Two Kinds of Bias in Visual Comparison Illustrate the Role of Location and Holistic/Analytic Processing Differences

Kyle R. Cave[1], Zhe Chen[2]

[1]Department of Psychological and Brain Sciences, University of Massachusetts, Amherst, MA, USA

[2]Department of Psychology, University of Canterbury, Christchurch, New Zealand

in press, *Attention, Perception, and Psychophysics*
accepted 6 August, 2017

Correspondence:

Kyle R. Cave

Department of Psychological and Brain Sciences
University of Massachusetts
Tobin Hall
135 Hicks Way
Amherst, MA 01003

Email: kcave@psych.umass.edu

Phone: 413-545-2787

Abstract

A number of studies have shown that two stimuli appearing successively at the same spatial location are more likely to be perceived as the same even though location is irrelevant to the task. This bias to respond “same” when stimuli are at the same location is termed “spatial congruency bias”. The experiments reported here demonstrate that the spatial congruency bias extends to letter strings: participants tend to respond “same” when comparing two strings appearing successively at the same location. This bias may arise because successive stimuli at the same location are more likely to be perceived as a single object. Bias is also affected by the nature of the comparison task. We show that if letters must be compared individually (analytical comparison), there is a bias to respond “different”, but if letter strings are compared as unified wholes (holistic comparison), there is no bias or a bias to respond “same”. This analytical bias is apparently separate from the spatial congruency bias. It appears whether the task requires localization of differences between strings, or counting the number of differences, or ignoring differences in some parts of the stimuli while attending to others. All of these analytical comparison tasks require that letters be selected individually, and the analytical bias may reflect difficulty in preventing interference from neighboring letters in this selection process. Each type of bias reflects a different aspect of visual processing, and both can be measured to probe how processing changes across different tasks.

Two Kinds of Bias in Visual Comparison Illustrate the Role of Location and Holistic/Analytic Processing Differences

In studies designed to explore visual processing mechanisms by measuring performance in visual tasks, the focus is generally on measures of response time, accuracy, or sensitivity. However, when Golomb, Kupitz, and Thiemann (2014) set out to test how two stimuli appearing successively at the same location are processed differently from two stimuli at two separate locations, they measured bias in a 2-alternative comparison task. Their participants were more likely to report two visual stimuli as being the same if they both appeared at the same spatial location, even though location was irrelevant to the visual matching task.

In Golomb et al. (2014), participants saw two sequentially presented objects that were either identical or different. The objects could appear at the same location or at different locations. The participants were more likely to judge the objects to be identical when they had appeared at the same location rather than at different locations, even though location was not relevant to the task. Furthermore, this effect was specific to location, because when the task changed to location judgment, object identity had no effect on the perception of location. Golomb et al. termed this effect the spatial congruency bias, and the effect has since been demonstrated in a number of studies with both simple and complex stimuli (e.g., Paradiso, Shafer-Skelton, Martinez, & Golomb, 2016; Shafer-Skelton, Kupitz, & Golomb, 2017).

Although Golomb et al.'s (2014) experiments showed that location could affect judgments of object identity, they found no evidence that object identity could affect judgments of location. Based on this asymmetry, they concluded that location plays a special role in this visual comparison task, complementing previous research showing that location plays a special role in other aspects of visual processing (Cave & Pashler, 1995; Chen, 2009; Tsal & Lavie, 1988, 1993; see also Lavie & Tsal, 2001, for a review). On the other hand, location is not the only visual property that can affect visual processing even when it is irrelevant to the task. In tasks that required comparison of pairs of abstract shapes, Egeth (1966) found that performance was affected by irrelevant variation in color, orientation, or shape, and Hawkins and Shigley (1972) found effects of irrelevant variation in color, shape, and size. Santee and Egeth (1980) confirmed that variation in shape or color could affect the comparison of two shapes, but that similar variation did not affect the classification of shapes when they appeared individually. Besner and Coltheart (1975) generalized the effect of size variation to a task requiring the comparison of two words. Thus, the spatial congruency bias demonstrated by Golomb et al. may be related to other congruency effects that are tied to visual properties other than location, although it should be noted that these other effects were demonstrated with measures of response time and accuracy, and with pairs of stimuli presented simulataneously rather than sequentially; not with the bias measure or stimulus presentation format used by Golomb et al.

The spatial congruency bias appears to occur only when the target objects are perceptually similar (Golomb et al., 2014, Experiment 3). This suggests that the bias likely reflects assumptions built into the interpretation of incoming visual information to reduce perceptual ambiguity. As Golomb et al. (2014; Shafer-Skelton et al., 2017) proposed, responses may be based on the implicit assumption that objects appearing at the same location are likely to be the same object.

The experiments presented below use the same type of bias measure as that of Golomb et al. (2014) to explore more fully the visual processing mechanisms underlying these comparison tasks. The computational demands of visual comparison vary considerably depending on how the stimuli can differ from one another, and on the information that must be extracted for the comparison. In these experiments, we will distinguish between two types of visual comparisons. The term “holistic” will be used here to describe comparisons in which each of the two stimuli is treated as a unified configuration to be compared as a unit against the other configuration. In the holistic comparisons, any difference between corresponding components of the two stimuli will trigger a “different” response, and a “same” response will only be warranted when the two configurations are identical in every component. The term “analytic” will refer to comparisons that require separate comparisons of each pair of corresponding parts from the two configurations. The analytical tasks may require that participants report which components differ, or how many components differ from one another, or they may require that certain components be compared while others are ignored. In all of these analytical tasks, the two stimuli cannot be compared as unified wholes; they must be broken down into individual components.

This analytical/holistic distinction is similar to a distinction between identity search and similiarity search drawn by Sekuler and Abrams (1968). Their participants also compared two stimuli, although in that experiment the stimuli were patterns created by filling in between 1 and 4 cells in a 4x4 matrix. In the identity search condition, participants responded “same” only if the two patterns were identical, and thus encouraged more holistic processing. In the similarity search condition, participants responded “same” whenever one of the filled-in squares in one pattern matched the location of a filled-in square in the other pattern. Because the individual components of each pattern had to be compared separately, a more analytical process was called for. The two tasks produced very different patterns of response times, supporting the conclusion that they require different processing modes. The analytical/holistic distinction is also related to Navon's (1977) local/global distinction that has served as the basis for a long series of experiments. (See also Kinchla, 1977; Kinchla & Wolfe, 1979.) Both distinctions rest on the assumption that some tasks require processing of local details while others require processing of more global patterns. These concepts draw on the idea that attention can shift from selecting low-level details to high-level configurations, as described in Eriksen and St. James' (1986) zoom lens metaphor of attention.

Most of the experimental tasks that have been used previously to demonstrate the spatial congruency effect have involved asking participants to make a non-speeded 2-alternative-forced-choice response regarding an object feature such as the identity or color of the target objects by pressing the "same" or the "different" response key (e.g., Golomb et al., 2014, Experiments 1 and 2; Finlayson & Golomb, 2016), or to make a graded similarity judgment by moving a response slider to indicate the degree of similarity between the target objects (e.g., Golomb et al., 2014, Experiment 3). These tasks, which used perceptually similar objects and did not require specific differences between the targets to be located or identified, could be completed by using a holistic matching strategy.

Unlike the earlier experiments by Golomb et al. (2014), in which 2 novel images were presented on each trial, the stimuli to be compared in the experiments reported here will be simple strings of three letters. With these stimuli, it will be relatively easy for participants to compare the individual components (letters) separately. If the spatial congruency bias reflects an underlying assumption of our visual system, the effect of location on the letter task should manifest as a higher likelihood of judging the two strings to be the same when they have appeared at the same location, and a lower likelihood of judging them to be the same when they have appeared at different locations. Alternatively, if this bias is tied to judgments of object sameness and continuity, then it may change depending on the similarity of the letter strings and the nature of the comparison task. A task that requires participants to determine whether two similar looking letter strings match would emphasize the "sameness" of the stimuli and induce participants to use a holistic matching strategy. In contrast, a task that requires localizing the exact letter of differences between the letter strings would encourage participants to focus attention to the individual letters and to use an analytical comparison approach.

In a series of experiments reported here, we investigate the effects of location congruency and task demand on bias in letter comparison tasks. Our paradigm was modelled loosely after Golomb et al. (2014). As in their study, two identical or different stimuli were presented at either the same location or different locations. Location was always task irrelevant. Unlike Golomb et al., we used two letter sets, with each set consisting of 3 heterogeneous letters. In some experiments, the task (e.g., to judge whether the letter sets were identical or different) could be performed by using a holistic matching strategy. In the other experiments, the task (e.g., to locate the letter of difference) would require more analytical processing. Our results demonstrate the robustness of the original spatial congruency bias; this effect appears in these experiments with letter strings just as it did in the earlier experiments with complex shapes. There is also a marked difference in bias between the holistic and the analytical tasks, but this bias effect appears to be separate from the spatial congruency bias. The results show that visual processing is subject to two different forms of bias, each reflecting a different aspect of visual processing, and each of these bias effects can be used as a tool to investigate a specific aspect of visual identification.

Experiments 1A and 1B

In Experiments 1A and 1B, two sequentially presented letter sets were presented briefly at either the same location or different locations. The letter sets cold be identical or different, and the task was to judge whether they matched via a “Same/Different” binary response. In both experiments, location was task irrelevant. The letter sets occurred at the same location on 50% of the trials in Experiment 1A, but on 25% of the trials in Experiment 1B. The experiments had two goals: to determine whether the spatial congruency bias observed in Golomb et al. (2014), i.e., the same location/same identity bias, could be generalized from novel images to letter stimuli, and whether the magnitude of the bias would be influenced by the proportion of the same location trials.

Method

Participants. Forty undergraduate students from the University of Canterbury volunteered to take part in the experiments in exchange for course credit. Half of them participated in Experiment 1A and the other half in Experiment 1B.[1]

Apparatus and stimuli. Stimuli were presented on a PC with a 50 cm x 30 cm monitor in width and height. E-Prime was used to generate the stimuli and collect responses. Participants were tested individually in two dimly lit rooms. The viewing distance was about 60 cm.

The stimuli were black against a white background. Each trial consisted of two sequentially presented letter sets (S1 and S2), and each set was preceded by a central fixation and followed by a brief blank screen and then a mask. (See Figure 1.) The fixation was a cross that subtended 0.48^o. Both S1 and S2 consisted of 3 heterogeneous, uppercase letters. The letters were written in bold, 40-point Courier New font, and the letter set subtended 4.01^o in width and 0.76^o in height. The letters in the letter set were randomly selected from a set of 24 letters, which comprised the entire alphabet except for the letters “I” and “O”. On half the trials, S1 and S2 were identical (the same-ID trials). On the other half of the trials, S1 and S2 differed in a single letter, which was equally likely to be the 1^{st}, 2^{nd}, or 3^{rd} letter (the different-ID trials). S1 and S2 could occur at 1 of 4 locations centered at 3.63^o left or right of fixation, or 3.63^o above or below the fixation. The location of S1 on a given trial was randomly determined, and there was equal probability for it to appear at any of the 4 locations. In the same location condition, which comprised 50% of the trials in Experiment 1A but 25% of the trials in Experiment 1B, S2 appeared at the same location as S1. In the different location condition, S2 was equally likely to appear at any of the 3 locations not occupied by S1 on a given trial.

The mask consisted of 4 identical rectangles made of black diagonal lines. Each rectangle subtended 5.06^o in width and 2.87^o in height. The center of each of the 4 rectangles matched the center of the 4 possible target locations. The entire mask subtended 12.42^o horizontally and 10.32^o vertically.

Design and procedure. Both experiments used a 2 x 2 within-subjects design, with Location (same location vs different location) and ID (same-ID vs different-ID) as the principal manipulations. Each trial started with the fixation for 500 ms, followed by a brief presentation of S1, whose duration varied across trials based on performance (see details below). The offset of S1 would trigger a 17 ms blank screen, followed by a 120 ms display of the mask, and then a blank screen of 50 ms. Afterwards, a 2nd fixation would appear for 1000 ms, followed by S2, again with varied duration. After another 17 ms blank screen, the 2nd mask would appear for 120 ms. The screen would then go blank until response. The intertrial interval was 500 ms.

In both experiments, the initial duration of S1 and S2 was 116 ms. Performance was assessed every 54 trials in Experiment 1A and every 48 trials in Experiment 1B. If accuracy was between 70% and 75%, no change in duration was made. If accuracy was above 75%, the presentation duration of both S1 and S2 would decrease by 33 ms, with a minimum duration of 50 ms. If accuracy was below 70%, the duration of S1 and S2 would increase by 33 ms, with the maximum duration capped at 216 ms.[2]

The task was to judge whether the two letter sets were identical or different. The participants used the index and middle fingers of their right hand to press one of the two labelled keys on a computer keyboard (the “4” key if S1 and S2 were identical, and the “5” key if they were different). They were told to keep their eyes on the fixation through the entire duration of a trial. Accuracy, but not speed, was emphasized.

Both experiments started with 20 practice trials, followed by 4 blocks of experimental trials. Each block consisted of 108 trials in Experiment 1A and 96 trials in Experiment 1B. The participants were encouraged to take short breaks after each block.

Results

To facilitate comparison between the current study and prior research, we modelled our analyses after Golomb et al. (2014). For each participant, we first calculated the “hit” and “false alarm” (FA) rates as a function of stimulus location. A response was a “hit” when S1 and S2 were identical and a “same” response was made correctly. A response was a “FA” when S1 and S2 were different but a “same” response was made incorrectly. We then calculated response bias (*c*) and sensitivity (*d*’) for each location by using signal detection theory (Macmillan & Creelman, 2005):

$$c = - (z(\text{hit rate}) + z(\text{false-alarm rate}))/2$$

$$d' = z(\text{hit rate}) – z(\text{false-alarm rate})$$

As reaction time (RT) was not the primary dependent measure, the RT data are not shown in the main text. Instead, they are reported, together with the accuracy data and the relevant statistical analyses, in the appendices.

Table 1 shows the mean proportions of “same” responses in terms of hits and FAs, and Figure 2 shows the mean response biases (*c*), with a negative bias indicating a greater tendency to make the “same” response (same-bias), and a positive bias a greater tendency to make the “different” response (different-bias). The RTs and error rates are shown in Appendix A1, with the statistical analyses in A2. To measure the effect of location on bias in Experiments 1A and 1B, we conducted a 2 x 2 mixed analysis of variance (ANOVA) on the response bias data with Location as a within-subjects factor and Experiment as a between-subjects factor. A main effect of Location was found, $F(1, 38) = 74.99$, $MSE = .01$, $p = .001$, $\eta^2 = .66$, indicating a significant difference in response bias between the same location condition (-.21) and the different location condition (.03). Neither the main effect of Experiment nor its interaction with Location was significant, $F(1, 38) < 1$ in both cases.

To test whether the observed bias in each condition was above chance (i.e., zero bias), we performed two additional one-sample *t*-tests. As Experiments 1A and 1B did not differ in the degree of bias, the data from the two experiments were collapsed. The results revealed a significant same-bias (negative bias) for the same location trials, $t(39) = -5.09$, $p = .001$, $d = 0.80$, but no significant bias for the different location trials, $t(39) < 1$, *ns*.

To examine the effect of location on stimulus sensitivity, a 2 x 2 mixed ANOVA was performed on the *d*' data. The main effect of Location was significant, $F(1, 38) = 11.93$, $MSE = .05$, $p = .001$, $\eta^2 = .24$, indicating a larger *d*' in the same location condition (1.73) than in the different location condition (1.56). No other effects were found.

Discussion

The results of Experiments 1A and 1B generalized the finding of Golomb et al. (2014). As in their study, our participants showed a greater tendency to judge the letter sets to be the same when the stimuli had occurred at the same location, and there was no evidence of a bias when the letter sets appeared at different locations. We attribute this result to the nature of the task in Experiments 1A and 1B, which was to determine whether the letter sets matched. When there was a difference, it did not need to be localized, and thus this task could be completed by using a holistic matching strategy, because it did not require attention to be focused on the individual letters within the target stimuli. As a result, the same-bias was found.

In addition to the spatial congruency bias, we also found a higher *d*' on the same-location trials than the different-location trials, suggesting that having the two letter sets appear at the same location increased the participants' sensitivity. This effect is not surprising. Many previous studies have shown that attending to a location in space enhances the perceptual sensitivity to an object that subsequently appears at that location (e.g., Hawkins, Hillyard, Luck, et al., 1990; Müller & Findlay, 1987; Pestilli & Carrasco, 2005; Posner, 1980).

In Experiments 1A and 1B, the participants were instructed to keep their eyes fixated on the fixation cross through the entire duration of a trial. However, it is possible that they oriented to the location of S1 after its onset on some trials. This raises the question whether the effects found in the present experiments were caused by overt eye movements. Although we cannot rule this explanation out, it is unlikely that overt orienting was the primary cause. One piece of evidence against the overt eye movements account is the lack of an interaction between Location and Experiment, even though the two experiments differed in the proportion of the same location trials, which was 0.5 in Experiment 1A and 0.25 in Experiment 1B. If overt orienting was a major contributor to the results, the magnitude of the spatial congruency bias should be larger in Experiment 1A than in Experiment 1B, because one would expect more eye movements to occur in Experiment 1A. The finding that this was not the case suggests that eye movements did not play much of a role in the effects observed in these experiments.

Experiment 2

In Experiments 1A and 1B, the task did not require attention to be paid to the individual letters within the letter sets. In Experiment 2, we tried to induce focal attention to the letters by requiring participants to locate the letter that differed between S1 and S2 on some trials. Each participant completed two sessions. In one session, the task was the same as that in the previous experiments. In the other session, two responses were required on some trials: a “Same/Different” response as before, and an additional “Which Letter” response to indicate which of the 3 letters was different between S1 and S2 if a “different” response had been made on that trial. This augmented letter identification task was meant to encourage participants to use an analytical comparison approach in stimulus processing. Of particular interest was whether the pattern of bias would change when the task required an additional “Which Letter” response.

Method

The method of Experiment 2 was the same as that of Experiment 1A except for the following differences. First, each participant completed two sessions, a 1Task session that required one response on each trial, and a 2Task session that required 2 responses on some trials. Each session consisted of 3 blocks of 96 trials, and the order of the two sessions was counterbalanced among the participants. Thus, the experiment used a 2 x 2 x 2 x 2 design, with TaskType (1Task vs 2Task), Location (same vs different) and ID (same-ID vs different-ID) as within-subjects factors, and Session order (1Task 1^{st} vs 2Task 1^{st}) as a between-subjects factor. Second, in the 2Task session, the participants first performed the “Same/Different” task on each trial with their right hand as before, by using the index or the middle finger to make the "same" or the "different" response. If a "same" response was made, the trial would end. However, if a "different" response was made, the pressing of the response key would then trigger the question "Which letter?" to appear on the screen, and the question would remain until 1 of 3 keys was pressed. The participants were instructed to use the ring, middle, or the index finger of their left hand to press the "1", "2", or the "3" key (all labelled) at the top of the keyboard to indicate that S1 and S2 differed in the 1st, 2nd,or the 3rd letter, respectively. Third, performance was assessed every 48 trials (i.e., the same as that in Experiment 1B). As in previous experiments, accuracy, but not speed, was stressed. Thirty-four participants from the same population took part in the experiment.[3] Half of them completed the 1Task session before the 2Task session, and the order was reversed for the other half.

Results

One participant did not complete the experiment due to computer malfunction. The "Same/Different" response data in Task 1 were analysed as before. Table 2 shows the mean proportions of "same" responses, and Figure 3 shows the mean response biases. The RT and error rates data can be found in Appendix B1, with the statistical analyses in B2. The error rates for Task 2 are presented in B3, and B4 shows error rates for Task 2 as a function of participant response in addition to location and stimulus type. As preliminary analyses with session order as a between-subject factor showed no significant effects, the session order data were collapsed in the analyses described below. As before, we conducted a 2 x 2 repeated-measures ANOVA on the response bias data, this time with TaskType and Location as the within-subjects factors. The main effect of TaskType was significant, $F(1, 32) = 7.30$, $MSE = .05$, $p = .01$, $\eta^2 = .19$, indicating a stronger same-bias (more "same" responses) in the 2Task session (-.14) than in the 1Task session (-.03). There was also a main effect of Location, $F(1, 32) = 58.53$, $MSE = .03$, $p = .001$, $\eta^2 = .65$, indicating a significant difference in resposne bias between the same location trials (-.19) and the different location trials (.02). TaskType and Location did not interact, $F(1, 32) < 1$. One-sample *t*-tests further showed that the bias in both the 1Task and 2Task session when S1 and S2 occurred at the same location was significantly below zero, indicating a "same" response bias, $t(32) = 2.66$, $p = .01$, $d = .46$, for 1Task trials; and $t(32) = 4.65$, $p = .001$, $d = .81$, for 2Task trials. No significant biases were found when S1 and S2 appeared at different locations in 1Task trials, $t(32) = 1.49$, $p = .15$, $d = .26$; or in 2Task trials, $t(32) < 1$.

An ANOVA on the *d*' data revealed both a significant main effect of TaskType, $F(1, 32) = 16.07$, $MSE = .10$, $p = .001$, $\eta^2 = .33$, and Location, $F(1, 32) = 15.27$, $MSE = .10$, $p = .001$, $\eta^2 = .32$. The participants were more sensitive to the letter sets in the 2Task session (2.00) than in the 1Task session (1.78), and in the same location condition (2.00) than in the different location condition (1.78). There was no interaction between the two factors, $F(1, 32) < 1$.

Discussion

Having to locate the letter of difference on the "different" response trials apparently affected the participants' processing strategy. The larger *d*' in the 2Task than the 1Task session, an indication of greater sensitivity to the target stimuli, suggests that the participants paid more attention to the letter sets in the 2Task session, presumably because they had to make an additional “Which Letter” response on some trials.

Despite this additional attention to individual letters, there was still a clear bias to respond “yes” when the two stimuli shared location. The 1Task session demonstrated the same location bias, which was expected given the similarity of the task to Experiments 1A and 1B. However, the 2Task session produced a similar pattern: the difference in bias between the same-location and different-location conditions was the same with or without the extra requirement to localize the different letter.

The localization task did affect bias, but the effect was independent of stimulus location: adding the localization task increased the tendency to respond “yes” somewhat, regardless of stimulus location. The shift in bias was small but significant. The participants might be more motivated to select the “same” response in the 2Task session because this response would save them from going through the effort of making the 2nd response. In addition, if they realized that they were not sure which of the letters had changed, that might give them extra motivation to make the “same” response. Both factors might have contributed to the observed shift in bias in the 2Task session.

One factor to consider in interpreting these results is the temporal order of the responses: the letter-of-difference task in the 2Task session was the 2nd response, one that came only after the “Same/Different” response. This might have allowed the participants to use two different processing strategies in response to the two tasks. They might start with a holistic matching strategy with attention focused on the representations of the letter sets as a whole to perform the 1st task. If a match was found, a "same" response was made. If a match was not found, the stimulus representations then underwent further processing to locate the difference. Such a strategy would result in the same-bias for the "Same/Different" matching task in the 2Task session. The procedure for reporting the nonmatching letter is modified in Experiment 3 to prevent this two-step approach.

Experiments 3A and 3B

Experiments 3A and 3B were designed to induce attention to be focused on the individual components within each letter set while minimizing use of a holistic matching strategy. Instead of making the letter-of-difference response a 2nd response as in Experiment 2, in Experiments 3A and 3B we used a 4-alternative forced choice (4AFC) task and required the participants to locate the letter of difference, if there was any, in the 1st and only response. The task was to judge whether S1 and S2 were the same, differed in the 1st letter, the 2nd letter, or the 3rd letter. S1 and S2 were different on 50% of the trials in Experiment 3A but 75% of the trials in Experiment 3B. The experiments had two objectives: to investigate whether a different-bias (positive bias) would be found, and to determine whether the percentage of the different-ID trials would affect the magnitude of the bias.

Method

The method was the same as that of Experiment 1A with the main difference being the number of response choices, which was 4 in the present experiments. On each trial, the participants used their index, middle, ring, or the little finger of their right hand to indicate whether the two letter sets had no difference, differed in the 1st

letter, the 2nd letter, or the 3rd letter by pressing the “7”, “8”, “9”, or “0” key at the top of the keyboard (all labelled), respectively. The experiment consisted of 384 trials divided into 4 blocks. As before, the two letter sets were equally likely to appear at the same location or at different locations. In Experiment 3A, S1 and S2 were identical on 50% of the trials. When they were different, they were equally likely to differ in the 1st, 2nd, or the 3rd letter position. In Experiment 3B, the same-ID trials comprised 25% of the trials. On the rest of the trials, S1 and S2 differed in a single letter, and there was equal probability that the difference was in each of the 3 letter positions. In both experiments, all types of trials were mixed within a block. Performance was assessed and stimulus duration was adjusted accordingly every 48 trials. Thirty-eight participants from the same population took part in the experiments. Eighteen participated in Experiment 3A and 20 in Experiment 3B.

Results

To compare the results of Experiments 3A and 3B with those of previous experiments, we collapsed the 3 types of different-ID trials into a single type of trial, and the 3 types of “different” responses into a single type of response. Specifically, when S1 and S2 were different, regardless of whether the difference occurred in the 1st, 2nd, or 3rd letter position, the trial was treated as a different-ID trial. Moreover, so long as the participants pressed 1 of the 3 keys indicating that S1 and S2 were different on these trials, the response was treated as a correct “different” response. This allowed us to convert 4AFC responses in the present experiments into 2AFC responses, making it possible to compare directly the results of the present experiments with those of the previous ones.

Table 3 shows the mean proportions of “same” responses, and Figure 4 shows the mean response biases. The RT and error rates data are in Appendix C, Table C1, and the statistical analyses are in Table C2. Table C3 shows the RT and error rates for the same-ID trials and each of the 3 types of different-ID trials. Table C4 further shows the error rates as a function of participant response in addition to location and stimulus type. A 2 x 2 mixed ANOVA on the response bias data with Experiment as a between-subjects factor and Location as a within-subjects factor showed a significant effect of Location $F(1, 36) = 28.97$, $MSE = .02$, $p = .001$, $\eta^2 = .45$, indicating a stronger different-bias (a bias to respond “different”) when S1 and S2 appeared at different locations (.27) rather than at the same location (.11). Neither the main effect of Experiment nor its interaction with Location was significant, $F(1, 36) < 1$, *n*s, in both cases. Subsequent one-sample *t*-tests further indicated that the bias was significantly above zero both when S1 and S2 occurred at the same location, $t(37) = 2.55$, $p = .02$, $d = .41$, and when they occurred at different locations, $t(37) = 5.61$, $p = .001$, $d = .90$. These results confirmed a different-bias regardless of whether S1 and S2 appeared at the same location or at different locations.

A 2 x 2 mixed ANOVA on the *d*’ data showed a marginally significant main effect of location, $F(1, 36) = 3.64$, $MSE = .06$, $p = .06$, $\eta^2 = .09$, arising from a slightly larger *d*’ in the same location condition (2.00) than in the different location condition (1.89).

Discussion

Experiment 2 required 2 separate responses on some trials, with the 1st response being a “Same/Different” one and the 2nd, if relevant, a “Which Letter” one.

As we discussed in Experiment 2, this methodological feature could induce the participants to use two different processing strategies in response to the two tasks, with a holistic matching strategy for the “Same/Different” task, resulting in the same-bias. In contrast, Experiments 3A and 3B required a single 4AFC response on every trial. As the task emphasized the localization of the letter of difference, the individual letters in the letter sets had to be attended from the beginning of the task. The results are striking both in how they differ from those of the previous experiments, and in how they are similar. With the requirement to localize the letter that is different, the bias is positive in every condition, indicating an overall tendency to respond “different”. However, although the bias is positive across conditions, it is still less positive when the two stimuli are at the same location than when they are at different locations. Thus, a shared stimulus location still makes a “same” response more likely. The bias measure seems to reflect the sum of two different effects: the now well-established same-bias, and a bias to respond “different” when the task requires analytical processing of individual elements.

The finding that the magnitude of the bias did not differ between Experiments 3A and 3B indicates that the proportion of the different-ID trials had a negligible effect on the degree of spatial congruency bias in the present paradigm.

Experiment 4

In Experiments 3A and 3B, the participants had to identify the letter of difference on the “different” response trials, and they showed a different-bias across both location conditions. Experiment 3 required that the different letter be localized, to encourage an analytical comparison, but the letter strings were always fairly similar to one another, never differing in more than a single letter. In Experiment 4, we used a slightly different paradigm to encourage participants to focus on the individual letters, in order to further explore how bias varies between analytical and holistic visual processing.

Unlike Experiments 3A and 3B, in which the two letter sets could differ in only 1 letter, In Experiment 4, S1 and S2 could differ in either 1 letter or 2 letters. The 2-letter-different trials were fillers, whose function was to provide extra incentive to attend to the individual letters in the letter sets. This more analytic approach might diminish the same-location bias, and/or it might affect the general positive bias seen in Experiments 3A and 3B.

Previous research has shown that the spatial congruency bias is a perceptual rather than response bias. Golomb et al. (2014) found the same-bias both when the task was to make a “Same/Different” response and when the task was to use a slider to indicate the degree of similarity between the target objects, suggesting that the manifestation of the bias did not depend on the response code of a task. It is important to note that neither of Golomb et al.’s tasks required participants to attend to the individual components in the targets.

In Experiment 4, we also manipulated the type of response code while still requiring all participants to use an analytical comparison approach. Each trial required a 3-alternative forced choice (3AFC) response. For half the participants (the same group), the task was described as comparing the “sameness” of the two letter sets, and the response choices were: 1-letter same, 2-letter same, and 3-letter same. For the rest of the participants (the different group), the task was described as comparing the “differentness” between the two letter sets, and the response choices were: 2-letter different, 1-letter different, and 0-letter different. Note that although the two tasks were framed differently, the nature of the tasks was the same in that both tasks required attention to the individual letters in the letter sets, and both tasks had the same stimuli to be compared.

Method

The method was the same as that in Experiment 1A except for the following differences. A new type of different-ID trials, in which S1 and S2 differed in 2 letters, was added, comprising 12.5% of the total trials. The remaining trials were divided equally into the same-ID trials and the 1-letter different trials. As before, when S1 and S2 differed in 1 letter, there was equal probability that the difference occurred in the 1st, 2nd, or 3rd letter position. Similarly, when S1 and S2 differed in 2 letters, there was an equal chance for any 2 letters to differ.

Forty new participants from the same population as before took part in the study. Half of them were randomly assigned to the same group, and the other half to the different group. All participants used the same keys (the “4”, “5”, and “6” keys on the computer keyboard) and the index, middle, and the ring finger of their right hand to respond. The participants in the same group were instructed to compare the “sameness” of the two letter sets. They pressed the “4”, “5”, or “6” key if S1 and S2 were the same in all the 3 letters, in 2 letters, or in 1 letter, and the 3 keys were labelled “3S”, “2S”, and “1S” respectively. The participants in the different group were instructed to compare the “differentness” of the letter sets. They pressed the “4”, “5”, or “6” key if S1 and S2 differed in 0 letter, in 1 letter, or in 2 letters, and the 3 keys were labelled “0D”, “1D”, and “2D” respectively. This arrangement ensured that the correspondence between a specific response key and the type of stimulus display was the same for all the participants regardless of which group they belonged to. The only difference was how the different stimulus types were framed in the instructions. The design of the experiment was a 2 x 2 x 2 mixed design, with ResponseCode (same vs different) as the between-subjects variable, and Location and ID as the within-subjects manipulation.[4]

Results

The results from the 2-letter different filler trials were not analysed. For the remaining trials, a correct response was defined as one in which S1 and S2 were identical and the response key "0D" (for the different group) or "3S" (for the same group) was pressed; or in which S1 and S2 differed in 1 letter and the response key "1D" or "2D" (for the different group), or "1S" or "2S" (for same group) was pressed. Table 4 shows the mean proportions of "same" responses, and Figure 5 shows the mean response biases. The RT and error rates data are in Appendix D1, with the statistical analyses in D2. Table D3 shows the RT and error rates for the 2-letter different trials in addition to the same and 1-letter different trials. A 2 x 2 mixed ANOVA on the response bias data with ResponseCode as a between-subjects factor and Location as a within-subjects factor showed a significant effect of Location, $F(1, 38) = 52.94$, $MSE = .02$, $p = .001$, $\eta^2 = .58$, indicating a larger positive bias when S1 and S2 appeared at different locations (.28) compared with the same location (.04). One-sample *t*-tests further revealed a significant different-bias when S1 and S2 occurred at different locations, $t(39) = 6.37$, $p = .001$, $d = 1.01$, but not at the same location, *t*(39) = 0.84, *ns*. Neither ResponseCode, *F*(1, 38) < 1, *ns*, nor its interaction with Location, *F*(1, 38) = 1.26, *MSE* = .02, *p* = .27, η^2 = .03, was significant.

A 2 x 2 mixed ANOVA on the *d'* data found a significant main effect of location, *F*(1, 38) = 4.18, *MSE* = .06, *p* = .05, η^2 = .10, indicating a larger *d'* in the same location condition (1.91) than in the different location condition (1.80). No other effects were *found, F(1, 38) < 1, in both cases.*

Discussion

The approach to encouraging analytical processing in Experiment 4 was somewhat different than in Experient 3A and 3B, but overall the results are similar across the two experiments. In both experiments, the bias to categorize a stimulus pair as being different in some way was greater when the two stimuli were at different locations, just as in the earlier experiments. Overall, the bias values in Experiment 4 tend to be positive, favoring a "different" response, although they were not significantly positive in the same-location condition. Also, response code did not influence the direction or the magnitude of the bias. This result provided converging evidence to Golomb et al.'s (2014) proposal that the spatial congruency bias reflects a perceptual rather than a response bias.

Experiments 1 through 4 were designed to test how bias in these visual comparison tasks varies between holistic and analytical processing tasks. However, there was a confounding factor in these experiments; i.e., the type of processing varied systematically with the number of responses, with holistic processing associated with 2 responses (Experiments 1A, 1B, and 2) and analytical processing with 3 or 4 responses (Experiments 3A, 3B, and 4). This raises the possibility that the bias to respond “different” could be caused by the number of choices for “different” responses rather than by analytical processing. Suppose participants had to make a guess on some trials, and that when they did, they selected among the available response options with equal probability. When there was one “same” response choice and more than one “different” response choices, the chance of making a “different” response would be larger than the chance of making a “same” response. For example, in an experiment with 3 “different” response choices but 1 “same” response choice, if participants were randomly choosing 1 of the 4 choices on some trials, they would be 3 times more likely to press a “different” response key than the “same” response key on these trials. This would produce a “different” bias, resulting in the pattern of data found in Experiments 3 and 4. The next two experiments investigated this issue.

Experiments 5A and 5B

Experiments 5A and 5B tested the hypothesis that a bias to respond “same” was not limited to tasks with a binary response so long as these tasks could be performed with a holistic processing strategy. Unlike previous experiments in which S1 and S2 were either identical or different in one or more letter identities, the letter sets in the present experiments were either identical in all aspects (as before) or different in physical appearance (style or font) while the individual letters used in the two displays were always the same. The task was to respond whether S1 and S2 were the same, differed in style, or differed in font. Because the task could be completed without attending to individual letters, we hypothesized that the participants would process the stimulus displays holistically. Thus, even though a

3AFC response was required on each trial, the participants would show the same-bias.

Method

The method was the same as that of Experiment 1B except for the following differences. While the letters in S1 were randomly selected on each trial, the letters in S2 were always the same as those in S1. S1 and S2 could be written in one of two styles: straight or italics, and in one of two fonts: Ariel Black or Bell MT. On some trials, the two displays were identical in both style and font (the same trials). On the other trials, they differed in either style (the DStyle trials) or font (the DFont trials), but never in both. In Experiment 5A, half of the trials were same trials, and the rest were divided equally between the two types of different trials. In Experiment 5B, the three types of trials were equally likely. A 2 x 3 within-subjects design was used in both Experiments 5A and 5B, with Location (same vs different) and Shape (same, DStyle, or DFont) as the principal manipulations. All the trials were randomly mixed within a block. The participants pressed 1 of 3 labelled keys on the number pad of the keyboard, with “4” indicating that S1 and S2 were the same, and “5” and “6” indicating that S1 and S2 differed in style and in font, respectively. Thirty-six participants from the same population, with 18 in each experiment, took part in the studies.

Results

As in the previous experiments, we collapsed the 2 types of different trials into a single type, and the 2 types of “different” responses into a single type of response.

Thus, regardless of whether S1 and S2 differed in style or in font, so long as one of the two “different” response keys was pressed, the response was treated as a correct “different” response.

Table 5 shows the mean proportions of “same” responses, and Figure 6 shows the mean response biases. The RTs and error rates are in Appendix E1, and the statistical analyses are in E2. E3 shows the RT and error rates for each of the 3 types of trials, and E4 further shows the error rates as a function of participant response in addition to location and stimulus type. To determine the degree of response bias, we conducted a 2 x 2 mixed ANOVA on the response bias data with Experiment as a between-subjects factor and Location as a within-subjects factor. A significant effect of Location was found, $F(1, 34) = 61.97$, $MSE = .02$, $p = .001$, $\eta^2 = .65$, indicating a stronger same-bias when S1 and S2 were at the same location (-.38) compared with when they appeared at different locations (-.14). No other significant effects were found, $F(1, 34) < 1$, *n*s, for both Experiment and Location by Experiment interaction. One-sample *t*-tests further showed that the bias was significantly below zero both when S1 and S2 occurred at the same location, $t(35) = -7.45$, $p = .001$, $d = 1.24$, and when they occurred at different locations, $t(35) = -2.57$, $p = .02$, $d = .43$.

A 2 x 2 mixed ANOVA was also conducted on the *d*’ data. Both the main effects of Experiment and Location were significant, $F(1, 34) = 7.06$, $MSE = .42$, $p = .02$, $\eta^2 = .17$, for Experiment; $F(1, 34) = 13.24$, $MSE = .05$, $p = .001$, $\eta^2 = .28$, for Location. There was no Experiment by Location interaction, $F(1, 34) < 1$, *ns*. These results indicated a larger *d*’ in Experiment 5B (1.47) than in Experiment 5A (1.06), and when the two stimulus displays appeared at the same location (1.37) than at different locations (1.17).

Discussion

The most important finding of Experiments 5A and 5B is the overall bias to respond “same”. In both experiments, the participants responded to the physical appearance of the letter sets in a 3AFC task. Despite multiple response choices, the task did not require attention to individual letters, and could therefore be completed by holistic matching. A “same” bias was found in both experiments. These results suggest that the “different” bias found in Experiments 3A, 3B, and 4 was not simply caused by the participants having to make a binary response in the former and more complex “different” responses in the latter. Instead, it is the nature of processing that determines the type of bias, with analytic processing eliciting a “different” bias. On top of this pattern, there is also once again a clear same-location bias, making the bias values even more negative when the two stimuli share a location.

Experiments 6A and 6B

So far we have shown, in Experiments 3A through 4, that a task requiring analytical processing and with 3 or 4 response choices can elicit a “different” bias, and that this bias does not arise in holistic tasks such as Experiments 1 and 5. If it is indeed the nature of processing that determines the level of bias, then it should be possible for a task with a binary response to also elicit a “different” bias so long as the task requires analytical processing. This hypothesis was tested in Experiment 6A.

In Experiment 6B, we tested the hypothesis that we could eliminate a “different” bias by changing the task demand of Experiment 6A such that the same task could now be performed with a holistic matching strategy on the majority of the trials. If Experiments 6A and 6B showed the pattern of data described above, this would provide strong evidence for our proposal that the type of spatial congruency bias is determined by the nature of processing strategy.

Methods

Experiments 6A and 6B used the same method as that in Experiment 1B with the following differences. Instead of comparing whether S1 and S2 were identical or different, the participants compared only the 2nd letter of each string. Trials with matching and with mismatching 2nd letters were equally likely, and the participants used their right hand to pressed the “4” key when S1 and S2 had the same 2nd letter (the same trials), and the “5” key when they had different 2nd letters (the different trials).

As in the previous experiments, the three individual letters that made up each letter set were always different from one another. In Experiment 6A, S1 and S2 were never completely identical; they always differed by at least two letters. On the “same” trials, the 2nd letter in S1 and S2 were the same while the 1st and 3rd letters were different (e.g., AGT in S1 and UGV in S2). On the “different” trials, all three letters differed between S1 and S2 (e.g., AGT in S1 and UXV in S2). The correct response was determined only by the middle letter so that attention would be focused narrowly on that position, thereby inducing analytical processing. In Experiment 6B, the 1st and/or the 3rd letter differed between S1 and S2 on 1/6 of the trials. On the rest of the trials, the 1st and the 3rd letters were identical, so that the two strings were completely identical on half of the trials within this set. Because S1 and S2 differed in only 1 letter on the majority of the trials (i.e., 5/6 or 83.3%) in Experiment 6B, participants could use a holistic matching strategy to complete the task successfully on the majority of the trials. If participants relied on analytical processing in Experiment 6A but holistic matching in Experiment 6B, we should find a “different” bias in Experiment 6A but not in Experiment 6B. Forty participants (20 in each) took part in the experiments.

Results

Experiment 6A. Table 6 shows the mean proportions of “same” responses, and Figure 7 shows the mean response biases. The RTs and error rates are in Appendix F1, and the statistical analyses are in F2. A t test on the response bias data showed a significant difference of location, $t(19) = -2.34$, $p = .03$, $d = .52$, indicating a larger different-bias on the different location trials (.38) than the same location trials (.29). One-sample t-tests further showed that the bias was significantly above zero both when S1 and S2 were at the same location, $t(19) = 4.36$, $p = .001$, $d = .97$, and when S1 and S2 were at different locations, $t(19) = 5.45$, $p = .001$, $d = 1.22$, indicating the tendency to select the “different” response in both cases. A similar t test was conducted on the d' data, and a marginally significant effect was found, $t(19) = - 1.88$, $p = .08$, $d = .42$, suggesting slightly higher letter discrimination sensitivity when S1 and S2 appeared at different locations (1.47) compared with the same location (1.37).

Experiment 6B. Table 6 shows the mean proportions of “same” responses, and Figure 7 shows the mean response biases. The RTs and error rates are in Appendix F1, and the statistical analyses are in F2. Once again, the results on the response bias data showed a significant difference of location, $t(19) = -5.53$, $p = .001$, $d = 1.24$. Importantly, the bias was positive in the different location condition (.11), but negative in the same location condition (-.17). One-sample *t*-tests further showed that whereas the negative value in the same location condition was statistically significant from zero, $t(19) = -3.56$, $p = .01$, $d = .80$, indicating a same-bias, the positive value in the different location condition was not, $t(19) = 1.76$, $p = .10$, $d = .39$, suggesting negligible bias.

Comparing Experiment 6A with Experiment 6B. To confirm that the participants in the two experiments indeed showed different patterns of response bias, we performed a mixed ANOVA with Location as the within-subjects factor and Experiment as the between-subjects factor. The main effects of Experiment and Location were both found. The response bias differed significantly between Experiment 6A (.34) and Experiment 6B (-.03), $F(1, 38) = 19.42$, $MSE = .14$, $p = .001$, $\eta^2 = .34$. It was also more positive in the different location condition (.25) than in the same location condition (.06), $F(1, 38) = 33.67$, $MSE = .02$, $p = .001$, $\eta^2 = .47$. In addition, there was a significant interaction between Location and Experiment, $F(1, 38) = 8.59$, $MSE = .02$, $p = .01$, $\eta^2 = .18$, indicating a larger spatial congruency bias in Experiment 6B (a difference of -.29) than in Experiment 6A (a difference of -.09). These results confirmed that the participants in the two experiments behaved differently. They are also consistent with the notion that different processing strategies were used in the two experiments. The (positive) analytical bias in Experiment 6A led to bias values that are quite high. This high positive bias might have tempered the (negative) same-location bias a bit.

Discussion

In Experiments 6A and 6B, we held the task constant while varying the processing demand. In Experiment 6A, S1 and S2 always differed in their 1st and 3rd letters, and focal attention to the 2nd letter was needed to perform the task. This apparently induced the participants to adopt a more analytical processing strategy, resulting in a bias to respond “different”. In this experiment, the different-bias that comes from analytical processing may have been made even more positive by another factor: the two strings in each stimulus pair are very different from one another, and even though much or all of that difference is in parts of the string irrelevant to the task, it may have biased participant to respond “different” more often. It is significant that this “different” bias was eliminated In Experiment 6B, in which S1 and S2 had the same 1st and 3rd letters on 83% of the trials. This methodological change allowed the participants to use a more holistic matching strategy, at least on the majority of the trials. The reversal of the pattern of data between the two experiments provides strong support for the idea that bias varies depending on processing strategy. Both conditions also confirm the effect of spatial congruency on bias.

Experiment 7

Between Experiments 1A and 1B we manipulated the proportion of the same-location trials, assuming that participants would pay more attention to the location of S1 when the proportion of same-location trials was higher (Experiment 1A) than when it was lower (Experiment 1B). The bias was, however, comparable in the two experiments, suggesting that the role of spatial attention in the spatial congruency bias was negligible. However, as the different proportion of the same-location trials between Experiments 1A and 1B did not affect the magnitude of *d'*, either, it is possible that our manipulation of spatial attention was not powerful enough.

In Experiment 7, we used a spatial cuing paradigm to investigate directly the role of spatial attention in the spatial congruency bias. Precues preceded the appearance of both S1 and S2. The cue indicating the location of S1 was always valid, but the cue indicating the location of S2 was uninformative: it was equally likely to be valid or invalid. We expect these exogenous cues to be effective in directing spatial attention (Posner, 1980), If spatial attention does not play an important role in spatial congruency bias, as suggested by the comparison of Experiments 1A and 1B, the magnitude of the bias should not differ as a function of cue validity in Experiment 7.

Method

The method was similar to that of Experiment 1A except for the following changes. First, the experiment consisted of 2 sessions: a nocue session with no cues on any trial, and a cue session that contained a precue before S1 and another before S2 on every trial. In both sessions, the two letter sets were equally likely to occur at the same location or at different locations. However, instead of having 4 target locations, Experiment 7 had only 2 target locations: 3.63^{o} left or right of the fixation (i.e., the same left and right target locations as in the previous experiments). Second, all the stimuli were presented against a gray background. The cue, which subtended 5.06^{o} in width and 2.87^{o} in height, consisted of a white, horizontal rectangle centered 3.63^{o} left or right of the center. Third, before the onset of S1 and of S2, the cue was shown for 100 ms, followed by a blank screen for 17 ms. Whereas the cue preceding S1 had 100% validity, the cue preceding S2 was uninformative. S2 was equally likely to appear at the location indicated by the cue (the valid trials) or at the other location not indicated by the cue (the invalid trials). Finally, the mask consisted of 2 identical rectangles made of black diagonal lines (instead of 4 such rectangles as in the previous experiments). The spatial separation between the inner boundaries of the two rectangles was 2.29^{o}. Twenty participants from the same population took part in the experiment. Half of them completed the nocue session before the cue session, and the order was reversed for the other half. The cue validity information was provided to the participants explicitly, and they were again instructed to keep their eyes fixated at the fixation cross throughout the entire trial. As in Experiments 1A and 1B, the task was to determine whether S1 and S2 were identical or different by making either a “same” or “different” response on each trial. Thus, the experiment used a 3 x 2 x 2 within-subjects design, with CueType (valid, invalid, or nocue), Location, and ID as the principal manipulations. The entire experiment consisted of 672 trials, with 288 trials in the nocue session and 384 trials in the cue session. All the other aspects of the experiment were the same as those in Experiment 1A.

Results

Table 7 shows the mean proportions of “same” responses, and Figure 8 shows the mean response biases. The RTs and error rates are in Appendix G1, with statistical analyses in G2. A 3 x 2 repeated-measures ANOVA on the response bias data with CueType and Location as the within-subjects factors was conducted. The main effect of CueType was found, $F(2, 38) = 3.83$, $MSE = .04$, $p = .03$, $\eta^2 = .17$. Tukey's Honest Significant Difference (HSD) test further showed no significant difference in the bias between the valid (-.18) and invalid (-.16) conditions, and no significant difference between the invalid and nocue (-.07) conditions. However, the bias was significantly larger in the valid condition than in the nocue condition. The effect of Location was also significant, $F(1, 19) = 34.43$, $MSE = .04$, $p = .001$, $\eta^2 = .64$, suggesting a larger same-bias in the same-location trials (-.25) than in the different-location ones (-.03). Cue and Location did not interact, $F(2, 38) < 1$.

To assess bias against zero for each condition, we again performed one-sample *t*-tests. The results showed a significant same-bias on the same-location trials for all 3 conditions: $t(19) = -3.42$, $p = .01$, $d = .76$, for the nocue trials; $t(19) = -3.93$, $p = .001$, $d = .88$, for the valid trials; and $t(19) = -4.16$, $p = .001$, $d = .93$, for the invalid trials. No significant effects were found for the different-location trials in any condition: $t(19) = 1.11$, $p = .28$, $d = .25$, for the nocue trials; $t(19) = -1.54$, $p = .14$, $d = .34$, for the valid trials; and $t(19) = -1.03$, $p = .32$, $d = .23$, for the invalid trials.

We also conducted a 3 x 2 mixed ANOVA on the *d'* data. A significant main effect of CueType was found, $F(2, 38) = 5.83$, $MSE = .38$, $p = .01$, $\eta^2 = .23$. Subsequent Tukey's HSD test showed a larger *d'* on the valid trials (2.17) than on both the invalid (1.80) and nocue trials (1.73), with no difference between the latter two. Neither the main effect of Location, $F(1, 19) = 2.17$, $MSE = .15$, $p = .16$, $\eta^2 = .10$, nor Location by CueType interaction, $F(1, 38) = 1.94$, $MSE = .08$, $p = .16$, $\eta^2 = .09$, was significant.

Discussion

Experiment 7 showed a same location congruency bias in all the 3 conditions. Furthermore, the magnitude of the bias was comparable regardless of cue validity. These results are consistent with the results of Experiments 1A and 1B. Furthermore, the finding of a larger *d*' in the valid cue condition than in the other two conditions indicates that our manipulation of spatial attention in Experiment 7 was successful. These results show that spatial attention allocated in response to a cue does not play a significant role in the manifestation of the spatial congruency bias.

The results of Experiment 7 also provide additional evidence that the spatial congruency bias observed in the present study cannot be attributed to overt orienting. If we assume that eye movements occurred on some trials during all the experiments despite the instruction of keeping the eyes fixated on the fixation cross, the effect of eye movements on the spatial congruency bias should be most pronounced in Experiment 7. This is because S2 always occurred at the same location as S1 in the valid condition while the two never occurred at the same location in the invalid condition. The fact that no difference was found between these two conditions provides strong evidence that overt orienting did not play much of a role in the spatial congruency bias reported in our study.

General Discussion

These experiments confirm and expand what can be learned about visual processing by examining the bias in participants responses to a comparison task. Table 8 shows a summary of the type of processing, the spatial congruency bias (the response bias in the same location condition minus the response bias in the different location condition) and the overall response bias (the average bias of all trials) in each experiment. Experiments 1A and 1B demonstrate that the spatial congruency bias found in previous studies also occurs in the comparison of simple letter strings: when the two strings are at the same location, participants are more likely to respond "same", perhaps because the consistent location makes it easier to perceive the two stimuli as the same object. The spatial congruency bias is proving to be a fairly general phenomenon, and it is probably illustrating something about visual comparisons that can be done using representations established in the relatively lower levels of the visual system in which location is still an integral part of the representation.

While it is surprising that participants succumb to this bias, and thus lower the accuracy of their responses, it is not surprising that location plays an important role in visuall processing, given the special role that location plays in attentional selection. A target stimulus is more likely to be detected if it is near another stimulus that is relevant to a concurrent task (Hoffman & Nelson, 1981; Hoffman, Nelson, & Houck, 1983). When attention selects a search target defined by color or shape, subsequent stimuli appearing at the same location also receive attentional benefit, which can be measured with accuracy and response time (Cave & Pashler, 1995; Chen, 2009; Kim & Cave, 1995), and also with ERPs (Mangun & Hillyard; 1995). Even when location is irrelevant to the task, the course of visual processing is shaped by stimulus location. (For a review, see Cave & Bichot, 1999).

It is conceivable that this spatial congruency bias might vary according to the type of comparison that must be performed. Comparing the two strings as two unified wholes might produce a different bias than comparing each individual letter in one string to its corresponding letter in the other. The results across Experiments 3-6 show that bias does indeed vary between holistic and analytical comparison tasks, but this new bias effect appears to be unrelated to the spatial congruency bias. The spatial congruency bias shows up consistently throughout these experiments, producing more “same” responses when the two stimuli share a location, regardless of whether the task requires a holistic or analytical comparison. This spatial congruency bias is combined with the newly detected bias to respond “different” if the two stimuli are compared letter-by-letter rather than as a complete pattern.

Experiments 5 and 6 demonstrate that the analytical/holistic differences in response bias do not arise from differences in the number of response alternatives. In Experiment 7, this bias is not associated with spatial selection of a location in response to a cue. Across Experiments 3-6, this bias occurs whether the task requires localizing or counting the number of differences between the two strings, or simply ignoring some components within each of the strings while comparing the others. All of these tasks require that individual letters be identified and compared separately from their neighboring letters. This analytic bias does not occur if the localization task is required after the same/different task, as in Experiment 2. In that case, participants seem to decide the same/different response first, and then try to do the localization later.

Why should this comparison at the level of individual components lead to a stronger positive bias than a more holistic comparison of letter strings as complete units? The source of this bias effect is not clear. Perhaps there is something about the holistic tasks that makes participants more likely to guess “same” when they are unable to fully compare the two stimuli, while something about the analytical tasks makes participants more likely to guess “different. If so, though, it is not clear what differs about the tasks that leads to these different default assumptions.

One possible difference between the holistic and analytical tasks is the role of location. In the analytical tasks, the location of each letter relative to other letters in the string may be important in a way that it is not in the holistic tasks. If the role of location differs across tasks, however, it does not change the spatial congruency bias that arises when strings share locations. Also, the analytical bias does not seem to change when the two stimuli to be compared are at different locations. The analytical/holistic effects seem to be separate from the same/different location effects. One factor that may limit the role of location in these particular tasks is that a letter that appears in S1 never appears at a different location within S2.

Perhaps the analytical and holistic comparison tasks differ in their attentonal demands in ways that could be relevant. In all of the analytical comparison tasks, each component letter to be compared is close to other letters that are irrelevant to its individual comparison. We know that the filtering of flanking distractors is imperfect, especially when they are very close to the selected target (B. A. Eriksen & C. W. Eriksen, 1974; Eriksen & Hoffman, 1972), allowing the distractors to interfere with the processing of the target. Even though the corresponding letters from two strings are identical, the interference from flanking distractors might cause their representations to differ considerably from one another, especially in the early processing stages before attentional mechanisms have fully inhibited the distractor signals. If the masks in these displays terminate the perceptual input before the attentional filtering is complete, the comparison of two identical letters could be based on representations tainted by their flanking letters, leading to a bias to conclude that the compared letters are different.

The representations of the letters in the two strings may also differ if attention shifts are executed during the presentation of each string before it is replaced by the mask. If the pattern of shifting attention is different for one string than for the other, then a letter may be more fully processed in one string than in the other, leading to differences in the representations across strings and contributing further to the bias to respond “different”.

Both of these factors would be much less of a problem when two strings are compared as complete units. The flanking letters do not need to be filtered out, because they are part of the same configuration that is being compared, and there is less reason for attentional adjustments to select individual letters. Thus, these two factors that could lead to representational differences in the analytical tasks will have less of an influence in the holistic tasks. If either or both of these factors is producing the positive, “different” bias in the analytical tasks, that bias should be diminished in holistic tasks. If either or both of these factors is responsible for analytical bias, then this is not a response bias, but is the result of the attentional mechanisms that are employed in the analytical processing of the different parts of a complex visual configuration.

This explanation is speculative, but it illustrates the large differences in processing that are likely to occur between holistic and analytical comparisons, and it shows how those differences could lead to differences in bias. The results from these experiments demonstrate consistent differences in bias between these two categories of visual task. All of the experiments demonstrating these differences in bias use letter strings as stimuli. Therefore, it is not clear whether this pattern arises from factors that are specific to letter and word recognition, or whether these results will generalize to other types of visual objects. Understanding the factors producing bias in these tasks will lead to a better understanding of visual identification and comparison.

References

Besner, D., & Coltheart, M. (1975). Same-different judgments with words and nonwords: The differential effects of relative size. *Memory and Cognition, 3*, 673-677.

Cave, K. R., & Bichot, N. P. (1999). Visuospatial attention: Beyond a spotlight model. *Psychonomic Bulletin and Review, 6*, 204-223.

Cave, K. R., & Pashler, H. (1995). Visual selection mediated by location: Selecting successive visual objects. *Perception & Psychophysics*, *57*, 421-432.

Chen, Z. (2009). Not all features are created equal: Processing asymmetries between location and object features. *Vision Research*, *49*, 1481-1491.

Egeth, H. E. (1966). Parallel versus serial processes in multidimensional stimulus discrimination. *Perception & Psychophysics, 1*, 245-252.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noice letters upon the identification of target letter in a nonsearch task. *Perception & Psychophysics*, *16*, 143-149.

Eriksen, C. W., & Hoffman, J. E. (1972). Temporal and spatial characteristics of selective encoding from visual displays. *Perception & Psychophysics*, *12*, 201-204.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40,* 225–240.

Finlayson, N. J., & Golomb, J. D. (2016). Feature-location binding in 3D: Feature judgments are biased by 2D location but not position-in-depth. *Vision Research*, *127*, 49-56.

Golomb, J. D., Kupitz, C. N., & Thiemann, C. T. (2014). The influence of object location on identity: A “spatial congruency bias”. *Journal of Experimental Psychology: General*, *143*, 2262-2278.

Hawkins, H. L., Hillyard, S. A., Luck, S., J., Mouloua, M., Downing, C. J., & Woodward, D. P. (1990). Visual attention modulates signal detectability. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 802-811.

Hawkins, H. L., & Shigley, R. H. (1972). Irrelevant information and processing mode in speeded discrimination. *Journal of Experimental Psychology, 96*, 389-395.

Hoffman, J.E., & Nelson, B. (1981). Spatial selectivity in visual search. *Perception & Psychophysics*, *30*, 283-290.

Hoffman, J.E., Nelson, B., & Houck, M.R. (1983). The role of attentional resources in automatic detection. *Cognitive Psychology*, *51*, 379-410.

Kim, M.-S., & Cave, K.R. (1995). Spatial attention in visual search for features and feature conjunctions. *Psychological Science, 6*, 376-380.

Kinchla, R. A. (1977). The role of structural redundancy in the perception of visual targets. *Perception & Psychophysics*, *22*, 19-30.

Kinchla, R. A., & Wolfe, J. M (1979). The order of visual processing: “Top-down,” “Bottom-up,” or “middle-out”. *Perception & Psychophysics*, *25*, 225-231.

Lamy, D., & Tsal, Y. (2001). On the status of location in visual attention. *European Journal of Cognitive Psychology*, *13*, 305-342.

Macmillan, N.A., & Creelman, C.D. (2005). *Detection Theory: A User’s Gui*de. Mahwah, NJ: Lawrence Erlbaum Associates.

Mangun, G.R., & Hillyard, S.A. (1995). Mechanisms and models of selective attention. In: M.D. Rugg and M.G.H. Coles (Eds), Electrophysiology of mind: Event-related brain potentials and cognition (pp. 41-85). Oxford: Oxford University Press.

Müller, H. J., & Findlay, J. M. (1987). Sensitivity and criterion effects in the spatial cuing of visual attention. *Perception & Psychophysics*, *42*, 383-399.

Navon, D. (1977). Forest before trees: The precedence of global fea- tures in visual perception. *Cognitive Psychology, 9,* 353-383.

Paradiso, M. M., Shafer-Skelton, A., Martinez, A. M., & Golomb, J. (2016). Object-location binding: Does spatial location influence judgments of facial identity and expression? Paper presented at 2016 Vision Sciences Society, St. Pete Beach, FL.

Pestilli, F., & Carrasco, M. (2005). Attention enhances contrast sensitivity at cued and impairs it at uncued locations. *Vision Research*, *45*, 1867-1875.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3-25.

Santee, J. L, & Egeth, H. E. (1980). Selective attention in the speeded classification and comparison of multidimensional stimuli. *Perception & Psychophysics, 28,* 191-204.

Sekuler, R. W., & Abrams, M. (1968). Visual sameness: Choice time analysis of pattern recognition processes. *Journal of Experimental Psychology, 77,* 232-238.

Shafer-Skelton, A., Kupitz, C. N.; & Golomb, J. D. (2017). Object-location binding across a saccade: A retinotopic spatial congruency bias. *Attention, Perception, & Psychophysics*, *79,* 765-781.

Tsal, Y., & Lavie, N. (1988). Attending to color and shape: The special role of location in selective visual processing. *Perception & Psychophysics*, *44*, 15-21. doi:

Tsal, Y., & Lavie, N. (1993). Location dominance in attending to color and shape. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 131-139.

Table 1

Mean proportions of "same" responses as a function of stimulus location and stimulus identify (ID) for Experiments 1A and 1B.

Experiment	Same Location		Different Location	
	Same ID (Hits)	Different-ID (FAs)	Same ID (Hits)	Different ID (FAs)
1A	.84 (.02)	.26 (.03)	.76 (.02)	.23 (.03)
1B	.84 (.02)	.28 (.02)	.77 (.02)	.24 (.02)

Note: A response is a "Hit" when S1 and S2 were identical and a correct "same" response was made. A response is a "FA" (False Alarm) when S1 and S2 were different but an incorrect "same" response was made. Standard errors of the mean are in the parentheses.

Table 2

Mean proportions of "same" responses as a function of task type, stimulus location, and stimulus identity (ID) for Experiment 2.

Task Type	Same Location		Different Location	
	Same ID (Hits)	Different-ID (FAs)	Same ID (Hits)	Different ID (FAs)
1Task	.84 (.02)	.23 (.02)	.76 (.02)	.20 (.02)
2Task	.89 (.01)	.23 (.02)	.82 (.02)	.21 (.02)

Note: A response is a "Hit" when S1 and S2 were identical and a correct "same" response was made. A response is a "FA" (False Alarm) when S1 and S2 were different but an incorrect "same" response was made. Standard errors of the mean are in the parentheses.

Table 3

Mean proportions of "same" responses as a function of stimulus location and stimulus identity (ID) for Experiments 3A and 3B.

Experiment	Same Location		Different Location	
	Same ID (Hits)	Different-ID (FAs)	Same ID (Hits)	Different ID (FAs)
3A	.79 (.04)	.16 (.02)	.71 (.04)	.14 (.02)
3B	.81 (.02)	.13 (.01)	.76 (.03)	.12 (.01)

Note: A response is a "Hit" when S1 and S2 were identical and a correct "same" response was made. A response is a "FA" (False Alarm) when S1 and S2 were different but an incorrect "same" response was made. Standard errors of the mean are in the parentheses.

Table 4

Mean proportions of "same" responses as a function of response code, stimulus location, and stimulus identity (ID) for Experiment 4.

Response Code	Same Location		Different Location	
	Same ID (Hits)	Different-ID (FAs)	Same ID (Hits)	Different ID (FAs)
Same	.79 (.02)	.16 (.02)	.72 (.03)	.13 (.02)
Different	.82 (.02)	.19 (.02)	.72 (.02)	.14 (.02)

Note: A response is a "Hit" when S1 and S2 were identical and a correct "same" response was made. A response is a "FA" (False Alarm) when S1 and S2 were different but an incorrect "same" response was made. Standard errors of the mean are in the parentheses.

Table 5

Mean proportions of "same" responses as a function of stimulus location and stimulus shape for Experiments 5A and 5B.

Experiment	Same Location		Different Location	
	Same Shape (Hits)	Different Shape (FAs)	Same Shape (Hits)	Different Shape (FAs)
5A	.81 (.02)	.41 (.03)	.71 (.03)	.35 (.03)
5B	.87 (.03)	.37 (.04)	.79 (.03)	.32 (.04)

Note: A response is a "Hit" when S1 and S2 were identical and a correct "same" response was made. A response is a "FA" (False Alarm) when S1 and S2 differed in style or in font but an incorrect "same" response was made. Standard errors of the mean are in the parentheses.

Table 6

Mean proportions of "same" responses as a function of stimulus location and stimulus ID for Experiments 6A and 6B.

Experiment	Same Location		Different Location	
	Same ID (Hits)	Different Shape (FAs)	Same Shape (Hits)	Different Shape (FAs)
6A	.65 (.03)	.18 (.02)	.63 (.03)	.15 (.02)
6B	.83 (.02)	.27 (.02)	.75 (.02)	.20 (.03)

Note: In Experiment 6A, the 1st and 3rd letters were always different. In Experiment 6B, the 1st and/or the 3rd letter differed on 1/6 of the trials. A response is a "Hit" when S1 and S2 had the same 2nd letter and a correct "same" response was made. A response is a "FA" (False Alarm) when S1 and S2 had different 2nd letters but an incorrect "same" response was made. Standard errors of the mean are in the parentheses.

Table 7

Mean proportions of "same" responses as a function of cue type, stimulus location, and stimulus identity (ID) for Experiment 7.

Cue Type	Same Location		Different Location	
	Same ID (Hits)	Different-ID (FAs)	Same ID (Hits)	Different ID (FAs)
Nocue	.82 (.03)	.30 (.04)	.79 (.02)	.20 (.03)
Valid	.86 (.04)	.25 (.04)	.84 (.03)	.21 (.04)
Invalid	.85 (.03)	.29 (.04)	.81 (.03)	.23 (.04)

Note: A response is a "Hit" when S1 and S2 were identical and a correct "same" response was made. A response is a "FA" (False Alarm) when S1 and S2 were different but an incorrect "same" response was made. Standard errors of the mean are in the parentheses.

Table 8

Processing type, spatial congruency bias (the response bias in the same location condition minus the response bias in the different location condition) and overall response bias (the average bias of all trials) in each experiemnt. A negative value indicates a greater tendency to make the "same" response and a positive value indicates a greater tendency to make the "different" response. The spatial congruency bias is generally consistent across conditions, but the overall response bias is more positive in analytical tasks than in holistic tasks.

Experiment	Processing Type	Spatial Congruency Bias	Overall Response Bias
1A	Holistic	-0.24	-0.05
1B	Holistic	-0.23	-0.13
2	Holistic	-0.21	-0.09
3A	Analytical	-0.18	0.18
3B	Analytical	-0.14	0.20
4	Analytical	-0.24	0.16
5A	Holistic	-0.25	-0.22
5B	Holistic	-0.23	-0.30
6A	Analytical	-0.09	0.34
6B	Holistic	-0.29	-0.03
7	Holistic	-0.22	-0.14

Notes:

1. Except for Experiments 2 and 4, the number of participants in each experiment varied from 16 to 20. This number was chosen based on the number of participants used in Golomb et al. (2014), which varied from 16 to 20. Experiment 2 included 34 participants because we expected an order effect, and thus included 17 subjects for each order. Experiment 4 consisted of 2 groups of participants (see Note 3 for detail), and this resulted in the use of 40 participants in total.
2. The average target display duration for each experiment was as follows: 85 ms in Experiment 1A; 92 ms in Experiment 1B; 82 ms in Experiment 2; 113 ms in Experiment 3A; 99 ms in Experiment 3B; 106 ms in Experiment 4; 169 ms in Experiment 5A; 154 ms in Experiment 5B; 100 ms in Experiment 6A; 92 ms in Experiment 6B; and 117 ms in Experiment 7.
3. Of the 248 participants who took part in the experiments reported here, 10 of them (4.0%) took part in 2 experiments, and the rest in only 1 experiment. There were 2 repeated participants in Experiment 2, 3 in Experiment 3B, 1 in Experiment 5B, 1 in Experiment 6B, and 3 in Experiment 7.
4. Two different participant groups were tested to assess the effect of the presentation time of the letter strings. For the “long” group, the presentation time was adjusted with the same parameters used in Experiment 1: initial presentation time of 116 ms; presentation time adjusted when accuracy was outside the range of 70-75%; and exposure time kept within the range of 50-216 ms. These parameters were changed for the “short” group to produce slightly shorter presentation times: initial presentation time of 100 ms; presentation time adjusted when accuracy was outside the range of 65-70%;

and exposure time kept within the range of 33-200 ms. For both the long and short groups, half the participants responded using the “same” response codes, and half responded using the “different” response codes. The long group (n = 22) had a mean presentation time of 124 ms, and the short group (n = 18) had a mean presentation time of 85 ms. No effects from the presentation time manipulation were found. Thus, the data from the two duration groups were collapsed.

Figure Captions

Figure 1. Examples of trials from Experiments 1A and 1B. On each trial, two sequentially presented letter sets, S1 and S2, were presented briefly at either the same location or different locations. The letter sets could be identical or they could differ in 1 letter, and the task was to judge whether they were the same or different by making a binary “same” or “different” response. In both experiments, location was task irrelevant. The letter sets occurred at the same location on 50% of the trials in Experiment 1A, but on 25% of the trials in Experiment 1B. Two frames, one after S1 and the other after S2, and each consisting of a 17 ms blank screen, were not shown in the figure.

Figure 2. Response bias (c) as a function of stimulus location in Experiments 1A and 1B. Error bars show ±1 standard error of the mean. A negative bias indicates a tendency to make the “same” response and a positive bias a tendency to make the “different” response.

Figure 3. Response bias (c) as a function of task type and stimulus location in Experiment 2. Error bars show ±1 standard error of the mean.

Figure 4. Response bias (c) as a function of stimulus location in Experiments 3A and 3B. Error bars show ±1 standard error of the mean.

Figure 5. Response bias (c) as a function of response code and stimulus location in Experiment 4. Error bars show ±1 standard error of the mean.

Figure 6. Response bias (c) as a function of stimulus location in Experiments 5A and 5B. Error bars show ±1 standard error of the mean.

Figure 7. Response bias (c) as a function of stimulus location in Experiments 6A and 6B. Error bars show ±1 standard error of the mean.

Figure 8. Response bias (c) as a function of cue type and stimulus location in Experiment 7. Error bars show ±1 standard error of the mean.

Figure 1

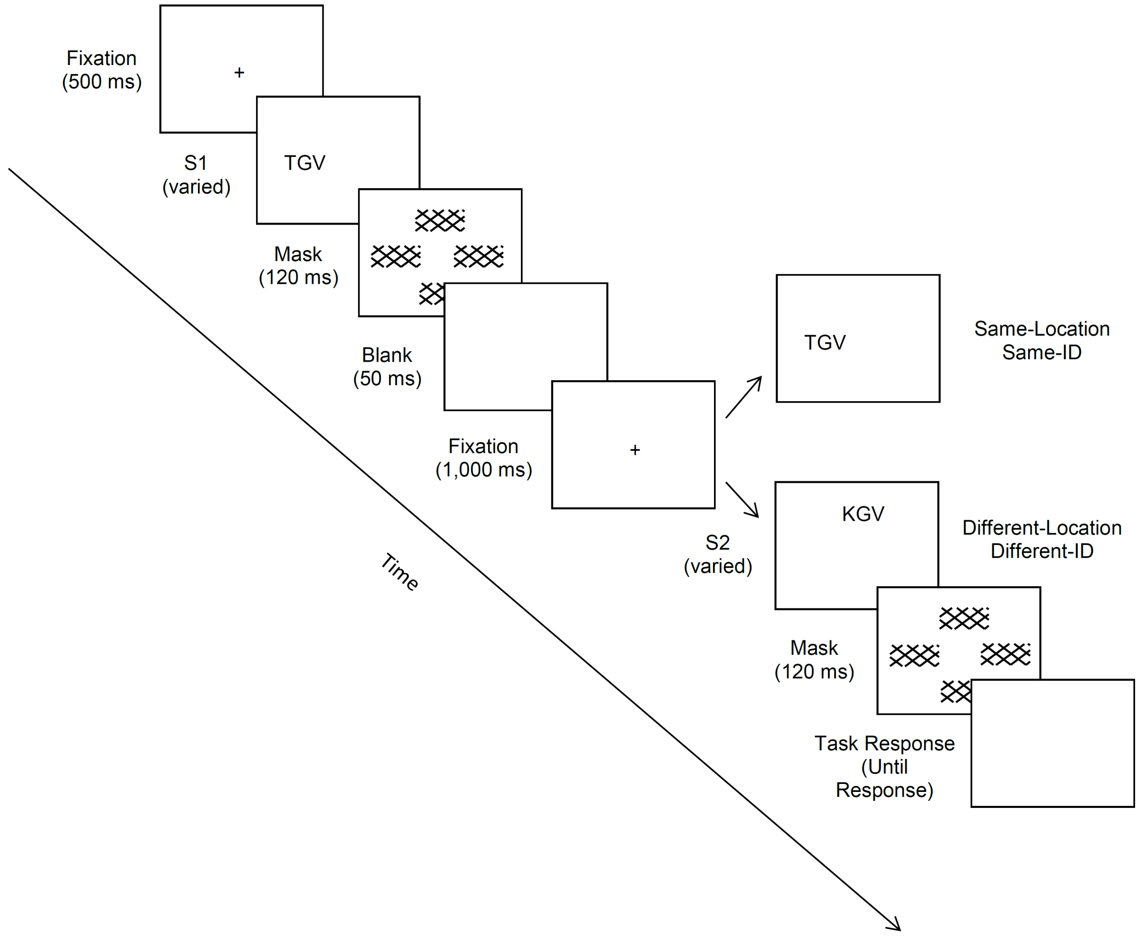

Fixation
(500 ms)
+
S1
(varied)
TGV
Mask
(120 ms)
Blank
(50 ms)
Fixation
(1,000 ms)
+
TGV
Same-Location
Same-ID
S2
(varied)
KGV
Different-Location
Different-ID
Mask
(120 ms)
Task Response
(Until
Response)
Time

Figure 2

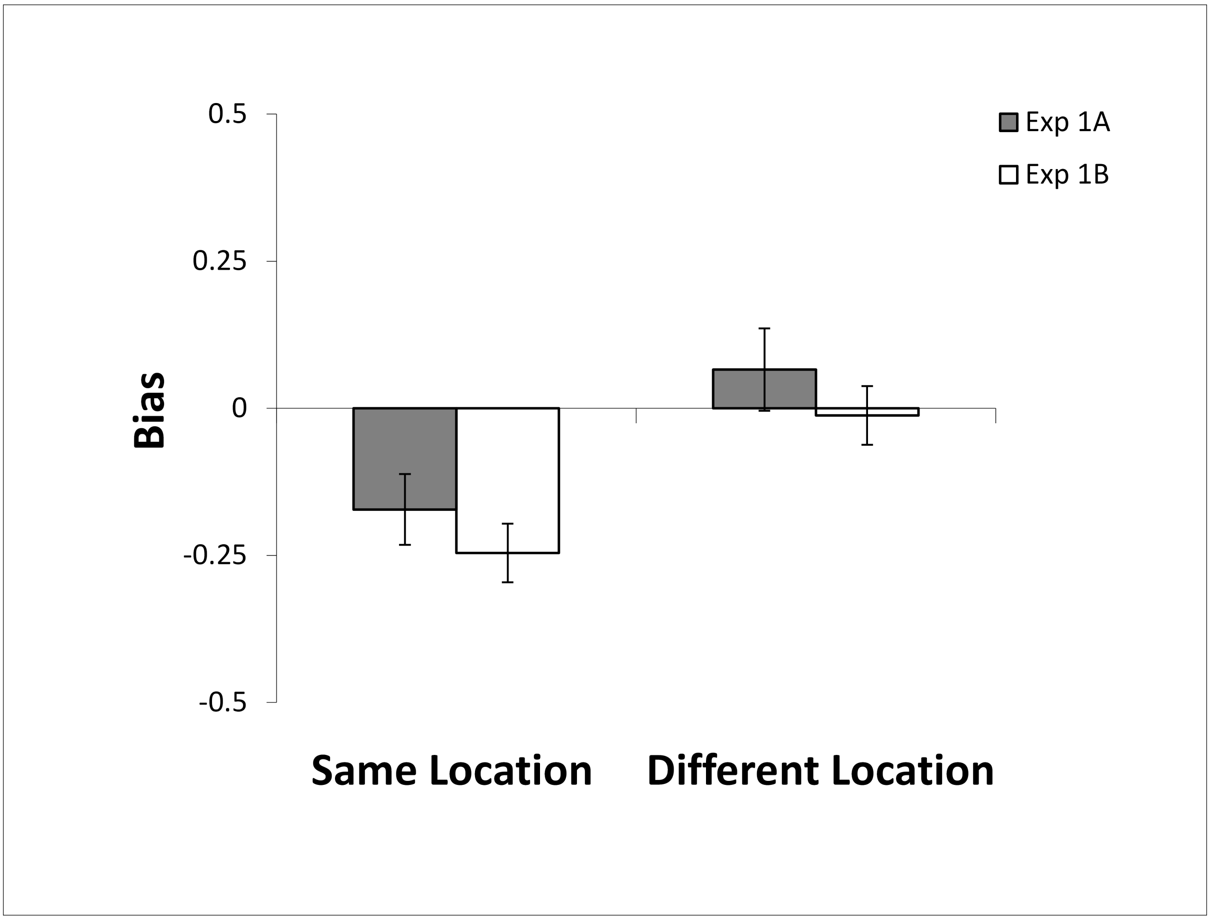

0.5
0.25
0
-0.25
-0.5
Bias
Exp 1A
Exp 1B
Same Location
Different Location

Figure 3

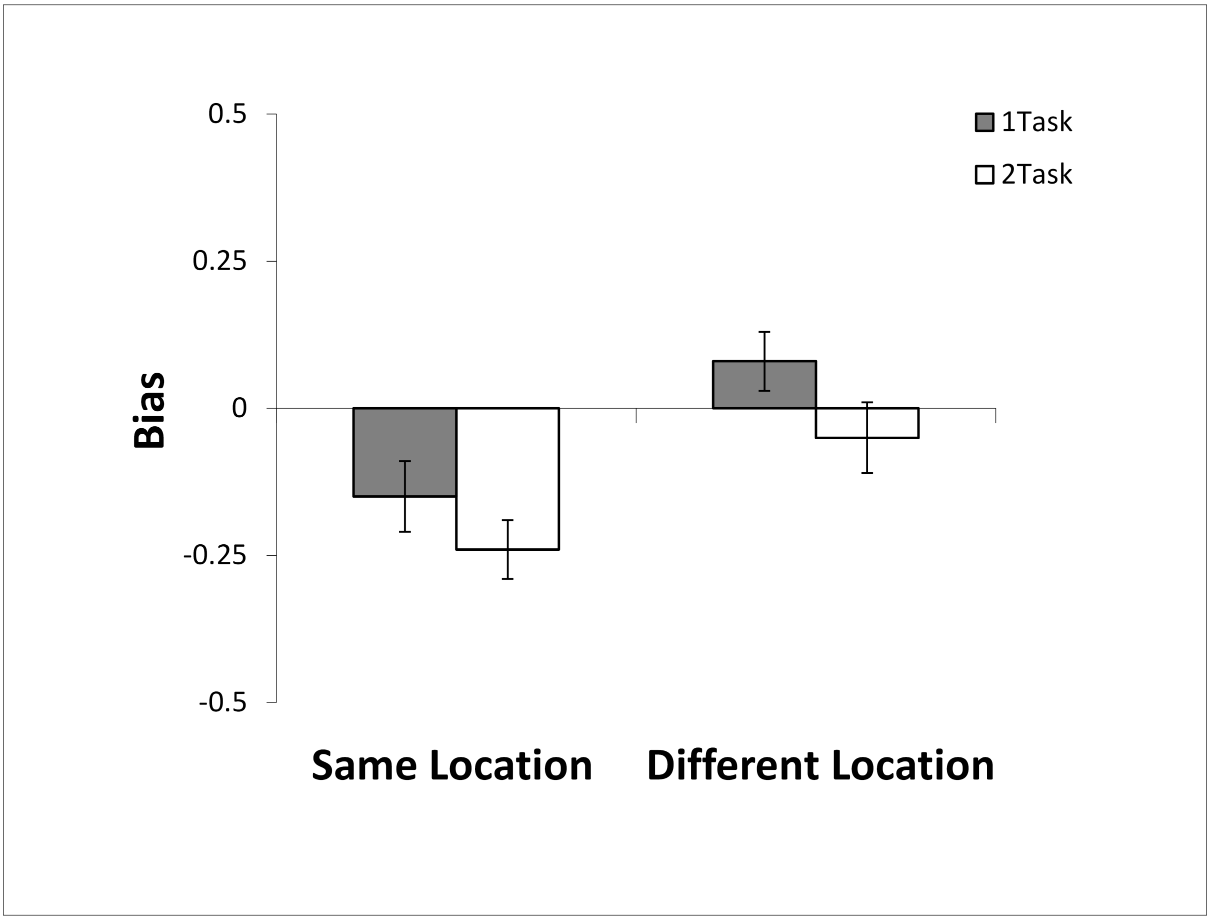

0.5
0.25
0
-0.25
-0.5
Bias
1Task
2Task
Same Location
Different Location

Figure 4

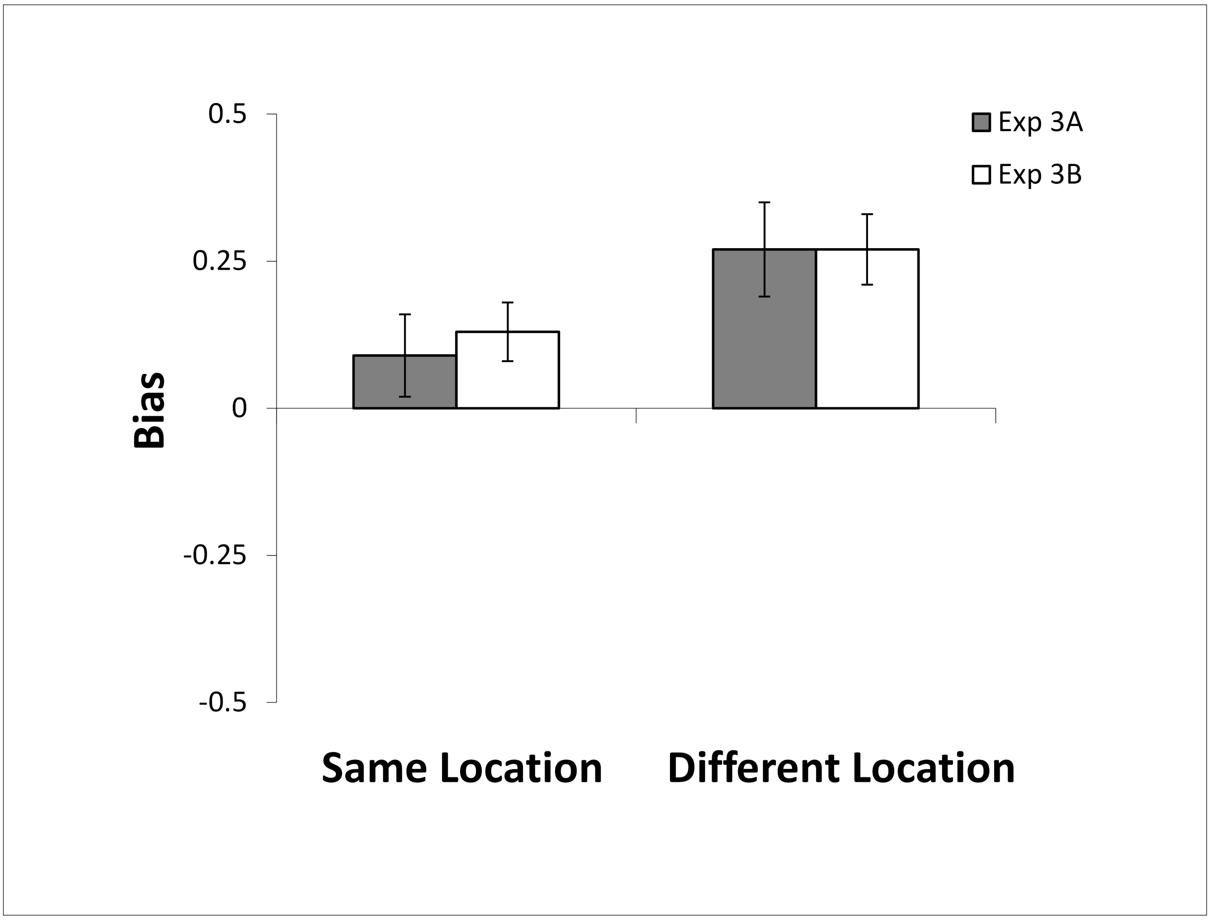

0.5
0.25
0
-0.25
-0.5
Bias
Exp 3A
Exp 3B
Same Location
Different Location

Figure 5

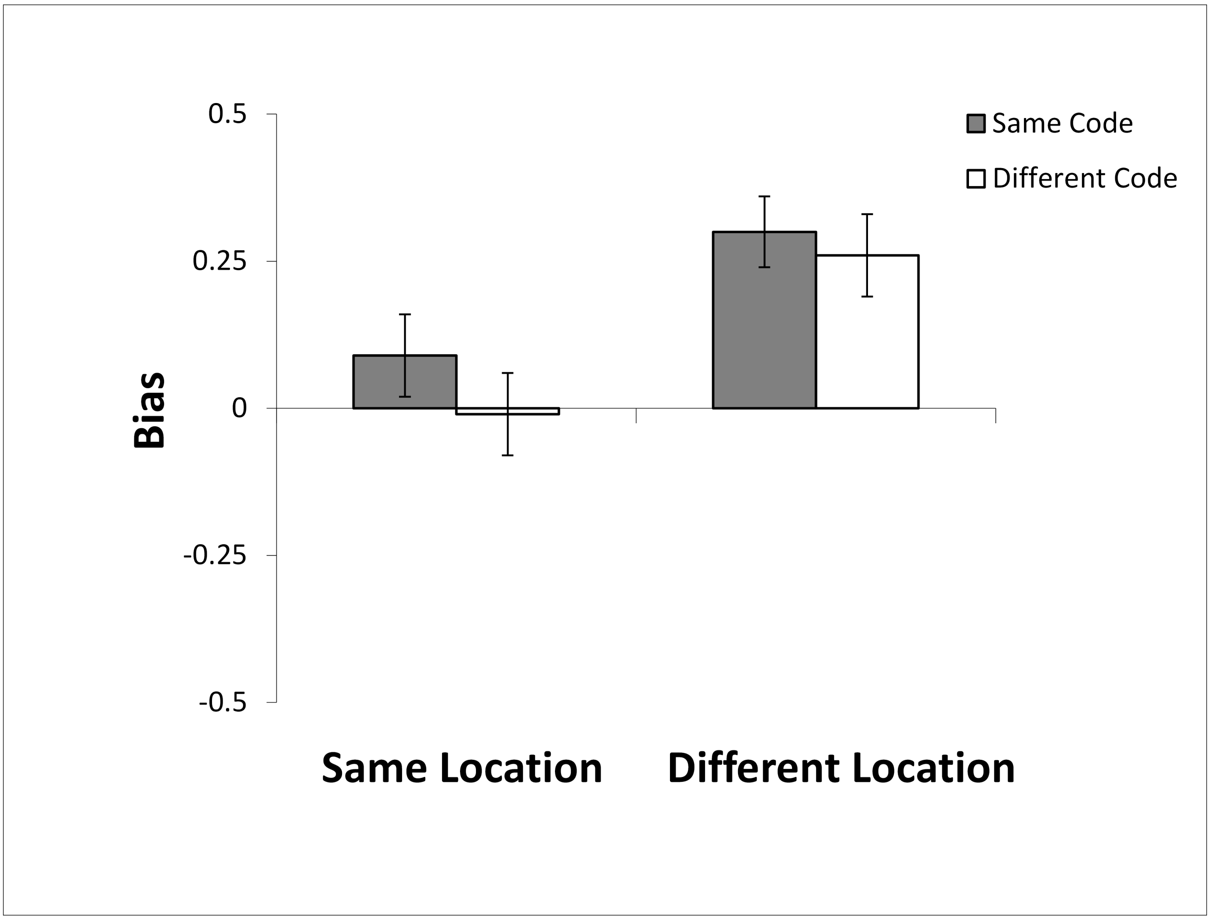

0.5
0.25
0
-0.25
-0.5
Bias
Same Code
Different Code
Same Location
Different Location

Figure 6

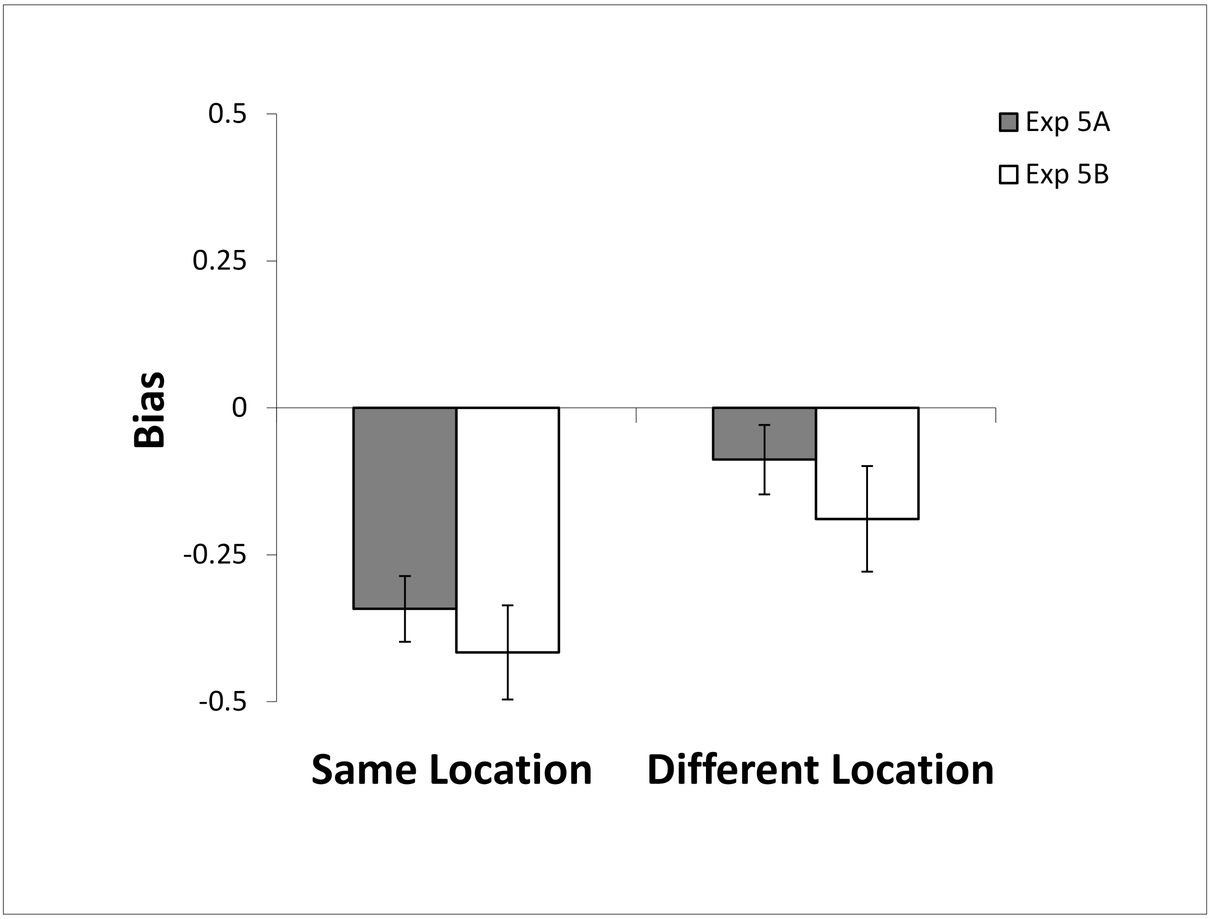

Bias
0.5
0.25
0
-0.25
-0.5
Exp 5A
Exp 5B
Same Location
Different Location

Figure 7

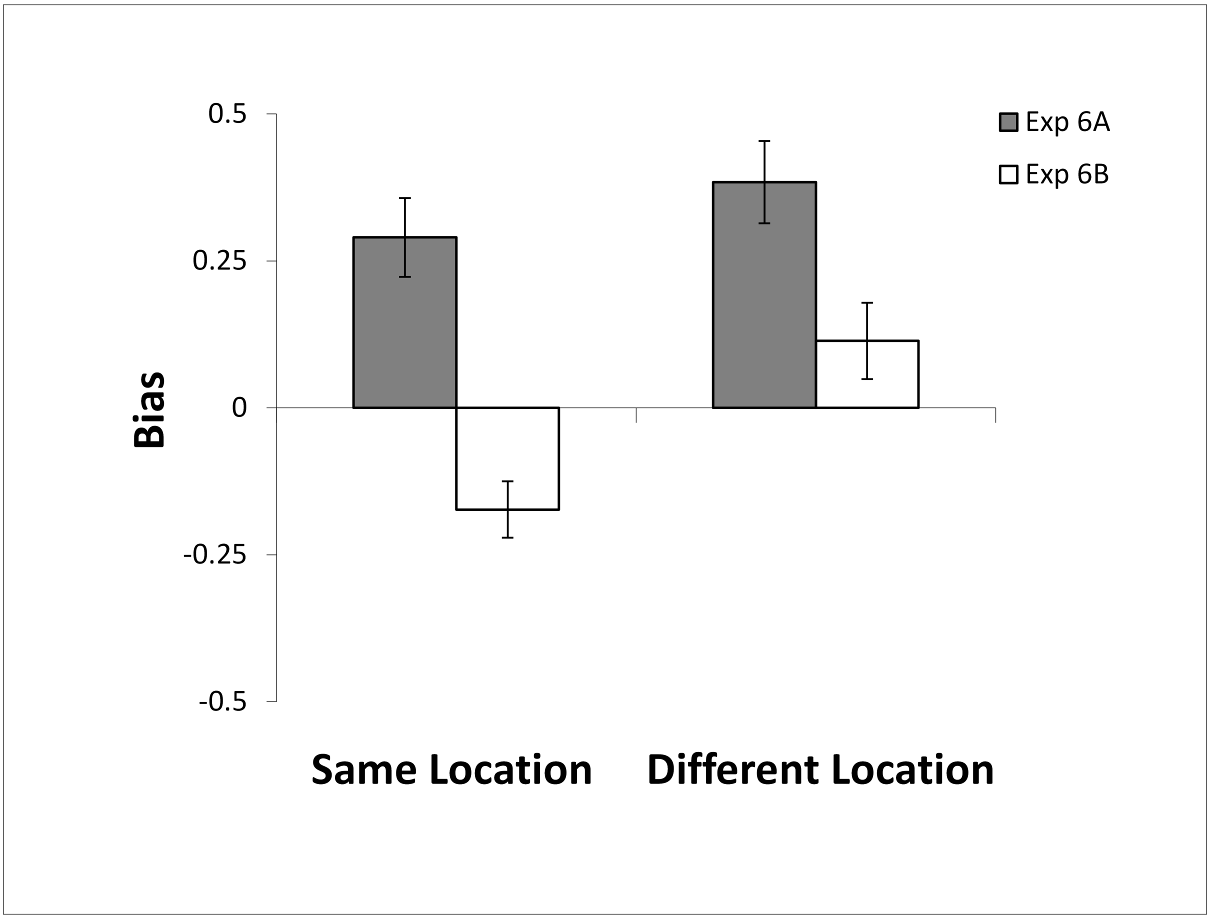
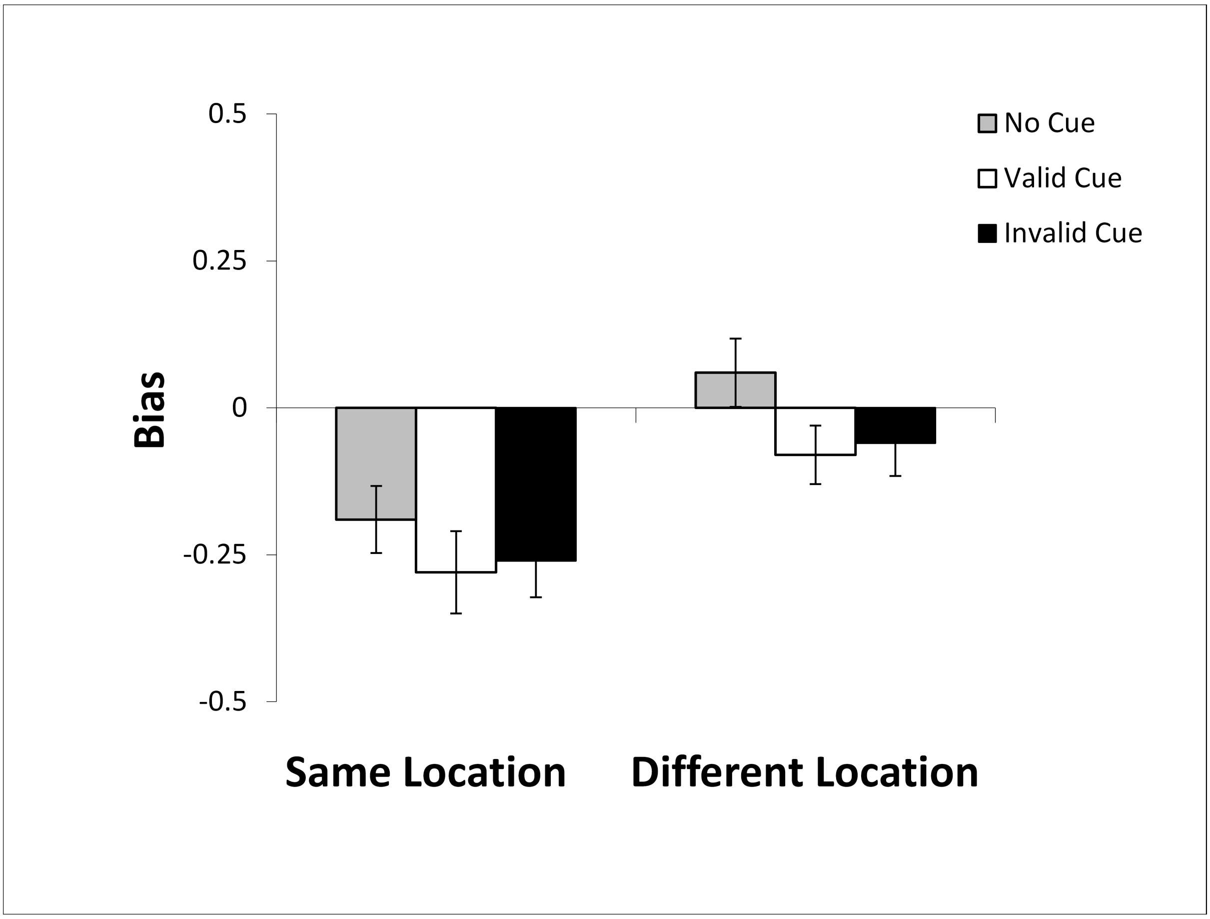

0.5
0.25
0
-0.25
-0.5
Bias
Exp 6A
Exp 6B
Same Location
Different Location

Figure 8


0.5
0.25
0
-0.25
-0.5
Bias
No Cue
Valid Cue
Invalid Cue
Same Location
Different Location

Appendix A

Table A1

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of stimulus location and stimulus identity (ID), with standard errors of the mean in the parentheses, for Experiments 1A and 1B. In all experiments, the reaction times were calculated from the offset of the 2nd mask.

	Same Location		Different Location	
	Same ID	Different ID	Same ID	Different ID
Experiment 1A				
RT	603 (44)	674 (43)	676 (55)	688 (45)
% Error	15.8 (1.9)	26.1 (3.2)	23.8 (2.0)	22.6 (3.3)
Experiment 1B				
RT	574 (37)	632 (36)	542 (34)	616 (36)
% Error	15.5 (1.7)	28.2 (2.1)	22.8 (1.5)	24.1 (2.3)

Table A2

Results of ANOVAs on the reaction times and error rates in Experiments 1A and 1B, with Experiment as a between-subjects factor, and location and stimulus ID as within-subjects factors.

	Reaction Times			Error Rates		
	F (1, 38)	*p*	η_p^2	*F* (1, 38)	*p*	η_p^2
Exp	1.49	.23	.04	.06	.80	.01
Location	1.02	.32	.03	11.25	.01	.23
Location*Exp	11.74	.01	.24	.31	.58	.01
ID	17.35	.001	.31	7.06	.01	.16
ID*Exp	.93	.34	.02	.32	.57	.01
Location*ID	2.07	.16	.05	76.39	.001	.67
Location*ID*Exp	6.45	.02	.15	.01	.94	.01

Note: Exp = Experiment.

Appendix B

Table B1

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of task type, stimulus location, and stimulus identity (ID), with standard errors of the mean in the parentheses, for Experiment 2.

Task Type	Same Location		Different Location	
	Same ID	Different ID	Same ID	Different ID
1Task				
RT	583 (36)	672 (38)	657 (47)	686 (42)
% Error	15.5 (1.5)	23.1 (1.9)	23.8 (1.8)	20.3 (1.8)
2Task				
RT	614 (35)	907 (44)	690 (41)	954 (49)
% Error	11.2 (1.1)	23.3 (2.3)	17.7 (1.6)	20.8 (2.3)

Table B2

Results of ANOVAs on the reaction times and error rates in Experiment 2.

	Reaction Times			Error Rates		
	F (1, 32)	p	η_p^2	F (1, 32)	p	η_p^2
Task	33.81	.001	.51	14.74	.001	.32
Location	26.80	.001	.46	12.37	.001	.28
ID	107.22	.001	.77	4.05	.05	.11
Task*Location	1.62	.21	.05	.64	.43	.02
Task*ID	71.94	.001	.69	8.30	.01	.21
Location*ID	16.73	.001	.34	52.26	.001	.62
Task*Location*ID	1.26	.27	.04	.57	.46	.02

Note: Task = TaskType

Table B3

Mean error rates (percentage incorrect) for the localization task (Task 2) in Experiment 2, with standard errors of the mean in the parentheses. Only those trials in which the two letter strings differed and a "different" response was made in Task 1 were included in the analysis.

	1st Letter Different	2nd Letter Different	3rd Letter Different
Same Location	5.6 (.1.1)	19.5 (2.5)	13.8 (2.8)
Different Location	6.3 (1.2)	22.5 (2.6)	20.0 (2.8)

Table B4

Mean error rates (percentage incorrect) as a function of location, stimulus type, and participant response in Experiment 2, with standard errors of the mean in the parentheses. The "Same ID" responses were made in Task 1, and the localization responses ("L1 Different", etc.) were made in Task 2.

		Stimulus Type			
		L1 Different	L2 Different	L3 Different	Same ID
		Same Location			
Response	L1 Different		5.1 (0.9)	3.4 (1.3)	2.7 (0.4)
	L2 Different	3.3 (0.7)		6.7 (1.4)	4.8 (0.7)
	L3 Different	1.3 (0.4)	6.8 (1.0)		3.7 (0.5)
	Same ID	13.3 (2.0)	34.6 (2.9)	22.0 (3.1)	
		Different Location			
Response	L1 Different		6.4 (1.3)	5.3 (0.9)	5.2 (0.7)
	L2 Different	3.5 (0.7)		9.5 (1.5)	6.4 (0.8)
	L3 Different	1.8 (0.4)	7.8 (1.1)		6.1 (0.7)
	Same ID	11.5 (1.8)	32.4 (3.2)	18.6 (2.8)	

The analyses presented in the main text show the frequency of errors in detecting that a letter has changed between S1 and S2. Here we present another analysis to test the accuracy of the localization responses in the secondary task. Because this analysis focuses specifically on localization performance, it includes only trials in which participants correctly respond that a letter has changed from S1 to S2, and includes only the rates at which they incorrectly report the location within the string of the letter that differs. This 2 x 6 ANOVA includes Location and Error Type as within-subjects factors. The letter that changes can occupy one of the three locations within the strings, and for each location, there are two possible incorrect localization responses, resulting in six different error types.

There was a main effect of location, $F(1, 32) = 8.40$, $MSE = .002$, $p = .007$, $\eta^2 = .21$, showing that more localization errors are made when the two strings occupy different locations. There is also a main effect of Error Type, $F(5, 160) = 10.98$, $MSE = .004$, $p < .001$, $\eta^2 = .26$, indicating that some types of errors occur more than others. Table B3 shows that the most common errors are confusions between locations 2 and 3. There is no interaction between Location and Error Type. Thus, when S2 appears at a different location than S1, it increases localization errors generally, but it does not produce more errors of any specific type.

Appendix C

Table C1

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of stimulus location and stimulus identity (ID), with standard errors of the mean in parentheses, for Experiments 3A and 3B.

	Same Location		Different Location	
	Same ID	Different ID	Same ID	Different ID
Experiment 3A				
RT	744 (40)	824 (51)	766 (41)	869 (57)
% Error	21.1 (3.7)	16.4 (1.7)	28.7 (4.0)	14.4 (2.1)
Experiment 3B				
RT	771 (45)	809 (47)	830 (53)	841 (50)
% Error	19.0 (1.8)	13.3 (1.4)	24.3 (2.5)	11.7 (1.4)

Table C2

Results of ANOVAs on the reaction times and error rates in Experiments 3A and 3B, with Experiment as a between-subjects factor, and location and stimulus ID as within-subjects factors.

	Reaction Times			Error Rates		
	F (1, 36)	p	η_p^2	F (1, 36)	p	η_p^2
Exp	.03	.86	.01	2.10	.16	.06
Location	12.52	.001	.26	8.99	.01	.20
Location*Exp	.33	.57	.01	.41	.52	.01
ID	6.84	.01	.16	14.08	.001	.28
ID*Exp	2.32	.14	.06	.01	.94	.01
Location*ID	.02	.88	.01	24.43	.001	.40
Location*ID*Exp	2.96	.09	.08	.60	.44	.02

Note: Exp = Experiment.

Table C3

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of stimulus location and stimulus identity (ID), with standard errors of the mean in parentheses, for Experiments 3A and 3B.

	Same ID	1st Letter Different	2nd Letter Different	3rd Letter Different
		Experiment 3A		
Same Location				
RT	744 (40)	788 (50)	907 (61)	841 (46)
% Error	21.1 (3.7)	10.2 (1.9)	23.8 (2.4)	15.1 (2.6)
Different Location				
RT	766 (41)	831 (47)	947 (72)	901 (74)
% Error	28.7 (4.0)	8.5 (1.7)	20.0 (2.9)	14.8 (2.5)
		Experiment 3B		
Same Location				
RT	771 (45)	750 (35)	896 (55)	854 (67)
% Error	19.0 (1.8)	5.8 (1.0)	22.4 (2.4)	11.7 (2.3)
Different Location				
RT	830 (53)	785 (38)	919 (66)	868 (59)
% Error	24.3 (2.5)	5.5 (1.0)	19.8 (2.3)	9.7 (1.9)

Table C4

Mean error rates (percentage incorrect) as a function of location, stimulus type and participant response in Experiment 3A (A) and Experiment 3B (B), with standard errors of the mean in the parentheses.

A

		Stimulus Type			
		Same ID	L1 Different	L2 Different	L3 Different
		Same Location			
Response	Same ID		10.2 (1.9)	23.8 (2.4)	15.1 (2.6)
	L1 Different	5.7 (1.3)		8.2 (1.8)	4.0 (1.1)
	L2 Different	9.0 (1.2)	4.6 (1.3)		11.1 (1.5)
	L3 Different	6.4 (1.6)	2.3 (0.9)	9.0 (1.8)	
		Different Location			
Response	Same ID		8.5 (1.7)	20.2 (3.0)	14.8 (2.5)
	L1 Different	7.5 (1.4)		9.6 (1.7)	7.9 (1.6)
	L2 Different	13.1 (1.6)	5.1 (1.7)		12.0 (1.8)
	L3 Different	8.2 (1.4)	3.2 (1.4)	9.7 (1.4)	

B

		Stimulus Type			
		Same ID	L1 Different	L2 Different	L3 Different
		Same Location			
Response	Same ID		5.8 (1.0)	22.4 (2.4)	11.8 (2.3)
	L1 Different	6.7 (1.1)		17.1 (5.9)	17.4 (6.9)
	L2 Different	7.4 (1.0)	5.1 (3.6)		10.4 (1.3)
	L3 Different	4.9 (1.0)	0.7 (0.5)	6.0 (0.8)	
		Different Location			
Response	Same ID		5.5 (1.0)	19.8 (2.3)	9.7 (1.9)
	L1 Different	8.3 (1.0)		20.8 (6.2)	18.3 (6.8)
	L2 Different	8.6 (1.3)	7.3 (3.6)		9.9 (1.8)
	L3 Different	7.3 (1.5)	1.8 (0.7)	9.8 (1.3)	

As in Experiment 2, we tested performance in the different-letter localization task. Separate 2 x 6 ANOVAs were conducted for Experiment 3A and Experiment 3B with Location and Error Type as factors. In Experments 3A and 3B, the localization response was not a separate task; it was combined with the same/different response. Because these analyses focus specifically on localization performance, they include only trials in which a letter was different between S1 and S2, and they include only the rates at which participants selected one of the two possible incorrect responses for the location of the differing letter.

For Experiment 3A, the results were very similar to the corresponding analysis in Experiment 2. There were more localization errors if S1 and S2 were in different locations, $F(1, 17) = 4.90$, $MSE = .002$, $p = .041$, $\eta^2 = .22$. There was a main effect of error type, $F(5, 85) = 14.70$, $MSE = .003$, $p < .000001$, $\eta^2 = .46$. The values in Table C4, panel A, suggest that once again participants were likely to confuse locations 2 and 3, and that in this case, a letter change at lcoation 2 was also often mislocalized to location 1. There was no interaction between Location and Error Type, $F(5, 85) = .71$, $MSE = .002$, $p = .615$, $\eta^2 = .04$.

In Experiment 3B, in which there were more trials with letters changing between S1 and S2, there were once again more localization errors when S1 and S2 were in different locations, $F(1, 19) = 25.86$, $MSE = .0008$, $p = .00007$, $\eta^2 = .58$. There was main effect of Error Type, $F(5, 95) = 3.65$, $MSE = .05$, $p = .005$, $\eta^2 = .16$. Table 4C, panel B, shows that changed letters at locations 2 and 3 were often reported to be at location 1. Also, this analysis differed from the previous localization analyses in that there was a significant interaction between Location and Error Type, $F(5, 95) = 2.90$, $MSE = .001$, $p = .017$, $\eta^2 = .13$. This interaction may arise because in the Same Location condition, it was an unusually small proportion of the changed letters at location 1 (0.7%) that were reported as being at location 3. Because there is no hint of a similar interaction in the other localization analyses, we are reluctant to attach much importance to it.

Appendix D

Table D1

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of response code, stimulus location, and stimulus identity (ID), with standard errors of the mean in parentheses, for Experiment 4. Only the same and 1-letter different trials were included in the analyses.

Response Code	Same Location		Different Location	
	Same ID	Different ID	Same ID	Different ID
Same				
RT	608 (32)	1046 (59)	645 (32)	1107 (64)
% Error	20.5 (2.2)	16.1 (2.0)	27.9 (2.5)	12.7 (1.6)
Different				
RT	590 (33)	999 (62)	639 (40)	1020 (70)
% Error	18.0 (1.8)	19.1 (2.4)	27.5 (2.0)	13.9 (1.9)

Table D2

Results of ANOVAs of the reaction times and error rates in Experiment 4.

	Reaction Times			Error Rates		
	F (1, 38)	p	η_p^2	F (1, 38)	p	η_p^2
RCode	.36	.55	.01	.06	.81	.01
Location	14.79	.001	.28	8.32	.01	.18
Location*RCode	.42	.52	.01	.01	.94	.01
ID	232.71	.001	.86	11.96	.001	.24
ID*RCode	.98	.33	.03	.58	.45	.02
Location*ID	.02	.89	.01	63.48	.001	.63
Location*ID*RCode	1.77	.19	.04	1.49	.23	.04

RCode = ResponseCode

Table D3

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of stimulus location, response code, and stimulus type, with standard errors of the mean in parentheses, for Experiment 4.

Response Code	Same ID	1-Letter Different	2-Letter Different
		Same Location	
Same			
RT	609 (31)	994 (50)	1374 (90)
% Error	20.5 (2.2)	32.4 (1.9)	36.0 (3.7)
Different			
RT	590 (33)	958 (59)	1273 (107)
% Error	18.0 (1.8)	31.7 (1.6)	48.3 (3.3)
		Different Location	
Same			
RT	645 (32)	1031 (57)	1363 (56)
% Error	27.8 (2.5)	32.6 (1.7)	35.1 (3.8)
Different			
RT	639 (40)	997 (68)	1241 (81)
% Error	27.5 (2.0)	29.9 (1.1)	38.9 (3.6)

Appendix E

Table E1

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of stimulus location and stimulus shape, with standard errors of the mean in parentheses, for Experiments 5A and 5B.

	Same Location		Different Location	
	Same Shape	Different Shape	Same Shape	Different Shape
Experiment 5A				
RT	560 (30)	783 (54)	650 (35)	814 (59)
% Error	18.7 (1.6)	41.2 (3.3)	29.5 (2.7)	35.0 (2.9)
Experiment 5B				
RT	531 (40)	706 (51)	617 (44)	749 (62)
% Error	13.5 (2.6)	36.8 (3.8)	21.3 (3.2)	32.3 (3.6)

Table E2

Results of ANOVAs on the reaction times and error rates in Experiments 5A and 5B, with Experiment as a between-subjects factor, and location and stimulus shape as within-subjects factors.

	Reaction Times			Error Rates		
	F (1, 38)	p	η_p^2	F (1, 38)	p	η_p^2
Exp	.77	.39	.02	4.14	.05	.11
Location	28.82	.001	.46	5.52	.02	.14
Location*Exp	.03	.86	.01	.13	.72	.01
Shape	29.6	.001	.47	23.58	.001	.41
Shape*Exp	.38	.54	.01	.24	.63	.01
Location*Shape	7.58	.01	.18	59.89	.001	.64
Location*Shape*Exp	.16	.70	.01	1.53	.22	.04

Note: Exp = Experiment.

Table E3

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of stimulus location and stimulus shape, with standard errors of the mean in parentheses, for Experiments 5A and 5B.

	Same Shape	Differ in Font	Differ in Style
		Experiment 5A	
Same Location			
RT	560 (30)	774 (53)	796 (59)
% Error	18.7 (1.6)	52.5 (4.4)	54.6 (4.5)
Different Location			
RT	650 (35)	784 (74)	847 (63)
% Error	29.5 (2.7)	48.3 (3.9)	52.8 (4.4)
		Experiment 5B	
Same Location			
RT	531 (40)	760 (67)	698 (42)
% Error	13.5 (2.6)	48.8 (6.9)	51.6 (5.7)
Different Location			
RT	617 (44)	842 (133)	807 (80)
% Error	21.3 (3.2)	45.6 (6.5)	50.9 (6.1)

Table E4

Mean error rates (percentage incorrect) as a function of location, stimulus type and participant response in Experiment 5A (A) and Experiment 5B (B), with standard errors of the mean in the parentheses.

A

		Stimulus Type		
		Same Shape	Differ in Font	Differ in Style
			Same Location	
Response	Same Shape		37.4 (3.6)	43.3 (4.6)
	Differ in Font	9.3 (1.0)		10.3 (1.6)
	Differ in Style	10.0 (1.4)	13.8 (1.8)	
			Different Location	
Response	Same Shape		32.8 (3.0)	39.2 (4.4)
	Differ in Font	13.1 (1.7)		14.8 (1.8)
	Differ in Style	15.5 (1.6)	16.8 (1.9)	

B

		Stimulus Type		
		Same Shape	Differ in Font	Differ in Style
			Same Location	
Response	Same Shape		29.9 (4.1)	44.6 (5.7)
	Differ in Font	5.1 (1.3)		6.7 (1.4)
	Differ in Style	8.2 (2.3)	20.0 (4.7)	
			Different Location	
Response	Same Shape		24.0 (3.6)	40.0 (5.8)
	Differ in Font	9.3 (1.4)		11.1 (2.9)
	Differ in Style	12.6 (2.4)	20.9 (4.8)	

In Experiments 5A and 5B, the task is not to detect differences in letter identity, but to detect differences in font and style. For each of these experiments, we performed an ANOVA to test whether errors in reporting changes differed between Same and Different Location conditions. These ANOVAs are analogous to the analyses of localization errors reported in Appendices B and C. Because these analyses are focused specifically on reporting the type of difference after a difference has been detected, they include only trials in which there was some difference between the two strings, and they include only the rates at which partipants reported the incorrect type of difference. The factors in these 2 x 2 ANOVAs are Location and Error Type.

In Experiment 5A, there were generally more errors in reporting the type of stimulus difference when S1 and S2 were at different locations, $F(1, 17) = 8.67$, $MSE = .003$, $p = .009$, $\eta^2 = .34$. There were more font changes reported incorrectly as style changes than there were style changes reported as font changes, but the difference did not reach significance, $F(1, 17) = 1.96$, $MSE = .007$, $p = .18$, $\eta^2 = .10$. There was no interaction, $F(1, 17) = .94$, $MSE = .001$, $p = .34$, $\eta^2 = .05$.

In Experiment 5B, there were more “different” trials. In this case, the effect of Location just barely missed significance, $F(1, 17) = 4.32$, $MSE = .003$, $p = .053$, $\eta^2 = .20$, and there were significantly more font changes reported incorrectly than style changes, $F(1, 17) = 4.51$, $MSE = .05$, $p = .049$, $\eta^2 = .20$. As in Experiment 5A, there was no interaction, $F(1, 17) = 1.71$, $MSE = .003$, $p = .21$, $\eta^2 = .09$. Taken together, these analyses suggest that a change in location from S1 to S2 leads to generally more errors in reporting a change in the letters, just as it led to more errors in localizing the different letter in Experiment 2, 3, and 5.

Appendix F

Table F1

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of stimulus location and the 2nd letter identity for Experiments 6A and 6B. In Experiment 6A, the 1st and 3rd letters were always different. In Experiment 6B, the 1st and/or the 3rd letter differed on 1/6 of the trials. Standard errors of the mean are in the parentheses.

	Same Location		Different Location	
	Same Letter	Different Letter	Same Letter	Different Letter
Experiment 6A				
RT	604 (30)	645 (34)	610 (28)	648 (36)
% Error	35.1 (2.5)	18.3 (2.0)	36.8 (2.6)	15.0 (2.0)
Experiment 6B				
RT	513 (27)	581 (34)	546 (29)	600 (31)
% Error	17.2 (1.8)	27.1 (2.3)	24.9 (1.9)	19.7 (2.5)

Table F2

Results of ANOVAs on the reaction times and error rates as a function of stimulus location and stimulus shape in Experiments 6A and 6B.

	Reaction Times			Error Rates		
	F (1, 19)	p	η_p^2	F (1, 38)	p	η_p^2
			Experiment 6A			
Location	0.36	.56	.02	.82	.38	.04
Letter ID	6.07	.02	.24	28.04	.001	.60
Location*Letter ID	.01	.91	.01	4.66	.04	.20
			Experiment 6B			
Location	5.77	.03	.23	0.04	.84	.01
Letter ID	20.73	.001	.52	0.68	.42	.03
Location*Letter ID	.71	.41	.04	34.39	.001	.64

Appendix G

Table G1

Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of cue type, stimulus location, and stimulus identity (ID), with standard errors of the mean in parentheses, for Experiment 7.

Cue Type	Same Location		Different Location	
	Same ID	Different ID	Same ID	Different ID
Nocue				
RT	513 (38)	567 (42)	488 (35)	558 (50)
% Error	17.8 (2.5)	29.6 (3.6)	20.9 (2.3)	19.7 (3.3)
Valid				
RT	495 (37)	527 (33)	450 (40)	528 (40)
% Error	13.4 (3.9)	25.4 (4.5)	15.7 (3.2)	20.6 (4.0)
Invalid				
RT	513 (35)	570 (31)	506 (37)	561 (47)
% Error	15.4 (2.9)	29.4 (4.0)	19.2 (3.0)	22.7(3.6)

Table G2

Results of ANOVAs of the reaction times and error rates in Experiment 7.

	Reaction Times			Error Rates		
	F (1, 38)	p	η_p^2	F (1, 38)	p	η_p^2
Cue	2.32	.11	.11	2.44	.10	.11
Location	2.38	.14	.11	7.54	.01	.28
ID	8.82	.01	.32	7.19	.01	.27
Cue*Location	.35	.71	.02	1.64	.21	.08
Cue*ID	.04	.96	.01	1.44	.25	.07
Location*ID	.78	.39	.04	29.87	.001	.61
Cue*Location*ID	.81	.45	.04	1.62	.21	.08

Cue = CueType

Author Note

Thanks to Julie Golomb and to an anonymous reviewer for insightful comments on this manuscript.

The code for the computer programs controlling these experiments and the data collected in each experiment are available on request from the second author at zhe.chen@canterbury.ac.nz.