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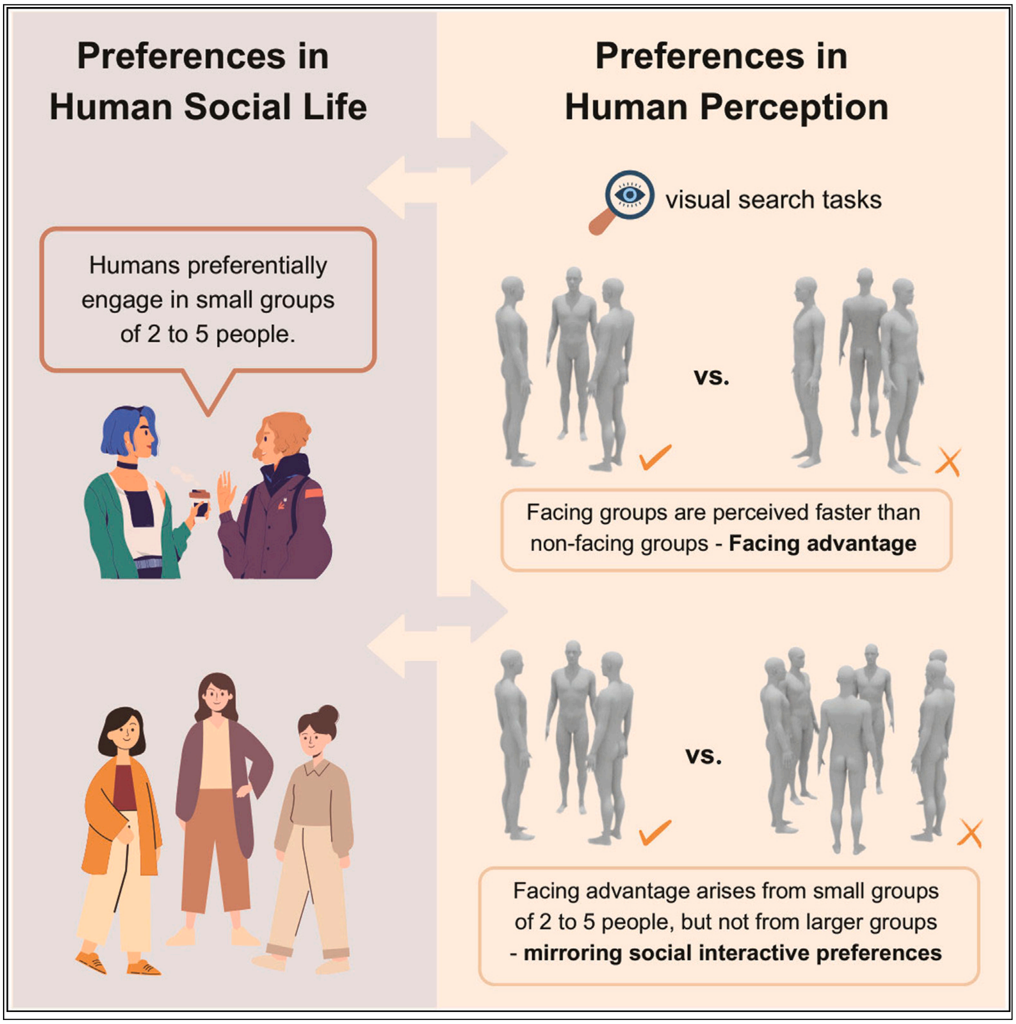

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Highlights

Humans typically interact in small groups of five or less

Humans find facing groups faster than non-facing ones

We found that this facing advantage is present only for small groups of five or less

Human perception of social groups tracks with interactive preferences in life

Yan et al., iScience 27, 111105
November 15, 2024
https://doi.org/10.1016/j.isci.2024.111105

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Search advantages for facing social groups reflect optimal interactive group sizes

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SUMMARY

Humans are sensitive to the presence of other people as well as their interactions. For example, two individuals are found faster when they face toward (vs. away from) each other. We asked if this perceptual preference for facing social groups might be modulated by group size, being most pronounced for small groups, which are most common in everyday life. In three preregistered experiments, participants searched for facing or non-facing groups, with group size varying from two to eight. Facing groups were found faster than non-facing groups but only for groups up to five people (Experiment 1). This effect replicated when controlling for the number of individuals in the displays (Experiment 2) and was reduced for displays in inverted orientations (Experiment 3). Thus, human perception seems to be well-tuned to detect interactions in small groups, which parallels social preferences in everyday life and bridges across visual perception and social cognition.

INTRODUCTION

Group formation and membership are foundational across species[1,2] as they enhance survivorship and reproductive success within the constraints of limited resources. For humans, groups are essential and play a pivotal role in satisfying our intrinsic need for social belonging.[3] Social groups are typically defined as two or more individuals who communicate with one another for an extended period of time.[4,5] Engaging in interactive and group behaviors requires sophisticated perceptual abilities that afford the detection of groups and their properties such as composition, numerosity, and interactive possibilities. Recent work has shown that visual perception aids in this endeavor by prioritizing the detection of humans in face-to-face (vs. back-to-back) configurations[6,7] as well as extracting and remembering socially relevant actions like handshakes.[8–10]

In group interactions, the number of group members is of particular relevance. Humans engage with one another in a range of configurations, from small groups of two (e.g., romantic partners) to large crowds of hundreds and more (e.g., sporting events).[11,12] Social and visual characteristics of large crowds are often extracted using ensemble perceptual coding,[13] which enables the computation of average values representative of the crowd as a whole. For example, upon seeing arrays of faces, humans can quickly extract the summary statistics of a number of social variables ranging from mean gaze direction[14] to trustworthiness[15] (see Whitney et al.[13] for a review). Smaller groups (i.e., groups of less than five members), however, do not typically invoke ensemble processing and still afford representations of individual members.[16] This qualitative distinction between smaller groups and crowds dovetails with limits in information processing, as both attention and working memory seem to be limited to about five simultaneously processed items.[17,18] For example, we are able to perceive numerosity up to about four via subitizing processes (i.e., quickly identifying the number of items without counting), and only later engage enumeration processes.[17,19] Similarly, we are able to attend to and track up to five individuals items,[20] and only involve ensemble processes with larger quantities.

Beyond these differential perceptual processes, small groups also seem distinct from larger crowds in their social function. James[21] observed that social groups such as those in shopping malls or stage plays are typically composed of less than five members, specifically of two to three individuals. Similarly, Bakeman and Beck[22] as well as Dunbar et al.[23] documented humans' natural tendency to congregate in small groups in public settings, such as a dining hall or an evening reception. Both studies found that people most frequently assembled in groups of four or fewer members. In the context of human development, work or family groups often consist of five individuals.[24,25] This group size enables support within the clique, efficient collaboration on tasks such as hunting or foraging, and direct interactive contact with the surroundings.[26] One explanation for these findings is that small groups may be particularly conducive to effective group interactions, since they enable individual members to interact and communicate with one another directly and simultaneously while also keeping track of the overall group dynamic.[27] Research on group dynamics supports this notion showing that small work groups consisting of three to four individuals are more productive than larger ones[28] and members report greater involvement and satisfaction.[29] Together, these studies

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https://doi.org/10.1016/j.isci.2024.111105

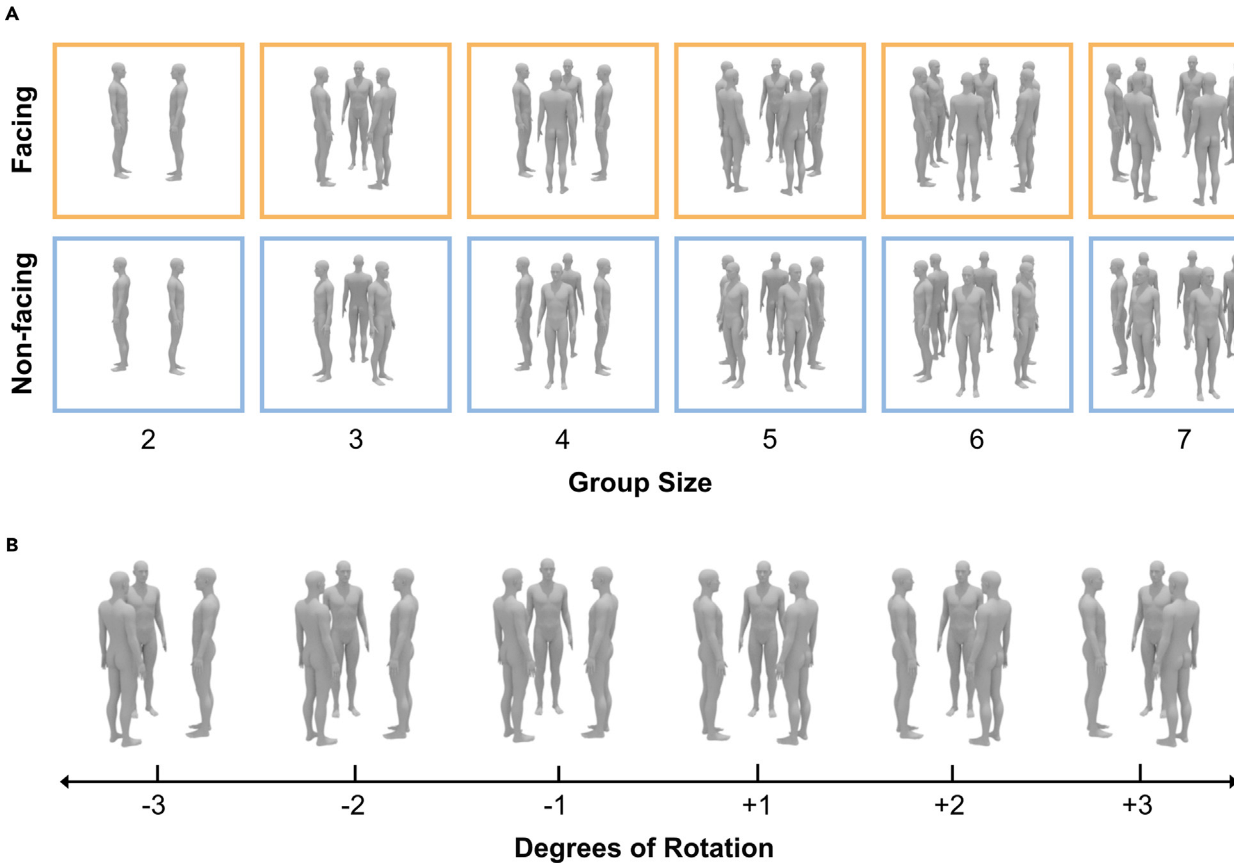

Figure 1. Illustration of stimuli

(A) Facing and non-facing groups of two to seven individuals.

(B) Example facing groups of three individuals from each viewing angle.

underscore the vital role of group size in interactive group dynamics, suggesting that small groups may be particularly conducive to effective group interactions and processes.

The preference for interacting in small groups, along with the perceptual sensitivity for actions and body orientations implying interactions, suggests an intriguing possibility that human perception may be optimized to detect small social groups. We addressed this possibility in three preregistered experiments in which we examined if the visual preference for facing groups varied with group size. Participants were presented with a series of displays that contained groups comprised of two to eight individuals. On half of the displays, they were asked to localize a facing target group (among non-facing distractor groups), and on the other half to localize a non-facing target group (among facing distractor groups; Figure 1 illustrates example facing and non-facing groups). We measured speed and accuracy of participants' responses (STAR Methods present further methodological details). Experiment 1 examined if the search advantage for facing groups varied as a function of group size. Because the manipulation of group size in experiment 1 also produced differences in the total number of individuals in the displays, experiment 2 sought to replicate the search advantage for facing groups when the total number of individuals in each search display was equated across group sizes. Finally, experiment 3 assessed if the search advantage for facing groups was sensitive to display orientation. If our visual sensitivity to groups mirrors human social preferences in real life, we expected to find search advantages for facing small groups but not larger ones.

RESULTS

Experiment 1

Experiment 1 tested if the search advantage for facing groups was sensitive to group size by measuring search performance for facing and non-facing groups, which varied in size between two and seven members (Figures 1A and 2A). Based on past work,[6,7] we expected to find an overall search advantage for facing groups, and we hypothesized that this advantage would be strongest for smaller groups, mirroring our real-life interactive preferences.

We analyzed participants' mean accuracy and mean correct response times (RT) using preregistered repeated-measures ANOVAs with Target Type (2: Facing, Non-facing) and Group Size (6: 2, 3, 4, 5, 6, and 7) included as factors. Overall, participants performed the task

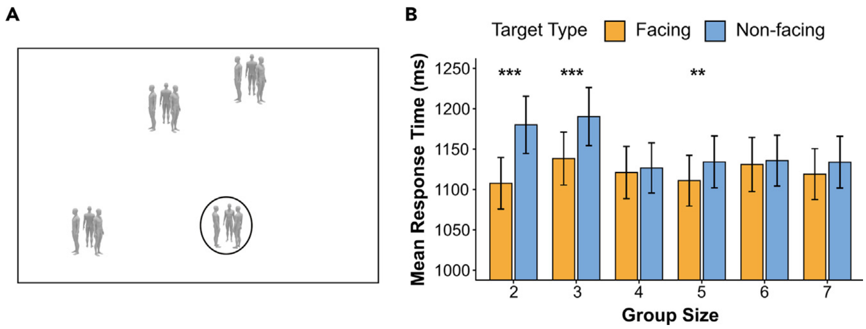

Figure 2. Example search display and results for experiment 1

(A) Example search display showing a facing target among three non-facing distractors for group size 3.

(B) Mean response time (RT) for Target Type as a function of Group Size. Error bars reflect 95% confidence intervals. Asterisks denote the significance level for post hoc paired t-tests corrected for multiple comparisons using the Bonferroni method (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Note: Stimuli are not drawn to scale. Target is highlighted for illustration purposes. Please see Figure S1 for a depiction of data using the same y axis range for all three experiments.

well with an average accuracy of 93.21%. Given these high accuracy rates, our analyses of accuracy were less informative, and so we interpret these results with caution (Data S1A). There was no speed-accuracy trade-off ($r(152) = -0.13$, $p = 0.116$).

Figure 2B illustrates mean correct RTs as a function of Target Type and Group Size. As predicted, participants were overall faster to detect facing groups, but critically this facing advantage also varied with group size. Indeed, there was a significant main effect of Target Type ($F(1, 153) = 18.75$, $p < 0.001$, $\eta_p^2 = 0.109$), with faster responses for facing targets (M = 1121.78ms, SE = 15.84) compared to non-facing targets (M = 1150.55ms, SE = 16.24), and a significant main effect of Group Size ($F(4, 601) = 18.60$, $p < 0.001$, $\eta_p^2 = 0.108$), with slower responses for smaller relative to larger groups. Importantly, there was a significant interaction between Target Type and Group Size ($F(4, 650) = 17.14$, $p < 0.001$, $\eta_p^2 = 0.101$), indicating a diminishing search preference for facing groups with increasing group size. Pairwise contrasts confirmed a reliable difference between RTs for detecting facing versus non-facing groups of two ($t(153) = -6.88$, $p < 0.001$, Cohen's $d = -0.554$), three ($t(153) = -5.26$, $p < 0.001$, Cohen's $d = -0.424$), and five ($t(153) = -2.97$, $p = 0.003$, Cohen's $d = -0.239$; all other t tests, $ts \leq -0.55$, $ps \geq 0.064$).

Discussion

Based on past work on preferred interactive group sizes, we hypothesized that the search preference for facing groups would be stronger for smaller groups and weaker for larger crowds. The data from experiment 1 supported this hypothesis. That is, the difference between RTs for detecting facing and non-facing groups was largest for smaller groups of two, three, and five individuals and diminished thereafter for larger group sizes. Of note, this interaction was driven by an overall decrease in response times for non-facing targets with increasing group size, while performance for facing targets remained relatively stable. This is consistent with the notion that facing individuals may be more salient and distracting, such that facing distractors could impair performance when searching for non-facing targets, resulting in longer response times for non-facing targets at smaller group sizes. We also note that response times overall decreased with increasing group size, consistent with the notion that larger crowds facilitate efficient ensemble processes.[16]

Experiment 2

Because in experiment 1 set size was constant at four, the total number of individuals in search displays varied with group size, from eight individuals in search displays of group size two up to 28 individuals in search displays of group size seven. To ensure that the search preference for small social groups was not due to the fewer number of people in the search display, in experiment 2 we kept the number of individuals in the search display constant at 24 (Figure 3A). If the data from experiment 1 reflected search changes due to an increasing number of individuals to search from, we expected to observe no modulation of search advantage for facing groups with group size in experiment 2. Alternatively, if the data reflected effects of group size, we expected to replicate the results of experiment 1.

The same analyses were run as in experiment 1. Once again, participants responded with an overall high accuracy of 91.68%; thus we interpret accuracy results with caution (Data S1B). A corrleation between RT and accuracy suggested a potential speed-accuracy trade-off ($r(149) = .19$, $p = .018$). Thus, as per the preregistration plan, we also analyzed inverse efficiency scores (Data S1C).[30]

Figure 3B shows mean correct RTs as a function of Group Size and Target Type. First to note from this Figure is a general decrease in RT with the increase in group size (and a corresponding decrease in set size), as supported by a reliable main effect of Group Size ($F(2, 310) = 996.64$, $p < 0.001$, $\eta_p^2 = 0.869$). Replicating experiment 1, facing targets were found overall faster than non-facing targets, and once again this facing advantage was strongest for small groups of two and three. This result was supported by a significant main effect of Target Type ($F(1, 150) = 8.25$, $p = 0.005$, $\eta_p^2 = 0.052$), indicating faster responses for facing (M = 1306.34ms, SE = 14.56) compared to non-facing targets (M = 1325.01ms, SE = 14.80), as well as by a two-way interaction between Target Type and Group Size ($F(3, 484) = 9.12$,

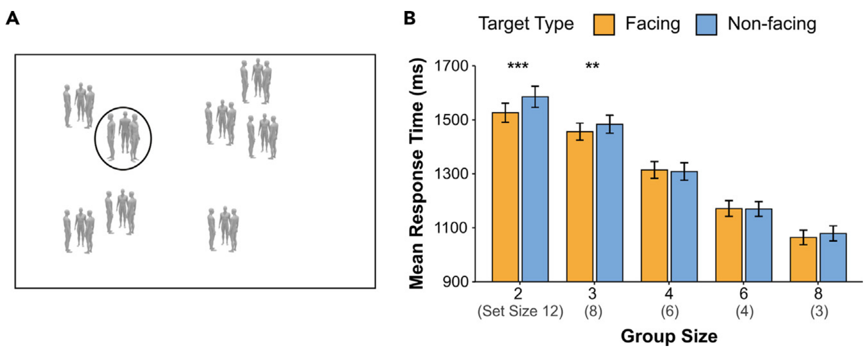

Figure 3. Example search display and results for experiment 2

(A) Example search display showing a non-facing target among seven facing distractors for group size 3.

(B) Mean response time (RT) for Target Type as a function of Group Size and the corresponding Set Size labeled in gray. Error bars reflect 95% confidence intervals. Asterisks denote the significance level for post hoc paired t-tests corrected for multiple comparisons using the Bonferroni method (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). Note: Stimuli are not drawn to scale. Target is highlighted for illustration purposes.

$p < 0.001$, $\eta_p^2 = 0.057$), which indicated larger search differences between small facing and non-facing groups (two-person groups $t(150) = -4.80$, $p < 0.001$, Cohen's $d = -0.391$; three-person groups $t(150) = -2.76$, $p = 0.007$, Cohen's $d = -0.225$; all other ts < 0.59, ps ≥ 0.090).

Discussion

The data from experiment 2 revealed a reliable difference between response times for facing group targets among non-facing distractors relative to non-facing group targets among facing distractors in small groups, even when the total number of individuals in the search display was kept constant. This shows that the search preference for facing social groups is robust to the total number of individuals present in the search display, and is driven by group size, with the largest difference between facing and non-facing conditions found for group sizes of two and three. As in experiment 1, participants were once again overall faster to respond to displays containing larger groups, suggesting the engagement of crowd-based processes with larger group sizes. This performance increase was further facilitated in experiment 2 with the decrease in set size for displays with larger groups. Overall, these results thus replicate experiment 1, both in terms of overall performance and the main result of a perceptual preference for smaller facing groups.

Experiment 3

Experiments 1 and 2 revealed a key role of group size in the perception of facing social groups. In experiment 3, we investigated how this search advantage may be influenced by stimulus inversion. Stimulus inversion is often thought to disrupt holistic social representations, which are most often formed from viewing individuals in familiar conditions. On the one hand, past research suggests that inversion disrupts the search for facing groups of two.[6,31] On the other hand, simple visual cues to social interactions such as face-to-face configurations remain easily discernible even in inverted displays—and indeed, other work on the perception of triads has found that the search advantage for facing groups can be preserved with inversion.[5] In experiment 3, we thus asked how the search advantage for small groups might be impacted by stimulus inversion. This experiment was identical to experiment 1, except that all search displays were inverted along the horizontal axis (Figure 4A). Overall accuracy was high (92.18%); thus we intepret these results with caution (Data S1D). There were no speed-accuracy trade-offs ($r(120) = -0.07$, $p = 0.421$).

Figure 4B shows mean correct RTs as a function of Group Size and Target Type. There was no main effect of Target Type ($F(1, 121) = 0.63$, $p = 0.431$, $\eta_p^2 = 0.005$), but there was a significant interaction between Target Type and Group Size ($F(5, 605) = 7.68$, $p < 0.001$, $\eta_p^2 = 0.060$), indicating that while participants were faster to respond to facing relative to non-facing groups of two ($t(121) = -2.61$, $p = 0.010$, Cohen's $d = -0.236$), they were faster to respond to non-facing groups of size four or more (group size six, $t(121) = 2.41$, $p = 0.017$, Cohen's $d = 0.218$; all other ts ≤ 1.75, ps > 0.082). There was also a main effect of Group Size ($F(4, 425) = 18.75$, $p < 0.001$, $\eta_p^2 = 0.134$) with an overall slowing of RTs with increasing group size.

Discussion

The data from experiment 3 indicated that while the search preference for facing groups was still reliable in groups of two, it diminished with increasing group size, and even reversed for larger groups (e.g., groups of six). This reversal of search preference in larger groups may reflect the adoption of lower-level cues to aid search in unfamiliar viewing conditions. In line with this and in contrast to experiments 1 and 2, overall performance decreased with increases in group size. To examine the effects of stimulus inversion more directly, we next compared search performance between upright and inverted stimuli across experiments 1 and 3.

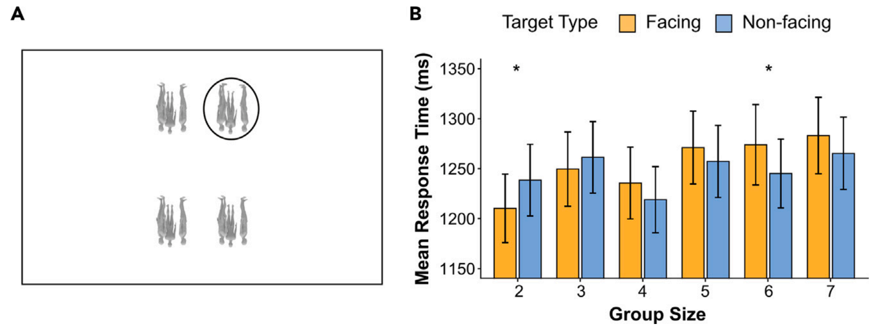

Figure 4. Example search display and results for experiment 3

(A) Example search display showing a facing target among three non-facing distractors for group size 3.

(B) Mean response time (RT) for Target Type as a function of Group Size. Error bars reflect 95% confidence intervals. Asterisks denote the significance level for post hoc paired t-tests corrected for multiple comparisons using the Bonferroni method (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). Note: Stimuli are not drawn to scale. Target is highlighted for illustration purposes.

Comparison between experiments 1 and 3

As per the preregistered plan, we subjected mean correct RTs to a mixed effects stimulus orientation (2: Upright, Inverted; between-subjects variable) × Target Type × Group Size ANOVA using the data from upright stimuli from experiment 1 and inverted stimuli from experiment 3 (Data S1E).

The analysis of RTs indicated a main effect of stimulus orientation ($F(1, 274) = 24.25$, $p < 0.001$, $\eta_p^2 = 0.081$), with slower RTs for inverted compared to upright stimuli. This result is consistent with the increased difficulty of searching through the inverted displays given the unfamiliar presentation conditions. Two key significant interactions with stimulus orientation emerged. The first was between Stimulus Orientation and Target Type ($F(1, 274) = 11.71$, $p < 0.001$, $\eta_p^2 = 0.041$), indicating an overall performance advantage for facing targets in upright orientations ($t(153) = -4.25$, $p < 0.001$, Cohen's $d = -0.342$) but not in inverted orientations ($t(121) = 0.78$, $p = 0.417$, Cohen's $d = 0.070$). This is consistent with the notion of reduced social processing in inverted displays. The second interaction was between Stimulus Orientation and Group Size ($F(5, 1370) = 21.65$, $p < 0.001$, $\eta_p^2 = 0.073$), which showed that while overall performance in experiment 1 sped up with increasing group size for upright displays, it slowed down in experiment 3 with increasing group size. The three-way interaction between Target Type × Group Size × Stimulus Orientation was not significant ($F(5, 1370) = 0.55$, $p = 0.738$, $\eta_p^2 = 0.002$). All other main effects replicated previous analyses.

To better explore the RT difference between target types in upright and inverted stimuli across group sizes, we conducted a series of independent samples t-tests (corrected for multiple comparisons, see STAR Methods) comparing differences between orientations within each group size. Statistical values of equal variances not assumed are reported when the Levene's test was significant. Results indicated a significantly greater search preference for facing targets in upright relative to inverted displays in groups of two (Upright M = 72.36ms, SE = 10.52; Inverted M = 28.16ms, SE = 10.81; $t(274) = 2.90$, $p = 0.004$, Cohen's $d = 0.351$), three (Upright M = 51.97ms, SE = 9.87; Inverted M = 11.75ms, SE = 10.02; $t(274) = 2.83$, $p = 0.005$, Cohen's $d = 0.342$), and five (Upright M = 23.15ms, SE = 7.79; Inverted M = −13.83ms, SE = 10.62; $t(2.81) = 232.85$, $p = 0.005$, Cohen's $d = 0.348$). Of note, the magnitude of the facing advantage in upright displays diminished and instead a search preference for non-facing targets in inverted displays emerged in groups of six (Upright M = 4.75ms, SE = 8.59; Inverted M = −28.78ms, SE = 11.94; $t(274) = 2.34$, $p = 0.020$, Cohen's $d = 0.283$) and seven (Upright M = 14.79ms, SE = 7.92; Inverted M = −17.84ms, SE = 10.19; $t(274) = 2.57$, $p = 0.011$, Cohen's $d = 0.311$).

Thus, the comparison between experiments 1 and 3 revealed that performance was overall impaired in inverted displays, and so was the preference for facing groups, which was stronger for small groups when participants searched through upright compared to inverted displays.

DISCUSSION

Social groups are the building blocks of human social life and fundamental units in which humans and other animals assemble and interact. Recent work has shown that the human perceptual system is fine-tuned to detect social groups of two and three members.[6,7] Given that groups in real life vary from small one-to-one interactions to large crowds, here we asked if the perceptual sensitivity to facing groups was modulated by group size. In particular, and following past work in evolutionary psychology, we hypothesized that perception would be specialized to detect small social groups (e.g., those comprised of about two to four individuals), as these group sizes are often preferred in real life interactions.[12,23] In three preregistered experiments, participants searched for either a facing group among non-facing distractors or a non-facing group among facing distractors. In experiments 1 and 2, we found a search preference for facing groups. This difference between facing and non-facing groups was most pronounced for smaller groups of less than five and did not depend on the variations in the number of total individuals present in the search display. Experiment 3 further demonstrated that stimulus inversion impaired performance overall, consistent with difficulties in perceiving stimuli presented in unfamiliar orientations. A comparison of the facing advantage in upright and inverted stimuli revealed that inversion also disrupted the search preference for facing targets, suggesting a role for configural processing in the perception of facing social groups. Even with inverted stimuli, however, the facing advantage was most pronounced for smaller groups. Collectively, these findings suggest that human perception may be well-tuned to detect smaller social groups, mirroring our interactive preferences.

This study was inspired by past work showing that in visual search with multiple people, groups like dyads and triads are detected quicker when the individuals are facing toward versus away from each other.[6,7] Such perceptual preference for facing social groups is evolutionarily adaptive, as it favors the perception of a "core group configuration" of face-to-face orientation among members, which promotes group organization, cohesiveness, and interactions.[26] While it is possible that facing groups may be marked by unique visual characteristics, our systematic control of stimulus properties across major visual and spatial components, as well as the impaired performance with stimulus inversion in experiment 3, suggest that those characteristics likely do not determine our effects. Even though the facing advantage was reduced with inversion, it was nevertheless still present—and if anything the advantage for non-facing was now reliable for larger groups. This reversal is especially pertinent given recent evidence that inversion effects may also apply to non-social stimuli.[31,32] Indeed, it is plausible that human visual mechanisms have evolved to support the processing of social attributes while also utilizing processing principles that apply to non-social stimuli, such as Gestalt grouping. In this context, any shared visual characteristics between "social" and "non-social" processing may contribute to results indicating similar effects across social and non-social objects, and social perception need not necessarily rely uniquely on underlying processes that are socially specific.[33]

Further to this point, there are at least two possible mechanisms by which the facing advantage may be driven. One possibility is that facing social groups are arranged in a "core configuration", which is theorized to promote group formation, cohesiveness, and reassembly,[26] and thus in turn may influence perceptual preferences due to evolutionary advantages of such group formation. Supporting this notion, our data indicated that the facing group advantage was driven by slower responses for non-facing distractors rather than faster responses for facing targets, suggesting that facing distractors may capture attention, resulting in processing disadvantages for non-facing targets. This advantage for "core configurations" may contribute to the effects of group size on the facing advantage given that smaller groups are often encountered in facing configurations, whereas crowd members are rarely facing each other.

Another possible mechanism underlying the facing advantage involves the spatial convergence of cues. The direction of head, body, and feet provides informative visual cues to the direction of others' attention. In facing groups, all individuals face toward the center, invoking a directional convergence of social cues toward the center of the group (i.e., an "attentional hotspot"), which in turn may promote visual assembly.[34] Non-facing groups instead face away from the center, invoking a directional shift outward, which may promote visual dispersion. On the one hand, the directional convergence account is consistent with the effects of group size on the facing advantage such that if social processing capacity is limited to around five group members,[20] the perception of the attentional direction of each member may be present for small groups, but would diminish for larger groups with crowding preventing member individuation. On the other hand, however, cues to others' attention in crowds may still be perceived via ensemble processing,[14] with the high consistency in directional convergence across numerous individuals acting as a strong cue to directional convergence, and in turn leading to stronger facing effects. This alternative is in line with existing evidence that gaze cueing of attention increases linearly with the number of individuals displaying consistent cues, up to about ten.[35–37] Because the current experiments were not designed to test these explanatory possibilities, and the attentional convergence explanation makes no predictions about the influence of group numerosity on the directional effects, future research is required to investigate the potential mechanisms underlying the facing advantage and related possible modulations of group size.

In addition to investigating specific mechanisms underlying the facing effect, future work may also explore the role of different types of group configurations. The current experiments employed non-facing individuals to preserve the perception of a common intention (e.g., all group members facing outward), but social groups in real life may be arranged in a variety of other configurations. For example, it would be important to examine in future work whether arrangements that suggest a common intention may be perceived differently than those that are randomly oriented. Thus, while our results support the notion of perceptual tuning for groups of preferred interactive sizes, this preference may be complemented and influenced by other canonical, perceptual, and social factors related to individual and group perception.

Intriguingly, in experiment 1 we also found a reduced, but nevertheless statistically significant search difference between facing and non-facing groups of five. Groups of five seem to hold a special status in human interactions. While these groups are somewhat larger than preferred social groups of two or three, some studies have identified groups of five as optimal for interactions, as group members are still able to interact without an excessive level of intimacy.[38,39] Others have similarly postulated that humans form social networks that start at the size of five, scaling in a factor of about three and ultimately converging on the so-called Dunbar's number (i.e., 5, 15, 50, 150).[26,40,41] As evolutionarily this group size is thought to promote group collaboration and direct interactive contact, the perceptual preference for facing groups of five in addition to smaller groups may also reflect evolutionary advantages.

Finally, these parallels between preferred interactive group sizes and preferred perceptual group sizes may reflect the processing limits of human cognitive and perceptual systems.[16] Humans (and other primates) perceive quantities up to about four spontaneously without item individuation.[17,19] The attentional system can track up to five individuals items[42] while social working memory has also been shown to operate at a limit of about four social relationships[43] and track with purported social network size.[44] The involvement of ensemble perceptual processing, which is one way of overcoming processing limits, may be observed for perceiving groups larger than five. In line with this, we found an overall increase in performance with increases in group size, with response times decreasing as the group size increased. Such crowd-based processing invokes a perceptual ensemble mechanism by which properties of visual displays are represented in an overall averaged or typical representation, rather than individual items,[13,45] reducing overall processing load.

Limitations of the study

Our investigation builds on existing research and offers additional insights by examining the links between perceptual and socio-interactive preferences. Future work is needed to elucidate the specific cues and mechanisms giving rise to and supporting the facing advantage. For example, facing individuals may be prioritized based on specific visual cues to orientation or intentionality—cues which may still be discernible in inverted groups, as suggested by the results of experiment 3. Another intriguing direction for future work relates to exploring perceptual sensitivity to interpersonal distances between group members, which is another important factor in group formation and social interactions. In particular, the study of proxemics[46] has found four main types of interpersonal distance in social groups, ranging from intimate and personal distance to social and public distance. However, only some of these distances (i.e., intimate and personal) are conducive to social interactions. This raises the possibility that perception may mirror interactive preferences not just in terms of group size but also in terms of interpersonal distance of group members. While the individuals in the current experiments were all positioned at a personal distance, future work may explore whether the sensitivity for detecting facing small groups is specific to those groups whose members are positioned at interpersonal distances that afford social interactions. Lastly, it would also be interesting to explore how attentional allocation to facing and non-facing groups is affected by member orientation and specific characteristics of the individuals.

Conclusion

In sum, here, we show that human perception is well-tuned to detect facing groups, but only of small interactive sizes. This perceptual advantage appears to track with interactive preferences in everyday life, where groups of two and three individuals are most common and preferred. As such, here, we experimentally show a perceptual preference that seems to support detection of social groups that afford social interactions, and track with human evolutionary adaptations and preferences for living in social groups.

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Jelena Ristic (jelena.ristic@mcgill.ca).

Materials availability

This study did not generate new unique reagents.

Data and code availability

- De-identified summarized human data for all experiments reported here can be accessed on Open Science Framework: *(i)* E1: https://osf.io/z8jc4; *(ii)* E2: https://osf.io/7frtj; *(iii)* E3: https://osf.io/x6zqu.
- Custom code on data exclusions can be accessed on Open Science Framework: *(i)* E1: https://osf.io/z8jc4; *(ii)* E2: https://osf.io/7frtj; *(iii)* E3: https://osf.io/x6zqu.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

ACKNOWLEDGMENTS

We thank Victoria Fratino for help with earlier versions of this work. This work was supported by grants from the Natural Sciences and Engineering Council of Canada (NSERC), Social Sciences and Humanities Council of Canada (SSHRC), William Dawson Funds, G. W. Stairs funds, and McGill University.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology: all authors; data curation, formal analysis, investigation, visualization, writing—original draft: L.Y.; software and validation: C.C.; funding acquisition and project administration: L.Y. and J.R.; writing—review and editing: all authors; resources and supervision: J.R.

DECLARATION OF INTERESTS

The authors declare no competing interests.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2024.111105.

Received: April 2, 2024
Revised: July 9, 2024
Accepted: October 1, 2024
Published: October 5, 2024

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Behavioral data	This paper	Experiment 1: https://osf.io/z8jc4 Experiment 2: https://osf.io/7frtj Experiment 3: https://osf.io/x6zqu
Software and algorithms		
JsPsych	de Leeuw et al.[47]	https://www.jspsych.org/7.3/; RRID:SCR_023508
DAZ Studio	DAZ Productions, Inc.	https://www.daz3d.com
R (version 4)	R Core Team[48]	https://www.r-project.org; RRID:SCR_001905
SPSS Statistics (version 29)	IBM SPS Inc.	https://www.ibm.com/spss; RRID:SCR_016479

EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS

Participants in experiments 1–3 were recruited from a volunteer pool of students at McGill University (SONA) and through Prolific Academic (www.prolific.com). They were required to have normal or corrected-to-normal vision. Informed consent was obtained from all participants prior to the experiment. All procedures were approved by the institutional Research Ethics Board. In experiment 1, 173 participants were recruited to complete the study and data from 154 participants were analyzed (Women = 113, Men = 38, Other = 3, Mean Age = 25 years old, Age Range = 18–65 years old). In experiment 2, 202 new naive participants were recruited and data from 151 participants were analyzed (Women = 92, Men = 55, Other = 4, Mean Age = 30 years old, Age Range = 18–68 years old). In experiment 3, 171 new naive participants were recruited and data from 122 participants were analyzed (Women = 78, Men = 43, Other = 1, Mean Age = 32 years old, Age Range = 19–74 years old). Details on participant exclusions are reported below.

The sample size for each experiment was determined and preregistered prior to data collection. The preregistered methods and analyses can be viewed at: *(i)* E1: https://osf.io/5ucyn; *(ii)* E2: https://osf.io/26tbe; *(iii)* E3: https://osf.io/gkre2.

In experiment 1, 173 participants (114 from SONA: Mean Age = 20, Age Range = 18–28; and 59 from Prolific: Mean Age = 36, Age Range = 20–70) were recruited. We excluded 13 participants recruited from the SONA platform (attrition rate of 11.40%) and 6 recruited from the Prolific platform (attrition rate of 10.17%). The final sample for the analyses consisted of 154 participants, without significant statistical differences between the cohorts' average error rates (SONA: 6.64%; Prolific: 7.06%; $U = 2664$, $z = -0.048$, $p = 0.962$) and average RTs on correct trials (SONA: 1140ms; Prolific: 1126ms; $t = 0.414$, $p = 0.680$, Cohen's $d = 0.070$).

In experiment 2, 202 participants (60 from SONA: Mean Age = 21, Age Range = 18–25; and 142 from Prolific: Mean Age = 36, Age Range = 18–75) were recruited. We excluded 12 participants recruited from the SONA platform (attrition rate of 20.00%) and 39 recruited from the Prolific platform (attrition rate of 27.46%). The final sample for the analyses consisted of 151 participants, without significant statistical differences between the cohorts' average error rates (SONA: 8.09%; Prolific: 8.43%; $U = 2411$, $z = -0.244$, $p = 0.807$) and average RTs on correct trials (SONA: 1282ms; Prolific: 1302ms; $t = -0.672$, $p = 0.502$, Cohen's $d = -0.117$).

In experiment 3, 171 participants (48 from SONA: Mean Age = 21, Age Range = 19–24; and 123 from Prolific: Mean Age = 38, Age Range = 19–74) were recruited. We excluded 7 participants recruited from the SONA platform (attrition rate of 14.58%) and 42 participants recruited from the Prolific platform (attrition rate of 34.15%). The final sample for the analyses consisted of 122 participants, without significant statistical differences between the cohorts' average error rates (SONA: 7.43%; Prolific: 8.02%; $U = 1568$, $z = -0.501$, $p = 0.616$) and average RTs on correct trials (SONA: 1280ms; Prolific: 1235ms; $t = 1.247$, $p = 0.215$, Cohen's $d = 0.239$). Please note that while we have recruited 171 participants for experiment 3, which was par with our preregistration and previous experiments, after exclusions, we reached a sample size of 122 participants, which did not quite make the preregistered sample size. We have decided to stop testing at this point (which occurred prior to any data analyses) given the substantial sample size reached and financial feasibility in data collection.

METHOD DETAILS

Experiment 1

Apparatus and stimuli

The experiment was programmed using the JsPsych libraries[47] and deployed online on participants' own computers. As illustrated in Figure 1A, the stimuli depicted facing and non-facing groups comprised of 2, 3, 4, 5, 6, or 7 members. Stimuli were created using DAZ Studio (version 4.22). The width of each group image was adjusted for each participant to 15% of the browser window's width, while the height was constrained to 5/6 of this width.

Each group was comprised of duplicates of the same model showing consistent physical features and the same posture. For facing groups, a regular polygon was drawn based on group size, with models positioned at each vertex (e.g., a regular triangle for groups of three individuals). The interpersonal angles between the centers of two adjacent individuals were kept constant for each group size and maintained at 90 units for all group sizes.

Models were rotated according to the angles of the specific regular polygon to ensure all group members were facing toward the center (Figure 1A, top). A corresponding non-facing group of the same size was created by rotating each individual 180° around the y axis and away from the center (Figure 1A, bottom). Images were rendered in grayscale.

To control for the potential differential influence of viewing angles, which could obscure one or more group members, six variations of each facing and non-facing group were generated (Figure 1B). Rotations were scaled for the interpersonal angle specific to each group size, with −3, −2, −1, +1, +2, and +3 degrees of rotation, where positive and negative degrees denoted counterclockwise and clockwise rotations away from the positive z axis, respectively (Data S1F).

Design

The experiment was a repeated measures design with three factors: Target Type (2: Facing or Non-facing), Group Size (6: 2, 3, 4, 5, 6 or 7) and Target Position (8: 30, 60, 120, 150, 210, 240, 300, or 330°). Set size was kept constant, with four groups in each search display (one target and three distractors).

Target Type was blocked such that participants searched for a facing group among non-facing groups in half of the blocks, and for a non-facing group among facing groups in the remaining blocks – with the ordering of blocks randomized for each participant. The response target was present in every trial.

Group Size varied within blocks from two to seven individuals and was constant within each search display, such that all four groups in each display were of equal size.

Target Position also varied within blocks. Specifically, to ensure spatial resolution of target presentation[49] and for consistency with past work,[6] the search display was designed such that stimuli were positioned along two imaginary ellipses centered on the fixation point as illustrated in Figure S2. The inner ellipse's radius spanned 25% of the participant screen's width and height, while the outer ellipse's radius spanned 40% of the participant screen's width and height. The stimuli could be positioned at eight possible locations along the circumference of each ellipse (30, 60, 120, 150, 210, 240, 300, and 330°). The target always appeared in one of the eight locations along the inner ellipse,[49] whereas the three distractors could appear in any of the remaining 15 locations along the two ellipses without replacement, ensuring that each quadrant contained only one stimulus. The groups' viewing angle was randomly determined on each trial and was constant for all groups within each display.

Each block contained 48 unique trials (6 Group Size × 8 Target Position) with 8 blocks (4 for each Target Type) of 48 trials, for a total of 384 trials per participant. Twelve practice trials (six with facing targets and six with non-facing targets) were run at the start.

Procedure

Example search displays for facing and non-facing targets are shown in Figure 2A. On each trial, participants were first presented with a central fixation cross (72 × 72 pixels) for 500ms. The search display was shown next and remained visible for 2500ms or until participants responded. Intertrial interval was 500ms.

Upon the start of each block, participants were instructed to search either for a facing group or a non-facing group. For each trial, they were asked to locate the target group on the left or right side of the fixation by pressing either the "b" or "h" key on their keyboard. The assignment of response option and response key was counterbalanced across participants. Participants were asked to respond quickly and accurately, using their preferred hand. The experiment took approximately 30 min to complete.

Experiment 2

All stimuli and procedures were identical to experiment 1, except that *(i)* group size was two, three, four, six, or eight; *(ii)* set size was adjusted accordingly to group size, such that set size was 12 (for groups of two), 8 (for groups of three; illustrated in Figure 3A), 6 (for groups of four), 4 (for groups of six), or 3 (for groups of eight). In this way, the displays varied in group size while the total number of individuals on the screen remained constant at 24. This design resulted in 40 unique trials per block (5 Group Size × 8 Target Position), with each participant completing 8 blocks of 40 trials, for a total of 320 trials. Ten practice trials were run at the start.

Experiment 3

In experiment 3, all stimuli and procedures were identical to experiment 1, except that all stimuli were inverted by rotating each group image 180° around the horizontal axis, as illustrated in Figure 4A.

QUANTIFICATION AND STATISTICAL ANALYSIS

The mean accuracy and mean RT on correct trials were subjected to repeated measures ANOVAs. Greenhouse-Geisser corrected degrees of freedom are reported when sphericity was violated. All multiple pairwise comparisons were adjusted for multiple comparisons using Bonferroni correction. Unless otherwise indicated, all t-tests are two-tailed and paired. The level of statistical significance is denoted by asterisks in the figures. Participant exclusions were performed using R[48] custom scripts. ANOVA analyses were computed using SPSS Statistics (version 29). Nominal significance threshold of $\alpha < 0.05$ was used.

Experiment 1

Participant exclusions

Following our preregistered criteria, data from 14 participants whose overall mean accuracy was below 65% were excluded. For the remaining participants, we excluded trials in which participants did not respond within the available response window (2.25% of trials per participant on average), and those with response times outside 2.5 standard deviations from the individual's mean (1.87% of trials per participant on average). This error removal procedure follows similar studies in literature[50–52] to ensure both data stability and restriction in RT range. Data from five additional participants were excluded for having too few remaining valid trials (i.e., less than 75% of all trials). Thus, the final sample was 154 participants.

Experiment 2

Participant exclusions

In experiment 2, we excluded 27 participants whose mean accuracy was lower than 65%. For the remaining participants, we excluded trials in which participants did not respond within the available response window (7.01% of trials per participant on average), and those with response times outside 2.5 standard deviations from the individual's mean (0.86% of trials per participant on average). Data from additional 24 participants were excluded for having too few remaining valid trials (i.e., less than 75% of all trials). The final sample was thus 151 participants.

Experiment 3

Participant exclusions

In experiment 3, we excluded data from 35 participants whose overall mean accuracy was lower than 65%. For the remaining participants, we excluded trials in which participants did not respond within the available response window (3.42% of trials per participant on average), or with response times outside 2.5 standard deviations from the individual's mean (1.51% of trials per participant on average). Data from an additional 14 participants were excluded for having too few remaining valid trials (i.e., less than 75% of all trials). The final sample was thus 122 participants.