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Bound Together: Social Binding Leads to Faster Processing, Spatial Distortion, and Enhanced Memory of Interacting Partners

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The binding of features into perceptual wholes is a well-established phenomenon, which has previously only been studied in the context of early vision and low-level features, such as color or proximity. We hypothesized that a similar binding process, based on higher level information, could bind people into interacting groups, facilitating faster processing and enhanced memory of social situations. To investigate this possibility we used 3 experimental approaches to explore grouping effects in displays involving interacting people. First, using a visual search task we demonstrate more rapid processing for interacting (vs. noninteracting) pairs in an odd-quadrant paradigm (Experiments 1a and 1b). Second, using a spatial judgment task, we show that interacting individuals are remembered as physically closer than are noninteracting individuals (Experiments 2a and 2b). Finally, we show that memory retention of group-relevant and irrelevant features are enhanced when recalling interacting partners in a surprise memory task (Experiments 3a and 3b). Each of these results is consistent with the social binding hypothesis, and alternative explanations based on low level perceptual features and attentional effects are ruled out. We conclude that automatic midlevel grouping processes bind individuals into groups on the basis of their perceived interaction. Such social binding could provide the basis for more sophisticated social processing. Identifying the automatic encoding of social interactions in visual search, distortions of spatial working memory, and facilitated retrieval of object properties from longer-term memory, opens new approaches to studying social cognition with possible practical applications.

Keywords: social binding, perceptual grouping, spatial perception, visual memory, social cognition

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The processing of current and potential actions and interactions between other people is crucial for successfully navigating our rich and complex social world. It has been argued convincingly (e.g., Xiao, Coppin, & Van Bavel, 2016) that the capacity to automatically extract key social information by simplifications, abstractions, and a priori assumptions, plays an important role in facilitating such processes; however, the relevant mechanisms are, as yet, poorly understood. In low-level perception, one well-established form of simplification takes place in the binding of features into perceptual wholes, known from perceptual binding and the gestalt illusions (e.g., Coren & Girgus, 1980). The current study investigates whether analogous effects occur at later stages of processing so that, just as visual elements are bound into perceptual wholes, people are bound into social groups—an idea that will be referred to throughout this article as Social Binding and is illustrated in Figure 1.

Our hypothesis is that when observing groups of people, we compute basic social interactions between them rapidly and automatically as an initial perceptual framework for further processing. Consider entering a social situation containing a gathering of people, such as a party or reception as shown in Figure 1 (top). One form of initial grouping could be in terms of the gestalt principle of proximity. However, we propose that rapid and automatic computations of basic social interactions would provide the framework for subsequent social analysis where attention is more closely focused on individuals of particular interest. Thus, such a first-pass analysis might initially identify those currently communicating with one another (see Figure 1, bottom), and provide the starting point for more subtle encoding, such as status, deception, competition, kinship, and intimacy between these observed people (Costanzo & Archer, 1989). This group-based rather than individual-based way of analyzing a social scene would not only be faster but might also be expected to benefit visual working memory (Peterson & Berryhill, 2013) in the same way that grouping numbers improves the immediate memory span for series of digits (Severin & Rigby, 1963).

More important, most previous studies have only investigated the perception of social interaction from an egocentric perspective. That is, the encoding is within an egocentric frame where the

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Parts of the results from Experiment 2 have been presented in abridged form at the 2017 annual Vision Sciences Society conference. All results have been presented in abridged form as posters at the 2018 annual VSS conference and the 2018 "Future of Social Cognition" workshop at the University of East Anglia. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. All data has been made public and can be accessed under: https://osf.io/65nky/.

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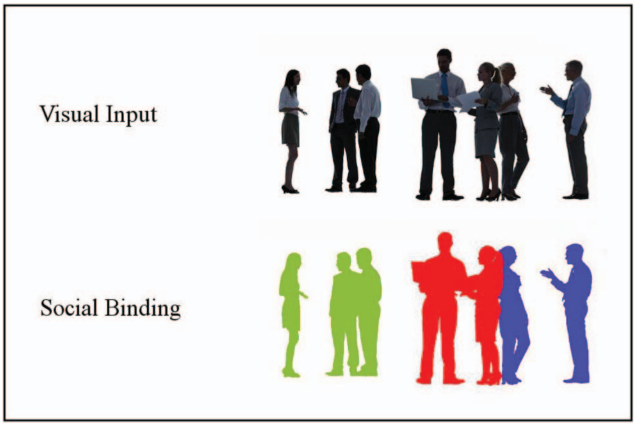

Figure 1. Representation of the central hypothesis. When viewing complex displays of interacting people (top), it is possible that the visual input is simplified to facilitate fast processing. We propose in this article that the evaluation of social interactions is used to bind individuals into groups (bottom). See the online article for the color version of this figure.

interaction of the perceiver and another individual is the basic unit of analysis, such as during joint action, negotiation, or courtship. For example, perceptual and visual working memory processes such as distance judgments are influenced by such egocentric factors as whether the viewed person is the same or different race to the observer (in- vs. out-group contrasts), or whether the participant observing other individuals has been primed to be socially excluded (see Xiao et al., 2016, for review). However, our main concern here is to investigate the automatic and goal-less processing of (potential) interactions in an allocentric frame, where the relationships between other people are encoded even when they are unrelated to the perceiver. Evidence for such an analysis of interactions that occur independently of the observer would provide a baseline for subsequent research into our ability to quickly assess human interactions, which factors influence it and how it might be distorted and disrupted. Our aim is to provide an initial theoretical framework for such investigations.

Therefore, we explore whether such allocentric computations of social interactions between third-parties take place, especially when not explicitly required. That is, where social interaction is not directed toward the perceiver, as they remain a third-party neutral observer. To explore this issue, we developed a series of tests based on established effects of gestalt illusions on visual processing. These effects can be categorized into (a) very short-term visual search benefits while viewing a display, (b) short-term memory (STM) effects measured over seconds where spatial distortions are detected, and (c) longer-term visual memory benefits. Below we briefly review evidence for each effect in terms of the perception of low-level visual gestalts and egocentric (i.e., self-other) social interactions. In each case we formulate an analogous prediction for the perception and memory of allocentric (i.e., third party) interactions, which will be investigated in the current study.

In visual search tasks, immediate effects are detected while stimuli are viewed. Previous work has demonstrated that elements bound together into a gestalt are detected faster and processed more quickly (e.g., Coren & Girgus, 1980). Other work has shown that egocentric social identities can also influence visual search performance. For example, priming racial identity influenced search for Black versus White faces in Black–White biracial individuals, such that priming their Black identity, for example, facilitated detection of Black faces (Chiao, Heck, Nakayama, & Ambady, 2006). Similarly, in multiple face displays attention can be preferentially oriented to faces within an individual's social in-group (Brosch & Van Bavel, 2012). In the current study, we examine social binding processes when there is no egocentric commitment to the searched-for items. That is, there is passive viewing of neutral displays that are not related to the observer and the observer's state, such as inclusion or exclusion from social groups, is not manipulated. To this end, we compare search for paired individuals who are either looking toward each other or looking away from each other. The prediction is that the social interaction in the looking-toward condition will be automatically computed and, hence, these displays will be detected more fluently. If such facilitated search effects are driven by social interactions, then we predict they will not be observed with inanimate objects with a front facing property, and not be solely determined by low-level perceptual properties such as symmetry.

The second series of studies investigate retrieval from STM after displays have been terminated for a few seconds. Perceptual binding is known to influence spatial judgments in that bound elements are remembered as being closer together than nonbound elements (e.g., Coren & Girgus, 1980). It might seem surprising to consider the possibility of top-down influences of abstract concepts on vision and visual memory, but current literature examining egocentric frames of reference supports the notion of high-level social influences on perception and spatial judgments (Xiao et al., 2016). One particular social behavior that has been mapped onto perception is the tendency of individuals to maintain a larger distance to other peoples' front than to their back (Hayduk, 1981). Jung et al. (2016) have shown that this egocentric distance judgment between self extends from immediate behavior and is reflected in subsequent memory. For example, participants remembered decreased distances to virtual avatars that were facing them as compared with those that were turning their backs. Jung et al.'s (2016) study leaves open whether these spatial distortions are caused by high level social or low level visual processing; a common question that the current study aims to examine more closely. Jung et al.'s (2016) manipulations of toward or away facing displays provide us with a convenient and easy way to manipulate the perceived interaction and, therefore, grouping of individuals. Hence, we intend to examine whether such distortions of spatial memory can also be detected and used to study allocentric third-person frames when a passive observer encounters interactions between other people. That is, we predict that when observing two individuals interacting, when they are looking toward each other, they will subsequently be recalled a few seconds later as being physically closer together than if they had been looking away from each other.

The final series of studies examines the encoding and retrieval of allocentric social interactions over longer periods of minutes in surprise memory tasks that participants were not expecting. That is, even though participants were never instructed to attend to individual identities or the social interactions between pairs of individuals, these are automatically computed. Literature investigating elements that are bound into figures according to low-level features found that such elements are bound into a single engram and retrieval of one is facilitated by the presence of the other (e.g., Horner & Burgess, 2013; Wallace, West, Ware, & Dansereau, 1998; Woodman, Vecera, & Luck, 2003). Therefore, we hypothesize that, because of social grouping processes, individuals implied to be socially interacting form coherent groups, they are encoded together and retrieval of individual features is facilitated. Therefore, memory for common as well as individual features of social interactions will be enhanced.

To review: We hypothesize that visual search is facilitated when the target is a pair of people who appear to be interacting; short-term spatial memory is distorted, where people who were previously viewed interacting are recalled as spatially closer, and this cannot be accounted for by spatial attention and potential future actions; and finally retrieval from longer-term memory is facilitated by social grouping processes, even when this property of observed displays was irrelevant.

Experiment 1: Social Binding Effects on Visual Search

In the first experiment we test for reaction time (RT) differences in visual search depending on whether a dyad of individuals is implied to be interacting. This interaction was manipulated using the body orientation of the individuals: Toward-oriented individuals were looking at each other, thereby implying the potential for interaction while Away-oriented individuals were not interacting. Any grouping processes resulting from social interaction would predict a faster processing of interacting individuals (Wagemans et al., 2012) and, therefore, faster detection of interacting pairs. To this end, we adapted the odd-quadrant task introduced by Pomerantz, Sager, and Stoever (1977). We also ran a control condition where the individuals were inverted (see Figure 1). Following on from known body inversion effects (Reed, Stone, Bozova, & Tanaka, 2003; see also Papeo, Stein, & Soto-Faraco, 2017) and the face perception literature (e.g., Yin, 1969) we assumed that inverted images, although possessing the same physical features as upright images would not be processed as socially interacting. Hence, such a control condition provides an initial examination of the role of low-level perceptual properties such as symmetry in our basic effects. Previous research (e.g., Bayliss & Tipper, 2006) has shown that gaze cueing can be produced even when the head is not viewed in the usual vertical orientation. However, while inverted 180° different frames-of-reference (head and spatial) can compete, and, hence, gaze cueing will not be consistent. As mutual gaze is clearly an important component of social interactions, the disruption of gaze should prevent social binding (see Experiment 2b for further considerations of gaze cueing vs. mutual gaze processes).

Experiment 1a

Method.

Participants. A power analysis was conducted in R for a planned two-way mixed analysis of variance (ANOVA) with an expected medium effect size (Cohen's $d = 0.5$) and a targeted power of 0.75. This yielded a target number of 29 participants per between-subjects group, which we rounded up to 30. Furthermore, importantly, in this and all following experiments, we also replicate and extend all our novel findings at least once.

Sixty participants (6 men, 54 women) were recruited from the student population of the University of York and reimbursed with either course credit or a payment of £3. Half of those participants (4 men, 26 women) were randomly assigned to the upright experimental condition with the other 30 (2 men, 28 women) assigned to the inverted control condition.

The study was approved by the ethics committee of the Department of Psychology at the University of York. All participants gave their informed consent before starting the experiment.

Materials. Photographs of two same-sex models were sourced from the Adobe Stock Service. Both featured a side-view of a male model in an upright standing position, hands at their side. The images were normed to a height of 350 pixels and mirror images for each model were generated on both axes so the to-be-localized target stimuli could be arranged either facing each other (Toward condition) or with their backs turned (Away condition). The distractor stimuli presented in the other three quadrants were the same two individuals facing in the same direction (either all facing to the left or to the right). In the inverted control condition all the displays were the same, except that the stimuli were inverted. See Figure 2 for an example of target stimulus pictures and Figure 3 for a typical search array. A simple image of a black cross on a white background served to divide the screen into four equal sections. The experiment itself was created using Unity3D (Version 5.2.1f1) and displayed on a ProLite T2735MSC 27-in. touchscreen at a resolution of 1920 × 1080.

Design. A mixed 2 × 2 ANOVA was used, analyzing the effect of orientation of stimuli (Toward or Away; within subjects) and type of stimuli (upright experimental, inverted control; between subjects) on response times in a visual search task. Response times were measured starting from the appearance of the stimuli caused by the participant holding down a key; and until the participant let go of the button at the start of the pointing response which caused the stimuli to disappear.

Procedure. Participants were invited into the experimental room individually. They were handed an information sheet containing a rough outline of the experiment as well as informing them about their right to withdraw at any point during the experiment. After they consented, they received both verbal as well as written instructions and completed four practice trials under the supervision of the experimenter.

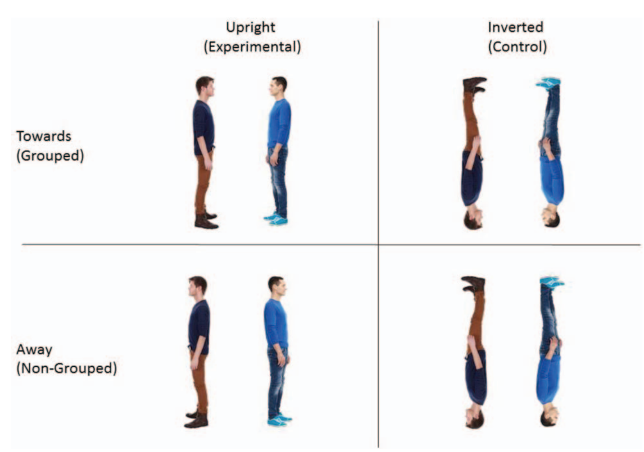

Figure 2. Upright (experimental) and Inverted (control) target stimuli in both Toward and Away orientation. See the online article for the color version of this figure.

Figure 3. An example of the search array presented to the participants. The target is an example of the Toward condition and in the upper left quadrant. See the online article for the color version of this figure.

The experiment was divided into two blocks, with the target of the visual search being either the Toward orientation in one block and the Away orientation in the other. Blocks started with a display of the target pair to familiarize the participant with their target. Participants were able to take a break in between blocks. Order of blocks was counterbalanced.

Each trial started with a cross that divided the screen in four equal sections. Whenever ready, participants held down the spacebar, which caused four pairs of people to appear on screen—one per quadrant. One of these pairs was in either consistently Toward or Away orientation (Target) within a block of trials while the individuals in all other pairs were looking in the same direction as their partners, either left or rightward (Distractors). Location of the Target among the four sections as well as facing direction of the distractors were randomized.

Participants were asked to find the Target pair as quickly as possible, by releasing the spacebar and touching the section of the screen that contained the target. Stimuli disappeared when participants released the spacebar, so the decision had to be made before starting the movement. For a visualization of the procedure, see Figure 4. Response time was measured from pushing down to letting go of spacebar. This allowed us to eliminate any confounds affecting the time it took participants to reach the target,[1] such as target location or whether the target area was attended by surrounding stimuli.

Participants completed 40 trials in each block. Overall the experiment took less than 15 min. Error rates were below 6% for all participants (<4% overall). Incorrect trials have been excluded from all further analyses. Additionally, all trials with RTs shorter than 200 ms and longer than 3,000 ms were excluded (<2% of trials).[2]

Results. All data for the experiments reported in this article as well as more detailed analyses are available in the Open Science Framework (OSF; https://osf.io/65nky/). A mixed 2 × 2 design showed a significant effect for Toward/Away orientation of target stimuli ($F(1, 58) = 13.77$, $p < .001$, $\eta_p^2 = .192$), confirming our prediction that target detection would be faster for Toward-oriented individuals There was also a main effect of Upright/Inverted target orientation $F(1, 58) = 10.52$, $p = .002$, $\eta_p^2 = .154$) where search speed was slower for Inverted individuals, as predicted. The important interaction between both variables was significant ($F(1, 58) = 6.25$, $p = .015$, $\eta_p^2 = .097$), indicating that the found orientation effect was driven by the upright stimuli. See left panel of Figure 5 for mean RTs.

Post hoc tests based on this interaction revealed that Toward-oriented pairs were found significantly (Bonferroni corrected) more quickly than Away-oriented stimuli in the experimental (Upright) condition, $t(29) = 3.45$, $p = .002$, $d = 0.63$ but not in the (Inverted) control condition, $t(29) = 1.39$, $p = .174$.

Discussion. Searching for pairs of people who are oriented toward one another leads to a significantly faster detection compared with searching for those in the Away orientation, but only when the people were viewed in a normal upright orientation. This supports our hypothesis that the computation of social interactions is of importance and given privileged access to later processes. This social interaction effect was not detected when the individuals were inverted, ruling out explanations based on low-level perceptual features.

Because this is the first demonstration that there appears to be preferential encoding of some kinds of social allocentric interactions during visual search, it is necessary to replicate and extend our findings to new situations. The lack of effect in the Inverted control condition would seem to support the idea that low-level explanations such as symmetry producing Kanizsa-like effects of closure and good continuation (e.g., Coren & Girgus, 1980) is an unlikely explanation of our results. However, to confirm this, the following study examines Toward and Away social interactions when there is no symmetry. The study further extends our findings by first examining a social situation involving a child and adult, rather than two very similar adults; and second tests a further control condition where inanimate objects with clear front and back properties are searched for in Toward and Away conditions.

Experiment 1b

Method. A further 60 participants were recruited from the same pool as the previous experiment and divided into the person experimental (1 man, 29 women) and wardrobe control (30 women) conditions.

Design and procedure were identical to Experiment 1a but stimuli were replaced with pictures of asymmetric social pairs (experimental) and asymmetric wardrobes (control). See Figure 6 for samples of all stimuli.

Error rates were below 5% for all participants. Incorrect trials have been excluded from all further analyses, as have all trials with RTs below 200 ms and above 3,000 ms (<2.5%).

Results. A mixed 2 × 2 ANOVA showed a significant effect for Toward/Away orientation of stimuli ($F(1, 58) = 20.99$, $p < .001$, $\eta_p^2 = .266$) but no significant main effect of Person/Wardrobe stimuli, $F(1, 58) = 0.12$, $p = .736$. The interaction between both

[1] Movement times were still recorded but did not differ significantly between conditions. Inclusion of movement times does not alter the pattern of results. See supplemental materials online for details.

[2] For details on these cutoffs and the reasoning behind them, see supplemental materials online.

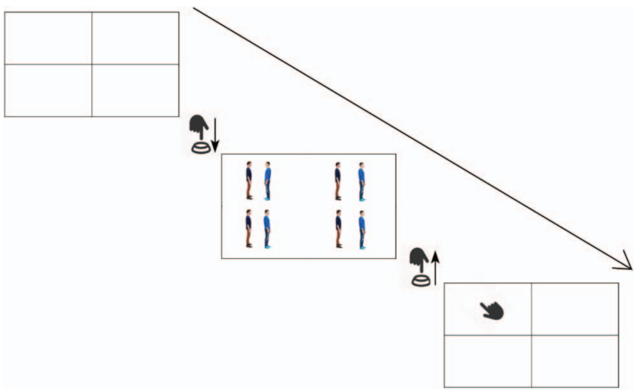

Figure 4. Experimental procedure involving an upright trial with the toward facing target in the top left. See the online article for the color version of this figure.

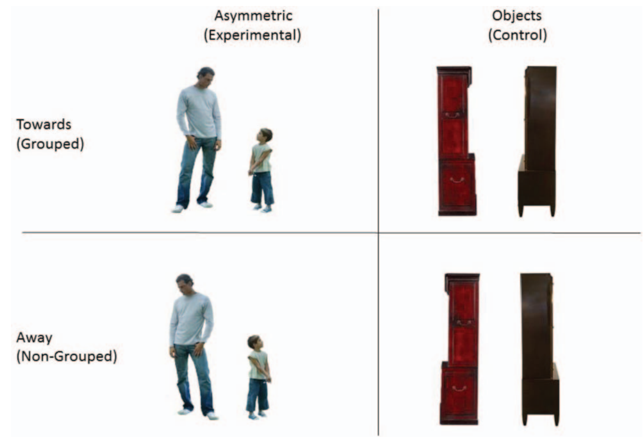

Figure 6. Asymmetric pairs (experimental) and Objects (control) in both Toward and Away orientation. See the online article for the color version of this figure.

variables was significant ($F(1, 58) = 18.65$, $p < .001$, $\eta_p^2 = .243$). See right panel of Figure 5 for group means and how they compare with the results from Experiment 1a.

Post hoc tests based on this interaction revealed that Toward-oriented pairs were again found significantly more quickly than Away oriented ones in the Person experimental condition, $t(29) = 7.40$, $p < .001$, $d = 1.33$ but not in the Wardrobe control condition, $t(29) = 0.17$, $p = .870$.

Discussion. These initial studies have examined the idea that when observing social situations containing a number of other people, some information receives preferential processing. In particular, even when the social information is not directed toward the viewer, detecting whether other people are interacting is of importance when interpreting the scene. Two visual search experiments have clearly confirmed our predictions. That is, participants were significantly faster to detect a target stimulus when it was two people oriented toward each other as in a social interaction, than when they were oriented away from each other.

It should be noted that the overall response time averages collapsed across orientations differed between groups, which may be caused by individual differences between samples. Hence, while the control conditions show the predicted absence of orientation effects, they cannot provide a "baseline" response time measure to differentiate whether the response times are decreased for the Toward conditions or increased for the Away conditions.

To argue that the search performance was determined by high-level computations of social interactions, it was critical that we rule out the lower-level perceptual properties that typically explain grouping and facilitated search, such as symmetry. Such low-level accounts were discounted in three ways. First, when images of people were inverted they contained the same physical properties

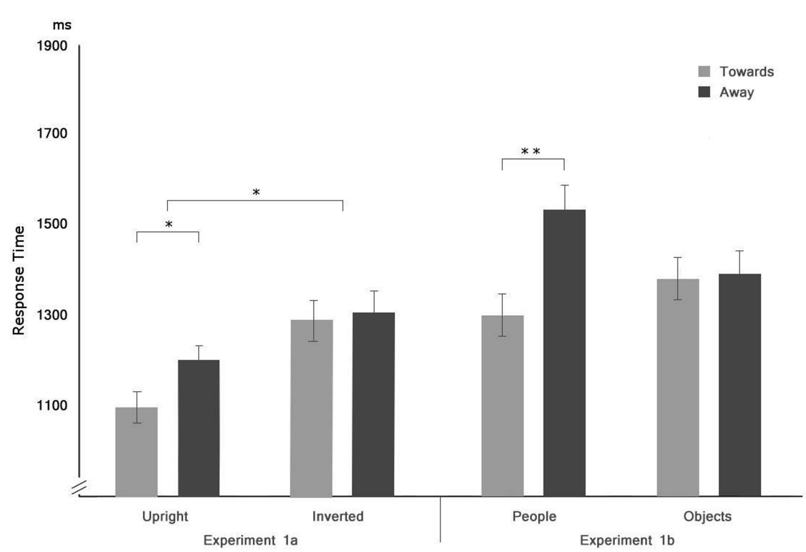

Figure 5. Mean response times for grouped and nongrouped stimuli for Experiment 1a (left panel) and Experiment 1b (right panel). Error bars represent *SE*. * $p < .05$. ** $p < .001$.

but social processing is disrupted in such situations, similar to body and face inversion effects. In this situation, social orienting effects were not detected (see also Papeo et al., 2017). Second, and similarly, when inanimate objects with a clear front and back were the search targets, no effects were detected, confirming the effects are associated with animate social stimuli. Third, and finally, the search advantage for social interactions was even detected when asymmetrical stimuli were used, and when the interaction was between a child and adult.

Experiment 2: Social Binding Effects on Short-Term Spatial Memory

In the previous experiments we examined the encoding of social situations when the displays were visible and a target had to be detected. However, we predict that the effects of encoding social interactions will also be observed in other cognitive processes, especially in recall from memory. Therefore, in Experiment 2, we investigated distortions of spatial memory when recalling properties of a prior social interaction in an allocentric third-party frame. The possibility of spatial distortions of reconstructive memory because of higher level information has been shown in egocentric frames. For example, the judged distance between one person and another in egocentric space can be modulated by psychosocial factors, such as the relationship of the individuals (e.g., Thomas, Davoli, & Brockmole, 2014), as well as whether a person has previously been socially rejected (Knowles, Green, & Weidel, 2014; for a review, see Balcetis, 2016). Hence, in all these instances, the observer or participant will remember the target as closer or further away from themselves, depending on their emotional state (e.g., fear), properties of the object and situational cues (e.g., Cole, Balcetis, & Zhang, 2013; Harber, Yeung, & Iacovelli, 2011; Teachman, Stefanucci, Clerkin, Cody, & Proffitt, 2008). It has not yet been studied whether similar distortion effects can be found in an allocentric framework without motivation and independent of the state of the observer.

Participants passively observe two individuals on a computer screen and are asked to recall the distance between them a few seconds after the initial view. Participants had no need to actively consider the relationship between the two individuals, so any detected effects would appear to be the automatic computation of the social interaction. The prediction of Experiment 2a was that when participants observe two people in a social interaction, they would recall them as closer together than those individuals who were not interacting.

Additionally, response times were recorded to test the prediction that individuals grouped together are encoded into memory as a single "event," which would lead participants to respond more quickly than in cases where noninteracting individuals are encoded separately.

Experiment 2a

Method.

Participants. Sixty participants were recruited and allocated to the Person experimental (2 men, 28 women) and Wardrobe control (1 man, 29 women) groups. The study was approved by the ethics committee of the Department of Psychology at the University of York. All participants gave their informed consent before starting the experiment.

Materials. Images of two additional models were sourced from the Adobe Stock Service, similar and in addition to the ones from Experiment 1a. The two images of wardrobes from Experiment 1b were also used again in addition to two more pictures of similar wardrobes. The height of all images was normed to 864 pixels, and mirror images for each model were generated so the stimuli could be arranged both facing each other and with their backs turned. See Figure 7 for an example of stimulus pictures.

A further picture was taken of an empty section of wall and carpet, to be used as a background on which the stimuli were to be superimposed. Using image manipulation software, all irregularities were removed from the background and a transparent-to-black gradient was applied to the edges to prevent participants from using the stark contrast between the image and the border of the screen as location cues. This background with a sample of stimulus pictures superimposed on it can be seen in the top panel of Figure 8. The experiment itself was created using Unity3D (Version 5.2.1f1) and displayed on a ProLite T2735MSC 27-in. touchscreen at a resolution of 1920 × 1080.

Design. A 2 × 2 mixed design was used, looking at the effect of orientation of stimuli (Toward or Away; within subjects) and type of stimuli (People or Wardrobes; between subjects) on spatial errors. Spatial error was measured as the fraction of the given distance that the response location was away from the target location (see below). As a second dependent variable, response times of participants were also recorded, measured from appearance of the cue stimulus to response.

Procedure. Participants were invited into the experimental room individually. They were handed an information sheet that contained a rough outline of the experiment as well as informing them about their right to withdraw at any point during the experiment. After they consented, they completed a practice version of the experiment together with the experimenter in which they were given instructions before each section on screen. Additionally, the experimenter completed two trials while verbally repeating the instructions and finally the participants were able to practice on two trials while the experimenter made sure that they understood the process. If a participant did not perform the trials correctly or if they expressed that they were not sure about the instructions, the

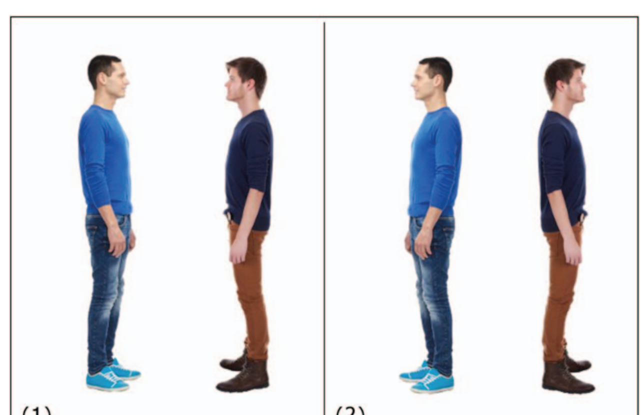

Figure 7. Interaction partners in the Toward (1) and Away (2) orientation. See the online article for the color version of this figure.

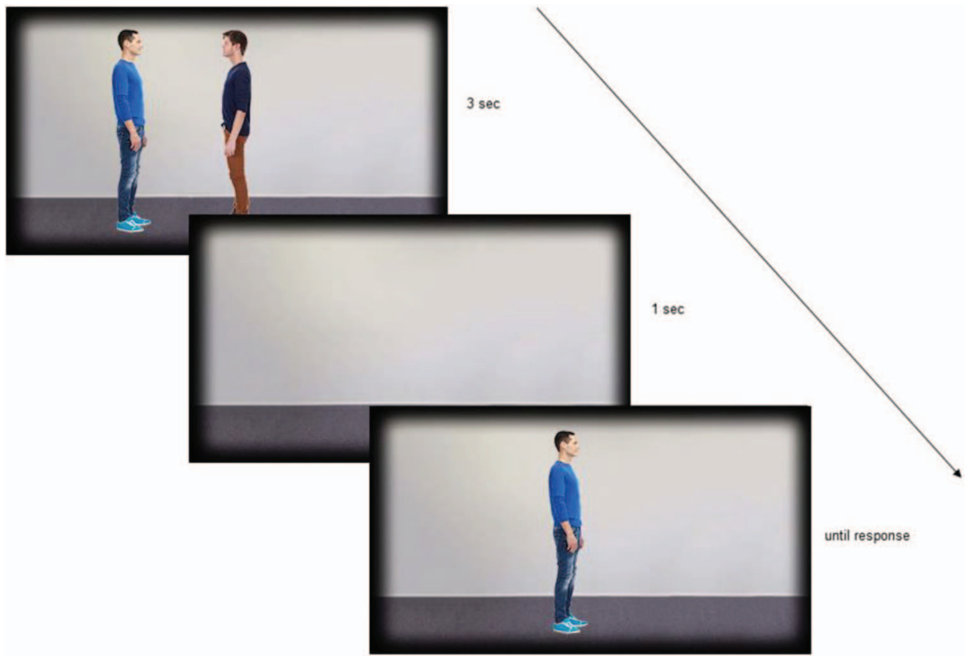

Figure 8. Procedure of a Toward oriented dyad with a reappearance of the left partner. Participants were asked to touch the screen where the other partner's head would be if they had reappeared at the same distance from their partner as before. See the online article for the color version of this figure.

practice session was repeated. If the participant was confident they had understood the instructions, the experiment was started.

Before the experiment, participants took part in a calibration session during which they were presented with each stimulus in both left and right orientations three times at different positions on the screen. Each time the participant was asked to use their finger to tap on the center of the head of the shown individual or the top center of the wardrobe. The purpose of the calibration session was to establish an individual baseline measure of responses as well as an offset for each stimulus, indicating the difference between perceived and geometric center. This was necessary to exclude the possibility that participants judged the center of the head closer to the face or eyes rather than the geometric center (see Bertossa, Besa, Ferrari, & Ferri, 2008; Starmans & Bloom, 2012 for examples of this). This would have led to an inward-bias in Toward-oriented pairs and an outward bias in Away oriented pairs and, therefore, presents a confound that needed to be excluded (and was further controlled for in Experiment 2b below). This offset for each stimulus was calculated by averaging the difference between response location and geometric center in the three presentations of each stimulus in each orientation. This was later subtracted from responses collected during the experimental session.

In the main section, participants completed 160 trials. In each trial, they were first shown one of the stimulus pairs in either a Toward or Away orientation superimposed on the background at a random distance from each other. After 3 s, both stimuli disappeared to leave an empty background. After one more second, one of the stimulus individuals reappeared but in a different position (cue stimulus). Participants were asked to tap the screen where the center of the head of the other person (target stimulus) would have been if they had also been represented. The reappearance location of the cue stimulus was constrained in a way that allowed for enough room to indicate the original distance. For a visualization of the main procedure, see Figure 8. At the end of the 160 trials participants were debriefed and received their reimbursement. Altogether the process took 20–25 min per participant.

Data processing. For each trial, spatial error was calculated according to the formula

$$Error = -\frac{(d_s - O_L + O_R - d_p)}{(d_s - O_L + O_R)}$$

where d_s and d_p are the absolute distance given on screen (center to center) and indicated by the participant, respectively. O_L and O_R are the offsets for the left and right appearing stimulus established in the calibration session. Negative values indicated that pairs were recalled as closer together than the given distance whereas positive values indicated they were recalled further apart. For example, a spatial error of -0.4 would indicate a 40% shorter distance while a spatial error of 0.6 would indicate a 60% larger distance. A score of 0 represents the participant exactly locating the target.

Randomized stimulus distances were used to make the spatial memory task reasonably demanding. The largest possible distance was 70% of screen width to give the represented stimulus enough potential to move away from the original location while still allowing for enough space to indicate the full length of the original distance.

Finally, trials in which the participant's response error was more than 3 *SD*s away from the mean in each group most likely were caused by accidental contact with the touchscreen and were excluded (<2% of trials). Additionally, all trials with response times

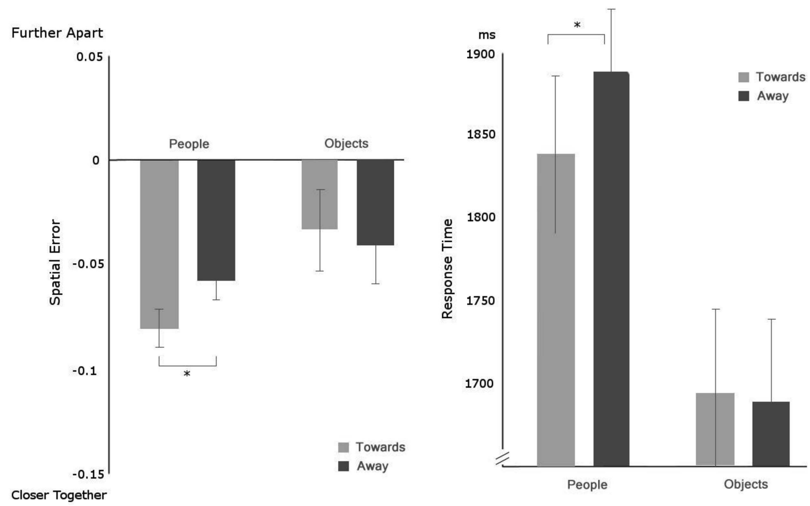

Figure 9. Mean spatial error (left panel) and response times (right panel) for all conditions. Negative spatial error indicates that stimuli were remembered as closer together. Error bars represent *SE*. * $p < .05$.

shorter than 500 ms and longer than 5,000 ms were excluded (<1.5% of trials).[3]

Results. Figure 9 shows the mean spatial error and mean response times for all conditions. Looking first at the spatial error, a 2 × 2 mixed ANOVA showed no significant effects of orientation, $F(1, 58) = 1.30$, $p = .259$ or stimulus, $F(1, 58) = 2.12$, $p = .151$ but a significant interaction between them ($F(1, 58) = 10.31$, $p = .002$, $\eta_p^2 = .151$). Post hoc tests showed the reason for this interaction was that people were remembered as significantly closer in Toward than in Away orientation, $t(29) = 3.59$, $p = .001$, $d = 0.68$, but no such effect exists for wardrobes, $t(29) = 1.30$, $p = .203$.

A 2 × 2 mixed ANOVA looking at response times showed only marginally significant effects of orientation, $F(1, 58) = 3.93$, $p = .052$ and type of stimulus, $F(1, 58) = 3.60$, $p = .063$ but a significant interaction between them ($F(1, 58) = 5.84$, $p = .019$, $\eta_p^2 = .091$). Post hoc tests showed that participants responded to person images more quickly when they were in Toward orientation, $t(29) = 2.92$, $p = .007$, $d = 0.5$ whereas the orientation had no effect when recalling the location of wardrobes, $t(29) = 0.33$, $p = .743$.

Discussion. We hypothesized that in a simple STM task where participants were required to recall the spatial location of a person in relation to another one second after viewing the display, such spatial recall could be distorted by whether the individuals were interacting. Two observations suggest that the encoding of social relationships does take place in such passive viewing tasks: First, as predicted, when two individuals are facing each other they are recalled as closer together than when they are facing away from each other. Second, speed to make the location memory response is faster when the two individuals are facing each other. Both observations are consistent with the hypothesis that the two individuals in the implied social interaction, while facing each other, are encoded into memory as one event.

However there are other properties because of which recall of location could be distorted in the direction of a person's gaze and implied action: These properties are gaze cueing (see Frischen, Bayliss, & Tipper, 2007, for review) where attention is automatically oriented to the location another person is seen to gaze toward, and forward models of action prediction (e.g., Wolpert, Ghahramani, & Flanagan, 2001) where future states of objects with the potential to move are encoded such that they produce representational momentum-like effects (e.g., Brehaut & Tipper, 1996; Finke & Shyi, 1988; Freyd & Finke, 1985). Experiment 2b investigated these alternative explanations.

Experiment 2b

This experiment replicates the central manipulation of Experiment 2a: That is, when recalling the location of people looking toward each other, this is closer and retrieved more rapidly than when they are facing away from each other. However, the experiment also includes two new conditions to investigate the alternative explanations mentioned above.

These alternative accounts would predict that when recalling the spatial location of a person in the Toward condition the direction that person was gazing and/or their potential future movements would be encoded. Hence, it could be these basic processes that subsequently distort the recall of the location of that person more toward the center of the image. This effect would not necessarily require the potential social interaction with the other person. Similarly, recall of the spatial location of the person facing away would be a drift outward, as this is the direction of the attention and potential future action.

The new conditions to examine explanations not based on social interaction but on gaze and forward predictions present both people facing in the same direction. These more basic gaze and forward modeling accounts make specific predictions. First, consider the example where both people are facing left. On average all recalled spatial loci should be generally more to the left, whereas

[3] These cut-offs are higher than in Experiment 1 because of participants having to also move towards the target and not being asked to be as fast as possible. See supplemental materials online for details.

when both are oriented to the right all responses should drift to the right. In contrast, when both people are facing in, or both facing out/away, then the average of gaze and forward modeling would be the center of the display. This is especially relevant in regards to the eye-ward bias mentioned above which, if not entirely accounted for by the calibration, would have led to a drift in responses along the gaze direction of both partners.

The second prediction is more specific, based on whether recall is of the person at the front or the back of these common direction displays. Consider Figure 10: When recalling the person at the back, gaze and forward modeling predict that this person will be recalled as closer to the front person. In contrast, when required to recall the person at the front of the pair, they will be recalled as further away. However, our proposal is that because there are no joint social interactions in these latter common direction conditions, and therefore spatial memory is not distorted. In this account, only when a common representation of two people interacting is encoded will spatial memory be distorted. Thus, only the Toward condition will produce a contraction of spatial memory, no such effects will be seen in the three other conditions of away, common right or common left conditions.

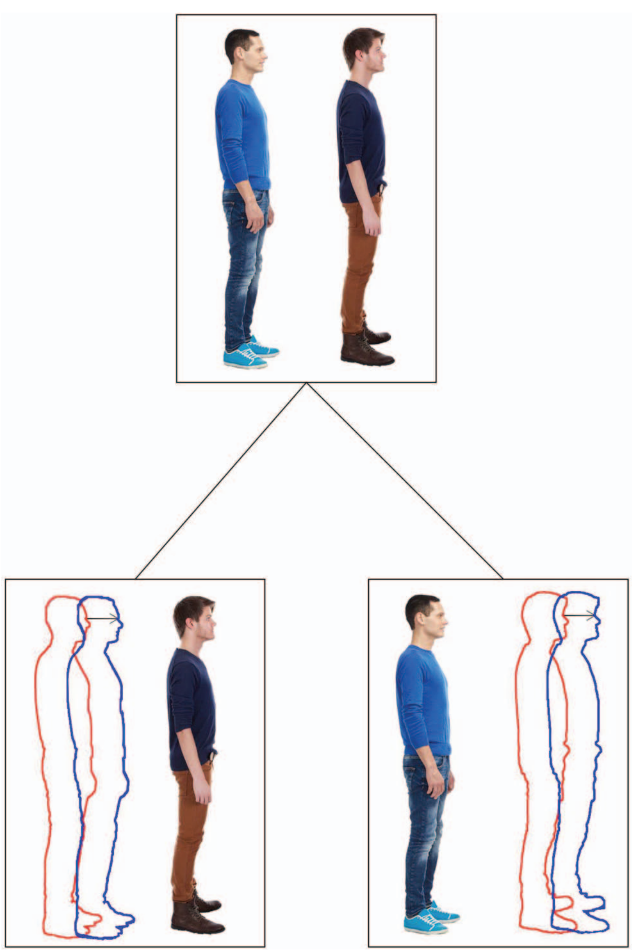

Figure 10. If either gaze direction or implied representational momentum of the target stimulus lead to their veridical position (red [light gray] silhouette) being recalled as further along the direction in which they are facing (blue [dark gray] silhouette), then the same distance between partners (top) would be recalled as being shorter when the target was in the back (bottom left) and larger when the target was in front (bottom right). See the online article for the color version of this figure.

Method.

Participants. A power analysis was conducted in R for a planned one-way repeated measures ANOVA with four levels, an expected medium effect size (Cohen's $d = 0.5$) and a targeted power of 0.75. This yielded a target number of 40 participants.

Forty participants, all students at the University of York, took part in the experiment and were reimbursed with course credit or a payment of 3 GBP. The study was approved by the ethics committee of the Department of Psychology at the University of York. All participants gave their informed consent before starting the experiment.

Materials. The same experimental stimuli as those of Experiment 2a were used with the addition of two more pictures of models of the same sex in the same position. They were arranged into six pairs in four different orientations, an example of the latter can be seen in Figure 11. Otherwise the same materials were used as in Experiment 2a).

Design. A repeated measures design was used to test for the effect of orientation (Toward, Away, Right, and Left) on spatial error. The effects of orientation on average response location on screen were also tested. A further separate repeated measures test was used to analyze the effects of which partner was recalled (front or back) on spatial error.

RTs, measured from appearance of the cue stimulus to response, were separately analyzed and compared depending on orientation of the dyad and whether the attended (front) or unattended (back) partner had to be recalled.

Procedure. The procedure was identical to that of Experiment 2a. Trials with response errors which were further than 3 *SD*s from the mean as well as those with RTs below 500 ms and above 5,000 ms were excluded (<4% of trials). Additionally, all trials in which the participant accidentally placed the target on the wrong side of the cue stimulus were removed (<1% of trials).

Results. Figure 12 shows the mean spatial error as well as response times across all four conditions. To test whether our previous results were replicated, a repeated measures ANOVA was carried out, which showed that orientation (Toward, Away, Left, and Right) had a significant effect on response errors ($F(3, 117) = 9.48$, $p < .001$, $\eta_p^2 = .434$). Pairwise comparisons with Bonferroni corrections revealed that people were remembered as having been closer together in the Toward orientation as compared with all other orientations (all $p < .05$), but no differences were found in response error between the Away, Left, and Right orientations (all $p \geq .26$).

Response times were compared using a repeated measures ANOVA to test for effects similar to those of Experiment 2a. Differences in response times depending on orientation of the pair were significant ($F(3, 117) = 10.66$, $p < .001$, $\eta_p^2 = .464$). Participants responded on average 43 ms more quickly in trials involving Toward oriented stimuli as compared with all other conditions (all $p < .05$) with no differences found between the remaining conditions (all $p > .9$).

Possible gaze cueing effects were tested using a paired samples t test on the Left and Right facing conditions to compare the response errors that resulted from remembering either the front or back interaction partner (Toward and Away conditions did not

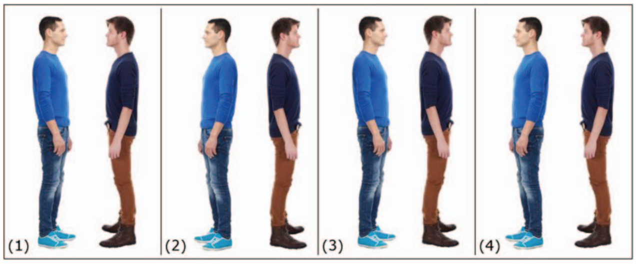

Figure 11. Interaction partners in the four orientation conditions (1) Toward, (2) Away, (3) Right, and (4) Left. See the online article for the color version of this figure.

have a front or back partner). There was no difference in distance recall between trials that prompted participants to recall the front partner or the back partner, $t(39) = 0.93$, $p = .179$ in the conditions where both people faced the same direction. Means can be seen in Figure 13.

Whether the fact that the target area was gazed at by the shown partner had any effect on response times was tested using a paired samples t test to compare the response times depending on whether the trial prompted the recall of the attended (front) partner and, therefore, involved a target location within the gaze direction of the visible partner. RTs did not differ significantly between response locations that were in the gaze direction of the cue stimulus and those that were not, $t(39) = 0.01$, $p = .496$.

A further repeated measures ANOVA tested general response location distortions to the left or right by comparing the averages of indicated response location on screen of all orientations. There was no effect of orientation on the average target location, $F(3, 117) = 0.58$, $p = .63$. Additionally, a post hoc one-sample t test showed that the target location averaged across all conditions was not significantly removed from the screen center, $t(39) = 0.92$, $p = .18$.

Discussion. This experiment has clearly replicated the findings of Experiment 2a. That is, when people are viewed looking toward each other implying a social interaction, they are recalled as closer together and access to this spatial memory is facilitated as reflected in shorter response times. However, this study also tested alternative accounts. The orienting of attention via gaze cues, and forward modeling of possible future action states, made specific predictions in the conditions where both individuals faced in the same direction. First, overall recall of spatial location will shift in the common direction when people face the same way; and second, there would be asymmetric recall, where the back person is recalled as closer to the front person, whereas the front person would be recalled as further away from the back person. None of these effects that would support an alternate explanation have been found and, therefore, although not necessarily mutually exclusive, we feel that the weight of evidence produced by Experiments 2a and 2b at this time supports our proposal that the spatial memory distortions we see occur only for socially interacting people.

Because of recent and as yet unresolved debates regarding social top-down effects on visual perception (Balcetis, 2016; Firestone & Scholl, 2016; Schnall, 2017; Xiao et al., 2016), we would like to stress that we interpret the spatial distortion effects found here in terms of reconstructive memory effects. The seen distortion effects are, therefore, outside the scope of this debate and we do not believe that they can lend substantial support to either position.

Experiment 3: Social Binding Effects on Longer-Term Visual Memory

Experiment 3a

In light of previous research showing increased recall for perceptually bound features that are not directly relevant to the binding process (e.g., Horner & Burgess, 2013; Woodman et al.,

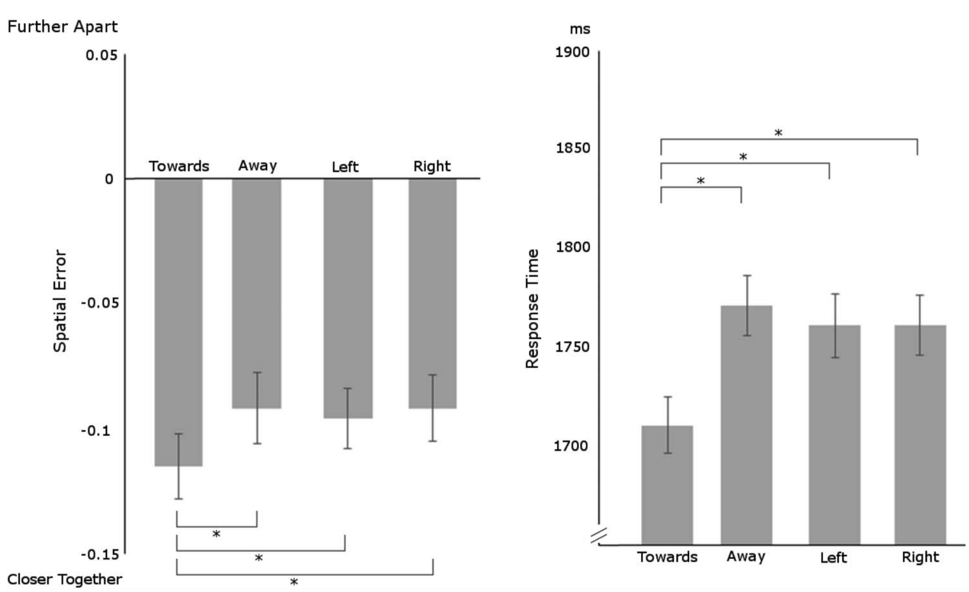

Figure 12. Mean spatial error (left) and response times (right) for the four orientation Conditions Toward, Away, Left, and Right. Error bars indicate *SE*. * $p < .05$.

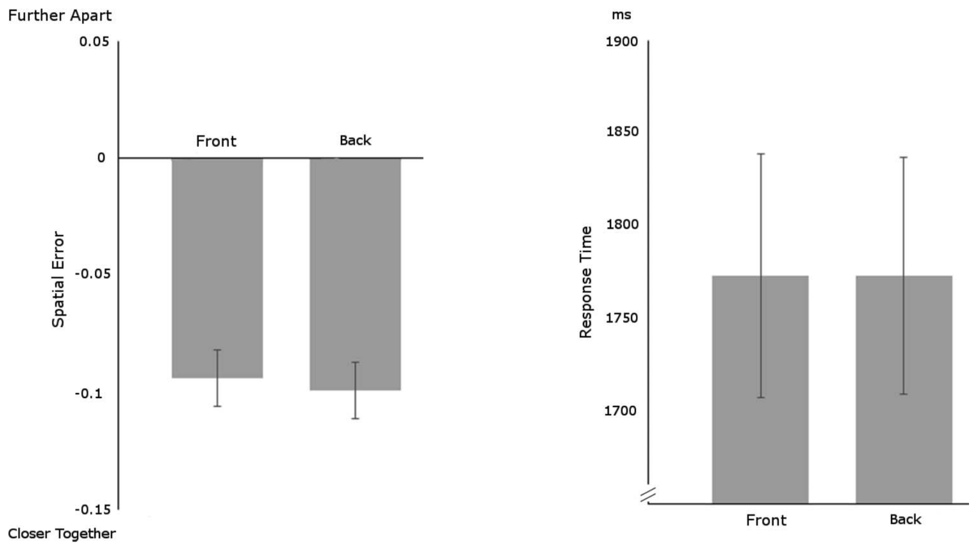

Figure 13. Mean spatial error (left) and response times (right) for conditions in which participants were prompted to remember the location of the front or back partner.

2003) we predict that retrieval accuracy is increased in individuals that were initially presented as members of Toward-oriented pairs rather than Away-oriented pairs. That is, in the final experiments we directly test the idea that individuals who are perceived to be interacting while facing each other are represented in a coherent combined form that facilitates encoding into and retrieval from memory. To this end we present the same spatial judgments task as in Experiment 2, followed by a surprise memory task. As participants were unaware that there would be a memory recall task until the end of the experiment after the spatial task was completed, any encoding into memory during the spatial task was incidental.

During the final memory task participants are asked to recall the individuals that made up each pair that they had seen before. To this end they were presented with pairs of individuals that either had been part of the same or different pairs during the spatial judgments task. In line with our central hypothesis that grouped individuals are bound into memory as a single event, we predict that recognition accuracy for those individuals that previously had been shown in Toward-orientation should be increased compared with individuals who had been seen in Away-orientation (Horner & Burgess, 2013). We also recorded response times to examine whether speed, as well as accuracy of recall, was also affected, although speed of response was never emphasized as a task goal to participants.

Method.

Participants. Forty participants (37 women, 3 men) were recruited from the student population of the University of York.[4]

Materials. The same pictures of upright standing individuals in side profiles as in Experiments 1 and 2 were used but the stimulus pool was extended to include pictures of 20 men and 20 women to present enough different features for the participants' memory to be tested.

Design. For the spatial task a paired *t* test was used to test for the same effects seen in Experiment 2: Differences in spatial error and response times between orientation of stimuli (Toward or Away). For the memory task a paired *t* test was used to test for differences in retrieval accuracy and response time according to orientation of stimuli (Toward or Away). RTs were measured starting from the appearance of the stimulus until the participant made their recall decision by pressing one of the response buttons.

Procedure. The experiment was carried out in two parts: a spatial judgments task as in Experiments 2a and 2b, followed by a surprise memory task. The spatial judgments task was identical to Experiment 2 with minor alterations to the stimuli: Stimulus individuals were divided into 10 men and 10 women pairs. Of those, 5 men and 5 women pairs were shown exclusively and repeatedly in Toward orientation with the remaining 5 men and 5 women pairs always shown in Away orientation. This was counterbalanced between participants. Looking direction of every individual was held constant throughout this part of the procedure (but counterbalanced between participants) as this was a part of the subsequent memory task. Each pair of people was shown exactly four times in the spatial recall task, yielding 80 trials per participant. Each person was the spatial recall target twice.

Immediately after the spatial judgments task followed a surprise memory task. Participants were informed that their memory for the stimuli they had observed in the first part was to be tested (this was not mentioned to them before). They were informed that they had seen 20 pairs in the first part and that each pair was always made up of the same two individuals. They were to now see 20 pairs again, some of which might be made up of two individuals that formed a pair in the first task, some consisting of two individuals that were part of different pairs in the spatial task. See Figure 14 for an overview of the possible retrieval cues. Pairs appeared in the same orientation as in the spatial judgments task. Participants were

[4] This experiment originally recruited 30 participants like the other experiments in this article. Because of post hoc power concerns raised during the review process we increased the sample size to 40. Both original analysis and the one with increased sample size show the same pattern of results. The data as well as the original analysis based on 30 participants are available in the supplemental materials online.

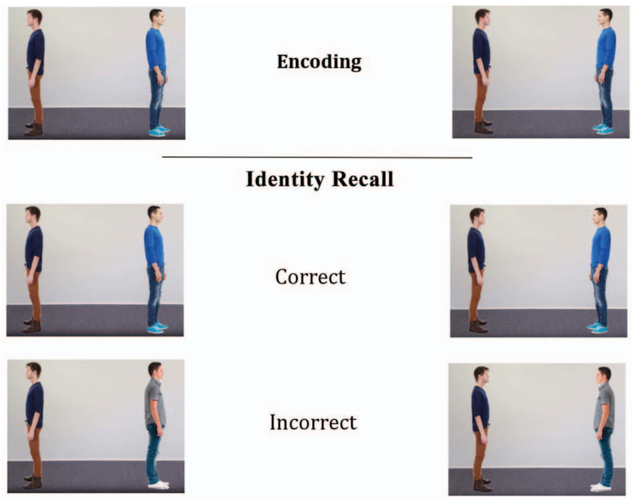

Figure 14. An example of an encoded pair in Away (left) and Toward (right) orientation with the corresponding possible retrieval prompts. See the online article for the color version of this figure.

asked to indicate for each pair whether they had seen it in this constellation before or whether the individuals had been part of different pairs by pressing the 'c' or 'v' key, respectively (counterbalanced between participants). As response time was only a secondary measure participants were not asked to respond as quickly as possible but rather only told to not overthink their response. The entire procedure took no more than 20 min after which participants were fully debriefed.

Results.

Spatial judgments. To test whether the spatial distortions found in Experiments 2a and 2b were replicated, we tested for spatial error and response time differences between Toward and Away oriented pairs across all 40 participants. As before, trials where participants placed the target on the wrong side of the cue stimulus and those that were more than 3 *SD*s away from the mean were excluded (<1% of trials).

As expected, Toward oriented pairs were remembered as closer together than Away oriented pairs, $t(39) = 3.04$, $p = .004$, $d = 0.48$ as well as processed faster, $t(39) = 2.73$, $p = .009$, $d = 0.43$; replicating again our findings from Experiments 2a and 2b; see Figure 15.

Visual longer-term memory. Binomial tests (.50) confirmed that participants performed significantly better than chance in the memory task, both when stimuli were shown in Toward as well as Away orientation ($p < .05$). As can be seen in Figure 16, pairs in Toward orientation were on average remembered 6.5% more accurately than those in Away orientation, $t(39) = 2.92$, $p = .006$, $d = 0.46$. A t test considering only the correct responses did not reveal any significant differences in response times, $t(39) = 0.03$, $p = .977$, see Figure 17.

Discussion. The differences in retrieval accuracy that were found are consistent with our prediction and in line with results expected if Toward-oriented individuals are bound into memory as a single event. Response times were seemingly not affected by orientation of individuals even though individuals were still in Toward or Away orientation during the memory retrieval task. This might be because of the nature of the task with participants taking the time they need to make a decision without having been told to be as quick as possible. It is also possible that the individual-level processing necessary to analyze the partners of each pair to come to a decision eliminated all orientation benefits that the group-level tasks in Experiments 1 and 2 as well as in the current spatial task.

Finally, because these longer-term memory effects are reported here for the first time, it is essential that they are extended and replicated. Note that the person identity property recalled here was

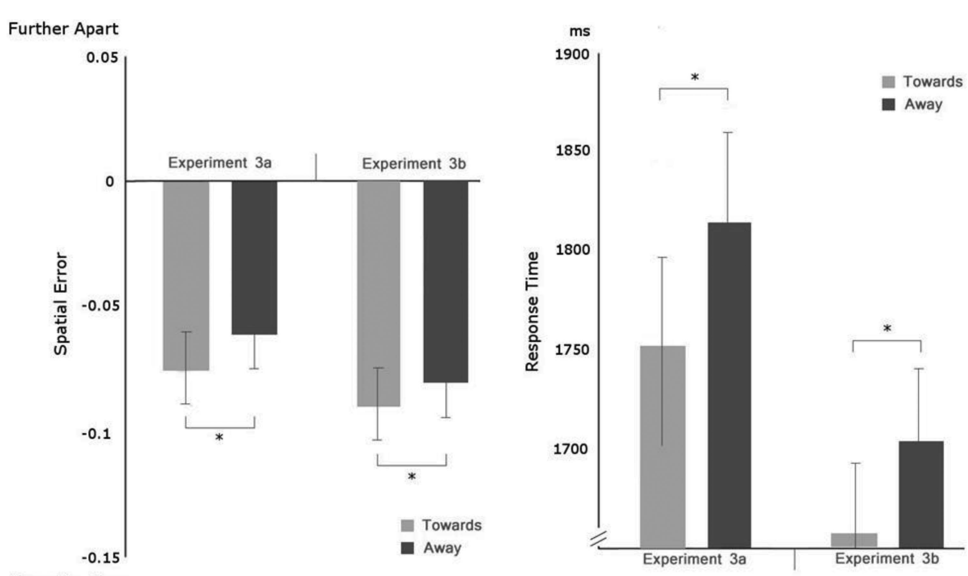

Figure 15. Mean spatial error (left panel) and response times (right panel) for Toward and Away oriented pairs in both Experiment 3a and 3b. * $p < .05$.

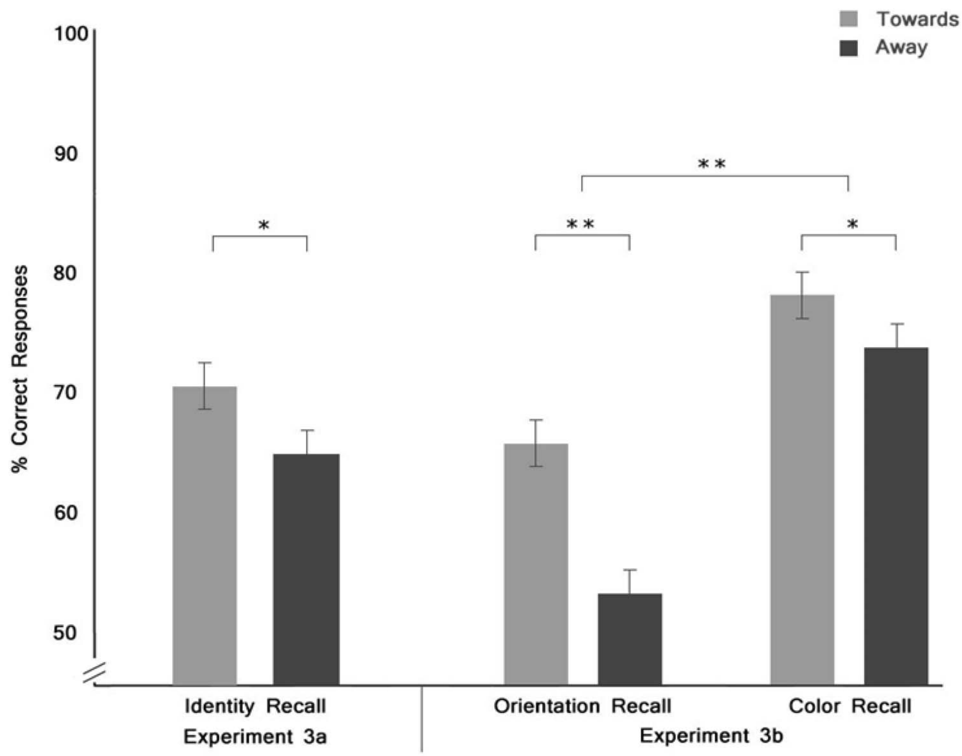

Figure 16. Mean retrieval accuracy of participants in all recall conditions. * $p < .05$. ** $p < .001$.

irrelevant to the previous spatial recall task; hence, the social binding processes produces encoding effects that appear to be automatic. In the next experiment we examine whether other properties, such as orientation and color, are also encoded in to memory more efficiently when perceiving social interactions. A further need for extension to the current study concerns the nature of the stimuli used in the final recognition task. Recall that these stimuli where the same as those perceived during initial encoding during the previous spatial recall task. That is, pairs of individuals either facing Toward or Away from each other. Therefore, an important issue is whether the facilitated recall in the Toward condition can also be observed when the stimuli during encoding (spatial recall task) and those during subsequent retrieval, are different; and where the stimuli during recall are identical for the Toward and Away condition.

Experiment 3b

As some of the previous research has found that memory for objects within a perceptual group is enhanced even for features that are not relevant at the group level and even differ between objects (Woodman et al., 2003), we further wanted to investigate whether memory for individual details that are not uniform across partners is also benefiting from Social Binding. In this experiment there are two properties of the Toward and Away conditions that are subsequently examined, these we refer to as group relevant and irrelevant features. However, it is important to note that both of these stimulus properties were irrelevant to the initial spatial recall task and, hence, any memory advantages during social binding in the Toward condition reflects incidental/automatic encoding in to memory.

The group relevant stimulus property was recall of the direction that a previously viewed person had been facing in the earlier spatial memory task. Although this property was not explicitly considered in the previous spatial task, direction an individual faced was of course a necessary feature determining whether the individuals were grouped because of social interactions (Toward) or not (Away condition). For the group irrelevant feature we chose recall of the color of an individual's clothing as this was neither relevant for computing social interactions nor a common feature of any pair.

If individuals in Toward-orientation are bound into groups then participants should recall the looking direction better and more quickly for those individuals as compared with those that had been presented in the Away orientation. Predictions for the clothing color recall task are less clear: On the one hand, a stimulus feature such as color might be recalled more easily and quickly in Toward-oriented pairs if the grouping is beneficial to individual features; on the other hand it is possible that the effects of social grouping determined by the property of Toward or Away orientation, might inhibit irrelevant features such as clothing color and, hence, there will be no recall advantages in the Toward condition.

There is even the possibility of a decrease of recall accuracy because of possible unitization (McLaren & Mackintosh, 2000; Welham & Wills, 2011), which has been shown to distort memory of features such as size toward the corresponding feature of the partner or the group average (Corbett, 2017; Corbett & Oriet,

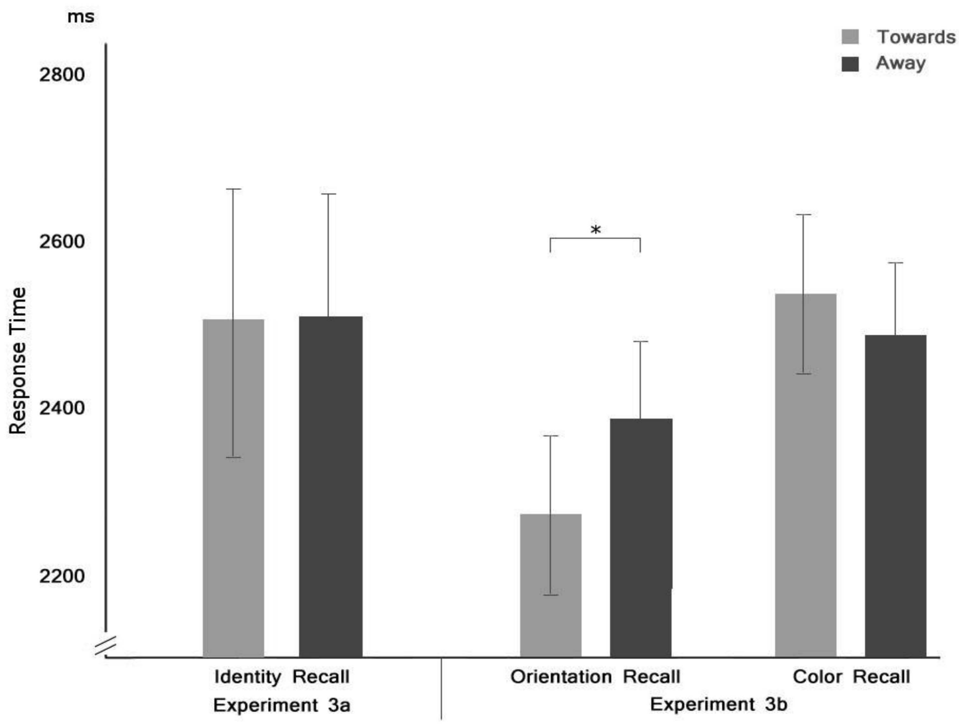

Figure 17. Mean response times of participants in all recall conditions. * $p < .05$.

2011). While this would be an interesting effect in its own right, the current study aims at establishing Social Binding in the absence of secondary effects and this kind of memory distortion would have presented a confound. Therefore, the experiment has been designed to decrease the possibility of this effect as much as possible, as described in the materials and procedure sections below.

Method.

Participants. Sixty participants were recruited and allocated randomly into task-relevant (looking direction; 30 women) and task-irrelevant (clothing color; 30 women) memory conditions. All participants were tested for color vision deficits with the Ishihara test (Clark, 1924) after the experiment; No participant showed such deficits.

Materials. The same stimuli as in Experiment 3a were used. Three variations of each stimulus person were produced that differed in color of clothing. To avoid potential color averaging effects between partners we chose colors that were perceptually very different for the corresponding clothing items between partners. Additionally, we varied which clothing items would change color between partners, for example, one individual's shirt versus another's trousers. See Figure 18 for an example. Otherwise the same materials as in Experiment 3a were used.

Design. The spatial task was analyzed in the same way as in Experiment 3a. For the memory task a mixed 2×2 ANOVA was used, looking at the effect of orientation of stimuli (Toward or Away; within subjects) and type of recall (group relevant direction or group irrelevant clothing color; between subjects) on response time and retrieval accuracy in a surprise memory task. Accuracy was represented by the percentage of correct responses.

Procedure. This experiment again used a spatial judgments task followed by a surprise memory task. The spatial judgments task was identical to Experiment 3a. For participants in the color memory condition, one of the color variations was chosen at random for each stimulus individual at the beginning of the experiment.

At the start of the surprise memory task, participants in the looking direction condition were informed that all individuals in the first part of the experiment always faced in the same direction. They would now see all previously viewed people again individually on screen and Participants were asked to indicate whether the individual was looking in the same or in the opposite direction as before by pressing the 'c' or 'v' key on the keyboard (counterbalanced between participants). Exactly half of individuals were shown in their original orientation and half in the opposite orientation (counterbalanced by gender and orientation).

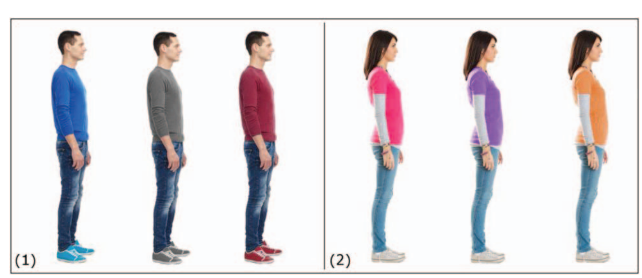

Figure 18. Three color variations of both a male (1) and female (2) model. See the online article for the color version of this figure.

Participants in the color memory condition were informed that they would see each individual from the first task again, but for each they would see two versions that differed by the color of their clothing, the correct one and one of the two alternates. They were asked to indicate which version they had seen before by pressing the 'c' key for the left version and the 'v' key for the right version. Response keys were not counterbalanced to avoid Simon task effects (Simon & Wolf, 1963). Exactly half of correct stimuli were appearing on the left, half on the right side of the screen (counterbalanced by gender and orientation). While in the interest of accuracy participants were not asked to make their decisions as quickly as possible, they were told to "not overthink it but just go with [their] first instinct." See Figure 19 for an overview of the two memory tasks with their possible retrieval cues.

The intention behind measuring color recall in the form of a two-alternative forced-choice task that always included the correct choice was to counteract any memory distortions resulting from unitization. The direction recall condition, however, necessarily used the same single-target recognition task as in Experiment 3a because a 2AFC task like in the color condition would have presented both the left and right orientation of each individual at the same time, which between them would have formed Together- or Away-oriented pairs, which in turn would have introduced additional confounds. Because of this difference between conditions we do recommend caution when comparing the overall main effects or effect sizes between the direction and color condition. However, this difference is not relevant to the hypotheses we were investigating as we were only interested in the orientation differences within conditions, not the overall performance between conditions.

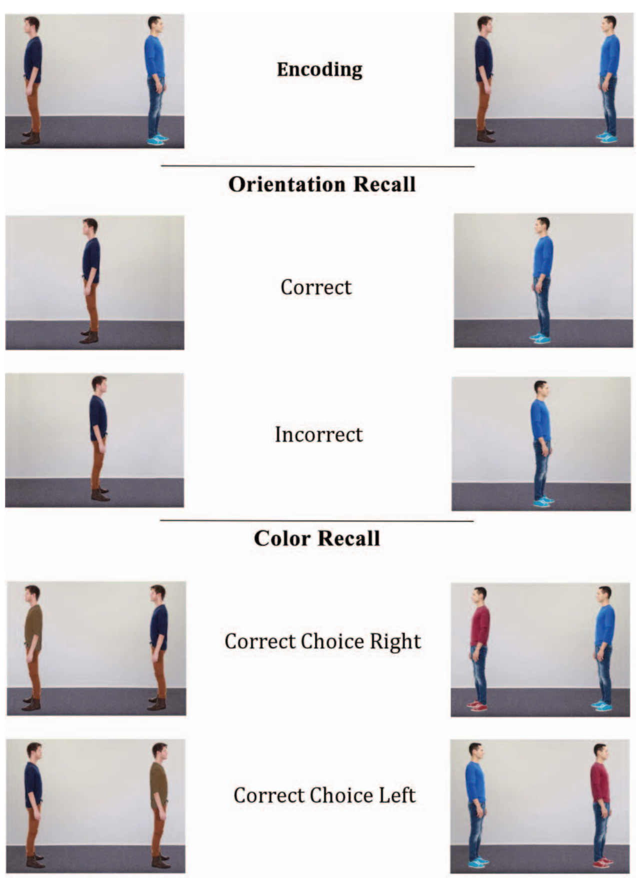

Figure 19. An example of an encoded pair in Away (left) and Toward (right) orientation with the corresponding possible retrieval prompts. See the online article for the color version of this figure.

Results.

Spatial judgments. To test whether the spatial distortions found in Experiments 2a, 2b, and 3a were replicated, we tested for spatial error and response time differences between Toward and Away oriented pairs across all 60 participants. As before, trials where participants placed the target on the wrong side of the cue stimulus and those that were more than 3 *SD*s away from the mean were excluded ($<$3% of trials).

As expected, Toward oriented pairs were remembered as closer together than Away oriented pairs, $t(59) = 2.83$, $p = .006$, $d = 0.36$ as well as processed faster, $t(59) = 2.80$, $p = .007$, $d = 0.37$; replicating again our findings from Experiments 2a, 2b, and 3a; see Figure 15.

Visual longer-term memory. Binomial tests (.50) confirmed that participants performed above chance in all conditions (all $p < .05$).

A 2 × 2 mixed ANOVA testing for memory accuracy showed significant main effects for initial Toward or Away orientation of stimuli ($F(1, 58) = 32.45$, $p < .001$, $\eta_p^2 = .359$), color or orientation feature to be recalled ($F(1, 58) = 48.02$, $p < .001$, $\eta_p^2 = .453$) as well as a significant interaction ($F(1, 58) = 5.70$, $p = .02$, $\eta_p^2 = .090$). Post hoc tests revealed that participants asked to remember looking direction were 12.2% more accurate if the originally presented pair was in Toward rather than Away orientation, $t(29) = 4.95$, $p < .001$, $d = 0.90$. Participants asked to recall clothing color were 5% more accurate if the individuals had previously been shown in Toward orientation, $t(29) = 2.87$, $p = .008$, $d = 0.52$. See Figure 16 for mean accuracies across conditions. Hence, the same recall advantage for Toward stimuli was observed for both orientation and color recall, though the effect was significantly more robust in the orientation recall condition.

A 2 × 2 mixed ANOVA considering only trials in which participants had made the correct response showed response times did not differ depending on initial orientation of stimulus, $F(1, 58) = 0.51$, $p = .48$ or feature to be recalled, $F(1, 58) = 1.91$, $p = .172$, but a significant interaction between these variables was found ($F(1, 58) = 7.28$, $p = .009$, $\eta_p^2 = .111$). Post hoc tests based on this interaction revealed that participants were significantly faster to respond to stimuli that had previously been shown in Toward orientation when they were asked to recall looking direction of an individual, $t(29) = 2.43$, $p = .022$, $d = 0.45$. When asked to recall clothing color there were no significant effects, $t(29) = 1.40$, $p = .174$. See Figure 17 for RTs across conditions.

Discussion. The main motivation for this experiment was the investigation of the previously observed social grouping effects on recall. We predicted that when people were observed interacting, there would be binding of these two individuals in memory into a single event. Hence, when later retrieving information from a single event file created by grouping social interactions (Toward condition), this would facilitate retrieval in comparison with conditions where each person is encoded as a separate event (Away condition).

The experiment examined retrieval of two kinds of information, the first we considered to be a property of the social interaction (direction of gaze) while the second was a property that was irrelevant to the social interaction (color of clothes). The prediction for the recall of the direction an individual had been facing was for facilitated retrieval of this socially relevant property when a social interaction between two people was encoded. This prediction was confirmed, where recall of direction was more accurate when a person had been encoded as a group with another individual in the Toward condition relative to separate individual representations of noninteracting individuals in the Away condition. This increased accuracy of recall was also accompanied by more efficient retrieval processes as time to respond was faster in the Toward condition.

The results regarding the unrelated property of clothing color suggest that even irrelevant properties are also more efficiently retrieved from grouped representations. While these effects appear weaker here than the Social Binding benefit in the direction condition, the slight difference in recall tasks makes a direct comparison unreliable. However, now that an effect of Social Binding on memory accuracy even for irrelevant features has been established, it is possible to design future studies to more directly compare these benefits for a variety of features. Possible unitization effects should now also be investigated but have been left to future studies because of the amount of carefully controlled experiments necessary to investigate them in detail.

In contrast, the response time effects in these memory retrieval studies are less clear. Although significant effects were observed when recalling person orientation, no effects were detected when recalling color of clothing or person identity (Experiment 3a). Hence, speed of memory retrieval may not be such a sensitive measure as accuracy of recall. Although of note, speed was not emphasized as a response requirement; hence, future studies requiring recall decisions to be made as fast as possible might detected effects in RT.

Overall our results support our hypothesis that interacting individuals are bound together and encoded into memory as a group rather than individually, and retrieval from such grouped representations is more efficient, in agreement with previously observed effects of perceptual grouping of objects according to gestalt principles on working memory (Woodman et al., 2003). Indeed, it appears that a range of properties are more efficiently encoded in to memory during social interactions, such as the identity of a person (Experiment 3a), the orientation the person is facing, and the color of their clothing (Experiment 3b). These properties were not explicitly processed in the initial spatial memory task and subsequent requirement for recall was not expected by participants; hence, supporting the notion that such incidental encoding is automatic when perceiving social interactions.

General Discussion

These experiments investigated the processing of allocentric third-person interactions between other people. That is, unlike previous research that has primarily been based on egocentric computations where the states of the observer, or the relationship between the observer and observed, have been important; the present work presented interactions between two other people, which were essentially irrelevant to the observer. Hence, participants did not have to consider and analyze any properties of the people in view, rather they simply had to detect and localize targets that were (non-)interacting pairs, recall the relative spatial location of individuals after viewing them and recall visual features of those individuals. The hypothesis was that when encountering complex social environments containing a number of people, an important initial computation was to detect where social interactions are taking place as an initial structural representation on which subsequent more sophisticated analysis of social interactions, such as detection of deception, social intimacy, and so forth, might be built. The results are consistent with our Social Binding model: Although irrelevant to task demands, the socially interactive nature of the observed people was computed leading to faster detection or localization of interacting dyads and distortions of space in STM and increased accuracy of recall in longer-term memory.

Various lower level explanations, such as symmetry, gaze cueing, attention, or representational momentum were investigated, but failed to explain the pattern of results. While similar perceptual grouping effects of objects according to gestalt principles have been found in the past (e.g., Coren & Girgus, 1980), none of the known principles can account for the current effects as the Toward and Away orientations do not vary in proximity or similarity, nor do they form a common figure to which the laws of closure or good continuation could be applied.

This elimination of low level and "nonsocial" effects also provides support in favor of a social explanation of Jung et al.'s (2016) results. While it is certainly possible that their effects of decreased distance estimates when looking at the front of a virtual avatar might be explained by low level processes, the fact that we have now found similar effects in an allocentric frame with decidedly different low-level visual information would favor a higher level explanation.

These high-level effects are most reminiscent of the well-established mechanism of perceptual grouping. This fundamental process binds separate visual elements and features together into perceptual wholes according to Gestalt principles, such as proximity, similarity, good continuation or closure (e.g., Coren & Girgus, 1980). Perceptual grouping is known to result in faster processing (Woodman et al., 2003) and decreased perceived distance (Coren & Girgus, 1980) of the individual elements. Similarly to binding elements into a perceptual whole it might be possible and advantageous to perceptually bind individuals into groups, which would provide a rapid and simplified framework for subsequent more subtle social analysis.

The social effects we observe may be part of a more general principle in which space is contracted between interacting partners. This is demonstrated even in simple interactions between objects. For example, in situations where a circle moves and then collides with a rectangle, which immediately causes a second circle to move, the length of the intervening rectangle is recalled as shorter than when there is no causal relationship between the two circle objects (Humphreys & Buehner, 2010). Furthermore, there is evidence for similar binding with objects that are perceived to be interacting, such as a hammer striking a nail (e.g., Bach, Peelen, & Tipper, 2010; Riddoch, Humphreys, Edwards, Baker, & Willson, 2002). Our findings reveal that these distortions of spatial memory may be caused by a gestalt-like principle of interaction and can also be identified with higher-level social interactions, where the potential for interaction is only implied and not overtly perceived via movement cues. We propose that when two people are jointly engaged in a social situation, they are grouped and encoded as one event, in a similar way to two interacting objects. This jointly encoded unit results in faster retrieval of the prior spatial information, and increased spatial proximity in such memory representations. Moreover, even higher level properties of the dyad members are grouped in such a way and accessed more rapidly. The results of Experiment 3 especially provide support for the binding account, where recall of the properties associated with interacting individuals such as the person identity, direction the person faced or the color of their shirt, was better than that of noninteracting individuals, in a manner similar to von Hecker, Hahn, and Rollings (2016). It should be noted that the current set of experiments only considered dyads, that is, interindividual interactions. Whether and how these effects extend to larger groups—especially abstract grouping of people beyond immediate social interactions—is an open question worthy of further research.

Although our current findings reveal the warping of spatial memory (Experiment 2) in a passive task where no actions are required and the object properties are of little relevance to the spatial memory task, we are not ruling out a potential role for egocentric processes to influence the current effects. It is possible that egocentric computations in space perception such as those found by Jung et al. (2016) are applied when observing allocentric interactions between two other people by way of perspective taking. Furthermore, other studies have shown that properties of an egocentric frame of reference can influence allocentric judgments of distance. For example, judgments of the length of a line are influenced by an observer's level of fatigue: after an effortful task has produced fatigue, lines are judged as longer (Clark, Ward, & Kuppuswamy, 2016). Hence, it may be the case that the ego states of the participant, such as social inclusion/exclusion, emotion, task goals, and ingroup or outgroup could also influence the warping of allocentric spatial memory.

On the other hand, it is possible that the basic effects we have revealed in the current studies are not affected by feedback from higher-level states of the perceiver (e.g., emotion, empathy etc.) or the observed social interaction (e.g., dominance, intimacy etc.). Rather, it is possible that the automatic detection of a social interaction is a midlevel representation that automatically facilitates detection and localization of interacting dyads as well as influencing later memory. This process could be modular and not influenced by feedback from higher-level social processes. Rather, this initial automatic computation extracting social interactions might provide the automatic input to these later, higher-level social computations.

Finally, an advantage of the range of techniques, from immediate perception in the target detection task to retrieval from later memory, is that examining such cognitive processes of perception and memory can provide new converging methods to explore the automatic computations of social relationships. That is, the automatic processing of the relationships may reveal higher-level information and judgments in the distortion of spatial memory and the speed of access to this memory. Such an approach could investigate individual differences in social cognition, such as depression (e.g., Bayliss, Tipper, Wakeley, Cowen, & Rogers, 2017) and autism (Shah & Sowden, 2015) in an implicit manner. For example, do people with autism also automatically compute social interactions such that their attention is more rapidly oriented to such interactions, and memory retrieval processes reflect these computations?

The appearance of social binding in our simple laboratory experiments raises several new questions about the interaction of social perception and higher-level social processing, and it opens up new possibilities for research. While it is up to future studies to explore the relationship between the automatic detection of social interactions, properties of the stimulus and states of the observer, the current series of studies has shown that interacting individuals are perceptually grouped according to a previously unknown late-stage gestalt-like principle that binds interacting partners into memory as single events.

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