

## Gaze following in multi-agent contexts: Evidence for a quorum-like principle.

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### **Abstract**

Research shows that humans spontaneously follow another individual's gaze. However, little remains known on how they respond when multiple gaze cues diverge across members of a social group. To address this question, we presented participants with displays depicting three (Experiment 1) or five (Experiment 2) agents showing diverging social cues. In a three-person group, one individual looking at the target (33% of the group) was sufficient to elicit gaze-facilitated target responses. With a five-person group, however, three individuals looking at the target (60% of the group) were necessary to produce the same effect. Gaze following in small groups therefore appears to be based on a quorum-like principle, whereby the critical level of social information needed for gaze following is determined by a proportion of consistent social cues scaled as a function of group size. As group size grows, greater agreement is needed to evoke joint attention.

**Key words:** gaze cuing; joint attention; small groups; social influence; socially acquired information.

**Gaze following in multi-agent contexts: Evidence for a quorum-like principle.**

Both human and non-human primates follow conspecifics' social cues, which are typically conveyed by their eye and head direction (Emery, 2000). Experimentally, this *gaze following* behavior is often investigated using the gaze cuing task, in which observers view images of faces looking toward or away from a response target (Frischen, Bayliss, & Tipper, 2007). Despite the fact that the social gaze cue remains task-irrelevant and participants are instructed to ignore it, people typically respond faster to gazed-at relative to not-gazed at targets (Driver et al., 1999; Friesen & Kingstone, 1998; Hayward & Ristic, 2017). This well-established result is interpreted as indicating that others' gaze direction elicits spontaneous orienting of attention and facilitates responses to gazed-at targets (Bayliss, Bartlett, Naughtin, & Kritikos, 2011). More generally, this finding showcases one of the most basic evolutionary advantageous behaviors which allows humans to quickly utilize and respond to social information in the environment (van Vugt, 2014; Zuberbühler, 2008).

Remarkably, to date gaze following has mostly been examined in dyadic contexts, in which one observer responds to social gaze cues displayed by another agent. In real-life, however, humans typically encounter more than one agent at the time, with multiple people often looking in different directions. How do humans respond to such multiple and diverging social cues? Intuitively, one might hypothesize that observers would systematically follow the direction of the majority of location-directed cues. A recent study on human crowds supports this intuition, suggesting that observers preferentially follow gaze cues displayed by the group majority (Sun, Yu, Zhou, & Shen, 2017).

However, it remains unknown if the "majority" principle similarly applies to small social groups of six or less individuals (Dunbar, Duncan, & Nettle, 1995), which in contrast to crowds

(e.g., a family meal vs. an audience at a football match) afford mutual interactions and joint attention states and require efficient handling of individual members' social cues (David-Barrett & Dunbar, 2013; Lewin, 1951). Research on social influence shows that perceivers are biased toward an opinion when it reaches a relevant proportion of group consensus (MacCoun, 2012). While in large groups this "relevant proportion" is often represented by the group majority (Insko, Smith, Alicke, Wade, & Taylor, 1985), in small groups it may also reflect the group minority (Tanford & Penrod, 1984). Thus, the proportion of group consensus needed to bias perceivers' responses may be mediated by group size, with larger groups requiring larger group-relevant consensus. In turn, responding to divergent gaze cues displayed by the members of a small social group may follow a "quorum-like" principle, in which the proportion of consistent social cues needed to bias an observer's attention would increase as a function of group size.

Reflecting the animal decision-making literature (Ward & Webster, 2016), here we use the term 'quorum' to denote instances in which the probability of a behavior changes dynamically as a function of the number of individuals exhibiting that same behavior.

In the current study, we tested if the relevant proportion of social cues needed to elicit gaze following in small groups follows a majority or a quorum-like principle. To do so, we utilized an adapted gaze cuing task in which we manipulated the proportion of consistent gaze cues displayed by three (Experiment 1) and five (Experiment 2) agent groups. If humans compute group social visual information using the majority rule, we expected to find gaze-facilitated target responses only when the group majority, independently of the group size, displayed consistent gaze cues. If, on the other hand, humans compute social visual information using a quorum-like approach, we expected to find that the relevant proportion of gaze cues

needed for gaze-facilitated target responses would increase with group size. Our results supported the quorum-like principle.

## Experiment 1

### Method

*Participants.* Thirty-six undergraduates (31 females; mean age=20.16 years; age range=18-23), naïve to the purpose of the study, with normal or corrected-to-normal vision, participated in the study in return for course credits. All procedures were in accordance with the World Medical Association Declaration of Helsinki (2013) and were approved by the University's research ethics board. The sample size was chosen based on past work examining the effects of inconsistent perspectives on the visual processing of social information (Capozzi, Cavallo, Furlanetto, & Becchio, 2014), and an a-priori power analysis with  $d_z=.5$ ,  $\alpha=.05$ ,  $1-\beta=.90$  [G\*Power; (Faul, Erdfelder, Lang, & Buchner, 2007)].

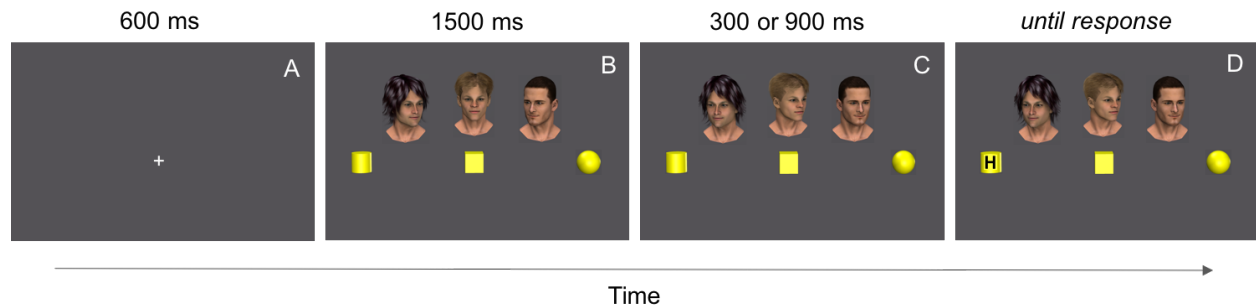
*Apparatus & Stimuli.* Stimulus presentation and data collection were controlled by Experiment Builder (SR Research). Stimuli (created using Smith Micro's Poser 9 software) included three male faces (varying in size from 4.4 to 5 cm in width and 7.1 to 7.5 cm in height), three placeholder objects, a cube, a cylinder, and a sphere (varying in size from 2.1 to 2.5 cm in width and 2.1 to 2.5 cm in height) used to facilitate inference of line of sight, and capital letters "N" and "H" (1.5 × 2 cm) used as response targets. The stimulus sequence was presented on a 16-in CRT monitor at an approximate viewing distance of 60cm.

*Design.* A repeated measures design with two factors was used. The first factor, the Number of faces cuing the target, had four levels - zero, one, two, or three faces cuing the target. In the one\_face\_cuing condition, the target appeared at the location cued by one face, while the two remaining faces cued the opposite location. In the two\_faces\_cuing condition, the target

appeared at the location cued by two faces, while the remaining face cued the opposite location. To compare the relative strength of gaze following as a function of the number of inconsistent gaze cues, we also included two conditions in which the target appeared at the location cued by no face (*zero\_faces\_cuing*) and by all faces (*three\_faces\_cuing*).

To investigate the time course of gaze following in multi-agent contexts, the second factor manipulated the time between the onset of the cue display and the onset of the target between 300 and 900ms.

The two factors were manipulated equiprobably, with a trial sequence presented in a pseudorandom order within participants. No face or groups of faces provided relevant information about the target. Each face identity appeared equally often at each position, and each target type occurred equally often in either the left or right position.



**Figure 1.** Illustration of stimuli and an example stimulus presentation sequence for Experiment 1. After the presentation of a 600ms fixation cross (A), three faces and three objects appeared directed at the central object for 1500ms (B). Then, the faces turned toward one of the lateral objects (C). After 300 or 900ms, a response target appeared in one of the two peripheral locations. The target could be cued by zero, one (illustrated here), two, or three faces (D). The display showing the target remained visible until response or for 2500ms. Intertrial interval was 600ms.

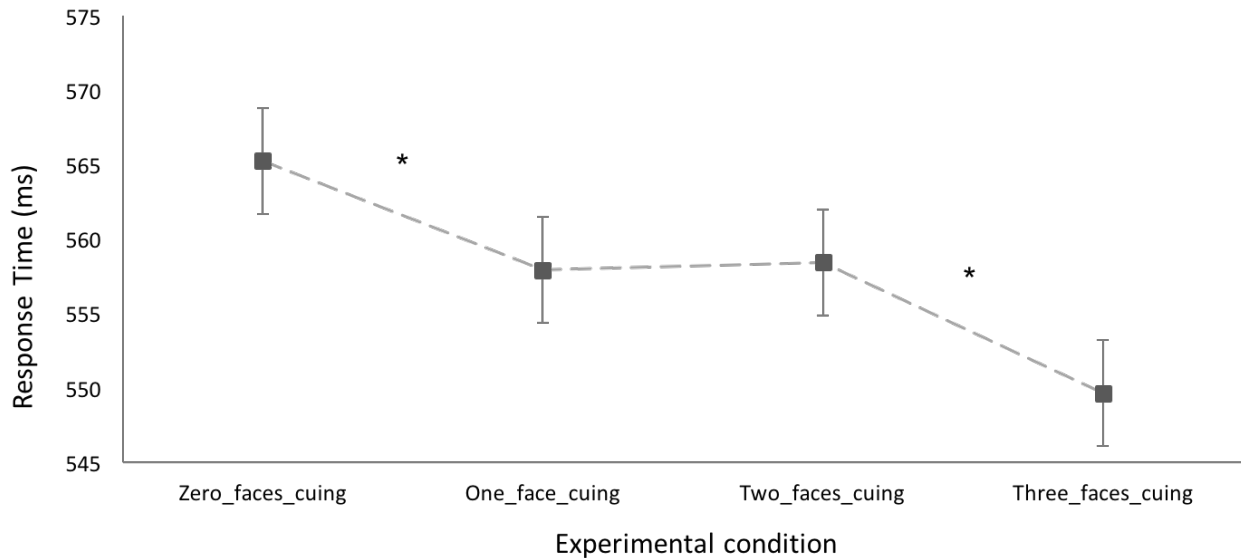
*Procedure.* Each trial started with a 600ms fixation display (Figure 1.A). Then, a display with all three faces turned towards the central placeholder was shown (Figure 1.B). After 1500ms, each face turned either towards the left or to the right object (Figure 1.C). The faces turned either in the same direction, creating the *zero\_faces\_cuing* or the *three\_faces\_cuing* conditions, or in different directions, creating the *one\_face\_cuing* and *two\_faces\_cuing* conditions. After 300 or 900ms, a response target, demanding an identification response, was presented on either the left or right object (Figure 1.D). The faces and the target remained visible until response or until 2500ms had elapsed. A feedback tone was presented upon missed or erroneous response. Intertrial interval was 600ms.

Participants were instructed to identify the target quickly and accurately by pressing one of two adjacent keyboard keys marked in yellow and blue. Key response-target identity assignment was counterbalanced across participants. Participants were instructed to ignore the face cues, and to maintain central fixation. After sixteen practice trials, in which only response targets appeared, the experiment proceeded over 576 trials split into four blocks.

## Results

We examined response accuracy and RT using repeated measures ANOVAs, run as a function of the Number of faces cuing the target and Cue-target interval. Bonferroni correction was applied where appropriate.

Participants performed the task well, with 95.5% average accuracy and no differential effects across experimental conditions ( $F_s < 1.736$ ,  $.778 < p_s < .946$ ). RT analyses were based on correct trials, and additionally excluded any anticipatory and timed-out responses (i.e., responses faster than 200ms and slower than 1200ms, 6.16% of trials). Figure 2 plots mean RTs as a function of the number of faces cuing the target.



**Figure 2:** Mean correct reaction times (RTs) as a function of the number of faces cuing for Experiment 1. Error bars depict SEM for within-subjects designs (Loftus & Masson, 1994), for the linear effect of the Number of faces cuing. Asterisks denote significance at the  $p < .05$  level.

RT analysis revealed a significant linear contrast [ $F(1,35)=17.632, p<.0001, \eta^2_p=.335$ ] following from a main effect of the Number of faces cuing,  $F(3,105)=10.093, p<.0001, \eta^2_p=.224$ . We explored this effect using paired sample t-tests, which compared performance at adjacent conditions (i.e., zero\_faces\_cuing vs. one\_face\_cuing, one\_face\_cuing vs. two\_faces\_cuing, two\_faces\_cuing vs. three\_faces\_cuing). In contrast to a “majority rule”, predicting that gaze-facilitated target responses would emerge when two out of three faces displayed consistent cues to the target, our data indicated that reliable gaze following emerged already with one agent looking at the target, as the comparison between zero\_faces\_cuing ( $M=565; 95\%CI=[537,594]$ ) and one\_face\_cuing ( $M=558; 95\%CI=[532,584]$ ) yielded a significant difference,  $t(35)=2.667, p=.036, dz=.479$ . No difference between the one\_face\_cuing and the two\_faces\_cuing ( $M=557;$



95%CI=[530,585]) conditions was found,  $t(35)=.204$ ,  $p>.999$ ,  $d_z=.032$ . Following from past work (e.g., Capozzi et al., 2014), the most pronounced target facilitation was observed when all three faces ( $M=550$ ; 95%CI=[523,576]) cued the target,  $t(35)=3.091$ ,  $p=.012$ ,  $d_z=.522$ .

The ANOVA also indicated a reliable main effect of Cue-target interval,  $F(1,35)=9.080$ ,  $p=.005$ ,  $\eta^2_p=.206$ , with faster overall responses at 900ms ( $M=554$ ; 95%CI=[527,581]) relative to the 300ms ( $M=561$ ; 95%CI=[534,587]), demonstrating a typical foreperiod effect (Hayward & Ristic, 2015). The interaction between Number of faces cuing and Cue-target interval was not significant,  $F(3,105)=.522$ ,  $p=.668$ ,  $\eta^2_p=.015$ .

Thus, Experiment 1 revealed that when participants were presented with divergent social visual cues from a group of three agents, one person looking at the target, a proportional representation of only 33%, was sufficient to elicit gaze-facilitated target responses. This finding supports the notion that the proportion of social cues needed to bias observers' attention in small groups does not follow a majority principle. To test if this relevant proportion is modulated by group size, in Experiment 2, we increased the size of the group from three to five.

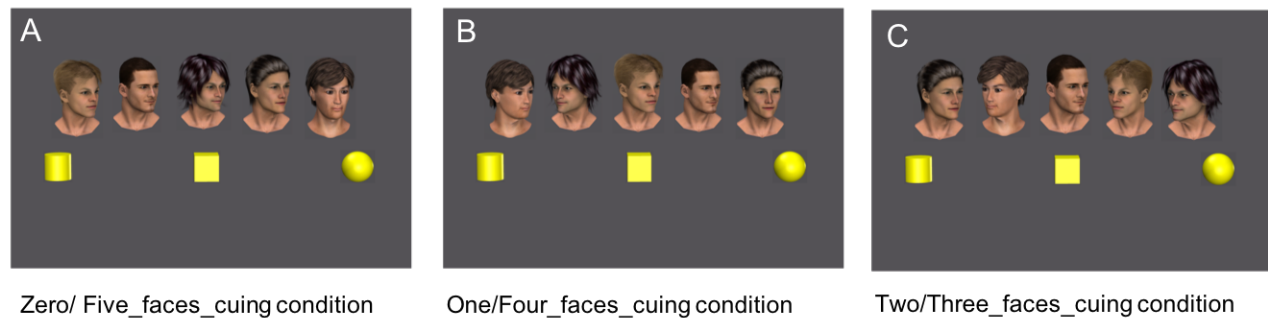
## Experiment 2

### Method

*Participants.* Thirty-two new naïve volunteer students participated (24 females; mean age=20.59; age range=18-26). None took part in the previous experiment, and all reported normal or corrected-to-normal vision. The sample size mirrored Experiment 1 preserving power tolerance of  $.80 > 1-\beta < .90$ .

*Apparatus, Stimuli, Design, and Procedure.* All parameters were identical to Experiment 1, except that (a) the number of faces was increased from three to five, by adding two additional male identities; (b) the number of faces cuing the target could be zero, one, two, three, four, or

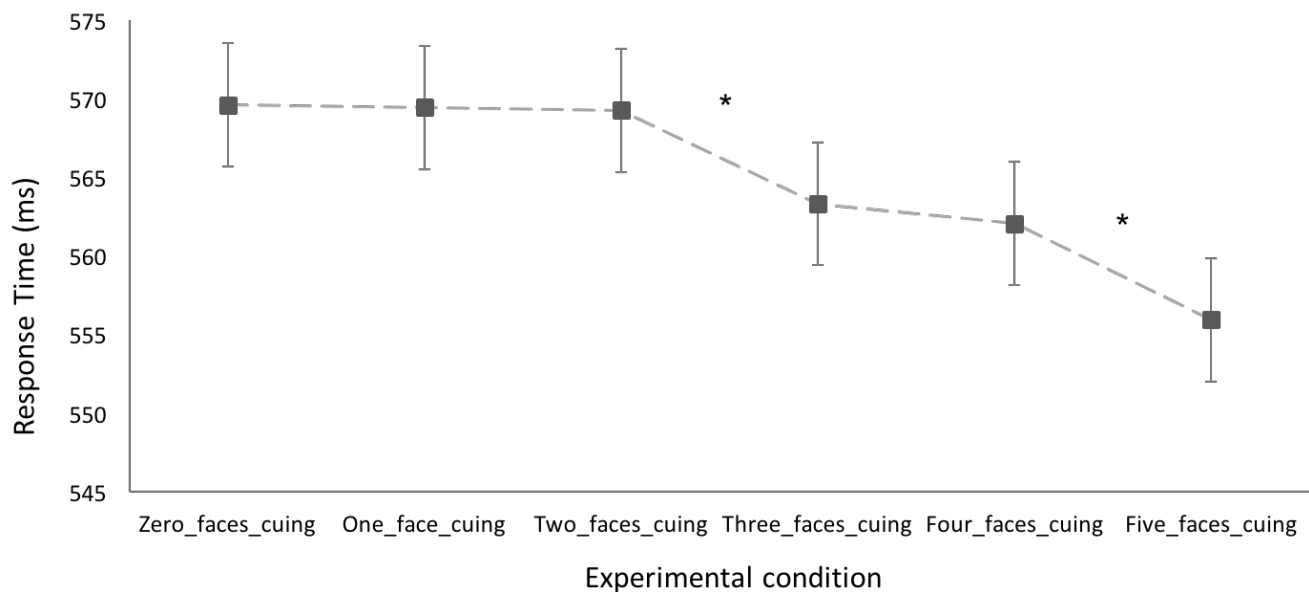
five; and (c) to account for the increase in the experimental conditions, 864 trials divided across six blocks were run. Each face identity appeared in each of five possible positions equally often. Group arrangement was manipulated randomly such that each face could turn to the left or right independently of other faces. Figure 3 shows example stimulus configurations.



**Figure 3:** Example of stimulus configurations for Experiment 2. Depending on the target location, images depict stimulus displays for the zero\_ or five\_faces\_cuing condition (A), one\_ or four\_faces\_cuing condition (B), and two\_ or three\_faces\_cuing condition (C).

## Results

Analyses mirrored Experiment 1. Participants performed the task well, with overall accuracy of 96.5% and no modulation of accuracy performance as a function of experimental variables ( $F_s < 2.271$ ,  $.075 < p_s < .310$ ). Mean correct RTs, trimmed for anticipations and response timeouts (5.44% trials), were examined using a repeated measures ANOVA as a function of the Number of faces cuing the target and the Cue-target interval. Figure 4 plots mean RTs as a function of the number of faces cuing the target.



**Figure 4:** Mean correct response times (RTs) as a function of number of faces cuing for Experiment 2. Error bars represent SEM for within-subjects designs (Loftus & Masson, 1994), for the linear effect of the Number of faces cuing. Asterisks denote significance at the  $p < .05$  level.

Again, a significant linear contrast [ $F(1,31)=17.824$ ,  $p<.0001$ ,  $\eta^2_p=.365$ ] followed the main effect of the Number of faces cuing,  $F(5,155)=6.516$ ,  $p<.0001$ ,  $\eta^2_p=.174$ . However, post-hoc t-tests demonstrated that reliable gaze-facilitated responses now emerged only when three agents looked at the target [ $t(31)=2.231$ ,  $p=.033$ ,  $dz=.478$ ], with faster responses in the three\_faces\_cuing condition ( $M=563$ ; 95%CI=[533,593]) relative to the two\_faces\_cuing condition ( $M=569$ ; 95%CI=[539,600]). As before, the most pronounced performance facilitation was found when all five faces ( $M=556$ ; 95%CI=[526,586]) cued the target,  $t(31)=2.100$ ,  $p=.044$ ,  $dz=.377$ . No other comparison was significant ( $ts<1.00$ ,  $.875<ps < .947$ ).

The ANOVA also indicated a main effect of Cue-target time,  $F(1,31)=13.764$ ,  $p=.001$ ,  $\eta^2_p=.307$ , with overall faster RTs at the 900ms ( $M=560$ ; 95%CI=[530,590]) relative to the 300ms

( $M=569$ ;  $95\%CI=[539,600]$ ), with no significant interaction with the Number of faces cuing,  $F(5,155)=.546$ ,  $p=.741$ ,  $\eta^2_p=.017$ .

In sum, the results from Experiment 2 showed that when participants were presented with divergent social visual cues from a group of five agents, the critical amount of consistent social information needed to facilitate their target responses was three people, or the group's proportional representation of 60%. This is in contrast to Experiment 1, in which a proportional representation of 33% was sufficient for the same response. Together, these data provide the first demonstration of a quorum-like representation of social visual information in small groups and indicate that a relevant proportion of gaze cues needed for a gaze-facilitated response increases with group size.

### **General Discussion**

How do people respond to diverging social cues displayed by members of a group? Previous work suggests that they would follow a “majority rule”, in that their attention would become biased toward the gaze direction displayed by the group majority (Sun et al., 2017). In contrast, and offering support for a “quorum-like” principle, here we show that a minority representation was sufficient to bias observers' attention in three-person group (Experiment 1) and that the proportion of gaze cues needed to elicit gaze following was modulated by group size (Experiment 2). Specifically, in Experiment 1, when viewing three agents with inconsistent gaze cues, participants responded to the target faster when it was cued by one agent relative to when it was cued by no agents. That is, a 33% proportional representation was sufficient to facilitate target responses. A different pattern of results emerged in a group of five agents (Experiment 2), in which a 60% proportional representation (or consistent cues from three out of five agents) was needed for gaze-facilitated target responses. Collectively, these data support the “quorum-like”

hypothesis, by showing that the amount of social information needed for a gaze following response does not follow a simple majority rule, but is determined by a relative proportion of social information computed as a function of group size.

Our finding is broadly consistent with past work on gaze following in human crowds, which showed that reliable gaze following emerged when seven out of ten (i.e., 70%), but not when six out of ten agents (i.e., the strict majority of 60%) displayed consistent visual social cues (Sun et al., 2017). Along with our data, this observation also supports a quorum-like principle, as a relevant proportion, rather than a strict majority of social cues, appears to have guided observers' responses in both cases (see Dyer, Johansson, Helbing, Couzin, & Krause, 2009).

Although our results are consistent with data supporting unique mechanisms of gaze perception (Bayliss et al., 2011) and higher order social processing (e.g., Capozzi, Bayliss, Elena, & Becchio, 2015), it remains possible that the processes that govern multi-agent social information processing may also involve some contribution of domain-general attentional mechanisms. However, the human ability to track multiple nonsocial stimuli appears to be constrained mostly by the spatial resolution of attention (Franconeri, Jonathan, & Scimeca, 2010), while in the social domain information processing is modulated by group size reflecting a power function, whereby increases in the group size are associated with increases in the size of the majority representation needed to sway responses in favor of the group's opinion (Latané & Wolf, 1981). It remains to be determined if such a power rule also applies to the computation of the relevant proportion of social visual cues in multi-agent contexts as well as the extent to which such an effect may rely solely on social information processing.

Our data also indicated that observers' responses remained most strongly modulated by a consistent social perspective. Both experiments found that a non-conflicting social perspective

(i.e., when all agents looked in the same direction), elicited the most powerful facilitation of target responses. This is in line with existing research which shows facilitated performance for consistent relative to inconsistent perspectives displayed by multiple agents (Capozzi et al., 2014). It also dovetails with work showing that a consistent group perspective may be understood as representing a single line of sight (e.g., Capozzi, Becchio, Willemse, & Bayliss, 2016; Gallup et al., 2012). An intriguing question related to this notion emerges from Experiment 1, which indicated an absence of a reliable difference between the responses to the targets occurring at locations cued by one face and those occurring at locations cued by two faces. Speculatively, this might be taken to suggest that participants compute the gaze cues from one and two agents similarly. Research on face perception indicates that humans are equipped with mechanisms that allow for an ensemble perception of group gaze (Sweeny & Whitney, 2014). Future research is needed to determine whether humans are also equipped with mechanisms that would allow ensemble computation of gaze cues from two (or more) sub-groups.

A novel theoretical insight that follows from our data is that humans do not apply a majority rule when responding to inconsistent visual social cues displayed by agents in small social groups. Instead, they appear to use a quorum-like heuristic, in which the proportion of social cues perceived as relevant increases with group size. These results provide a compelling instance of a sophisticated social mechanism that allows for a quick computation of the relative relevance of social information, and fluctuates as a function of group size. Previous research shows that increased group size modulates the perceived reliability and generalizability of social information (Capozzi et al., 2015; Mason, Dyer, & Norton, 2009). We add to this literature by showing that humans also utilize group size information in order to determine the proportional

relevance of available social cues. This is consistent with research on consensus decision making in social animals (Sumpter, Krause, James, Couzin, & Ward, 2008), and carries implications for understanding the mechanisms that allow humans to benefit from socially acquired information in the exploration of the environment. Specifically, utilizing information about the group size may serve an important function in handling conflicting social information (e.g., Merkle, Sigaud, & Fortin, 2015). While information acquired from social sources may not always yield optimal decisions, utilizing information about the group size may serve a preventative function in progressively decreasing, as group size increases, the risk of following uninformative social cues (Giraldeau, Valone, & Templeton, 2002).

In sum, when humans encounter divergent visual social cues from members of a small social group, they follow the gaze direction displayed by a relevant proportion of agents. This relevant proportion is determined by and increases with group size. This result highlights the general notion that contextual and environmental factors play an important role in the dynamic interpretation of available social information.

### **Acknowledgements**

Supported by the Social Science and Humanities Research Council of Canada (SSHRC; FC and JR), Natural Sciences and Engineering Council of Canada (NSERC; JR), William Dawson Chairs Fund (JR), Leverhulme Trust Project Grant RPG-2016-173 (APB). Many thanks to K. Stadel for support in data collection.

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