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Collaboration during visual search

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Two experiments examine how collaboration influences visual search performance. Working with a partner or on their own, participants reported whether a target was present or absent in briefly presented search displays. We compared the search performance of individuals working together (collaborative pairs) with the pooled responses of the individuals working alone (nominal pairs). Collaborative pairs were less likely than nominal pairs to correctly detect a target and they were less likely to make false alarms. Signal detection analyses revealed that collaborative pairs were more sensitive to the presence of the target and had a more conservative response bias than the nominal pairs. This pattern was observed even when the presence of another individual was matched across pairs. The results are discussed in the context of task-sharing, social loafing and current theories of visual search.

Visual search is often a collaborative process. For instance, consider how couples might search for a street address while driving. This task is often distributed among the individuals in the automobile, with one person searching on the left side of the road while the other person searches on the right. Or, consider security in public places such as airports. Before boarding an airplane, bags can be searched by multiple individuals and X-ray images of luggage are sometimes scanned by two observers working together to detect weapons and illegal substances. Though visual search can often be a collaborative process, experimental studies of visual search have focused primarily on how individuals search on their own (e.g., Treisman & Gelade, 1980; Wolfe, 1994). Here we report a new methodology developed to investigate how collaboration influences search performance. Specifically, we evaluate how the search performance of two individuals working together compares to the pooled search performance of two individuals working alone.

The importance of studying how collaboration impacts search performance is reinforced by a growing body of evidence from studies of navigation (e.g., Hutchins, 1995), collaborative memory (e.g., Ross, Spencer, Linardatos, Lam, & Perunovic, 2004), joint attention (e.g., Tomasello, 1995), and joint action (e.g., Sebanz, Bekkering, & Knoblich, 2006), which show that social collaboration and interaction can have a substantial impact on basic cognitive and brain processes. These studies reflect a more general trend in which cognition is seen as being part of a more complex system that includes the whole physical body and the local physical and social environment (see Clark, 1999; Kingstone, Smilek, Ristic, Kellend Friesen, & Eastwood, 2003). The main assumption of this "embodied" or "situated cognition" approach is that a complete understanding of various aspects of cognition (such as attention) will include an understanding of the interaction between individuals and their physical and social environments.

Following this general line of inquiry we report two studies investigating how social collaboration influences visual search. Pairs of individuals performed a simple visual search task both together and on their own. Samples of the search displays used in the experiments are shown in Figure 1. Participants searched for a "backward C" which had a solid line on the right side, among distractor items, which had gaps on both sides. The target was present in half of the displays and participants were required to press a key on the keyboard if a target was present, and to withhold making a response when the target was absent. The visual search displays were presented briefly (see Klein & Farrell, 1989) so that it was difficult to find the target on every trial. In this way, it was possible to measure correct target detection (hits) and false target detection (false alarms) and to calculate estimates of target sensitivity and response bias.

There were two critical conditions: collaborative and nominal. In the collaborative condition, participants sat

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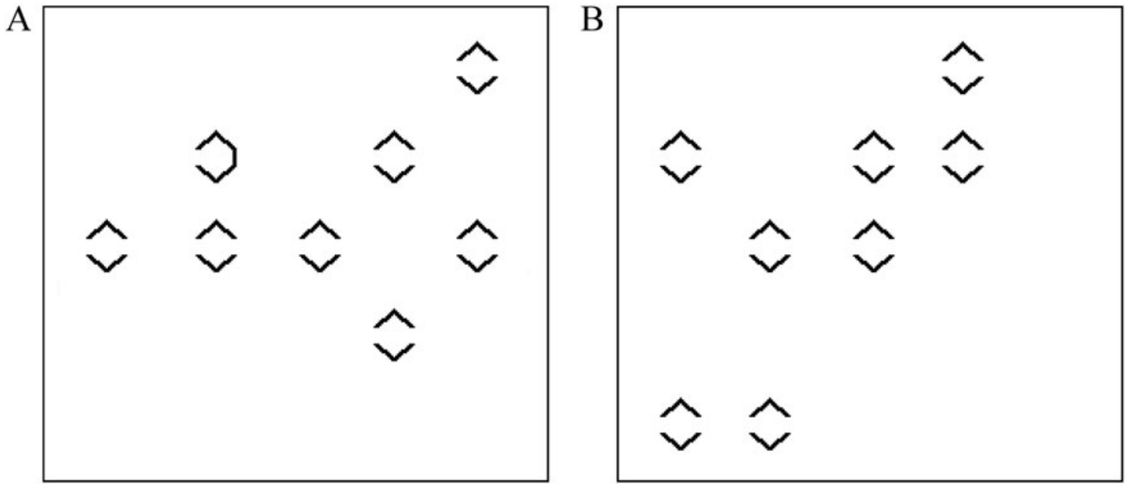

Figure 1. A schematic representation of the (A) target present and (B) target absent displays used in Experiments 1 and 2. Items are presented in reverse contrast.

side-by-side in front of a computer screen, shared a single "target present" response button and performed the visual search task together. Collaborative pairs were encouraged to discuss how they might best perform the task together. In the nominal condition, each participant independently performed the search task on a separate computer. Within a given nominal pair, each member was presented with exactly the same sequence of displays so that it was possible to combine the responses from the two individuals on a trial-by-trail basis. In both collaborative and nominal conditions, a response was designated as "present" when one or both participants indicated the target was present and a response was designated as "absent" when both participants indicated the target was absent. In this way, the pooled performances of the nominal pairs were directly comparable to the performance of the collaborative pairs (see Ross et al., 2004). Specifically, we used the hits and false alarms to calculate and compare target sensitivity and response bias across the collaborative and nominal pairs.

How might collaboration influence search performance? We first consider how collaboration might influence perceptual sensitivity to search targets. Unfortunately, the existing literature supports several contradictory predictions. One possibility is that, collaboration may lead to task sharing (e.g., dividing up the search display) and therefore greater sensitivity to targets when searching in collaborative pairs than in nominal pairs. More specifically, based on a shared understanding of the task derived through dialog (i.e., script sharing; see Jack & Roepstorff, 2002; Roepstorff & Frith, 2004), each individual could execute top-down control to selectively process nonredundant aspects of the display. Compared to performance of a nominal pair, such collaboration should result in a greater hit to false alarm ratio resulting in a greater sensitivity to the targets. Another possibility is that collaboration might reduce perceptual sensitivity to targets. There is an overwhelming consensus across a wide range of research areas including memory (e.g., Weldon & Bellinger, 1997), brainstorming (e.g., Harkins & Petty, 1982), vigilance (e.g., Harkins & Petty, 1982), and joint action (e.g., rope pulling; Ingham, Levinger, Graves, & Peckham, 1974), that the performance of groups is often poorer than the pooled performance of individuals working alone. This counterintuitive phenomenon is broadly referred to as social loafing (see Karau & Williams, 1993, for a review). Given the prevalence of this outcome, it certainly seems plausible that nominal pairs might outperform collaborative pairs during search. A final possibility is that individuals in collaborative pairs may not be able to share task demands and thus complete the task independently of one another. This would result in no difference in sensitivity across collaborative and nominal pairs as has recently been found in studies of collaborative recognition memory (Ross et al., 2004). Thus, at the outset, it is difficult to make a strong prediction regarding the influence of collaboration on the perceptual sensitivity to search targets.

Collaboration might also influence response bias, which in this context is the willingness to report that a target was present. Though it is unclear how task sharing and social loafing might influence response bias, a rather clear prediction comes from a recent study of how collaboration influences recognition performance (Ross et al., 2004). In this study spouses generated shopping lists and then completed a recognition test of the items either together or separately. The results showed that collaborative pairs had a more conservative response bias than nominal pairs implying that collaborative pairs require more certainty or evidence before they report an item as recognized. Given these findings, it seems reasonable to predict that in the context of visual search collaborative pairs may require more evidence before they say that a target is present. If so, then collaborative pairs should have a more conservative response bias than nominal pairs. These predictions were evaluated in Experiment 1.

EXPERIMENT 1

Method

Participants. Forty-eight undergraduates (24 pairs) from the University of Waterloo participated in a one-hour session in exchange for one course credit. All participants had normal or corrected-to-normal vision.

Stimulus displays. Examples of the types of stimulus displays used in the experiment are shown in Figure 1. One half of the displays contained the target object (target present), while the other half did not (target absent). The target (a "backwards C") and distractor (an "upside-down V" on top of a "right-side up V") differed only in terms of the features on the right side of each object; the target always had a solid line connecting the bottom and top pieces, while there was a gap between these pieces on the distractors. The set size was varied randomly from trial to trial within participant such that there were either 8 or 16 items in each display. The items in each display were presented in random locations of an imaginary 5 × 5 grid. The search objects measured 1 cm (1º) in width and 1.4 cm (1.4º) in height at a viewing distance of 57 cm. The gap between the top and bottom pieces was 0.5 cm (0.5º). Each search display grid measured 17 cm (17º) in width and 15 cm (15º) in height. The search items were presented in white against a black background. The stimulus displays were presented by E-Prime (Psychology Software Tools, www.pstnet.com) on ViewSonic PT775 monitors that were driven by Pentium based computers.

Procedure. Each trial of the experiment began with a fixation cross (+) presented for 1,500 msec. The offset of the fixation cross coincided with the onset of a search display which was presented for 300, 400, or 500 msec. The exposure durations (300, 400, or 500 msec) were varied across participants (i.e., 8 pairs at each exposure duration). The offset of the search display was followed by a blank display which remained on the screen for a maximum of 2,000 msec or until the participant responded. Participants were required to press the space bar on the keyboard if the target was present and to withhold a response if the target was absent. Responses were accepted during both the stimulus display screen and the blank display. By presenting the displays only briefly it was possible to measure both correct target detection (hits) as well as false target detection (false alarms) and to derive measures of sensitivity and response bias. After a response was given or the maximum time elapsed, a feedback display was presented for 1,500 msec indicating whether the response was correct or incorrect. All together there were 16 practice trials and 120 experimental trials in each of the collaborative and nominal conditions.

Participants completed the task once as part of a collaborative pair and once as part of a nominal pair. When in the collaborative condition, participants were instructed to complete the search task as a team and to try to think of a strategy that would take advantage of the fact that there were two of them searching the displays. The collaborative pairs were seated in front of a single computer screen and shared a response key (the space bar). A response was coded as "present" if one or both members of the pair pressed the response key. A response was coded as "absent" if both members withheld a response. Every 40 trials, participants were instructed to: "Take some time to evaluate how well your search strategy is working. Discuss with your partner whether you want to change the strategy you are using." This was done to encourage collaboration. In the nominal condition, each person performed the visual search task independently on separate computers. Each pair received exactly the same displays in the same order. Response coding was done on a trial-by-trial basis; a response was counted as "present" if on a given trial one or both individuals pressed the response key and it was coded as "absent" if both members withheld a response. To match for the breaks given in the collaborative condition for discussion of strategy, similar breaks were given in the nominal condition. Every 40 trials, each participant was instructed to: "Take some time to evaluate how well your search strategy is working. Decide whether you want to change the strategy you are using."

The order in which the pairs participated in the collaborative and nominal conditions was counterbalanced across pairs. Half of the pairs performed the task as a collaborative pair first, followed by the nominal condition in which they each performed the task on their own. The other half of the pairs first completed the nominal condition followed by the collaborative condition. To ensure that participants did not receive the same set of displays in the collaborative and nominal conditions so that there was no possibility of contextual cuing (Chun & Jiang, 1998), two different sets of displays were created. The display sets were counterbalanced across the collaborative and nominal search conditions.

After completing each of the collaborative and nominal conditions, each individual was asked by the experimenter about the strategy they used to search the displays when performing in the nominal and collaborative conditions. Participants' subjective reports were recorded by the experimenter for later analysis.

Results and Discussion

Table 1 shows the overall search performance[1] of the collaborative and nominal pairs in terms of hits, false alarms, sensitivity (d') and response bias (β) (see Kadlec, 1999). Each of the measures (hits, false alarms, sensitivity, sand response bias) was submitted to a repeated measures t test assessing the effects of collaboration (collaborative pairs vs. nominal pairs).

As can been seen in the table, collaborative pairs had fewer hits than did nominal pairs [$t(23) = 6.39, p < .001$]. However, collaborative pairs also had a much lower proportion of false alarms than the nominal pairs [$t(23) = 9.70, p < .001$]. Taking into account both the hits and false alarms, collaborative pairs showed a greater sensitivity (d') for detecting the target than did the nominal pairs [$t(23) = 2.86, p < .01$]. This pattern was highly consistent across pairs (see Figure 2). In addition, the collaborative pairs had a more conservative response bias (β) than did the nominal pairs [$t(23) = 2.63, p < .05$], meaning that collaborative pairs were less likely to respond that the target was present.

The greater sensitivity in collaborative than normal pairs suggests that the collaborative pairs were effectively sharing task demands rather than engaging in social loafing or searching independently of one another. Not predicted by the task sharing account, however, we found that the response bias of the collaborative group was also much more conservative than that of the nominal group. With regard to response bias, our findings echo those reported by Ross et al. (2004) based on their studies of collaborative memory.

Subjective reports of individuals were consistent with the idea that the collaborative advantage is, at least in part, due to task sharing between members of the pair. Of the 24 collaborative pairs, 23 chose to divide up the search space. The most common solution was splitting the screen down the center; 19 of the 24 pairs (79.2%) split the screen so that one person searched on the left

Table 1
Mean Proportion of Hits, Proportion of False Alarms, Sensitivity (d'), and Response Bias (β) for the Collaborative and Nominal Pairs in Experiment 1

Condition	Hits	False Alarms	d'	β
Collaborative	.806	.162	2.103	3.627
Nominal	.935	.499	1.620	0.304
Difference	−.129	−.337	0.483	3.323
p	<.001	<.001	<.01	<.05

Note—The difference scores represent collaborative performance minus nominal performance.

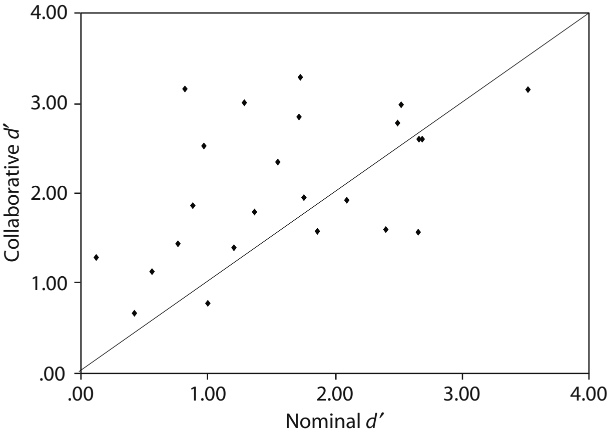

Figure 2. Sensitivity (d') for detecting the target in the collaborative and nominal conditions for each pair in Experiment 1. The diagonal line indicates equivalence between conditions.

half while the other person searched the right half. Two pairs (8.3%) split the screen horizontally with one person searching the top half and the other person focusing on the bottom half. Of the remaining three pairs, two chose to split the screen in some combination of the two former strategies, while the one pair that did not divide up the task chose to have each member of the pair randomly search the entire screen.

EXPERIMENT 2

In Experiment 2 we sought to examine whether the difference in search between the collaborative pairs and nominal pairs in Experiment 1 was due to social presence. The mere presence of another individual could have increased motivation and made people more vigilant, leading to greater sensitivity when searching with a partner in a collaborative pair than when searching alone as part of a nominal pair. The mere presence of a partner could also have led to a more conservative response bias in collaborative pairs. Indeed, participants commented that when they searched with a partner and responded "present" on target absent trials, they "felt bad" and would apologize to their partners.

To evaluate the effects of social presence during search, pairs again completed the search task used in Experiment 1 either separately or together. This time however, when participants completed the task separately, we had an experimenter sit beside each participant. Participants were informed that the experimenter would be monitoring their performance. In this way we matched for social presence across collaborative and nominal conditions. If the differences in search performance between the collaborative and nominal pairs found in Experiment 1 were simply due to the mere presence of another individual in the collaborative condition, then the differences should now be eliminated.

Method

Participants. Forty-eight undergraduates (24 pairs) from the University of Waterloo participated in a one-hour session for one course credit. All participants had normal or corrected-to-normal vision.

Stimulus displays. The displays from Experiment 1 (Figure 1) were used in this experiment.

Procedure. The procedure was identical to Experiment 1 with the exception that an experimenter sat beside each individual while they performed the task separately in the nominal condition.

Results and Discussion

Having matched for social presence across the collaborative and nominal pairs we obtained a very similar pattern of results to those found in Experiment 1. Overall search performance in terms of hits, false alarms, sensitivity (d') and response bias (β) can be seen in Table 2. As in Experiment 1, the collaborative pairs had fewer hits [$t(23) = 4.70$, $p < .001$], and false alarms [$t(23) = 7.79$, $p < .001$], than the nominal pairs. In addition, the collaborative pairs were again more sensitive at detecting the target [$t(23) = 3.63$, $p < .005$], than the nominal pairs, and this pattern was highly consistent across pairs (see Figure 3). The collaborative pairs were again more conservative than the nominal pairs [$t(23) = 2.68$, $p < .05$]. In these respects, the results of Experiment 2 replicate the findings of Experiment 1 and suggest that the search differences between collaborative and nominal pairs found in Experiment 1 cannot simply be attributed to differences in social presence across pairs.

GENERAL DISCUSSION

To summarize, the results showed that collaborative pairs were more sensitive to the presence of the target than were nominal pairs. This finding, taken together with participants' subjective reports that they split the screen when collaborating, indicates that collaborative pairs can effectively share the task load rather than engaging in social loafing or completing the task independently of one another. However, we also found that collaborative pairs had a more conservative response bias than did nominal pairs, which was not directly predicted by a task sharing account.

An interesting analogue to our studies of collaborative search occurs in studies of patients with separated cerebral hemispheres (Luck, Hillyard, Mangun, & Gazzaniga, 1989, 1994). The evidence suggests that split-brain patients are more efficient at finding targets when search items are evenly split across hemispheres than when all search items are presented to a single hemisphere. Taken together, these and our findings imply that search is more efficient when the search task can be efficiently shared or divided across two processors that either collaborate (as

Table 2
Mean Proportion of Hits, Proportion of False Alarms, Sensitivity (d'), and Response Bias (β) for the Collaborative and Nominal Pairs in Experiment 2

Condition	Hits	False Alarms	d'	β
Collaborative	.806	.178	2.037	2.332
Nominal	.913	.432	1.628	0.404
Difference	−.107	−.254	0.409	1.928
p	<.001	<.001	<.005	<.05

Note—The difference scores represent collaborative performance minus nominal performance.

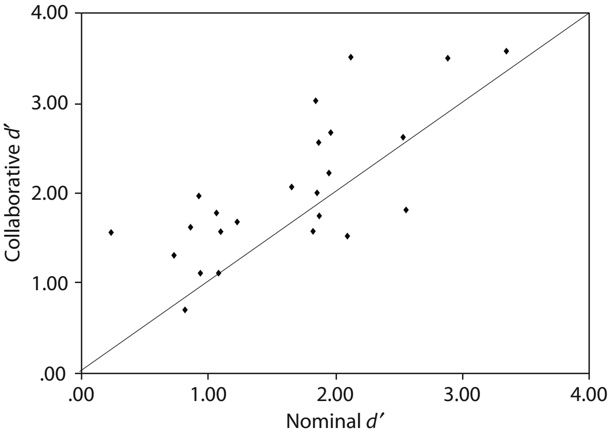

Figure 3. Sensitivity (d') for detecting the target in the collaborative and nominal conditions for each pair in Experiment 2. The diagonal line indicates equivalence between conditions.

in our studies) or are physically constrained (as in studies of split-brain patients) to search nonredundant aspects of the displays.

Our findings also have important implications for theories of visual search. Though most theories of visual search maintain that search efficiency is determined by both bottom-up and top-down processes (e.g., Treisman & Gelade, 1980; Wolfe, 1994), the experimental focus has been largely on bottom-up processes (e.g., Wolfe & Horowitz, 2004). By demonstrating that collaborative pairs can coordinate top-down strategies such that they are able to selectively process nonredundant aspects of the displays, our study reveals the importance of investigating top-down processing. Further, we believe that collaborative search may be an important tool for (1) identifying the sorts of top-down strategies people use in various contexts and (2) directly testing whether these reported strategies are effective. In the present study, the majority of the collaborative pairs chose to divide the displays spatially into a left and right side with fewer dividing the display from top to bottom. In future studies we plan to investigate what sorts of other task divisions are possible and useful in various search contexts.

Further along these lines, our findings are consistent with Roepstorff and Frith's (2004; Jack & Roepstorff, 2002) suggestion that "top-down processes" can be understood as the "sharing of scripts" among individuals. Though many models of visual search include top-down processes, it remains unclear where these top-down processes originate. Roepstorff and colleagues suggest that in many studies, "the origin of the 'executive top'" is not inside the brain of the participant but rather "in the mind of the experimenter" (Roepstorff & Frith, 2004, p. 192). In other words, the top-down plans emerge out of the shared representation of the task that is communicated through dialogue (see also Pickering & Garrod, 2004). Most studies of visual search do not discuss the dialogue between experimenter and participant because it is seen as a necessary precondition for conducting the experiment and not as a part of the experiment proper. In contrast, our studies of collaborative search highlight the importance of shared dialogue because we include collaborative dialog in the experiment proper.

Finally, we would like to highlight that the present findings also have important implications for search in real world situations. For instance, consider security searches at airports. Should such searches be conducted by individuals working together (collaborative pairs) or working apart (nominal pairs)? Our findings suggest that the answer depends on whether it is desirable to detect as many targets as possible or whether it is more important to have the highest hit to false alarm ratio with minimal false alarms. If it is preferable to detect as many targets as possible, search should be conducted by individuals working independently because nominal pairs have a greater hit rate than do collaborative pairs. If, on the other hand, it is more important to have the highest hit to false alarm ratio with the fewest false alarms, security search should be conducted by collaborative pairs. Thus, the present findings have direct bearing on the policies and procedures that might be implemented in real world contexts. More generally, we believe that including collaboration in studies of visual search brings the field one step closer to the real world.

AUTHOR NOTE

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NOTE

1. We varied exposure duration between pairs and set size within participants in order to ensure that we had a wide range of hits and farms alarms. We decided not to titrate exposure duration for each individual because this would make the experiment different for each member of the nominal pair, making it impossible to pool their responses. In both the nominal and collaborative conditions, search performance was averaged across exposure duration and set size and no formal analyses of these factors were conducted.

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