_p^2 = .10$ (see Figure 4; higher order contrasts were not significant).

Gaze bias. As in Experiment 1, we observed significant fixation biases for the to-be-chosen object in both the gaze congruent condition ($M = .517$) and the gaze incongruent condition ($M = .518$), $ts(37) > 3.7$, $ps < .001$. Again, this did not vary across gaze congruency conditions (*F*'s < 1).

Saccade latency during choice. As in Experiment 1, mean sRT (352 ms) reduced over blocks, $F(5, 185) = 7.40$, $MSE = 9{,}583$, $p < .001$, $\eta_p^2 = .167$, but did not vary as a function of gaze congruency (*F*s < 1). This showed again that gaze congruency condition did not affect the sRT of the primary task itself.

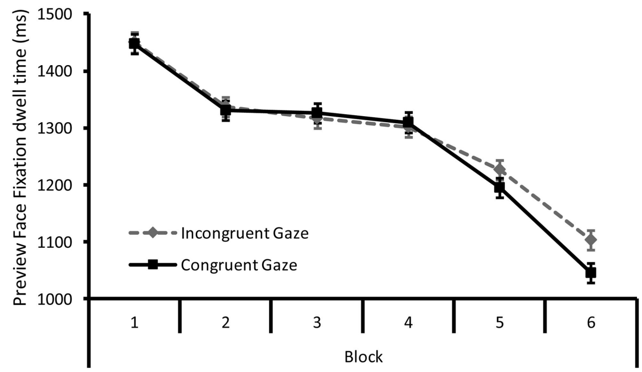

Figure 4. Graph of the average total fixation dwell time on the face, for each face type in Experiment 4. As in Experiment 1, participants spent progressively less time fixating the congruently gazing faces than the incongruently gazing faces. Error bars represent within-subjects standard error for the linear contrast interaction (Loftus & Mason, 1994).

Return-to-face latency. Participants fixated the object for an average of 1,637 ms before returning to the face. There was again a significant effect of block, $F(5, 185) = 23.7$, $MSE = 187{,}125$, $p < .001$, $\eta_p^2 = .39$ (e.g., mean in Block 1 = 2,051 ms, mean in Block 6 = 1,380 ms). Replicating the finding from Experiments 1 and 3, participants returned to gaze congruent faces ($M = 1{,}604$ ms) quicker than to gaze incongruent faces ($M = 1{,}670$ ms), $F(1, 37) = 6.08$, $MSE = 82{,}403$, $p = .018$, $\eta_p^2 = .14$. As in Experiment 1, the Gaze Congruency × Block interaction did not approach significance, $F(5, 185) < 1$ (see Figure 5).

Choice consistency. To calculate a measure of choice consistency, we took the absolute value of the number of times Object 1 was chosen from the number of times Object 2 was chosen (i.e., |Obj1 – Obj2| = choice consistency) for each object pairing . Thus, if for a given object pair, a participant always chooses Object 1, then the choice consistency measure would be 12 (as each pair appears a dozen times). If the participant alternates choices (i.e., choose Object 1 six times and Object 2 six times), the choice consistency is zero. Because the absolute value is taken, it does not matter if the participant chooses Object 1 or Object 2 more often. The choice consistency for each object pair is averaged with those for the other object pairs to produce a mean object choice consistency value for each participant.

On average, choices between object pairs were made consistently: One object was favored over the other in a given pair on an average of 9.14 times out of 12. Importantly, a paired-samples *t* test showed that this consistency was significantly higher for object pairs that appeared alongside faces in the gaze congruent condition than alongside faces in the gaze incongruent condition, $t(37) = 2.72$, $p = .01$, $d = 0.45$ (see Figure 6). Because the data trended toward violating normality assumptions (Kolmogorov–Smirnov $ps < .07$), we also performed a nonparametric test (Wilcoxon's signed ranks test), which was also significant ($p = .037$). Hence, participants made more consistent forced-choice decisions for object pairs that were presented alongside a face that would follow their gaze to the object than with a face that would look at the alternative object.

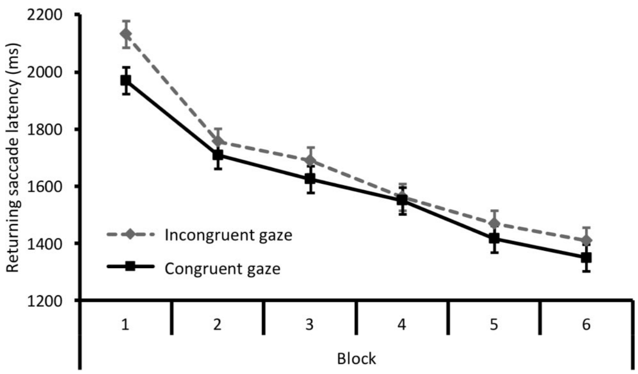

Figure 5. Graph illustrating the average latency of saccades returning to the face at the end of trials in Experiment 4. As in Experiment 1, participants returned more rapidly to faces that had looked in the same direction as the participant than to faces that looked in the opposite direction. Error bars represent within-subjects standard error for the main effect of the gaze congruency condition (Loftus & Mason, 1994).

Object ratings and face preferences. As in Experiment 1, the correlation coefficient between the pleasantness rating a given participant assigned to an object and the number of times that object was chosen during the main experiment was calculated. One participant had an extreme, negative correlation ($>$2.5 *SD* from the mean) and was removed from subsequent analyses. Mean correlation coefficients were greater than zero, as revealed by *t* tests performed on data relating to objects in the gaze congruent condition, $t(36) = 13.2$, $p < .001$, $d = 2.17$, $M = .50$, and objects in the responding gaze incongruent condition, $t(36) = 9.79$, $p < .001$, $d = 1.61$, $M = .43$. Interestingly, the difference between these average correlation coefficients trended toward significance, as revealed by a paired-samples *t* test, $t(36) = 1.91$, $p = .064$, $d = 0.31$. Hence, the condition in which the objects appeared influenced the degree to which the participant's choice behavior during the experiment matched the participant's explicit ratings of the objects. The relationship between explicit ratings and earlier choice behavior was more consistent with objects that had appeared next to faces that made congruent gaze shifts in response to the participant's saccade than with objects that had appeared alongside faces that always looked in the opposite direction. This is an intriguing result, but as it is only a statistical trend that emerged following the removal of a third outlier, we simply cautiously note the trend. As to the face preference task, participants did prefer the congruently gazing faces (55% of pairs), but unlike in Experiment 1, this bias did not reach significance, $t(37) = 1.31$, $p = .20$, $d = 0.22$.

Discussion

This experiment replicated the temporal aspects of fixation during an incidental gaze-based interaction that we observed in Experiment 1 and partially observed in Experiments 2 and 3. Of particular note was the face preview fixation dwell time effect, by which participants spent progressively less time fixating the gaze congruent faces prior to object choice as the experiment progressed. The return to face latency effect, whereby participants rapidly reengage with gaze congruent faces, was again observed. All of the null effects observed in Experiment 1 were also replicated in Experiment 4 (e.g., choice saccade latency, overall viewing time).

One effect that failed to replicate from Experiment 1 was face preference. In the ratings session after the gaze leading task, participants in Experiment 1 preferred the faces that followed their gaze significantly more often than the faces that gazed in the opposite direction. Although the participants in Experiment 4 also selected more following faces as preferable, this effect was not statistically reliable. This is surprising, given that Experiment 4 had a greater sample size. One possibility for the less reliable effect in Experiment 4 is that this effect was transferred to the objects: As Experiment 4 used consistent object–face condition pairings, it is possible that gaze congruency behavior was attributed to the objects rather than the faces, for instance because consistent gaze congruency–object pairings implicitly refocused attention away from the faces (we thank a reviewer for this interesting suggestion). On the other hand, it is important to note that we had reduced the number of faces in Experiment 4, so each participant made only eight choices, as opposed to nine in Experiment 1. Hence, dropping one pair of faces disproportionately affected the sensitivity of this measure. In sum, therefore, although our data with this measure are inconclusive, we suspect that an affective boost for faces that follow participants' eyes likely does occur, but future work with more powerful designs is required to determine this one way or the other.

Of greater importance to this experiment was the way in which having one's eyes followed or not followed influenced the object choice behavior of our participants. The novel finding here is that observers are more likely to persist in choosing one individual object over another in a forced-choice evaluation task if they experience an interactive partner follow their eyes to that chosen object. Whereas, if a face looks the other way, toward the other object, then the next time that object pair is encountered, participants are more likely to alter their explicit preference and choose the alternate object. In other words, relative to a gaze congruent

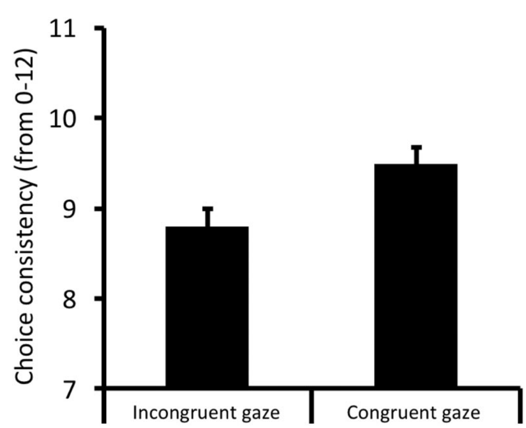

Figure 6. Graph showing choice consistency for objects appearing in the two gaze congruency conditions in Experiment 4. Participants' preferences were significantly more reliable for choices between objects that appeared alongside gaze congruent faces than for object pairs that appeared next to gaze incongruent faces in Experiment 4. Error bars represent within-subjects standard error (Loftus & Mason, 1994).

scenario, observing a face look in the opposite direction to one's gaze shift disrupts evaluative decision making. Note that this effect of object choice emerges despite (a) the measure being taken before the face on each trial has actually moved its eyes and (b) the fact that while faces and object pairs appeared in only one condition, specific object pairs were not tied to specific face identities.

General Discussion

We investigated the temporal aspects of eye movements during a computer-based triadic interaction and the impact of observed gaze congruency on affective preference for faces and objects. In particular, we were interested in examining the behavior and evaluative judgments of participants when their saccades were mirrored by a face on the screen, compared with when their eye movements caused the face on the screen to orient in the opposite direction.

The approach we utilized combined strong experimental control over the stimuli participants were exposed to with a naturalistic, free-viewing eye movement task (cf. Redcay et al., 2010; Wilms et al., 2010). This approach enabled us to establish the temporal dynamics of eye movements during scenarios where the responding face produces congruent and incongruent gaze shifts with respect to the participant's own eye movement. Furthermore, we were able to examine the influence of gaze congruency on subsequent behavior with a particular person. We did this by introducing participants to the faces of different individuals; some of these would consistently follow participants' eyes to their favored object, and others would always look to the other object on the screen.

Finally, in Experiment 4 we were also able to ask whether these interactions had an impact on participants' choice preference behavior when deciding which of two objects they preferred. In each experiment, participants saw a face, flanked by two objects, and were simply asked to look at each object at least once and decide which they preferred. They then looked at their preferred object. The face on the screen would then respond—if it were a gaze congruent face, it would look at the same object, whereas a gaze incongruent face always looked at the nonchosen object. The participant then returned their eyes to the centrally positioned face. During these trials, we discovered systematic biases in participants' gaze behavior. Therefore this paradigm provided answers regarding (a) the online behavior of an individual whose eyes are followed/ignored during an interaction, (b) the influence of consistent exposures to congruent or incongruent gaze behavior with a particular face identity on behavior during subsequent interactions, and (c) the impact of congruent or incongruent responses on the affective evaluation of the interactive face and on the objects in the gaze leading scenario.

First, the amount of time participants spent fixating on the face changed over the course of the experiment. They spent progressively less time looking at the face while they were making their choice between the two objects. This presumably reflects a familiarization effect, both with the task and with the face stimuli themselves. More important, however, in Experiments 1 and 4, this decline in face fixation dwell time over time was exaggerated with the gaze congruent faces, relative to faces that consistently oriented in the opposite direction to the participant's gaze (and in Experiment 3, this effect trended toward significance). Note that this measure applies only to the *preview* period of the trial (i.e., before the face has "done" anything in the trial). Hence, this effect can be driven only by the participant's memory of the behavior of a given face in previous encounters. We speculate this is because faces that consistently fail to follow one's eyes are perceived as norm violators, and as such they require additional processing during social interactions (cf. Chiappe et al., 2004). Conversely, faces that consistently follow the observer's gaze may not capture gaze in this way, because their behavior, although just as *predictable* as the other faces, is expected and easier to process than that of the faces that act in a contrary manner. This effect was absent in Experiment 2, in which the objects were masked during half of the blocks, suggesting that this learning effect is highly sensitive to contextual factors (i.e., similar to "influential companions" effects; Poulton, 1982).

To help us further contextualize these effects, we note that there were several informative null effects during this preview period, examined closely in the experiments with larger sample sizes (Experiments 1 and 4). For example, participants did not simply spend more time deciding between the objects when confronted with an incongruent face. Furthermore, their gaze bias in favor of the object they eventually chose on a given trial was also completely unaffected by the experimental condition of the face. Finally, the saccadic reaction time elicited when demonstrating their preference was also equivalent for both gaze congruency conditions. These null effects suggest that the decision-making process per se was not disrupted by the gaze leading manipulation. Instead, only the interactive component, namely the face fixation dwell time, was sensitive to the manipulation. It therefore appears that the gaze direction information contained in the interactive episodes (congruent or incongruent gaze) with the previous encountered faces, rather than the specific object choices made by the participant, was driving this face fixation dwell time effect.

The second important finding relates to the latency of the final saccade during each trial that the participants were asked to execute. After fixating their chosen object, participants returned their gaze to the center of the screen, where the face remained looking either at the object the participant had chosen or the alternative. In Experiments 1, 2, and 4, participants were indeed reliably quicker to look back to the center of the screen on responding gaze congruent trials than on responding gaze incongruent trials. This effect was stable over time and so did not depend upon learning the contingencies of the task. Because this measure was taken following the faces' own eye movement toward one of the objects on the screen, the difference in saccade latency between the conditions most likely reflected a response to the online behavior of the face. Experiment 2 was able to show that this effect is indeed face based, rather than due to prolonged object processing. Hence, perceiving the face's eye movement occurring in their peripheral vision after following their own may have facilitated this return saccade more strongly than observing the face look in the opposite direction. However, Experiment 3 showed that this effect was unreliable under speeded saccadic reaction time conditions, giving little support to a purely low-level, stimulus-driven account of the effect.

These experiments also tapped into the affective processes that may be involved in incidental gaze leading episodes. During casual debrief, participants were never able to verbalize the central manipulation of the experiment—they did not explicitly notice that the faces were consistent in behavior. Nevertheless, in Experiment

1, participants preferred the faces that consistently engaged in joint attention to the faces that did not. Although this effect did not reach significance in Experiment 4, we feel it is worthy of discussion. A preference for faces that engage in congruent gaze behavior has been noted in previous studies investigating *gaze cuing*, which in some ways is the mirror paradigm to the present gaze leading task (Bayliss et al., 2009; Bayliss & Tipper, 2006). In their studies, Bayliss and colleagues showed faces that consistently looked at the location of an upcoming target were preferred to faces that looked toward empty space. Hence, the observed effect described in the present report shows that the inverse relationship can also be true: Someone who follows you is liked more than someone who does not.

In Experiment 4 we also explored the affective impact of the congruity of the face's response to the participant's eye movement on choice behavior and object ratings. We were able to do this not only by controlling the conditions in which different faces appeared (i.e., responding gaze congruent vs. incongruent) but also by ensuring that particular object pairs appeared in only one congruency condition throughout an experimental session. We found that participants' choice behavior was more consistent when the objects they were choosing between were presented in the congruent gaze condition than the incongruent condition. In particular, participants' choices between object pairs—indicated by moving their eyes to the object—were less likely to change on subsequent presentations of that same object pair. Note here that again, this choice decision occurred before the face on the screen followed or opposed the participants' eye movement. This effect therefore reflects the recall of the previous encounters with that particular object pair. This learning appears to emerge rapidly as a subsequent analysis of this choice consistency measure showed that consistency was equivalent in the first and second halves of the experiment (we thank a reviewer for suggesting this analysis). We again note that although our eye movement measures revealed a certain sensitivity to the outcomes of previous interactions with these faces, participants were not able to report the experimental manipulation, suggesting that explicit processes do not primarily drive these effects.

We propose that after choosing one of the objects and seeing another person also look at it in the gaze congruent condition, participants implicitly felt that their choice had been vindicated and supported by the second party, reinforcing their judgment. On the other hand, in the gaze incongruent trials, the face looked at the other object, thus indicating that its own opinion undermined the participant's choice (Bayliss et al., 2006, 2007). In subsequent presentations of the object pair—likely alongside a different individual incongruently gazing face—participants may become biased to choose differently. Because the congruency of another individual's gaze behavior affects choice behavior, we can imagine that one benefit of monitoring whether one's eyes are being followed is to use social cues as confirmatory feedback about the wisdom of one's own behavior. Again, note that the object gaze bias and choice saccade latency null effects show that how they execute that choice in terms of eye movements is unaffected, but gaze congruency condition nevertheless influences the decision.

A second finding from the object ratings part of the experiment was that participants in Experiment 4 showed a (nonsignificantly) weaker correlation between the number of times an object from the gaze incongruent condition was chosen as preferred during the eye movement task and the affective rating they later gave it in the post-session questionnaire, compared with the objects in the gaze congruent condition. Again, this result suggests a lack of consistency in the evaluative decision making under conditions of anticipated incongruence of the face's eye movement. This interpretation is based on the finding that participants' object ratings—which are made in a different context on a scale from 1 to 9—are less in line with their earlier choice behavior when the object was involved in incongruent gaze interactions than in congruent gaze interactions.

Limitations and Implications for Future Work

By investigating the *initiation* of gaze-based behavior, we have looked at simulated triadic interactions from the perspective of the individual who first looks at the object of joint attention. This topic is understudied relative to the majority of joint attention studies concerned with the follower. However, looking at something in the presence of others is an important social act. Further work is needed to expand on the paradigm presented here. For example, we were concerned with broad fixation pattern over the faces and objects, and despite our crude regions of interests, our data yielded consistent and intriguing results. Future work could focus on fixation patterns within the face, because it is possible that fixations around the eyes of the face may reveal further insights into these effects. Manipulating the manner in which the interactive partner face executes its shift of gaze (e.g., latency between initiator and follower saccades) could also be used as a lever with which to explore the effects of gaze leading. In particular, the execution of the responding shift of gaze could vary in temporal distance from the onset of the leading saccade to reflect more closely the variance in real-life interactions.

To what extent might the effects described in these experiments rely on the operation of processes based on social information? Although we have presented some evidence against a purely low-level explanation of the return to face latency effect (Experiment 3), low-level perceptual information does appear to be vitally important in early gaze following in infants (Farroni, Johnson, Brockbank, & Simion, 2000) and may very well also drive other gaze-based interactions such as social referencing. Moreover, although gaze cuing appears to be based upon low-level visual features of the eye, high-level social, emotional, and other contextual factors influence—and are influenced by—gaze cuing (see Frischen et al., 2007, for review). The specificity to social stimuli or social processes of the effects that we describe here is therefore clearly an interesting question for further research. Might a similar experiment, using nonsocial stimuli, yield identical results?

To answer this, let us refer to the gaze cuing literature, which, in some ways is the inverse paradigm to the present gaze leading paradigm, as it is concerned with incidental, laboratory-based gaze following. The gaze perception system decodes observed gaze direction and then the attention system acts upon this directional information, producing the gaze cuing effect (Bayliss, Bartlett, Naughtin, & Kritikos, 2011; Friesen & Kingstone, 1998). However, directional arrows potentiate almost indistinguishable behavioral effects (e.g., Bayliss, di Pellegrino, & Tipper, 2005; Bayliss & Tipper, 2005; Tipples, 2002). Therefore, gaze and arrow cuing may rely upon the very same domain-general attentional mechanism. However, although the attentional effects appear to be similar, arrows fail to induce affective evaluative effects (Bayliss et al., 2006). Objects that are looked at by faces are preferred to objects that are ignored, yet objects that are pointed at by an arrow are rated equally pleasant as objects that are never pointed at by an arrow. Translating these findings to the present paradigm, one might predict that a symbolic cue version of Experiment 4 would replicate the eye-tracking results but fail to observe the object choice consistency effect. However, we do not know if the learning processes engaged when observing arrows is identical to that engaged when observing face behavior—or whether similar learning processes are engaged at all. This, among other issues, complicates any direct comparisons between arrows and faces, though this issue is clearly worthy of further study.

We aimed to balance our design between ecologically valid tasks and stimuli while concurrently maintaining experimental control. However, we do note that interactive encounters with real people, where true joint attention is available for study—as in the naturalistic experiments employed in the developmental literature—have been shown to uncover rather different attention effects than computer-based designs such as ours (Laidlaw, Foulsham, Kuhn, & Kingstone, 2011; see also a recent field study by Gallup, Hale, et al., 2012, and Schilbach, 2010, for discussion). Our design was focused on measuring task-irrelevant behavior that could serve as indices of processing under conditions where joint attention had—or had not—been achieved on a particular trial or on previous trials with a particular face. It is unknown whether the present paradigm can reliably reproduce behavior similar to that of real-life joint attention episodes. Nevertheless, during casual debrief after Experiments 1 and 4, the experimenter noted that participants found the face's behavior convincing and interactive. For our combined sample in Experiments 2 and 3 (which were the last experiments conducted chronologically), we asked the participants to rate how real the interaction with the faces appeared to them. Of course without a comparison task, these ratings may be of limited utility, but they nevertheless are of interest. Participants gave reality ratings from 1 to 9, anchored by statements by the experimenter that they should "give a rating of one if you felt disengaged with the faces—to you they were just pixels on a computer screen" and "give nine if you actually felt as if you were directly interacting with a real person who was reacting to your actions." The mean rating ($n = 24$) was 6.02, $SD = 1.78$, maximum = 9 (two participants), minimum = 3 (two participants). Clearly, all participants found the task somewhat interactive, though as expected most felt it lacked something they experience in a real interaction.

Again, we note an interesting effect from the gaze cuing literature that shows that when a participant believes that an observed individual can see, gaze cuing is boosted relative to when the same physical stimulus is presented but under conditions where the participant believes the gazer cannot see (Nuku & Bekkering, 2008; Teufel et al., 2010). So, when a real social interaction is assumed, others' gaze information is prioritized; these are small effects but nevertheless imply that the participants' experience when interacting with such stimuli is very important. Similarly highlighting the importance of perceived or potential social interactions, Böckler et al. (2011) showed that observing cartoon faces initially sharing attention toward a common object prior to shifting gaze elsewhere was a more powerful gaze cue than not observing a simulated social interaction prior to the onset of the gaze cue. We believe our participants felt that they were engaging with the faces in an approximation of a social interaction, but further work is clearly required to establish the extent and importance of how convincing the stimuli are at establishing an ecologically valid feeling of a social interaction between stimuli and participant (see also Laidlaw et al., 2011).

Of note also is that the samples in our critical experiments (1 and 4) comprised only female adults. We focused on testing female participants partly because several lines of investigation have shown that male participants show poorer performance in face-based social perception skills. Males show weaker gaze-cuing effects (Alwall, Johansson, & Hansen, 2010; Bayliss et al., 2005) and face recognition (e.g., Lewin & Herlitz, 2002). In pilot testing and in Experiments 2 and 3, which had small numbers of male participants, we found that a generally similar pattern of performance in male and female participants, though it is an open question whether a full sample of men would show effects similar to those presented here, especially given the subtlety of some of our measures. We strongly suspect that individual differences among the normal population—including sex differences—may be found in joint attention initiation, but further work will be required to establish such effects. In this series of experiments, we did not test sufficient men to test for sex differences, so the generalizability of the effects may not extend to men.

With modifications to task demands and optimizations that improve the sensitivity of our measures, this paradigm will hopefully prove useful for studying gaze-based interactive abilities in clinical groups. As noted above, however, the next step will be to examine any sex differences (or lack thereof) in the typical population. But assuming that generalizability can be demonstrated, paradigms such as these will advance our understanding of disrupted social attention from a novel perspective. Individuals with autism spectrum conditions often have particular problems with the development of joint attention skills in infancy (e.g., Leekam, Lopez, & Moore, 2000). Despite these deficits, certain aspects of gaze perception appear to be less disrupted than would be predicted by the social difficulties shown by these individuals. For example, some studies have shown that gaze cuing is impaired in autism (Ristic et al., 2005), but other studies have shown little or no disruption whatsoever (e.g., Kuhn et al., 2010; see Frischen et al., 2007, for review). We suspect that it is in the subtleties of online fluent social interaction that the most profound difficulties will be identified (e.g., Schilbach, Eickhoff, Cieslik, Kuzmanovic, & Vogeley, 2012).

Indeed, it is with joint attention *initiation* rather than with gaze following that individuals with autism appear to have persisting difficulties (see Mundy & Burnette, 2005, for review). Hence, paradigms such as the one described here may be ideal for revealing the underlying mechanisms of impaired social orienting in autism. One may predict that individuals with autism may not be sensitive to the social contingencies of the gaze behavior of the faces in our study (cf. Nichols, Fox, & Mundy, 2005), and hence they may not show the biases in gaze fixation patterns and may be relatively unaffected by the gaze behavior of the faces in their object choices. This is why designs with open-loop interactions that avoid the use of impoverished stimulus displays common to the study of visuospatial attention will prove very useful in the understanding of joint attention and social cognition in general (for a review, see Gallup, Chong, & Couzin, 2012; Schilbach et al., in press). With future work, therefore, we may uncover a more complete picture of the mechanisms underlying the initiation of joint attention, as we have for gaze following (e.g., Bayliss et al., 2011).

Conclusions

We have demonstrated that systematic biases in gaze exploration behavior and forced-choice decision making are induced through the observation of an interactive partner either engaging or failing to engage in gaze following. Initiating joint attention and understanding the consequences of being engaged in such a state are critical for social functioning. Social cognition involves not only understanding other people's independently motivated behavior but also interpreting their responses to our actions (Schilbach et al., in press). In addition, these findings underscore the importance of considering objects as integral components of social interactions that can reveal important aspects of social cognition (Bayliss & Tipper, 2005; Becchio, Bertone, & Castiello, 2008; Frischen et al., 2007; Lobmaier, Fischer, & Schwaninger, 2006). The present work shows that the congruency of responsive gaze shifts can impact decision making and object evaluations as well as modulate the social interaction itself. Future work will continue to elaborate on these complex, multifaceted, yet ubiquitous interactions.

References

Alwall, N., Johansson, D., & Hansen, S. (2010). The gender difference in gaze-cueing: Associations with empathizing and systemizing. *Personality and Individual Differences, 49,* 729–732. doi:10.1016/j.paid.2010.06.016

Argyle, M., & Cook, M. (1976). *Gaze and mutual gaze.* Cambridge, England: Cambridge University Press.

Baron-Cohen, S. (1995). The eye direction detector (EDD) and the shared attention mechanism (SAM): Two cases for evolutionary psychology. In C. Moore & P. J. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 41–59). Hillsdale, NJ: Erlbaum.

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,* 634–644. doi:10.1037/a0020559

Bayliss, A. P., di Pellegrino, G., & Tipper, S. P. (2005). Sex differences in eye gaze and symbolic cueing of attention. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 58*(A), 631–650.

Bayliss, A. P., Frischen, A., Fenske, M. J., & Tipper, S. P. (2007). Affective evaluations of objects are influenced by observed gaze direction and emotional expression. *Cognition, 104,* 644–653. doi:10.1016/j.cognition.2006.07.012

Bayliss, A. P., Griffiths, D., & Tipper, S. P. (2009). Predictive gaze cues affect face evaluations: The effect of facial emotion. *European Journal of Cognitive Psychology, 21,* 1072–1084. doi:10.1080/09541440802553490

Bayliss, A. P., Paul, M. A., Cannon, P. R., & Tipper, S. P. (2006). Gaze cuing and affective judgments of objects: I like what you look at. *Psychonomic Bulletin & Review, 13,* 1061–1066. doi:10.3758/BF03213926

Bayliss, A. P., Schuch, S., & Tipper, S. P. (2010). Gaze cueing elicited by emotional faces is influenced by affective context. *Visual Cognition, 18,* 1214–1232. doi:10.1080/13506285.2010.484657

Bayliss, A. P., & Tipper, S. P. (2005). Gaze and arrow cueing of attention reveals individual differences along the autism-spectrum as a function of target context. *British Journal of Psychology, 96,* 95–114. doi:10.1348/000712604X15626

Bayliss, A. P., & Tipper, S. P. (2006). Predictive gaze cues and personality judgments. Should eye trust you? *Psychological Science, 17,* 514–520. doi:10.1111/j.1467-9280.2006.01737.x

Becchio, C., Bertone, C., & Castiello, U. (2008). How the gaze of others influences object processing. *Trends in Cognitive Sciences, 12,* 254–258. doi:10.1016/j.tics.2008.04.005

Böckler, A., Knoblich, G., & Sebanz, N. (2011). Observing shared attention modulates gaze following. *Cognition, 120,* 292–298. doi:10.1016/j.cognition.2011.05.002

Carpenter, M., Nagell, K., Tomasello, M., Butterworth, G., & Moore, C. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development, 63*(4), 1–174. doi:10.2307/1166214

Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Cox, A., & Drew, A. (2000). Testing joint attention, imitation, and play as infancy precursors to language and theory of mind. *Cognitive Development, 15,* 481–498. doi:10.1016/S0885-2014(01)00037-5

Chiappe, D., Brown, A., Dow, B., Koontz, J., Rodriguez, M., & McCulloch, K. (2004). Cheaters are looked at longer and remembered better than co-operators in social exchange situations. *Evolutionary Psychology, 2,* 108–120.

Corkum, V., & Moore, C. (1995). Development of joint visual attention in infants. In C. Moore & P. J. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 61–83). Hillsdale, NJ: Erlbaum.

Dawson, G., Meltzoff, A., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to social stimuli. *Journal of Autism and Developmental Disorders, 28,* 479–485. doi:10.1023/A:1026043926488

Decety, J., & Sommerville, J. A. (2003). Shared representations between self and other: A social cognitive neuroscience view. *Trends in Cognitive Sciences, 7,* 527–533. doi:10.1016/j.tics.2003.10.004

Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze perception triggers reflexive visuospatial orienting. *Visual Cognition, 6,* 509–540. doi:10.1080/135062899394920

Emery, N. J. (2000). The eyes have it: The neuroethology, function and evolution of social gaze. *Neuroscience & Biobehavioral Reviews, 24,* 581–604. doi:10.1016/S0149-7634(00)00025-7

Farroni, T., Johnson, M. H., Brockbank, M., & Simion, F. (2000). Infants' use of gaze direction to cue attention: The importance of perceived motion. *Visual Cognition, 7,* 705–718. doi:10.1080/13506280050144399

Feinman, S., Roberts, D., Hsieh, K. F., Sawyer, D., & Swanson, D. (1992). A critical review of social referencing in infancy. In S. Feinman (Ed.), *Social referencing and the construction of reality in infancy* (pp. 15–54). New York, NY: Plenum Press.

Franco, F., Perucchini, P., & March, B. (2009). Is infant initiation of joint attention by pointing affected by type of interaction? *Social Development, 18,* 51–76. doi:10.1111/j.1467-9507.2008.00464.x

Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic Bulletin & Review, 5,* 490–495. doi:10.3758/BF03208827

Frischen, A., Bayliss, A. P., & Tipper, S. P. (2007). Gaze cueing of attention: Visual attention, social cognition, and individual differences. *Psychological Bulletin, 133,* 694–724. doi:10.1037/0033-2909.133.4.694

Gallup, A. C., Chong, A., & Couzin, I. D. (2012). The directional flow of visual information transfer between pedestrians. *Biology Letters.* Advance online publication. doi:10.1098.rsbl.2012.0160

Gallup, A. C., Hale, J. J., Sumpter, D. J. T., Garnier, S., Kacelnik, A., Krebs, J. R., & Couzin, I. D. (2012). Visual attention and the acquisition of information in human crowds. *Proceedings of the National Academy of Sciences, USA.* Advance online publication. doi:10.1073/pnas.1116141109

Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition, 40,* 1–19. doi:10.1016/0010-0277(91)90045-6

Kleinke, C. L. (1986). Gaze and eye contact: A research review. *Psychological Bulletin, 100,* 78–100. doi:10.1037/0033-2909.100.1.78

Krajbich, I., Armel, C., & Rangel, A. (2010). Visual fixations and the computation and comparison of value in simple choice. *Nature Neuroscience, 13,* 1292–1298. doi:10.1038/nn.2635

Kuhn, G., Benson, V., Fletcher-Watson, S., Kovshoff, H., McCormick, C. A., Kirkby, J., & Leekham, S. R. (2010). Eye movements affirm: Automatic overt gaze and arrow cueing for typical adults and adults with autism spectrum disorder. *Experimental Brain Research, 201,* 155–165. doi:10.1007/s00221-009-2019-7

Laidlaw, K. E. W., Foulsham, T., Kuhn, G., & Kingstone, A. (2011). Potential social interactions are important to social attention. *Proceedings of the National Academy of Sciences, USA, 108,* 5548–5553. doi:10.1073/pnas.1017022108

Leekam, S. R., Lopez, B., & Moore, C. (2000). Attention and joint attention in preschool children with autism. *Developmental Psychology, 36,* 261–273. doi:10.1037/0012-1649.36.2.261

Lewin, C., & Herlitz, A. (2002). Sex differences in face recognition: Women's faces make the difference. *Brain and Cognition, 50,* 121–128. doi:10.1016/S0278-2626(02)00016-7

Lobmaier, J. S., Fischer, M. H., & Schwaninger, A. (2006). Objects capture perceived gaze direction. *Experimental Psychology, 53,* 117–122. doi:10.1027/1618-3169.53.2.117

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin and Review, 1,* 476–490.

Mathews, A., Fox, E., Yiend, J., & Calder, A. J. (2003). The face of fear: Effects of eye gaze and emotion on visual attention. *Visual Cognition, 10,* 823–835. doi:10.1080/13506280344000095

Moore, C. (2008). The development of gaze following. *Child Development Perspectives, 2,* 66–70. doi:10.1111/j.1750-8606.2008.00052.x

Moore, C., & D'Entremont, B. (2001). Developmental changes in pointing as a function of attentional focus. *Journal of Cognition and Development, 2,* 109–129. doi:10.1207/S15327647JCD0202_1

Morales, M., Mundy, P., & Rojas, J. (1998). Following the direction of gaze and language development in 6-month-olds. *Infant Behavior & Development, 21,* 373–377. doi:10.1016/S0163-6383(98)90014-5

Mosconi, M. W., Cody-Hazlett, H., Poe, M. D., Gerig, G., Gimpel-Smith, R., & Piven, J. (2009). Longitudinal study of amygdala volume and joint attention in 2- to 4-year-old children with autism. *Archives of General Psychiatry, 66,* 509–516. doi:10.1001/archgenpsychiatry.2009.19

Mumme, D. L., & Fernald, A. (2003). The infant as onlooker: Learning from emotional reactions observed in a television scenario. *Child Development, 74,* 221–237. doi:10.1111/1467-8624.00532

Mundy, P. (1995). Joint attention and social-emotional approach behavior in children with autism. *Development and Psychopathology, 7,* 63–82. doi:10.1017/S0954579400006349

Mundy, P., & Burnette, C. (2005). Joint attention and neurodevelopmental models of autism. In F. R. Volkmar, R. Paul, A. Klin, & D. J. Cohen (Eds.), *Handbook of autism and pervasive developmental disorders: Diagnosis, development, neurobiology, and behavior* (pp. 650–681). New York, NY: Wiley.

Mundy, P., & Gomes, A. (1998). Individual differences in joint attention skill development in the second year of life. *Infant Behavior & Development, 21,* 469–482. doi:10.1016/S0163-6383(98)90020-0

Mundy, P., & Newell, L. (2007). Attention, joint attention, and social cognition. *Current Directions in Psychological Science, 16,* 269–274. doi:10.1111/j.1467-8721.2007.00518.x

Nichols, K. E., Fox, N., & Mundy, P. (2005). Joint attention, self-recognition, and neurocognitive function in toddlers. *Infancy, 7,* 35–51. doi:10.1207/s15327078in0701_4

Nuku, P., & Bekkering, H. (2008). Joint attention: Inferring what others perceive (and don't perceive). *Consciousness and Cognition, 17,* 339–349. doi:10.1016/j.concog.2007.06.014

Öhman, A. (2005). The role of the human amygdala in human fear: Automatic detection of threat. *Psychoneuroendocrinology, 30,* 953–958. doi:10.1016/j.psyneuen.2005.03.019

Poulton, E. C. (1982). Influential companions: Effects of one strategy on another in the within-subjects designs of cognitive psychology. *Psychological Bulletin, 91,* 673–690. doi:10.1037/0033-2909.91.3.673

Redcay, E., Dodell-Feder, D., Pearrow, M. J., Kleiner, M., Mavros, L., Wang, J., . . . Saxe, R. (2010). Do you see what I see? The neural bases of joint attention during a live interactive game. *NeuroImage, 50,* 39–47.

Research Network on Early Experience and Brain Development. (2002). *NimStim Face Stimulus Set.* Retrieved from http://www.macbrain.org/resources.htm

Ristic, J., Mottron, L., Friesen, C. K., Iarocci, G., Burack, J. A., & Kingstone, A. (2005). Eyes are special but not for everyone: The case of autism. *Cognitive Brain Research, 24,* 715–718. doi:10.1016/j.cogbrainres.2005.02.007

Scaife, M., & Bruner, J. S. (1975, January 24). The capacity for joint visual attention in the infant. *Nature, 253,* 265–266. doi:10.1038/253265a0

Schilbach, L. (2010). A second-person approach to other minds. *Nature Reviews Neuroscience, 11,* 449. doi:10.1038/nrn2805–c1

Schilbach, L., Eickhoff, S. B., Cieslik, E., Kuzmanovic, B., & Vogeley, K. (2012). Shall we do this together? Social gaze influences action control in a comparison group, but not in individuals with high-functioning autism. *Autism, 16,* 151–162. doi:10.1177/1362361311409258

Schilbach, L., Timmermans, B., Reddy, V., Costall, A., Bente, G., Schlicht, T., & Vogeley, K. (in press). Towards a second-person neuroscience. *Behavioral and Brain Sciences.*

Schilbach, L., Wilms, M., Eickhoff, S. B., Romanzetti, S., Tepest, R., Bente, G., . . . Vogeley, K. (2010). Minds made for sharing: Initiating joint attention recruits reward-related neurocircuitry. *Journal of Cognitive Neuroscience, 22,* 2702–2715. doi:10.1162/jocn.2009.21401

Schneider, D., Bayliss, A. P., Becker, S. I., & Dux, P. E. (2011). Eye movements reveal sustained implicit processing of others' mental states. *Journal of Experimental Psychology: General.* Advance online publication. doi:10.1037/a0025458

Schneider, D., Lam, R., Bayliss, A. P., & Dux, P. E. (in press). Cognitive load disrupts theory of mind processing. *Psychological Science.*

Schotter, E. R., Berry, R. W., McKenzie, C. R., & Rayner, K. (2010). Gaze bias: Selective encoding and liking effects. *Visual Cognition, 18,* 1113–1132. doi:10.1080/13506281003668900

Senju, A., Southgate, V., White, S., & Frith, U. (2009, August 14). Mindblind eyes: An absence of spontaneous theory of mind in Asperger syndrome. *Science, 325,* 883–885. doi:10.1126/science.1176170

Shimojo, S., Simion, C., Shimojo, E., & Scheier, C. (2003). Gaze bias both reflects and influences preference. *Nature Neuroscience, 6,* 1317–1322. doi:10.1038/nn1150

Teller, D. Y. (1979). The forced-choice preferential looking procedure: A psychophysical technique for use with human infants. *Infant Behavior & Development, 2,* 135–153. doi:10.1016/S0163-6383(79)80016-8

Teufel, C., Alexis, D. M., Clayton, N. S., & Davis, G. (2010). Mental-state attribution drives rapid, reflexive gaze following. *Attention, Perception, & Psychophysics, 72,* 695–705. doi:10.3758/APP.72.3.695

Tipples, J. (2002). Eye gaze is not unique: Automatic orienting in response to uninformative arrows. *Psychonomic Bulletin & Review, 9,* 314–318. doi:10.3758/BF03196287

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., . . . Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research, 168,* 242–249. doi:10.1016/j.psychres.2008.05.006

Whalen, P. J., Kagan, J., Cook, R. G., Davis, F. C., Kim, H., Polis, S., . . . Johnstone, T. (2004, December 17). Human amygdala responsivity to masked fearful eye whites. *Science, 306,* 2061. doi:10.1126/science.1103617

Williams, J. H. G., Waiter, G. D., Perra, O., Perrett, D. I., & Whiten, A. (2005). An fMRI study of joint attention experience. *NeuroImage, 25,* 133–140. doi:10.1016/j.neuroimage.2004.10.047

Wilms, M., Schilbach, L., Pfeiffer, U., Bente, G., Fink, G. R., & Vogeley, K. (2010). It's in your eyes: Using gaze-contingent stimuli to create truly interactive paradigms for social and cognitive and affective neuroscience. *Social Cognitive and Affective Neuroscience, 5,* 98–107. doi:10.1093/scan/nsq024

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