Visual letter matching: Hemispheric functioning or scanning biases?

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Abstract

Finding two mixed-case letters that share the same name is easier to do when the letters are presented in opposite visual fields than when they are both in the same field. By contrast, finding a match between two same-case letters is easier when they are in the same field. These visual field effects have been attributed to the ability of the corpus callosum to coordinate the work of the cerebral hemispheres [Banich, M. T. (1998). The missing link: The role of interhemispheric interaction in attentional processing. *Brain and Cognition, 36*, 128–157; Weissman, D. H., & Banich, M. T. (2000). The cerebral hemispheres cooperate to perform complex but not simple tasks. *Neuropsychology, 14*, 41–59]. The present study considers the alternative hypothesis that attentional scanning biases may be at work. Experiment 1 examined the effects of explicit instructions to scan items in a specific order; Experiment 2 examined influences of implicit location biasing; Experiment 3 considered the possibility that same-case letter matching is different because a perceptual grouping mechanism can be used in that task. In each experiment, we first interpreted the results within the hemispheric framework before considering the alternative accounts. We concluded that two scanning biases may be in effect: (1) an automatic bias favoring items in locations relatively distant from the current focus of attention and (2) a learned bias to scan letters in a left-to-right direction.
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Fig. 1 shows displays from a letter-matching task that has been used to study human cognition since the 1960s (Posner, Boies, Eichelman, & Taylor, 1969; Posner & Mitchell, 1967). The task is to make a speeded response indicating whether the letter appearing below the fixation marker on one side (the *target*) shares the same identity as one of the two letters that appear above and to either side of the fixation marker (the *probes*). Three robust findings from this task have been the focus of interest in recent studies. First, when the target and probe letters are in mixed case, so that their identity is based on an abstract letter code, matching is most efficient when each of them appears on opposite sides of fixation. This is called an *opposite side advantage*. Second, when the probe and target letters are in same case, so that they can be matched by visual form alone, the opposite side advantage disappears, sometimes even giving rise to a small *same side advantage*. A third outcome of this task is that performance is more efficient when the matching probe appears in the left visual field. This

left field advantage is observed more reliably for mixed case than for same-case letter-matching (e.g., Banich & Belger, 1990; Belger & Banich, 1992; Weissman & Banich, 2000).

There are, at present, two distinctly different ways in which these display side and visual field effects of letter-matching tasks can be interpreted. On the one hand, they may be indexes of hemispheric functioning, with field advantages pointing to the hemisphere most efficient at performing the task at hand, and side advantages indexing the relative costs and benefits of sharing information between the hemispheres (Banich, 1998). Alternatively, these biases might represent general biases in visual selective attention. We begin by considering each of these views in turn.

1. Opposite side and left field benefits as indices of hemispheric functioning?

The side effects in letter matching have been interpreted as indices of the dynamic interactions between the cerebral hemispheres (Banich, 1998). In brief, it is claimed that each

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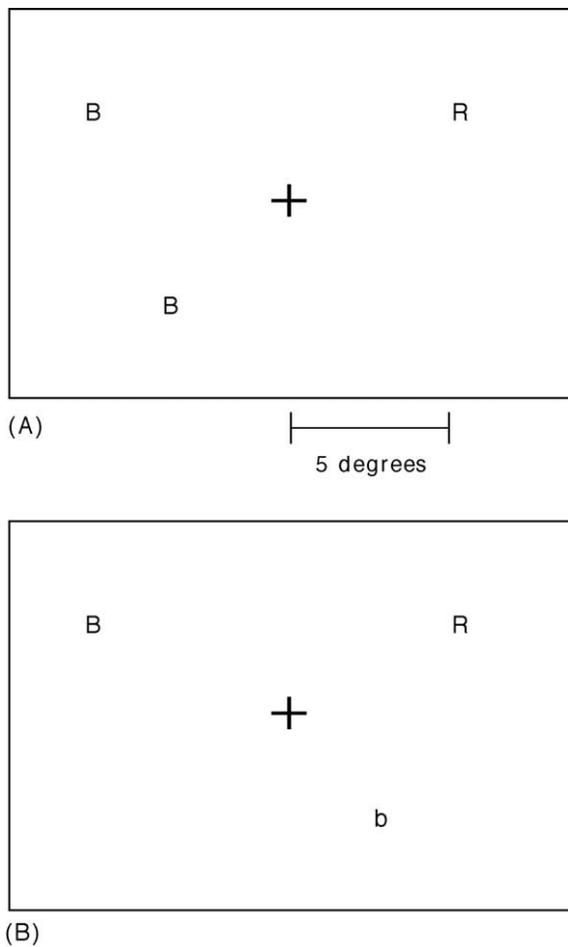*E-mail address:* j.fecteau@ioi.knaw.nl (J.H. Fecteau).

Fig. 1. The letter-matching task. (A) An example of same-case letter matching, with the matching letters in the same field (target b on the left; Probe B on the left). (B) An example of mixed-case letter matching, with the matching letters on opposite sides (target b on the right; probe B on the left).

hemisphere processes the information that it receives directly, if possible (Banich, 1998). This duplication of resources, along with the ability of the two hemispheres to work in parallel, effectively doubles the total amount of information that can be processed by the brain at one time (Banich, 1998).

Such parallel processing confers an advantage in overall task efficiency, which is evidenced in the opposite side advantage for mixed-case letters (Banich, 1998; Banich & Belger, 1990; Brown & Jeeves, 1993; Davis & Schmidt, 1973; Weissman & Banich, 2000). It also predicts that in the rare circumstance where only one hemisphere is able to perform the identification task (e.g., rhyming), there will not be an opposite side advantage because processing cannot be distributed across the hemispheres (Belger & Banich, 1998). Furthermore, it predicts the absence of an opposite side advantage for the matching of same-case letters, on the grounds that this matching can be done very simply by a direct comparison of visual features. In this case, the cost of integrating the processes of the two cerebral hemispheres outweighs the benefits of independent parallel processing (Banich & Belger, 1990; Belger & Banich, 1992; Weissman & Banich, 2000).

2000). Finally, from this perspective, the left field advantage in mixed-case letter matching reflects a general advantage for the right hemisphere that is independent of the manner in which the hemispheres interact (Banich, 1998).

These interpretations have exciting implications for how parallel processes are managed between the hemispheres, with the corpus callosum being proposed as the "missing link" in discussions of the neural mechanisms of selective attention (Banich, 1998). This theory has garnered significant support in recent years, as it generalizes across modalities (Passarotti, Banich, Sood, &Wang, 2002), it indexes changes in hemispheric recruitment with age (Reuter-Lorenz, Stanczak, & Miller, 1999), and its neural underpinnings have been established in fMRI (Pollmann, Zaidel, & von Cramon, 2003). Indeed, understanding the interactions between the cerebral hemispheres has been proposed to be one of the most important scientific questions of the 21st century (Banich & Weissman, 2000; Hellige, 2000).

2. Do opposite side and left field benefits reflect general biases in visual attention?

But there are also good reasons to consider alternative interpretations of letter matching data. First, the proposed cerebral specialization—right hemisphere is more efficient at letter identification—runs counter to much other research showing that letter tasks are favored by the left hemisphere. Mixed-case letter matching by split-brain patients is favored in the right visual field and therefore the left hemisphere (Eviatar & Zaidel, 1994). Moreover, letter identification elicits a BOLD response in fMRI that is lateralized to left extrastriate areas in healthy observers (Flowers et al., 2004). One of the longest standing interpretations of the left field advantage is that it indexes a left-to-right bias in the direction that English readers scan bilateral letter displays (Heron, 1957). This interpretation is supported in tests of English-Hebrew readers, who produce a left field advantage when scanning English letter displays and a right field advantage when scanning Hebrew letter displays (Lubow, Tsal, Mirkin, & Mazliah, 1994). For all these reasons, the left field advantage may say more about attentional biases in scanning the display than hemispheric specialization.

Second, the proposed index of hemispheric sharing—an opposite side benefit in mixed-case letter matching—may also arise for reasons other than the proposed interactions between the hemispheres. For example, same-case letter matching sometimes produces an opposite side advantage when two rather than three letters are shown in the display (e.g., Brown & Jeeves, 1993; Coney, 1985; Davis & Schmidt, 1973; Ludwig, Jeeves, Norman, & DeWitt, 1993; but see Banich & Shenker, 1994). This finding is not easily attributed to hemispheric interactions because processing two letter displays requires fewer computational steps than processing three letter displays. Also, in mixed-case letter matching, the opposite side advantage grows smaller as the letters are moved closer

together and grows larger when they are moved farther apart (e.g., Coney, 1985; Schmitz-Gielsdorf, Willmes, Vondenhoff, & Hartje, 1988). Distance in itself should have little bearing on the capacity of the cerebral hemispheres process information in parallel, provided that the letters are more than 2° from fixation (Sugishita, Hamilton, Sakuma, & Hemmi, 1994).

Third, evidence for a general "distant location" advantage can be found in many visual tasks. For example, finding two letters that match in an array of distractor letters is most efficient when these letters are distant from one another (Bahcall & Kowler, 1999; Cutzu & Tsotsos, 2003). In visual search tasks that are combined with a secondary probe detection task, probe detection is best at the location of the target and is next best at locations most distant from the target (Cave & Zimmerman, 1997; Kim & Cave, 1999). When simultaneously viewing several rapid sequences of items, accuracy for the second of two targets is best when they appear in locations most distant from the first target (Kristjansson & Nakayama, 2002). In a predictive spatial cueing task, Vernier acuity is best at the cued location and at the location farthest from the cue (Kristjansson & Nakayama, 2002). Similarly, the so-called inhibition of return effect refers to the finding that a target is processed most efficiently at a location that is relatively distant from the recent spatial focus of attention (Bennett & Pratt, 2001; Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985; Pratt, Spalek, & Bradshaw, 1999). Many additional examples of such "distance advantages" can be found in the literature (e.g., Kröse & Julesz, 1989; Mounts, 2001a, 2001b; Skelton & Eriksen, 1976; Steinman, Steinman, & Lehmkuhle, 1995).

A common factor linking all these examples of distance effects is that two spatially separated objects compete for the observer's attention. We note that the letter-matching task shown in Fig. 1 can be interpreted in the same way. The observer must first determine the identity of the target letter and then decide whether one of two probe letters matches the target. If there were a bias favoring distant items, then one would expect the probe letter farthest from the target to be processed most efficiently. In this view, the distant location advantage would reflect a very general mutually inhibitory property of visual selection, such that selecting one item for processing imposes a suppressive annulus around it (Tsotsos, 1995). Neurophysiological evidence supports this claim. When monkeys perform a search task in which they must select the odd-colored item from a spatial array, all of the items are represented in parallel in the frontal eye fields. Over time, however, the neural activity evolves to favor the odd-colored item, with the others being differentially represented. Specifically, non-target items located nearer the target are suppressed more strongly than those located farther away (Schall & Hanes, 1993; Schall, Hanes, Thompson, & King, 1995; Schall, Sato, Thompson, Vaughn, & Juan, 2004).

It is therefore still an open question as to whether the opposite side advantage in mixed-case letter matching should be interpreted as evidence of hemispheric cooperation or as another instance of a more general distant location advantage.

Indeed, proponents of hemispheric cooperation may even see the distant location advantage as derivative of cooperation between the hemispheres. But two observations argue against such a strong interpretation. First, the advantage occurs for items placed within the same visual field (Bahcall & Kowler, 1999) and even when all the items are placed along the vertical meridian (Pan & Eriksen, 1993; Pratt et al., 1999). Second, tasks showing this effect do not require any explicit comparison between the selected targets (Cave & Zimmerman, 1997; Kim & Cave, 1999; Kristjansson & Nakayama, 2002).

3. Overview of study

We addressed the question of whether mixed-case letter matching is better viewed as an index of *hemispheric functioning* or *attentional selection* in three experiments. In Experiment 1, we gave participants explicit instructions on the order in which probe letters should be examined, in an effort to see whether these effects were subjected to strategic influence. The instructions were either consistent with a left field bias ("left first") or inconsistent with it ("right first"), and either consistent with an opposite side advantage ("opposite first") or inconsistent with it ("same first"). In Experiment 2, we varied the probability of targets appearing in various locations following a similar design, to see whether these effects were subject to implicit biases. It has been claimed that instructions and probability biases should not alter the left field and opposite side advantages associated with mixed-case letter matching because the biases represent fundamental properties of hemispheric functioning that are not a result of or influenced by spatial attention (Hardyck, Chiarello, Dronkers, & Simpson, 1985; Weissman & Banich, 2000). Instead, we found that both manipulations dramatically influenced the field and side advantages observed in the data.

Experiment 3 sought an explanation for why same-case letter matching produces a different pattern of results than mixed-case letter matching. The claim made by proponents of the hemispheric hypothesis is that same-case letter matching is computationally less complex. In this case, the cost of integrating the processes of the hemispheres outweighs the benefits of parallel processing (Banich, 1998). Instead, our analysis of this task suggested that same-case letter matching could be solved by a pattern matching strategy whereas mixed-case letter matching requires conversion from each letter shape to an abstract code. To test this interpretation, color variation was introduced to the letter displays, because shape matching is very sensitive to manipulations of perceptual grouping (Duncan & Humphreys, 1989; Snowden, 1998). Consistent with this account, color variation resulted in left field and opposite side advantages even for same-case letter matching, suggesting that it had disturbed the processes that can normally be used to match identical shapes.

Our conclusion from these three experiments is that the visual field and display side effects of mixed-case letter matching tasks are not unambiguous indices of hemispheric

functioning, at least not without invoking many provisos. The possibility that they reflect general biases of spatial selective attention cannot be ruled out.

4. Experiment 1: explicit instructions influence letter matching

An effective approach for studying the role of observer strategies is to compare performance under conditions of *explicit instruction* versus *no instruction*. For example, in the literature on attentional capture (Egeth & Yantis, 1997; Yantis & Egeth, 1999), this approach has helped to isolate the factors that capture attention independently of participant intent or goals (e.g., appearance of a new object or abrupt luminance transients, e.g., Jonides & Yantis, 1988; Rauschenberger, 2003; Yantis & Hillstrom, 1994; Yantis & Jonides, 1990) from those that capture attention only when the participant is 'set' to expect these features (e.g., color changes) (e.g., Caputo & Guerra, 1998; Folk, Remington, & Johnson, 1992; Folk, Remington, & Wright, 1993). A similar approach has been used effectively for covert spatial orienting (Jonides, 1981).

Here we adopted a similar approach to examine the influence of specific scanning instructions on the opposite side and left field advantages. Observers were given explicit instructions regarding the order in which the probe letters should be examined. In one comparison, these instructions were consistent with either a left field or a right field bias, with no regard for the side of the probe letter. In a second comparison, the instructions were consistent with either an opposite side or a same advantage, with no regard given to the field of the probe letter. In all cases, these instructional sets were compared with a *no instruction* condition. It is important to note that displays were presented for only 210 ms, to ensure that eye movements were not a contributing factor (Munoz et al., 1998). This meant that any instructional influence reflected a bias in the order in which letters were examined in the mental trace of the display, not in the order of eye movements made to various physical locations.

A comparison between biases that were either consistent or inconsistent with the standard pattern of results was intended to reveal the extent to which strategies can influence the results. The claim made by proponents of the hemispheric hypothesis is that these effects are not susceptible to manipulations of intentional strategy (Hardyck et al., 1985; Weissman & Banich, 2000). This prediction has been supported by previous failures to influence these effects with manipulations of spatial attention (Copeland & Zaidel, 1996; Hardyck et al., 1985). However, in these studies, attention was directed only to a single location, whereas the letter-matching task under consideration requires examination of at least two locations, the target and at least one probe letter.

Finally, if the opposite side and left field advantages typically seen in letter matching originate from scanning strategies, then the outcome of the *inconsistent instruction* conditions can also be predicted on the basis of the existing literature. The left field advantage should be changed into a right field advantage under 'attend right' instructions, because others have reported a full reversal of the left field advantage when the stimuli presented in the display encourage a right-to-left scanning pattern (Lubow et al., 1994). Things are not quite as clear for the 'attend same side' instructions. For example, the attempt to alter the inhibition of return with probability biasing weakens and sometimes even reverses the effect (Fecteau, Bell, & Munoz, 2004; Lum, Enns & Pratt, 2002; Mounts, 2000a, 2000b; Wright & Richards, 2000). Any weakening of the opposite side advantage in letter matching would speak against a strong hemispheric hypothesis; a complete reversal would rule it out entirely.

Note that in this experiment (and in Experiment 2) we tested only mixed-case letter matching, delaying a consideration of same-case letter matching to Experiment 3. There were three reasons for this focus. First, historically it has been the presence of an opposite side advantage in this task that has been used as the index of hemispheric interactions (e.g., Berger, Perrett, & Zimmermann 1988; Coney, 1985; Davis & Schmidt, 1973; Dimond & Beaumont 1971; Liderman & Meehan, 1986).

Second, proponents of the hemispheric hypothesis themselves focus on this task, describing it as the best behavioral index of cooperative interactions between the cerebral hemispheres in visual tasks (Banich & Belger, 1990; Banich, 1998; Belger & Banich, 1998; Weissman & Banich, 2000). Recent behavioral and electrophysiological studies have also focused on this task independent of how the results compare with same-case letter matching tasks or other tasks of lesser complexity (Brown & Jeeves, 1993; Larson & Brown, 1997; Ludwig et al., 1993; Scalf et al., in press).

Third, it is practical to focus on this task because it is where the behavioral 'action' is. The effects are large and very robust. By contrast, the effects in same-case letter matching are invariably much smaller, either yielding a same side advantage or no effect that achieves statistical significance. The possibility of demonstrating that the opposite side advantage in mixed-case letter matching is influenced by instructions to participants would thus make a strong case that the hemispheric hypothesis should be reexamined.

4.1. Method

Seventy-two right-handed university students with normal or corrected-to-normal visual acuity participated for extra course credit. Their task was to examine the lower case target letter, which appeared below fixation in one field, and then to decide whether one of the two upper-case probe letters, presented one to each side above fixation, matched the target. A probe letter matched the target on a random 1/2 of the trials. Responses involved a key press, made with the index and middle fingers on one hand. The mapping of fingers to the match-no match responses, as well as the hand used to make responses, were counterbalanced across observers.

Participants were seated at a table, with their chins supported, so that their eyes were 57 cm from the display. On each trial, following a 500 ms period in which only a small fixation cross appeared at the center of the screen, three letters were displayed for 210 ms. The set of possible letters included upper and lower case letters (B, D, F, G, H, N, P, Q, R, T) printed in black 48-point Helvetica font ($1.5 \times 1.1°$ of visual angle) on a white background. Distances between letters are indicated in Fig. 1. Each observer was tested on 224 trials divided into 4 blocks of 56 trials, after practicing on a block of 56 trials in which responses were not recorded. The presentation of the stimuli and the collection of the responses were controlled by VScope (Enns & Rensink, 1992), running on MacIntosh computers.

In the *no instruction* condition, participants were told only to respond as quickly and as accurately as possible. In the *left first* condition, participants were also told to check the left probe letter before the right probe letter. Participants in the *right first* condition were told to examine the right probe letter first. In the *opposite first* condition, participants were told to check the probe letter on the opposite side of the target before checking on the same side. The *same first* instructions were to first compare the probe on the same side as the target.

Twenty-four participants were tested in each condition. Those in the neutral condition were tested in both mixed-case and same-case letter matching, although the same-case results are not reported (they replicated the expected absence of left field and opposite side advantages). Participants given biased instructions were each tested in two conditions in a counterbalanced order. Twelve were tested in *left first* followed by *right first*; 12 were tested in *right first* before *left first*. Twelve were tested in *opposite first* before *same first*; 12 were tested in *same first* before *opposite first*.

All the experiments in this study were conducted in accordance with the ethical standards of the American Psychological Association (4th ed.) and the Behavioral Research Ethics Board at the University of British Columbia.

4.1.1. Data analyses

Trials with a reaction time exceeding 2000 ms were eliminated from analysis in all experiments to be reported. These accounted for less than 1% of all trials in any experiment. Preliminary analyses indicated, as expected, that target mismatch trials yielded longer response times than did target matching trials, all p's < .05. Data from no target trials will not be described further because a matching letter needs to be present for the side and field advantages to be examined. Preliminary analyses also indicated that the counterbalancing factors had no influence on performance, all p's < .05

Mean correct response time (RT) and errors from the matching trials are shown in Table 1. These data were transformed into inverse efficiency scores, which is the mean correct reaction time divided by the correct mean proportion for each participant in each condition. These efficiency scores can be treated as reaction time that has been corrected for accuracy. They provide a succinct way of describing the coordi-

Table 1
Mean correct response time (ms) and mean proportion errors in Experiment 1: instructional bias conditions

Instruction condition	Field of display			
	Left		Right	
	Same	Opposite	Same	Opposite
Neutral				
RT	828	771	860	799
Errors	.114	.074	.170	.108
Left first				
RT	807	749	873	816
Errors	.106	.069	.194	.126
Right first				
RT	854	783	818	758
Errors	.154	.084	.148	.110
Opposite first				
RT	898	802	946	850
Errors	.115	.069	.143	.061
Same first				
RT	862	892	905	895
Errors	.088	.085	.120	.097

nated results when reaction time and error analyses yield similar findings, as they did in every experiment here (Townsend & Ashby, 1983).

Efficiency scores were analyzed in this experiment with a mixed-design analysis of variance (ANOVA) in which the factor of Instruction was between groups, and Letter Case (same, mixed), Side (same, opposite), and Field (left, right) were within participants. Simple effects were tested with separate ANOVAs or means comparisons.

4.2. Results

Efficiency scores for the five conditions are shown in Fig. 2. The *no instruction* condition replicated the typical pattern of data associated with mixed-case letter matching, namely a significant opposite side advantage, $F(1,23) = 41.1$, $p < .05$, and a left field advantage, $F(1,23) = 10.4$, $p < .05$.

Comparing the consistent with the inconsistent instructions indicated that instructions had a strong influence. For the participants given opposite first versus *same first* instructions, there was a Condition × Side interaction, $F(1,23) = 12.39$, $p < .05$. Simple effects revealed an opposite side advantage in the *opposite first* condition, $F(1,23) = 40.00$, $p < .01$, but no side advantage in the *same first* instructions, $F(1,23) < 1$. The left field advantage was also still significant in these instruction conditions, F's > 5.0, p's < .05. Importantly, there were no significant differences between the *no instruction* and the consistent *opposite first* condition, all F's < 3.62, all p's > .05.

In the case of *left first* versus *right first* instructions, there was a Condition × Side × Field interaction, $F(1,23) = 4.8$, $p < .05$, reflecting a significant left field advantage for the *left first* instructions, $F(1,23) = 12.96$, $p < .05$, and a right field advantage for the *right first* instructions, $F(1,23) = 8.5$, $p < .05$. Notably, the opposite side advantage was still signif-
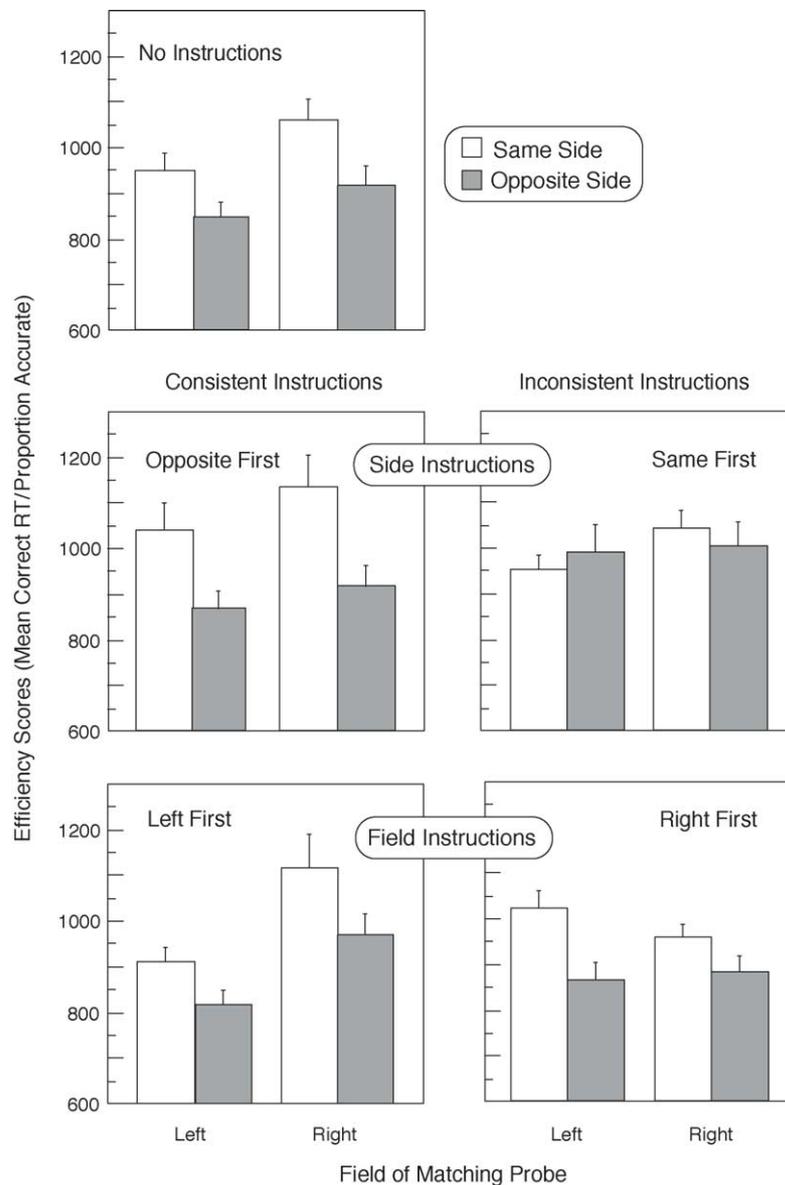
Fig. 2. Efficiency scores in Experiment 1: instructional bias conditions. Error bars are 1 S.E.

icant in the left first, $F(1,23) = 29.5$, $p < .05$ and in the *right first* instructions, $F(1,23) = 21.0$, $p < .05$. Again, there were no significant differences between the *no instruction* and the consistent *left first* condition, all F's < 2.4, all p's $> .1$. These analyses show that the standard opposite side and left field advantages in letter matching are influenced quite strongly by instructions to attend to the letters in a specific order.

An important final question was whether giving participant explicit instructions resulted in any measurable influences in performance. If the adoption of a cognitive strategy adds to the mental steps required to perform a task, then it should lead to increases in RT or errors. An examination of the correct RT indicated that overall, the side instruction conditions (look opposite and look same combined) took 59 ms longer than the *no instruction* condition (Table 1). However,

this was accompanied by an overall improvement in accuracy of 2%, indicating that participants in the instruction conditions were both slower and more accurate. It is these tradeoffs in speed for accuracy that the efficiency scores are designed to correct. When efficiency scores were examined by ANOVA, the difference between conditions was 47 ms. This is a non-significant difference, $F < 1$, and one that is much smaller in magnitude than the effects of side and field (both averages well over 100 ms). An analysis of the statistical power of this null result indicated that the number of participants required to measure an effect of such small magnitude would be in several hundreds (Cohen, 1989). This means that if there is a real effect of instructions on performance, it will be small as not to be practically measurable as a between-participant factor in this paradigm.

4.3. Discussion

The strong claim made by proponents of the hemispheric functioning account, that instructions should not alter the left field and opposite side advantages for mixed-case letter matching (Hardyck et al., 1985; Weissman & Banich, 2000), was clearly not supported by these findings. However, it is possible to interpret these findings within the context of that account, provided these strongest claims concerning cognitive impenetrability are relaxed. For example, if we allow for the possibility that instructions have an influence over and above the effects of hemispheric specialization and coordination, then these findings can be interpreted to show that instructions are simply an additional factor. In the *no instruction* condition, the opposite side advantage was a little over 100 ms. When consistent instructions were added to the task the opposite side advantage increased to over 200 ms and when inconsistent instructions were added it shrank to 0 ms. Thus, it could be argued that scanning instruction added or subtracted a constant of 100 ms to the opposite side advantage that would otherwise be there.

However, it is also not clear that a hemispheric functioning account is even needed to account for these data. The left field advantage is easily explained by a left-to-right scanning bias, as attested to by the fact that changing the instructions to a right-to-left scanning bias reversed the results for that factor. The opposite side advantage can be understood as the reflection of a distant location effect, one that can be strongly influenced by instructions to scan either the nearest or the farthest target letter first. In this case, however, the opposite side advantage cannot be reversed by these instructions to produce a same side advantage; same-side first instructions are only sufficient to overcome the distant location advantage that is otherwise there by default. This is consistent with the distant location advantage being caused by a general bias to inhibit the processing of items that are near-neighbors of an initial target.

The point that instructions may be an additional factor to those of hemispheric functioning is questioned from this perspective because instructions had no measurable influence on the efficiency scores. That is, if the underlying effects are due to hemispheric functioning, and cognitive strategies have an additional influence, then one would expect these additional influences to result in measurable increases in overall RT or errors, simply because additional mental processes are required. The fact that there were no such increases raises doubts about the hemispheric interpretation of these results.

5. Experiment 2: location probability influences letter matching

In Experiment 2 we tested whether similar results could be obtained with an implicit biasing manipulation. Previous studies have reported that observers are very sensitive to spatial probabilities of visual items (Bowman, Brown, Kertzman, Schwarz, & Robinson, 1993; Wright & Richards, 2000), even when they are not aware of them (Geng & Behrmann, 2002). Such biases permit items in the probable locations to be processed more rapidly and accurately than items presented elsewhere. We varied the probability of the matching probe location in four conditions, following the design of Experiment 1.

5.1. Method

The same methods were employed here as in Experiment 1, with the following exceptions. Forty-five observers participated, after being assigned to one of the four different instruction conditions. Unlike Experiment 1, separate groups of participants were tested in each of the biasing conditions to guard against possible carry-over effects from one implicit biasing condition to the next. Participants were given no instructions about the probability of target locations.

The biasing manipulation involved having the matching probe letter appear in a designated location on 75% of the target present trials. For the 12 participants in the *left bias* condition, the matching probe appeared in the left field 75% and in the right field 25% of the time. For the 11 participants in the *right bias* condition, these probabilities were reversed. The 12 participants in the *opposite bias* condition received the matching probe to the opposite side of the target on 75% and on the same side 25% of the time. The 10 participants in the *same bias* condition had these probabilities reversed. The percentage of target present trials was increased in this experiment from 50% to 66%, because of the reduced number of trials overall in the 25% target conditions. Participants were tested on a total of 772 trials in each condition, divided into 6 blocks of 112 trials. A block of 56 trials was given as practice. The data from one participant in the opposite bias condition were removed because of poor performance in one condition.

5.2. Results

Table 2 shows the mean correct RT and errors in Experiment 2, and efficiency scores are shown in Fig. 3. Analyses of the two consistent biasing conditions (opposite bias, left bias) indicated that they each elicited the expected advantages. For the opposite bias condition, the opposite side and left field advantages were significant, F's$(1,10) > 7.5, p < .05$, and for left bias condition, the left field and the opposite side advantages were significant, F's$(1,11) > 11.5, p$'s $< .05$. Overall there was a non-significant tendency for observers to respond more efficiently in the consistent biasing conditions compared to the *no instruction* condition of Experiment 1, $F(2,44) = 3.2, p > .05$), the tendency for a greater opposite side advantage in the bias condition, $F(1,33), p > .07$, and a greater left field advantage in the left bias condition, $F(1,34) = 4.4, p < .05$. This means that "consistent" implicit biasing of the target location produced a very similar, if not slightly ex-

Table 2
Mean correct response time (ms) and mean proportion errors in Experiment 2: location probability biases

Bias condition	Field of display			
	Left		Right	
	Same	Opposite	Same	Opposite
Left first				
RT	710	659	841	766
Errors	.070	.050	.134	.096
Right first				
RT	847	793	789	720
Errors	.082	.084	.057	.031
Opposite first				
RT	838	691	853	712
Errors	.112	.038	.107	.048
Same first				
RT	784	812	817	809
Errors	.037	.060	.047	.047

Data for the no-instruction condition are shown in Table 1.

aggerated, pattern of results to that typically reported when targets are likely to appear equally in all locations and that "inconsistent" implicit biasing either reversed these effects (left-right effects) or eliminated them (opposite same side effects). Notably, this occurred with no overall decrease in the overall task efficiency; if anything the trend was for an improvement in efficiency.

The second analysis compared the consistent and inconsistent biasing conditions. For the opposite versus same side bias, there was a Condition × Side interaction, $F(1,19) = 61.2$, $p < .05$, indicating that there was a significant opposite side advantage in the opposite bias condition, $F(1,11) = 59.8$, $p < .05$, and a same side advantage in the same bias condition, $F(1,9) = 6.3$, $p < .05$. There were no significant differences in the left versus right field biasing conditions, $F(1,19) < 1$. For the left versus right field biasing conditions, there was a Condition × Field interaction, $F(1,21) = 56.8$, $p < .01$. Simple effects showed that this was because of a left field advantage in the left bias condition, $F(1,11) = 52.0$, $p < .05$, and a right field advantage in the right bias condition, $F(1,10) = 13.7$, $p < .05$. These two conditions also showed significant opposite side advantages (left instructions, $F(1,11) = 11.5$, $p < .05$; right instructions, $F(1,10) = 7.8$, $p < .05$).

5.3. Discussion

These results show that implicit biasing of the target location influences the order in which letters are processed in the same way as explicit instructions did in Experiment 1. As such, they speak against the strong claim that hemispheric effects are encapsulated from cognitive or strategic influence (Hardyck et al., 1985; Weissman & Banich, 2000). Yet, in the same way as Experiment 1, these findings could be interpreted as showing that implicit biases again added
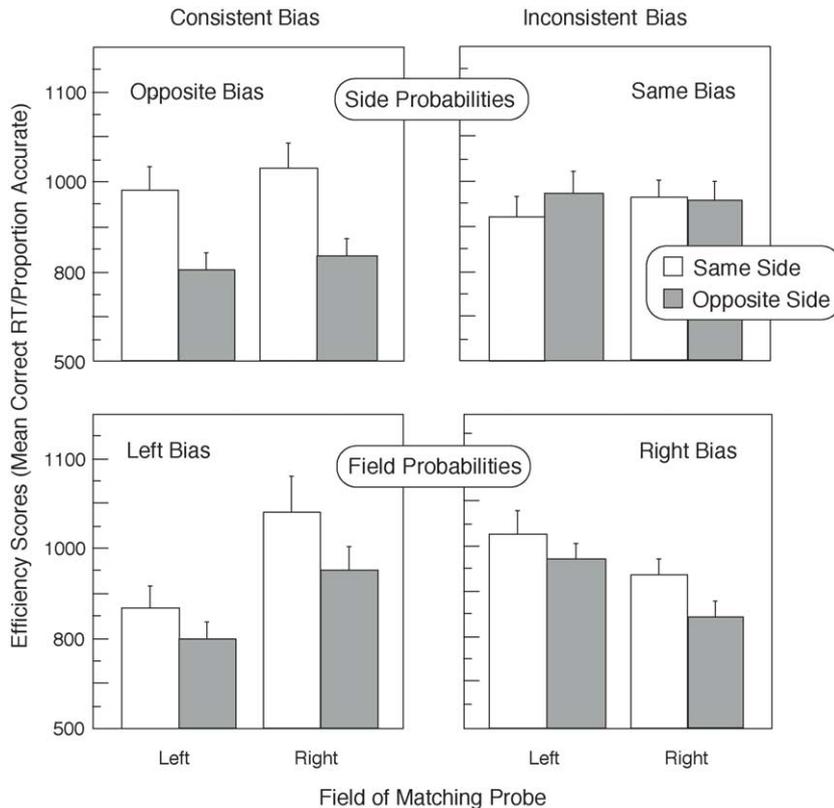

Fig. 3. Efficiency scores in Experiment 2: location probability biases. Error bars are 1S.E.

or subtracted a constant of approximately 100 ms to the opposite side advantage that would otherwise be there as a reflection of hemispheric functioning.

But, once again it is also not clear that a hemispheric functioning account is even needed to account for these data. As in Experiment 1, the finding that responding to these biases did not reveal any additional costs in mental processing time or errors undermines the notion of additive influences of hemispheric functioning and implicit biases.

6. Experiment 3: opposite side advantage for same-case letter matching

Experiments 1 and 2 showed that the left field and opposite side advantages are clearly under the influence of both explicit and implicit strategies of observers. Yet, these data involving the mixed-case letter matching task do not provide any insight as to why same-case letter matching produces a different pattern of results. One explanation that we have considered is that same-case letter matching is solved using a different strategy. Rather than individuating each letter and shifting attention across each item in turn, the observers base their decision on their detection of a perfect perceptual match in the display.

In the literature on spatial attention, color has often been used effectively to either promote the perceptual grouping of items (when the items to be grouped are in the same color) or to discourage perceptual grouping (when the items to be grouped are in different colors) (Bacon & Egeth, 1991; Duncan & Humphreys, 1989; Snowden, 1998). If the standard same-case letter matching results depended on uniform colored letters, then simply changing the color would modify the pattern of results so that it more closely matched the outcome of mixed-case letter matching.

More direct tests of this perceptual grouping hypothesis are possible with a focused comparison among the trials of the varied color condition of same-case letter matching. This hypothesis predicts that the negative effects of varied colors will be especially strong when the target and probe letters are different in color. By contrast, varied color displays should have the smallest influence when target and probe letters are of the same color because their shapes can be compared most directly.

6.1. Method

The methods were those in the *no instruction* condition of Experiment 1, with the following exceptions. Forty-eight right-handed university students with normal or corrected-to-normal visual acuity participated for extra course credit. Letters were drawn in black on a white background for 24 participants. For another 24 participants the letters were randomly white or black and appeared on a medium-gray background.

Efficiency scores were analyzed in this experiment with a mixed-design analysis of variance (ANOVA) in which the

factor of Color (uniform, varied) was between groups, and Letter Case (same, mixed), Side (same, opposite), and Field (left, right) were within participants.

For varied color displays, we conducted an additional analysis to determine whether the magnitude of the opposite side advantage changed when the target and matching probe were of the same color or of different colors. To gain enough power for this analysis, we added the three-item same-case and mixed-case letter matching data from an additional 29 participants who performed the same varied color task described here, except that the three-item displays were intermixed with nine-item displays.

6.2. Results

Tables 3 and 4 show the mean correct RT and errors; efficiency scores are shown in Fig. 4. The most important find-

Table 3

Mean correct response time (ms) and mean proportion errors in Experiment 3: uniform vs. varied color letters

Condition	Field of display			
	Left		Right	
	Same	Opposite	Same	Opposite
Uniform same-case				
RT	635	629	645	637
Errors	.037	.038	.042	.046
Varied same-case				
RT	636	616	683	653
Errors	.026	.029	.074	.042
Uniform mixed-case				
RT	803	732	834	767
Errors	.142	.125	.217	.116
Varied mixed-case				
RT	765	720	853	781
Errors	.108	.076	.203	.128

Table 4

Mean correct response time (ms) and mean proportion errors in Experiment 3: same vs. different color relations between target and probe letters

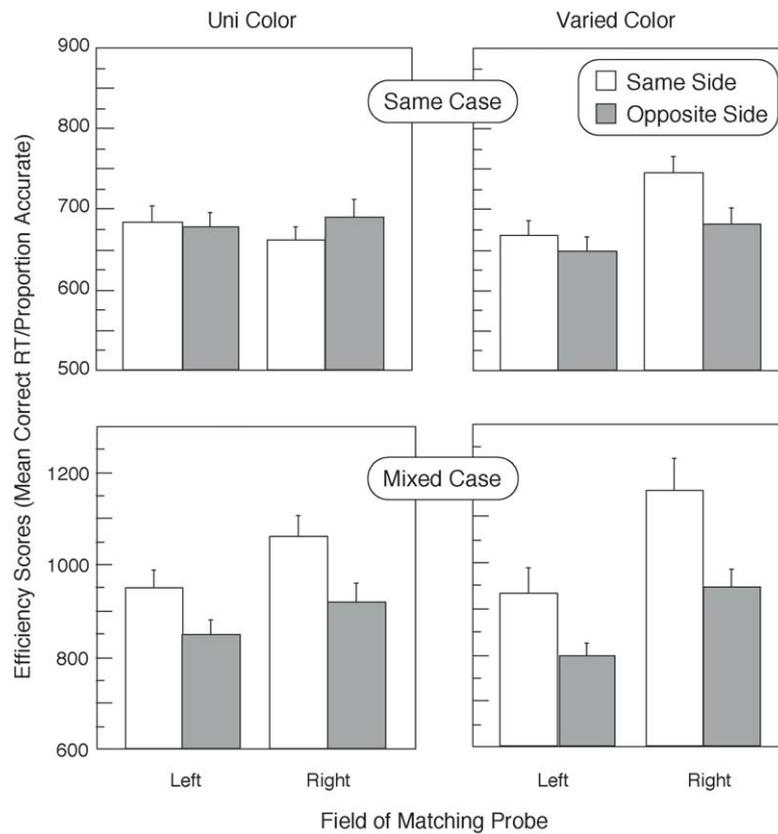| Condition | Field of display | | | |
	Left		Right	
	Same	Opposite	Same	Opposite
Uniform same-case				
RT	665	657	726	699
Errors	.024	.026	.077	.038
Varied same-case				
RT	696	652	761	700
Errors	.052	.030	.077	.061
Uniform mixed-case				
RT	791	781	916	813
Errors	.107	.085	.222	.123
Varied mixed-case				
RT	809	780	920	810
Errors	.110	.100	.217	.111

Fig. 4. Efficiency scores in Experiment 3: uniform vs. varied color letters. Error bars are 1S.E.

ings concerned the same-case letter condition shown in the top panel (the mixed-case results in the lower panel replicated those in previous experiments and are reported briefly below). There were no side or field effects of any kind in the uniform color condition, all F's < 1.0. However, in the varied color condition there was a significant opposite side advantage, $F(1,23) = 20.7$, $p < .05$, as well as a significant left field advantage, $F(1,23) = 7.0$, $p < .05$. In addition, the interaction of Side × Field was significant, $F(1,23) = 9.3$, $p < .05$, indicating that the opposite side advantage was obtained in the right field, $F(1,23) = 34.2$, $p < .05$, but not in the left, $F(1,23) = 2.4$, $p > .1$. This difference between uniform and varied color conditions in same-case letter matching was supported further by significant interactions of Color × Side, $F(1,46) = 10.3$, $p < .05$, Color × Field, $F(1,46) = 3.7$, $p < .07$, and Color × Side × Field, $F(1,46) = 7.1$, $p < .05$.

To determine whether the opposite side advantage was exaggerated when the target and matching probe appeared in different colors, the within-subject ANOVA factors included Side (same, opposite), Field (left, right), and Target-Probe Color Relationship (same, different). As shown in Fig. 5, the Side × Target-Probe Color Relationship was significant, $F(1,57) = 7.3$, $p < .05$, indicating that the opposite side advantage was larger when the target and matching probe were different colors than when they were of the same color. In addition, the main effect of color was also significant,

$F(1,57) = 9.7$, $p < .05$, indicating that performance was most efficient when the target and matching probe were presented in the same color overall.

The remaining results concerned the mixed-case conditions (lower panel Fig. 4), which generally replicated the results of previous experiments. There were both: a significant opposite side advantage, $F(1,46) = 42.3$, $p < .05$, and a left field advantage, $F(1,46) = 26.0$, $p < .05$. The one novel result
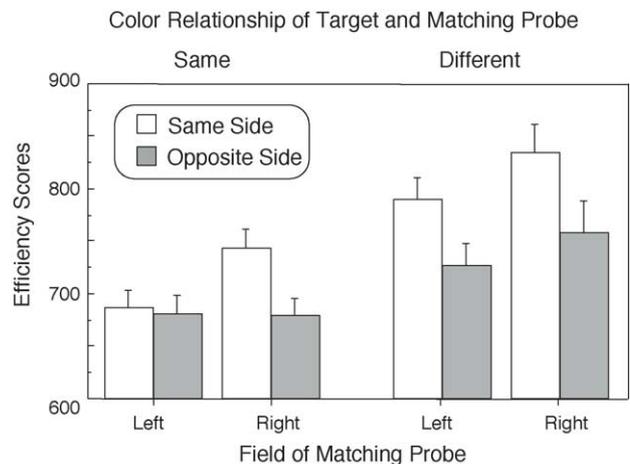

Fig. 5. Efficiency scores in Experiment 3: same vs. different color relationships between target and matching probe letters. Error bars are 1S.E.

was that the opposite side advantage did not vary significantly depending on whether the letters were uniform in color or varied (all F's < 2.7, p's $> .10$). This is consistent with our hypothesis that only same-case letter matching is performed via shape matching and therefore it alone will be influenced by perceptual grouping factors such a color variation.

An ANOVA including both same and mixed-case letters as a factor showed that the magnitude of the opposite side advantage was larger for mixed-case letter matching, $F(1, 23) = 33.8$, $p < .05$, than for same-case letter matching, $F(1, 23) = 10.8$, $p < .05$, when uniform and varied color conditions were combined. Similarly, the left field advantage was larger for mixed-case letter matching, $F(1, 23) = 13.2$, $p < .05$, than for same-case letter matching, $F(1, 23) = 4.9$, $p < .05$. Finally, the magnitude of the opposite side advantage was larger for the right visual field than the left visual field, even when only the varied color condition was considered, $F(1,23) = 4.3$, $p < .05$.

6.3. Discussion

The data from this experiment can again be interpreted in two ways. Consider first the hemispheric functioning account. If the same and opposite side advantages index the co-ordinated efforts of the cerebral hemispheres, then adding the irrelevant color dimension may tip the balance of complexity to favor cooperation. In support of this model, the magnitude of the opposite side advantage was larger for mixed-case letter matching than for same-case letter matching. Additional support for the hemispheric functioning account comes from the finding that the left field and opposite side advantages seen in the varied color same-case letter matching task (upper right panel of Fig. 4) were not as large as the same advantages obtained for mixed-case letter matching. This is consistent with each additional level of difficulty, tipping the scales in favor of hemispheric cooperation over independence.

However, two additional findings in this experiment lead us to question this interpretation. First, if adding an irrelevant color generally increases the complexity of letter matching, then it is unclear why this manipulation influenced same-case letter matching only. If both matching tasks are governed by the same considerations, then when same-case matching is influenced by an additional factor mixed-case letter matching should be too. The fact that these two tasks are influenced differentially by a factor that should increase task complexity for both of them (i.e., grouping by color) hints that they may be accomplished in different ways. However, it is also possible is that the effects of difficulty are non-linear, having larger influences under less complex conditions than more complex conditions. We cannot rule out this possibility and so raise this point as a suggestion for further study.

Second, there was a significant interaction between field and side. From the hemispheric functioning perspective, this means that there is more cooperation when the right hemisphere receives the target and the left hemisphere receives the probe than the opposite arrangement. Such a finding sug-

gests that field and side effects are not as independent as the hemispheric functioning account predicts. Interestingly, this interaction has been observed in other experiments in our lab (Fecteau & Enns, unpublished results) and has been reported previously in another study (Banich, Passarotti, & Janes, 2000). Its existence undermines the claim that hemispheric cooperation and specialization are separable components of the letter-matching paradigm.

The alternative explanation under consideration, based on scanning biases, suggests that same-case letter matching produces a different pattern of results than mixed-case letter matching under some conditions because participants are able to use a shape matching strategy when letters are identical in form and color. Disrupting this strategy by adding color variation causes participants to perform same-case and mixed-case letter matching in very similar ways that are well characterized by two scanning strategies: a left-to-right bias and a distant location advantage. Additional support for these differences in same-case and mixed-case letter matching comes from a recent fMRI experiment and is described in Section 7.

7. General discussion

Studies of mixed-case letter matching have consistently reported both an opposite side advantage (target and probe letters in different visual fields) and a left field advantage (benefit for targets presented to the right hemisphere). To date, these two findings have been interpreted most often within the theoretical framework of hemispheric interactions, where these ideas have been favorably accepted and have resulted in a valuable body of research concerning hemispheric coordination and specialization (Banich, 1998; Banich & Belger, 1990; Reuter-Lorenz et al., 1999). The present study considered the alternative possibility that these results might actually be better described as the outcome of more general biases of spatial selective attention.

We began by testing the influence of scanning strategies directly. In Experiment 1, participants were given either *no instructions* with regard to scanning order, or they were explicitly instructed to scan the letters in an order *consistent* with the left field advantage (left first) and the opposite side advantage (opposite first), or they were instructed to scan the letters in an order *inconsistent* with the left field advantage (right first) and the opposite side advantage (same first). The results showed that the expected patterns of data were obtained in the *no instruction* and *consistent instruction* conditions. There was a strong left field advantage and a strong opposite side advantage in each case. Importantly, the consistent instructions yielded results that were statistically indistinguishable from the neutral instructions. This implies that participants incurred no cognitive costs in attempting to follow the instructions of the experimenter.

By comparison, large differences were obtained between consistent and inconsistent instructions. Here the pattern of results either reversed completely (for visual field) or disap-

peared (for display side). It is important to note in interpreting this result that even the "inconsistent" instructions placed no undue burden on the participants. The overall level of performance as measured by RT and errors was very comparable in all conditions. Yet the pattern of means with regard to display side (same versus opposite) and visual field (left versus right) varied markedly as a function of instruction set. This is less consistent with a dual model that includes factors of both hemispheric functioning and scanning biases than it is with a model based solely on scanning biases.

This pattern of results was also observed in Experiment 2, in a situation in which participants were not explicitly instructed to use any particular strategies. Simply varying the probability of the probe letter location, so that it was usually either consistent or inconsistent with the typical pattern of results, had a large influence on performance. This suggests that participants are spontaneously scanning the letter arrays in a particular way when they are given the standard letter-matching task. One of their biases is to test for a matching probe letter on the opposite side of the display from the target letter; a second bias is to test for a matching letter on the left-hand side of the display before checking for a match on the right side. Again, if this were not so, then one would expect that taking the biases into account should increase RT or errors in the task. If anything, supporting these biases increased task efficiency.

In Experiment 3, we addressed the question of why same-case and mixed-case letter matching yield different results. On the face of it, one should expect to see the same spatial selection biases at work in both of these tasks. However, a clue from other studies of visual attention suggests that this task may be solved using perceptual grouping strategies (Duncan & Humphreys, 1989). Experiment 3 tested this hypothesis by comparing same-case letter matching for uniform and varied color displays. The results showed that varied color displays, which disrupted perceptual grouping, also produced a pattern of results that were very similar to those of mixed-case letter matching: both an opposite side advantage and a left field advantage were now in evidence. Moreover, this opposite side advantage was exaggerated when target and probe letters were in different colors and was reduced when they were of the same color, just as predicted by the perceptual grouping hypothesis. By contrast, the mixed-case letter matching was unaffected by color variation in the letters. This is consistent with same-case letter matching being accomplished by a simple shape comparison process. When this process is disrupted, the normal attentional biases of left-to-right scanning and distant target locations are again at work.

7.1. Theoretical implications

For several decades, visual field differences have been interpreted as evidence of hemispheric functioning. This is true for left-right field differences, which are interpreted as the benefit of processing information in one cerebral hemisphere over the other (e.g., Hellige, 1993; Kimura, 1964,

1966, 1973). It is also true for same-opposite side differences, which are interpreted as the relative costs or benefits of sharing information across the cerebral hemispheres (e.g., Banich, 1998; Dimond & Beaumont, 1971). These interpretations have made a valuable contribution, providing a simple way to reveal the specializations of the cerebral hemispheres on one hand and to reveal the collaborative efforts of the hemispheres on the other (reviewed in Banich, 1998; Hellige, 1993).

Although the hemisphere interaction hypothesis has had many adherents, interpreting field and side advantages in behavioral tasks has never been easy. Field advantages have been notoriously difficult to replicate (e.g., Sergent, 1983) and they sometimes yield results that are inconsistent with hemispheric functioning (e.g., Robertson & Lamb, 1988, 1989). A similar mixed story holds for side advantages.

Following the seminal work of Dimond and Beaumont in the early 1970s, who interpreted the opposite side advantage as evidence of the cooperative hemispheric interactions, there was much controversy surrounding its replicabilty (Beaumont & Dimond 1975; Berger, 1988; Berger & Landolt 1990; Berger & Perret 1986; Berger et al., 1988; Coney, 1985; Davis & Schmidt, 1973; Diamond & Beaumont, 1974; Diamond, Gibson, & Gazzaniga, 1972; Dimond and Beaumont, 1971, 1972; Jeeves & Lamb 1988; Leiber, 1982; Liderman, 1986; Liderman & Meehan 1986; Liderman, Merola, & Martinez, 1985; Miller, 1981; Norman, Jeeves, Milne, & Ludwig, 1992). In the early 1990s, Banich breathed new life into this field with the suggestion that task complexity determines whether the hemispheres work alone or together. In support of this idea, she used the three-item matching task to show that whereas the seemingly simpler task (same-case) led to a same side advantage, the more difficult task (mixed-case) resulted in an opposite side advantage. This has turned out to be a very productive idea, even though like any theory, it may not have accounted for all the relevant data (Berger et al., 1988; Coney, 1985; Schmitz-Gielsdorf et al., 1988).

In our view, the results of the present three experiments are also difficult to reconcile fully with either the hemispheric cooperation account of the opposite side advantage (Banich, 1998; Banich & Belger, 1990; Weissman & Banich, 2000) or the hemispheric specialization account of the left field advantage (Banich & Belger, 1990; Hardyck et al., 1985). Rather, we propose that they are more consistent with the existence of two separate scanning biases influencing the order of mixed-case letter matching. The left-to-right scanning bias is the easiest to understand. It likely reflects the spontaneous tendency of English readers to examine letters in the familiar order (Heron, 1957; Lubow et al., 1994). Outside of the context of the hemispheric-based accounts of letter matching, this interpretation is not controversial, since many previous studies have arrived at a similar conclusion (Butler, 1978, 1979, 1981; Krueger, 1976; Levine & Banich, 1982; Scheerer, 1972, 1973; Tramer, Butler, & Mewhort, 1985; White, 1976).

The second factor, resulting in the opposite side bias, is less intuitive, but it is entirely consistent with a pattern of results that can be seen in rapid saccade tasks (Carpenter, 2001), covert spatial orienting tasks (Bennett & Pratt, 2001; Kristjansson & Nakayama, 2002; Pratt et al., 1999), the attentional blink (Kristjansson & Nakayama, 2002), visual distractor tasks (Caputo & Guerra, 1998; Pan & Eriksen, 1993) and several variants of visual search (Cave & Zimmerman, 1997; Cutzu & Tsotsos, 2003; Kim & Cave, 1999; Mounts, 2000a, 2000b; Steinman et al., 1995; Woodman & Luck, 1999). The general finding is that once attention has been allocated to an item at a given location, there is a strong tendency to favor processing of items that are distant from that location. It is as though there is reluctance on the part of the selection mechanisms to process neighboring items in sequence. Importantly, these distance effects are obtained irrespective of whether the observer must compare the identity of the objects; that is, whether or not coordination between the hemispheres is even necessary.

As described in the introduction, neurophysiological evidence points to a plausible mechanism for this distant location bias. Studies that combine behavioral analysis of an "oddball" visual search task with electrophysiological recordings in the frontal eye fields of monkey cortex (Schall & Hanes, 1993; Schall et al., 1995, 2004), report that neurons increase their rate of firing when either a target item or a distractor item falls within their receptive field. However, shortly after the display of items is presented, these neurons behave differently, depending on the task relevance of the item in their receptive field. Target items elicit an increase in firing rate, whereas distractor items have a suppressed rate of activity. Most importantly for the present discussion, the neural suppression associated with these distractor items is related directly to their distance from the target, with those closest showing the lowest rates of activity. A mechanism such as this would bias letter matching toward probe letters that were farthest away from a target letter, corresponding to what is called an opposite side advantage by proponents of the hemispheric hypothesis.

This provides an interpretation of the interaction between field and side that is sometimes obtained when using this task (present Experiment 3; Banich et al., 2000). Although these biases may seem functionally independent, the neural structures representing these biases are not. Both suppression of a nearby distractor (Schall & Hanes, 1993) and facilitation linked to the goals of observers (Bichot & Schall, 1999, 2002) have been observed in the frontal eye fields. In this structure, both attentional biases work against the selection of the right probe when the target appears on the same side because the observer first attends to the locus of the target, then to the probe appearing in the left field, before shifting attention to the probe in the right field. In this instance, the neural representation of the right probe would have been inhibited twice, significantly delaying its eventual selection.

7.2. Limitations and applications of the present findings

The implications of the present study are strictly limited to the interpretation of behavioral data from letter matching tasks as performed by healthy participants. The present results do not address the merits of the hemispheric functioning account in explaining the pattern of behavior observed in different behavioral paradigms, or of behavior in individuals with various neurological conditions. Yet, the present findings suggest that when studies use letter-matching tasks as the basis for making inferences about hemispheric functioning, they would be well advised to consider the alternative that scanning biases may provide an equally good account of the data.

In this section, we will briefly consider findings from studies using fMRI (Pollmann et al., 2003), studies on elderly participants (Reuter-Lorenz et al., 1999), and studies involving cross modal sensory interactions (Passarotti et al., 2002) that have all used letter-matching as the primary behavioral task under investigation. In each case, we will summarize the hemispheric functioning account of the data, before pointing to the alternative interpretation implicated by the present findings.

In the fMRI study by Pollmann et al. (2003), a same-different letter-matching task was used in which four letters were presented at a time, either in same-case or mixed-case. Only two of the letters in any display were relevant to the observers, which were identified with spatial cues (red boxes) that outlined the upcoming location of these letters. There were three main findings concerning the BOLD response measured in this task. First, mixed-case letter matching produced less unilateral blood flow in extrastriate visual areas than same-case letter matching, consistent with greater hemispheric cooperation for more complex tasks. Second, there was greater blood flow in the anterior cingulate complex when matching same-case letters appeared on each side of fixation as opposed to mixed-case letters, consistent with the costs of hemispheric coordination when the matching task is too simple. Third, only mixed-case letter matching yielded unique activity in the intraparietal and frontal brain areas that are typically recruited during spatial attention tasks. This finding was not linked specifically to the hemispheric account, nor was it linked the possibility that mixed-case letter matching placed greater demands on spatial attention than same-case letter matching. Instead, it was attributed to a difference in the global demands of attention in these conditions.

This last finding is completely consistent with the attentional scanning account we propose: mixed-case letter matching requires at least two sequential shifts of attention before the decision can be reached, whereas same-case letter matching can be solved through a parallel perceptual grouping strategy. Closer examination of the first two findings, furthermore, casts its own doubt on the proposed link between the letter matching and hemispheric functioning. The unilateral BOLD activity observed in same-case letter matching was largely limited to a single hemisphere, namely the right, which was

also associated with the least efficient performance (left visual field). If same-case letter matching is achieved through independent processing, then both hemispheres should show this effect and this benefit should be translated into a clear-cut advantage in behavior. The elevated BOLD signal in the anterior cingulate complex, interpreted as the difficulty of sharing information between the hemispheres in same-case latter matching, was actually associated with an opposite side advantage in behavior. Thus, the neural index of sharing information between the hemispheres was not linked to the proposed behavioral index of information sharing.

Reuter-Lorenz et al. (1999) used letter-matching tasks to index age-related changes in cooperation between the hemispheres that may occur in elderly adults. The data of the comparison among young adults replicated the standard pattern associated with letter matching: a same side advantage for same-case matching and an opposite side advantage for mixed-case matching. However, the elderly adults performed more efficiently when the target and matching letter were in opposite fields under all conditions, including the same-case letters. This was interpreted, within the framework of hemispheric functioning, as evidence that increased cooperation between the hemispheres helps to offset the general reduction in processing efficiency that occurs with advancing age. In contrast, a scanning account of these data would interpret this result as further evidence that the spotlight of attention, sometimes called the "useful field of view," shrinks with advancing age (Plude, Enns & Brodeur, 1994) and that this causes elderly participants to compare both mixed and same-case letters sequentially, instead of being able to use the more efficient perceptual grouping strategy adopted by younger adults.

Passarotti et al. (2002) claimed to demonstrate that the benefits of hemispheric cooperation extend across modalities. In this study, participants were presented with auditory and somatosensory versions of a 3-digit task. Digits in the auditory version were presented in sequence over headphones. In a matching task, participants indicated whether one of the probe digits had the same identity as the target; in an ordinal task they compared the values of the digits. The main finding was a large same side advantage in the matching task, which was effectively eliminated in the ordinal comparison task. A parallel set of experiments was conducted with somatosensory stimuli (i.e., blocks that were either identical or differed in metrical properties from one another). In these experiments same side and opposite side comparisons did not differ significantly, regardless of the difficulty of the comparison.

These results are difficult to interpret without considerable ambiguity from within either of the two theoretical frameworks. This is because the data patterns are so different from the previous expectations that have been developed in the visual matching literature. For example, in the auditory tasks, increasing the apparent complexity of the task (from identity match to ordinal comparison) was not associated with an overall increase in response time, as one would expect if the task was really more complex. The data in the so-

matosensory tasks were even more difficult to interpret, since no performance differences between conditions were found. Cleary, more research is needed to link the cross modal research to the existing research in the visual modality, before strong interpretations from within any framework are possible.

In summary, the present findings pose significant challenges to the view that an opposite side advantage in mixed-case letter matching reflects cooperation between the cerebral hemispheres, and to the view that a left field advantage in the same task reflects a right hemisphere advantage for letters (Banich, 1998; Weissman & Banich, 2000). Here we offer an alternative account that fares at least as well as the hemispheric account in many cases. We therefore suggest that future researchers consider seriously the possibility that the side and field effects of letter matching tasks can be the consequences of more general biases in attentional selection. Whether our specific interpretation of the origins of the biases will be supported by future studies remains to be seen. More tests are clearly needed that will focus on systematic comparisons of easy and difficult conditions, especially those in which task difficulty is manipulated independently of the phenomenon under study. We also call for future studies in which distance and crowding effects are systemically studied in conjunction with hemisphere effects. Only these kinds of comparisons are ultimately going to decide this debate. In the meantime, what the present findings show is that letter matching is far from being a transparent index of hemispheric cooperation or specialization.

Acknowledgements

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