Two kinds of bias in visual comparison illustrate the role of location and holistic/analytic processing differences

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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.

Keywords Visual perception · Attention · Spatial congruency bias · Holistic/analytic processing

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 two-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

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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 Lamy & 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 simultaneously 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 analytic/holistic distinction is similar to a distinction between identity search and similarity 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 one and four cells in a 4×4 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 analytic/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 C. W. Eriksen and St. James’s (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 nonspeeded two-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., Finlayson & Golomb, 2016; Golomb et al., 2014, Experiments 1 and 2), 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 two 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 three 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 could 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 × 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 Fig. 1). The fixation was a cross that subtended 0.48°. Both S1 and S2 consisted of three heterogeneous, uppercase letters. The letters were written in bold, 40-point Courier New font, and the letter set subtended 4.01° in width and 0.76° 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 first, second, or third letter (the different-ID trials). S1 and S2 could occur at one of four locations centered at 3.63° left or right of fixation, or 3.63° 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 four 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 three locations not occupied by S1 on a given trial.

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

Design and procedure Both experiments used a 2 × 2 within-subjects design, with location (same location vs. different

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 two groups of participants (see note 4 for detail), and this resulted in the use of 40 participants in total.

Fig. 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 one 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

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 second fixation would appear for 1,000 ms, followed by S2, again with varied duration. After another 17-ms blank screen, the second 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 labeled

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 four 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 modeled 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 an “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):

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

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

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.

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 an “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

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 Fig. 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 A, Table 9, with the statistical analyses in Table 10. To measure the effect of location on bias in Experiments 1a and 1b, we conducted a 2×2 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.

Fig. 2 Response bias 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

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 2×2 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 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 three 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 one-task session that required one response on each trial, and a two-task session that required two responses on some trials. Each session consisted of three blocks of 96 trials, and the order of the two sessions was counterbalanced among the participants. Thus, the experiment used a $2 \times 2 \times 2 \times 2$ design, with task type (one-task vs. two-task), location (same vs. different) and ID (same ID vs. different ID) as within-subjects factors, and session order (one-task first vs. two-task first) as a between-subjects factor. Second, in the two-task 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 one of three 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 labeled) at the top of the keyboard to indicate that S1 and S2 differed in the first, second, or third 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 one-task session before the two-task 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 analyzed as before. Table 2 shows the mean proportions of “same” responses, and Fig. 3 shows the mean response biases. The RT and error rates data can be found in Appendix B, Table 11, with the statistical analyses in Table 12. The error rates for Task 2 are presented in Table 13, and Table 14 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-subjects factor showed no significant effects, the session-order data were collapsed in the analyses described below. As before, we conducted a 2×2 repeated-measures ANOVA on the response-bias data, this time with task type and location as the within-subjects factors. The main effect of task type was significant, $F(1, 32) = 7.30$, $MSE = .05$, $p = .01$, $\eta^2 = .19$, indicating a stronger same-bias (more “same” responses) in the two-task session ($-.14$) than in the one-task 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 response bias between the same-location trials ($-.19$) and the different-location trials ($.02$). Task type and location did not interact, $F(1, 32) < 1$. One-sample t tests further showed that the bias in both the one-task and two-task 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 one-task trials; and $t(32) = 4.65$, $p = .001$, $d = .81$, for two-task trials. No significant biases were found when S1 and S2 appeared at different

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)
One task	.84 (.02)	.23 (.02)	.76 (.02)	.20 (.02)
Two task	.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 an “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

³ Of the 248 participants who took part in the experiments reported here, 10 of them (4.0%) took part in two experiments, and the rest in only one experiment. There were two repeated participants in Experiment 2, three in Experiment 3b, one in Experiment 5b, one in Experiment 6b, and three in Experiment 7.

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

locations in one-task trials, $t(32) = 1.49$, $p = .15$, $d = .26$; or in two-task trials, $t(32) < 1$.

An ANOVA on the d' data revealed both a significant main effect of task type, $F(1, 32) = 16.07$, $MSE = .10$, $p = .001$, $\eta^2 = .33$, 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 two-task session (2.00) than in the one-task 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 two-task than in the one-task session, an indication of greater sensitivity to the target stimuli, suggests that the participants paid more attention to the letter sets in the two-task 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 one-task session demonstrated the same location bias, which was expected, given the similarity of the task to Experiments 1a and 1b. However, the two-task 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 two-task session because this response would save

them from going through the effort of making the second 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 two-task session.

One factor to consider in interpreting these results is the temporal order of the responses: The letter-of-difference task in the two-task session was the second 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 first 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 two-task 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 second response, as in Experiment 2, in Experiments 3a and 3b we used a four-alternative forced-choice (4AFC) task and required the participants to locate the letter of difference, if there was any, in the first and only response. The task was to judge whether S1 and S2 were the same, or differed in the first letter, the second letter, or the third letter. S1 and S2 were different on 50% of the trials in Experiment 3a but on 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 four 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 first letter, the second letter, or the third letter by pressing the 7, 8, 9, or 0 key at the top of the keyboard (all labeled), respectively. The experiment consisted of 384 trials divided into four 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 first, second, or third 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 three 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: 18 participated in Experiment 3a and 20 participated in Experiment 3b.

Results

To compare the results of Experiments 3a and 3b with those of previous experiments, we collapsed the three types of different-ID trials into a single type of trial, and the three 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 first, second, or third letter position, the trial was treated as a different-ID trial. Moreover, so long as the participants pressed one of the three 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 Fig. 4 shows the mean response biases. The RT and error rates data are in Appendix C, Table 15, and the statistical analyses are in Table 16. Table 17 shows the RT and error rates for the same-ID trials and each of the three types of different-ID trials. Table 18 further shows the error rates as a function of participant response in addition to location and stimulus type. A 2×2 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 $F(1, 36) = 28.97$, $MSE = .02$, $p = .001$, $\eta^2 = .45$,

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 an “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.

Fig. 4 Response bias as a function of stimulus location in Experiments 3a and 3b. Error bars show ± 1 standard error of the mean

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, $F(1, 36) < 1$, ns , 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 2×2 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 first response being a “same/different” response and the second, if relevant, a “Which letter” response. 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 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 one letter, in Experiment 4, S1 and S2 could differ in either one letter or two letters. The two-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 three-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 one-letter same, two-letter same, and three-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 two-letter different, one-letter

different, and zero-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 two letters, was added, comprising 12.5% of the total trials. The remaining trials were divided equally into the same-ID trials and the one-letter-different trials. As before, when S1 and S2 differed in one letter, there was equal probability that the difference occurred in the first, second, or third letter position. Similarly, when S1 and S2 differed in two letters, there was an equal chance for any two 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 three letters, in two letters, or in one letter, and the three keys were labeled 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 zero letters, in one letter, or in two letters, and the three keys were labeled 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 $2 \times 2 \times 2$ mixed design, with response code (same vs. different) as the between-subjects variable, and location and ID as the within-subjects manipulation.⁴

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 was adjusted when accuracy was outside the range of 70%–75%; and exposure time was 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.

Results

The results from the two-letter different filler trials were not analyzed. 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 one 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 Fig. 5 shows the mean response biases. The RT and error rates data are in Appendix D, Table 19, with the statistical analyses in Table 20. Table 21 shows the RT and error rates for the two-letter different trials in addition to the same and one-letter different trials. A 2×2 mixed ANOVA on the response-bias data, with response code 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 response code, $F(1, 38) < 1$, ns , nor its interaction with location, $F(1, 38) = 1.26$, $MSE = .02$, $p = .27$, $\eta^2 = .03$, was significant.

A 2×2 mixed ANOVA on the d' data found a significant main effect of location, $F(1, 38) = 4.18$, $MSE = .06$, $p = .05$, $\eta^2 = .10$, indicating a larger d' in the same-location condition (1.91) than in the different-location condition (1.80). No other effects were found for response code or its interaction with location, $F(1, 38) < 1$, in both cases.

Discussion

The approach to encouraging analytical processing in Experiment 4 was somewhat different than in Experiments 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

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 an “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

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

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—that is, the type of processing varied systematically with the number of responses, with holistic processing associated with two responses (Experiments 1a, 1b, and 2) and analytical processing with three or four 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 three “different” response choices but one “same” response choice, if participants were randomly choosing one of the four 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 2×3 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 one of three labeled 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 two types of different trials into a single type, and the two 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 Fig. 6 shows the mean response biases. The RTs and error rates are in Appendix E, Table 22, and the statistical analyses are in Table 23. Table 24 shows the RT and error rates for each of the three types of trials, and Table 25 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 2×2 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, $F(1, 34) < 1$, ns , for both experiment and the location $\times$ 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 2×2 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 $\times$ 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

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 an “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

Fig. 6 Response bias as a function of stimulus location in Experiments 5a and 5b. Error bars show ± 1 standard error of the mean

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 three or four 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.

Method

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 second letter of each string. Trials with matching and with mismatching second letters were equally likely, and the participants used their right hand to pressed the 4 key when S1 and S2 had the same second letter (the same trials), and the 5 key when they had different second 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 second letter in S1 and S2 were the same, while the first and third 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 first and/or third letter differed between S1 and S2 on one sixth of the trials. On the rest of the trials, the first and the third 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 one 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 Fig. 7 shows the mean response biases. The RTs and error rates are in Appendix F, Table 26, and the

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

Note. In Experiment 6a, the first and third letters were always different. In Experiment 6b, the first and/or the third letter differed on one sixth of the trials. A response is a “hit” when S1 and S2 had the same second letter and a correct “same” response was made. A response is an “FA” (false alarm) when S1 and S2 had different second letters but an incorrect “same” response was made. Standard errors of the mean are in the parentheses

Fig. 7 Response bias as a function of stimulus location in Experiments 6a and 6b. Error bars show ± 1 standard error of the mean

statistical analyses are in Table 27. 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 Fig. 7 shows the mean response biases. The RTs and error rates are in Appendix F, Table 26, and the statistical analyses are in Table 27. 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 first and third letters, and focal attention to the second 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 were very different from one another, and even though much or all of that difference was 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 first and third 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 two sessions: a no-cue 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 four target locations, Experiment 7 had only two target locations: 3.63° 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° in width and 2.87° in height, consisted of a white, horizontal rectangle centered 3.63° 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 two identical rectangles made of black diagonal lines (instead of four such rectangles as in the previous experiments). The spatial separation between the inner boundaries of the two rectangles was 2.29°. Twenty participants from the same population took part in the experiment. Half of them completed the no-cue 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 $3 \times 2 \times 2$ within-subjects design, with cue type (valid, invalid, or no cue), location, and ID as the principal manipulations. The entire experiment consisted of 672 trials, with 288 trials in the no-cue 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 Fig. 8 shows the mean response biases. The RTs and error rates are in Appendix G, Table 28, with statistical analyses in Table 29. A 3×2 repeated-measures ANOVA on the response-bias data, with cue type and location as the within-subjects factors was conducted. The main effect of cue type 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 no-cue (−.07) conditions. However, the bias was significantly larger in the valid condition than in the no-cue 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 three conditions: $t(19) = -3.42$, $p = .01$, $d = .76$, for the no-cue 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 no-cue 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 3×2 mixed ANOVA on the d' data. A significant main effect of cue type was found, $F(2, 38) = 5.83$, $MSE = .38$, $p = .01$, $\eta^2 = .23$. Subsequent Tukey’s HSD tests showed a larger d' on the valid trials (2.17) than on both the invalid (1.80) and no-cue trials (1.73), with no difference

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)
No cue	.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 an “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

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

between the latter two. Neither the main effect of location, $F(1, 19) = 2.17$, $MSE = .15$, $p = .16$, $\eta^2 = .10$, nor location $\times$ cue type 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 three 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

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 experiment

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

Note. 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

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 visual 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 event-related potentials (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 attentional 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 & Eriksen, 1974; C. W. 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.

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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

Appendix A

Table 9 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 second 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 10 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

Table 10 (continued)

	Reaction times			Error rates		
	$F(1, 38)$	p	η_p^2	$F(1, 38)$	p	η_p^2
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 11 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
One task				
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)
Two task				
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 12 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 = task type

Table 13 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

	First letter different	Second letter different	Third 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 14 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		
		First letter different	Second letter different	Third letter different
Response Same location				
First letter different			5.1 (0.9)	3.4 (1.3)
Second letter different	3.3 (0.7)			6.7 (1.4)
Third letter 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)	
Response Different location				
First letter different		6.4 (1.3)	5.3 (0.9)	5.2 (0.7)
Second letter different	3.5 (0.7)		9.5 (1.5)	6.4 (0.8)
Third letter 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 2×6 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 14 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 15 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 16 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 17 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	First letter different	Second letter different	Third 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 18 Mean error rates (percentage incorrect) as a function of location, stimulus type and participant response in Experiment 3a and Experiment 3b, with standard errors of the mean in the parentheses

		Stimulus type			
		Same ID	First letter different	Second letter different	Third letter different
Experiment 3a					
Response	Same location				
	Same ID		10.2 (1.9)	23.8 (2.4)	15.1 (2.6)
	First letter different	5.7 (1.3)		8.2 (1.8)	4.0 (1.1)
	Second letter different	9.0 (1.2)	4.6 (1.3)		11.1 (1.5)
	Third letter different	6.4 (1.6)	2.3 (0.9)	9.0 (1.8)	
Response	Different location				
	Same ID		8.5 (1.7)	20.2 (3.0)	14.8 (2.5)
	First letter different	7.5 (1.4)		9.6 (1.7)	7.9 (1.6)
	Second letter different	13.1 (1.6)	5.1 (1.7)		12.0 (1.8)
	Third letter different	8.2 (1.4)	3.2 (1.4)	9.7 (1.4)	
Experiment 3b					
Response	Same location				
	Same ID		5.8 (1.0)	22.4 (2.4)	11.8 (2.3)
	First letter different	6.7 (1.1)		17.1 (5.9)	17.4 (6.9)
	Second letter different	7.4 (1.0)	5.1 (3.6)		10.4 (1.3)
	Third letter different	4.9 (1.0)	0.7 (0.5)	6.0 (0.8)	
Response	Different location				
	Same ID		5.5 (1.0)	19.8 (2.3)	9.7 (1.9)
	First letter different	8.3 (1.0)		20.8 (6.2)	18.3 (6.8)
	Second letter different	8.6 (1.3)	7.3 (3.6)		9.9 (1.8)
	Third letter 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 2×6 ANOVAs were conducted for Experiment 3a and Experiment 3b, with location and error type as factors. In Experiments 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 18, Experiment 3a, suggest that once again participants were likely to confuse Locations 2 and 3, and that in this case, a letter change at location 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 18, Experiment 3b, 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 19 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 one-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 20 Results of ANOVAs of the reaction times and error rates in Experiment 4

	Reaction times			Error rates		
	<i>F</i> (1, 38)	<i>p</i>	η_p^2	<i>F</i> (1, 38)	<i>p</i>	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

Note. RCode = response code

Table 21 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	One-letter different	Two-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 22 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 23 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		
	<i>F</i> (1, 34)	<i>p</i>	η_p^2	<i>F</i> (1, 34)	<i>p</i>	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 24 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 25 Mean error rates (percentage incorrect) as a function of location, stimulus type and participant response in Experiment 5a and Experiment 5b, with standard errors of the mean in the parentheses

		Stimulus type		
		Same shape	Differ in font	Differ in style
Experiment 5a				
Response	Same location			
	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)	
Response	Different location			
	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)	
Experiment 5b				
Response	Same location			
	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)	
Response	Different location			
	Same shape		24.0 (3.6)	40.0 (5.8)
	Differ in font	9.3 (1.4)		11.1 (2.3)
	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 participants reported the incorrect type of difference. The factors in these 2×2 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 Experiments 2, 3, and 5

Appendix F

Table 26 Means of median reaction times (in milliseconds) and error rates (percentage incorrect) as a function of stimulus location and the second letter identity for Experiments 6a and 6b

		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)

Note. In Experiment 6a, the first and third letters were always different. In Experiment 6b, the first and/or the third letter differed on one sixth of the trials. Standard errors of the mean are in the parentheses

Table 27 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	$F(1, 19)$	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 28 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
No cue				
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 29 Results of ANOVAs of the reaction times and error rates in Experiment 7

	Reaction times			Error rates		
	<i>F</i>	<i>p</i>	η_p^2	<i>F</i>	<i>p</i>	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

Note. Cue = cue type

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