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LEFT AND RIGHT VISUAL FIELD SUPERIORITY FOR LETTER CLASSIFICATION*

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Two letter classification experiments examine the hypothesis that lateral asymmetries in perceptual processing are sensitive to subtle changes in task demands. The first experiment reports a right visual field superiority for an easy letter classification, but a left field superiority for a difficult classification using the same population of stimuli. Experiment II demonstrates that the right field superiority can be reversed if the easy classification trials are embedded among more difficult trials. The implications of these results for theories of hemispheric localization are discussed.

Introduction

The psychological literature contains many demonstrations of lateral asymmetries of visual perceptual processing in normal subjects. For example, many investigators have documented right visual field performance advantages in right-handed subjects for such tasks as digit and letter naming (Kimura, 1961, 1966) and word report (Dimond, 1971; Ellis and Shepard, 1974; McKeever and Huling, 1970). Also, there have been a number of demonstrations of left visual field superiority in non-verbal processing tasks such as dot localization (Kimura, 1969), face recognition (Geffen, Bradshaw and Wallace, 1971), and visual orientation matching (Atkinson and Egeth, 1973). The number of demonstrations of lateral asymmetries in perceptual performance has, in fact, increased dramatically in recent years (see, for example, the bibliography of Fudin and Masterson, 1975). Although the facts are becoming increasingly clear, however, their interpretation is still open to question.

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Most theories of lateral asymmetries share one fairly uncontroversial feature: They assume a functional asymmetry of the brain in processing strategies.* The specialization of each hemisphere is assumed to be essentially immutable in the sense that each hemisphere is confined to its characteristic processing strategy. This may be either because each hemisphere has no ability to engage in its counterpart's specialty, or because there is normally inhibition between the hemispheres such that each prevents the other from processing on appropriate occasions. In any case, the asymmetry has been variously characterized as a distinction between verbal and spatial processes (Kimura, 1966), between analytic and wholistic processes (Patterson and Bradshaw, 1975), or between serial and parallel processes (Cohen, 1973) among others. Whatever its exact character, the fact that such an asymmetry exists has been amply well-documented in studies of unilaterally brain-damaged populations (e.g. Hecaen, 1969; Paterson and Zangwill, 1944), and in studies of split-brain patients (e.g. Levy-Agresti and Sperry, 1968; Sperry, Gazzaniga and Bogen, 1969).

Recently, it has become increasingly clear that the determination of hemispheric processing responsibility is not solely constrained by these well-documented specializations, however. That is, there appear to be more factors involved in the allocation of "dominance"† in a task than merely the match between a hemispheric ability and a task to be performed. For example, in cases in which both hemispheres may be capable of successfully completing a particular task (albeit by the use of different strategies), the hemisphere of input may be the one that dominates. If so, either no asymmetry in performance will result, or there will be an asymmetry based on relative differences in efficiency with which each hemisphere can perform the particular task in question.

Alternatively, one hemisphere may come to dominate processing for an entire task regardless of which hemisphere initially received the input. In this case, asymmetries in reaction time and accuracy can be explained by assuming that stimuli that happen to be routed to the inappropriate or "non-dominant" hemisphere in a particular task (because of the anatomical pathways between the hemiretinae and the hemispheres), are shunted across to the appropriate hemisphere (via the corpus callosum) for processing. This results in a measurable loss of time and, perhaps, in a loss of information quality due to degradation during the crossing.‡

*One theory that does not share this feature rests on the principle that perceptual asymmetrics are a result of acquired covert patterns of scanning the visual field. These patterns develop, by hypothesis, with practice at such tasks as reading (e.g. Heron, 1957; Mishkin and Forgays, 1952). Careful investigation of a situation in which a cerebral specialization hypothesis makes predictions opposite to such a scanning hypothesis (the study of lateral asymmetrics in Hebrew vs. English readers), however, disconfirms a scanning account of many laterality effects (Orbach, 1952; Barton, Goodglass and Shai, 1965). Both Hebrew and English readers show a right visual field superiority for word recognition. Thus, although reading experience may influence perceptual field asymmetries, there is also an overriding effect of right field superiority for a reading task.

†The reader will note that the use of the word "dominant" here differs from its classic usage. It is here intended to refer to the hemisphere that assumes major processing responsibility, not to the one that specializes in language functions (see, e.g. Levy and Trevarthen, 1976, for a similar usage).

‡In order to explain why reaction time asymmetries are typically larger than the 5 ms or so that it should take a signal to cross the corpus callosum, one only needs to posit that complex information is sent as packets of signals strung out in time.

According to this alternative hypothesis, hemispheric dominance in a task is determined by several factors. The differential specializations of the hemispheres may constrain the choice, of course. But in addition, recent research has uncovered several other factors that seem to enter into the determination of which hemisphere will be dominant.

In a series of experiments concerned with this issue, Kinsbourne (1970, 1973, 1975) has shown that the hemisphere that performs the processing in a particular situation can be determined by another task that is performed concurrently. In one experiment, for example, the requirement to hold six words in memory during performance of a gap detection task resulted in a right visual field superiority; when there was no verbal memory requirement on the other hand, there was no asymmetry in gap detection performance (a similar finding has been reported by Hellige, 1978, but see Gardner and Branski, 1976, for a failure to demonstrate sensitivity differences under similar conditions). Kinsbourne attributes this result to the "priming" effect that the memory task has on activating the left hemisphere for processing in the experiment. A similar kind of priming effect has been demonstrated by Hellige (1978) by comparing performance on a form recognition task under either pure list (only forms presented) or mixed list (words presented as well) conditions. He found that the left field superiority obtained under the pure list condition changed to a right field superiority when the forms were mixed with words in the stimulus list. An interpretation of this result consistent with the Kinsbourne hypothesis is that the words primed the left hemisphere to dominate in processing on the mixed list trials, and this hemisphere took over the recognition of the forms as well once activated.*

Geffen, Bradshaw and Nettleton (1973) have also reported a result that indicates the effect that one task can have on another performed concurrently. In the absence of any competing task, they found that digits were responded to faster in a go/no go reaction time task when presented to the right visual field. When subjects performed a secondary verbal detection task (detecting a vocal letter in a string of other letters), however, this effect reversed: There was now a left field superiority.†

*Bryden and Allard (1976) have reported a result that appears, at first blush, to be inconsistent with these priming effects (although see Hellige, 1978, for a failure to replicate Bryden and Allard's mixed list effect). They found that subjects in a letter identification task produced reliable left or right field accuracy superiorities for different typefaces under conditions in which the typefaces were presented in a mixed list. The left field superiority was found for those typefaces that produced lower accuracies in letter identification performance.

A priming theory might have predicted that the processing strategy adopted for the majority of the typefaces would have dominated for all typefaces. However, there may not be an inconsistency here at all. Accuracy in this task was quite low overall (35%). Although the left hemisphere may have dominated processing initially on each trial, on those trials on which the discrimination was quite difficult, a right hemisphere strategy may have overcome the left in order to facilitate the feature extraction operation required prior to identification. Hence, a left field superiority would arise on these trials. Note that the intrusion of such a right hemisphere mechanism would only be expected if a visual discrimination were made so difficult (by, e.g., degraded presentation) as to overcome the form recognition capacity of which the left hemisphere is presumably capable.

†While on the face of it, there appears to be a discrepancy between the priming effect reported by Kinsbourne (1970, 1973, 1975), and the overload effect reported by Geffen, Bradshaw and Nettleton (1973), it has recently been suggested that this discrepancy is due to the varying load placed on memory by the difficulty of the secondary task (Hellige and Cox, 1976).

Task instructions as well can influence where processing occurs. Levy and Trevarthen (1976) instructed split-brain subjects to match chimerically constructed line drawings of objects according to either a functional-conceptual criterion or a visuo-structural one. That is, the instructions stressed matching the line drawings either on the criterion of similarity in how the objects are used, or similarity in their physical appearances. These instructions produced left and right hemisphere superiorities respectively.

Finally, Patterson and Bradshaw (1975) have demonstrated that the difficulty of a task can also influence which hemisphere dominates processing. In two experiments, they required subjects to perform a target versus non-target judgement for schematic faces presented singly to the left or right visual fields. They found that when the physical differences between targets and non-targets were large and salient a left field superiority resulted; when the discrimination was difficult, a right field superiority was found. Bryden and Allard (1976) have also demonstrated a shift in lateral superioity with increasing discrimination difficulty in a letter identification task, but in the reverse direction from that found by Patterson and Bradshaw (1975). Whatever the resolution of the opposite asymmetries found in these two studies, it does seem clear that increasing the difficulty of a discrimination has the effect of changing the direction of a lateral superiority.

Of course, in order for such factors as priming, overload, instructions, or difficulty to be effective, there must be some ability for each hemisphere to perform a variety of tasks, including some for which the opposite hemisphere is specialized. In support of this possibility Gazzaniga (1970) argues, for example, that the non-language hemisphere is capable of some language functions, albeit not many. Also, for example, Levy, Trevarthen and Sperry (1972) report data on a visual pattern recognition task with nonsense forms that can be performed by both hemispheres in split-brain subjects. Interestingly, the task was normally performed by the right hemisphere, but Levy *et al.* (1972) showed that when forced to take over (by requiring a verbal response), not only could the left hemisphere perform the task, it was, in fact, superior to the right. This is another indication that ability and dominance in a task are separable from one another.

The present experiments further explore the nature of this flexibility in the localization of processing. We demonstrate that a fairly subtle change in task demands can reverse a hemispheric superiority effect. The subtlety results from the fact that we demonstrate this reversal in superiority between two tasks with the same instructions and with the same explicit task demands. In Experiment I, the variable that produces a change in hemispheric superiority is discrimination difficulty. In Experiments II and III, however, we demonstrate that the *effective* variable is the *expected* difficulty of a discrimination, not its true difficulty.

Experiment I

In much of the previous empirical work on the lateralization of mental processing, there has been an intentional confounding between task demands and the verbal or non-verbal nature of the stimuli, in order to bias the experimental situation in favour of demonstrating an asymmetry in one direction or the other. In order to demonstrate that an asymmetry can be reversed under appropriate conditions, however, we required a task that was more neutral with respect to its processing requirements. That is, we required a task that could successfully be completed by each cerebral hemisphere, presumably by the use of different processing strategies.

Letter classification seemed as if it would be a good candidate. On the one hand, the stimuli can be encoded as linguistic entities and a classification can be based on such a verbal code. On the other hand, they can be treated as visual shapes, unconnected with any linguistic identity, so that a classification judgement can be based on visual feature information alone. In fact, the previous literature concerned with hemispheric asymmetries in letter discrimination and classification is in conflict. Several studies demonstrate a right visual field superiority while others demonstrate the reverse (e.g. Rizzolatti, Umilta and Berlucchi, 1971; Umilta, Frost and Hyman, 1972; also, see the reviews by White, 1969, 1972). This suggests that the letter classification task is one that can be executed using more than one strategy. In order to manipulate the "choice" of strategy adopted, we merely manipulated the difficulty of the physical discrimination which, according to Bryden and Allard (1976) and Patterson and Bradshaw (1975), ought to cause a reversal in the visual field superiority effect.

Method

Subjects

Subjects were 12 right-handed undergraduates who were paid for participation in six experimental sessions of 40 min each. The first three sessions were spaced one day apart, as were the last three sessions. A week intervened between the start of the first three sessions and the start of the last three for all subjects.

These subjects were selected after screening a pool of potential subjects for self-reports of right-handedness, for family history of right-handedness, and for performance on a slightly modified version of the Edinburgh Handedness Inventory (Oldfield, 1971). All 12 subjects reported having no left-handed relatives whom they could recall in their immediate families. Furthermore, no subject responded that he used his left hand for any more than 20% of the activities tested in the Edinburgh Inventory. Thus, on the basis of self-reports of handedness, of family histories of handedness, and of performance on a handedness inventory, we felt confident in concluding that these 12 subjects were consistently right-handed.

Apparatus and stimulus materials

The stimuli were presented in an Iconix tachistoscope (model 6137–4). On each trial, subjects first carefully fixated a dot in the centre of the screen (15·5 ml) and then initiated the trials by depressing a footswitch. Five hundred ms after the switch was depressed, a stimulus card was presented for 25 ms. Following this, the fixation dot reappeared and remained in view until the initiation of the next trial. On those trials on which a subject responded to a target item, he did so by depressing a telegraph key with his left hand. Reaction times were recorded from the onset of stimulus exposure until the subject pressed the key.

The stimuli consisted of single letters (Letraset Copperplate Gothic Heavy, 18 point, 0·35° in height) mounted either 2° to the left or to the right of centre on plain white cards. The letters were chosen from the set C, E, F and G.

The test trials numbered 144. There were 18 trials with each of the stimulus letters appearing on the left, and 18 with each on the right. These trials were divided into three blocks of 48 with each block containing six trials of each letter in each position. The order of trials within a block was randomized with the two constraints that no more than three trials occur consecutively in which a letter appeared in the same position, and that there be no more than three occurrences of any particular letter consecutively. The three blocks of trials were presented in an order counterbalanced (according to a Latin square principle) within subjects across experimental sessions.

In each session, 32 trials of practice preceded presentation of the test trials. These practice trials were constructed according to the same principles outlined above for the test trials.

Procedure

For the first three sessions, half of the subjects were instructed to respond on the trials (50% of the total) on which either a C or an E appeared, and not to respond on the other 50% of the trials on which an F or a G appeared. For the last three sessions these subjects were to respond only to E or F, and not to C or G. The other half of the subjects had these conditions reversed in order: They responded to E and F in the first three sessions, and to C and E in the last three.

We reasoned that the EF vs. CG classification would be considerably easier than the CE vs. FG classification because in the former case, there are many single features which will serve to reliably discriminate the targets from the non-targets, while in the latter case there are only two (the bottom horizontal on E vs. F and the middle horizontal on C vs. G). Thus a more careful analysis, presumably by a fine visual processor, is required for the CE vs. FG judgement in order to respond accurately.

All subjects were given identical instructions in each session regardless of the difficulty of the classification. They were told their targets for that session, and told to respond as accurately as possible, but within that limitation as quickly as possible. At the beginning of the experiment, they were also familiarized with the set of stimuli, with the apparatus, and with the procedure for running each trial. They were cautioned not to initiate each trial until they were fixating the dot in the centre of the screen because this was the optimal place to be looking in order to see a letter either on the left or on the right (position, recall, was unpredictable within blocks of trials).

Results

Reaction times

Figure 1 displays the mean reaction times as a function of experimental session for both the condition in which subjects responded to the targets C and E (top panel) and for the condition in which they responded to the targets E and F (bottom panel). All reaction times beyond 2·5 S.D. of the mean for each subject and each condition were excluded from analysis (in this and the next experiments). The reaction times for each subject were entered into an analysis of variance that included the factors of order of target condition, target condition, visual field and session. Naturally, as expected from the choice of stimuli, responses to E and F were considerably faster than were responses to C and E ($F=134{\cdot}57$, $df=1{,}10$, $P<0{\cdot}001$). More importantly, however, there was a statistically significant interaction between target condition and visual field that was present in the data of 11 of the 12 subjects ($F=55{\cdot}54$, $df=1{,}10$, $P<0{\cdot}001$). Tests of the simple effects contributing to this interaction indicate that when C and E were targets, there was a reliable *left* visual field superiority ($F=15{\cdot}95$, $df=1{,}10$, $P<0{\cdot}01$); when E and F were targets, there was a reliable *right* visual field superiority ($F=73{\cdot}68$, $df=1{,}10$, $P<0{\cdot}001$). Evidently, the manipulation of classification difficulty caused a reversal in the lateralization effect.

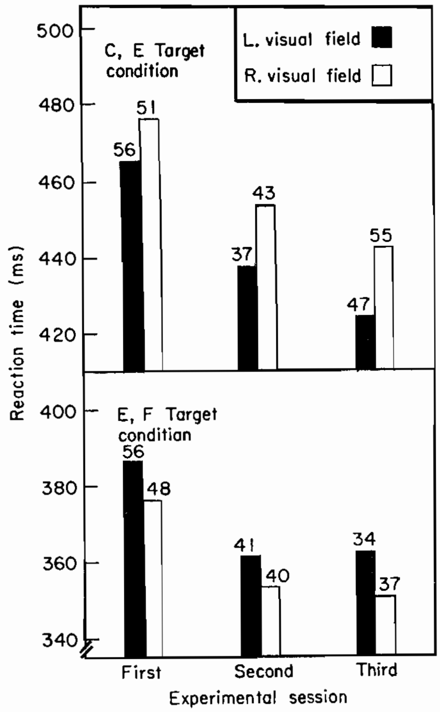

FIGURE 1. Mean reaction times (and standard deviations above the bars) for both conditions of Experiment I as a function of visual field and experimental session.

Figure 1 also shows that subjects generally responded faster with increased sessions of practice ($F=15 \cdot 90$, $df=2,20$, $P<0 \cdot 01$). This practice effect is of the same magnitude for both target conditions as indicated by the lack of reliable interaction between practice and target condition ($F<1$). Furthermore, the practice effect does not interact with visual field of presentation ($F=1 \cdot 14$, $df=2,20$, $P>0 \cdot 10$). The order in which subjects participated in the two target conditions also did not reliably affect reaction time ($F<1$), nor did it interact with any other experimental variable.

Errors

Errors were generally very few in number. As expected, subjects had higher error rates when responding to the targets C and E than to the targets E and F: 2·3 vs. 0·7% respectively ($F=24 \cdot 67$, $df=1,10$, $P<0 \cdot 01$). Also, there was a reliable trend for errors to decrease over experimental sessions ($F=6 \cdot 10$, $df=2,20$, $P<0 \cdot 01$). There was not, however, any effect of visual field of presentation on error rates, nor any interaction of the visual field variable with the others. In general, then, the pattern of errors roughly mimics the pattern of processing difficulty indexed by reaction time. One could not effectively argue on the basis of these data that subjects were trading speed for accuracy in producing the reaction time data reported.

Discussion

Experiment I demonstrates that response times are faster to stimuli presented in the right as compared to the left visual field when a fairly easy classification is required; a difficult classification, however, results in faster responses to stimuli in the left than in the right field. This result is generally consistent with the data reported by Bryden and Allard (1976) on recognition of letters in typefaces varying in internal confusability. Although Patterson and Bradshaw (1975) demonstrated a right field superiority for a difficult classification, they used schematic face stimuli and a long interstimulus interval that may have contributed to their result.

One interpretation of the present result hinges on the well-documented specializations of each cerebral hemisphere. When the classification task places no unusual emphasis on the subtle differences in visual features between the target and the distractor items, subjects treat the items as verbal entities and make a judgement on the basis of a verbal encoding (even though the task does not demand such an encoding). The verbal code may be used as the basis for judgement because subjects "automatically" code letter forms in this manner by dint of experience (i.e. it is an habitual response), or because such a code renders the target-non-target judgement easier. In any case, we here claim that in the absence of any reason to the contrary, subjects are biased to process letters using a verbal code which is processed by the left hemisphere. Stimuli presented to the right visual field thus stand in a priviledged position in terms of processing speed because they have more direct access to the hemisphere of processing (and, perhaps, have less degraded internal representations to be processed).

When the task requires a judgement about the targets C and E and the non-targets G and F, a difficult classification arises, and the use of verbal codes by the left hemisphere will be inadequate to the task. This follows on the assumption that verbal codes can only serve as the basis of accurate classifications to the extent that they can accurately be assigned to the various stimuli. In the case of a difficult classification, however, this is limited by the visual similarity of the items. That is, a verbal code could just as well mediate responses in the CE vs. FG task if only subjects could assign the codes to the stimuli accurately and with confidence. But the physical confusability of targets and non-targets in this case prevents such accurate and confident code assignment. Thus, we claim, subjects must retreat from their habitual use of verbal codes, and instead rely on a more accurate "visual" representation of each stimulus item which will be better suited to the visual difficulty of the required classification. It has been demonstrated repeatedly that the right hemisphere is specialized for effectively processing such representations; this would therefore result in a left visual field reaction time superiority because of the more direct anatomical route between the left field and the right hemisphere. In short, according to this interpretation, the right field superiority for the easy classification is a result of habitual verbal encoding of alphabetic stimuli; this code is inadequate to the accuracy requirement of the task when a difficult classification is required, so in this case a visual code is used.

Note that this change in the locus of processing is presumed to occur in the absence of any explicit set caused by the task instructions. The instructions simply tell subjects *what* to do, not *how* to do it. Under these circumstances, by hypothesis, there must be some internal setting of which hemisphere will dominate processing from one condition to the next (or, perhaps, from one block of trials to the next). The decision about which hemisphere will dominate must be based on the implicit task demands of the experimental situation (the classification difficulty) in addition to the explicit task demands and the kind of stimuli involved. In Experiment II we test the hypothesis that an internal set is created by inducing a set that is occasionally violated.

Experiment II

Experiment II involved the same basic task as Experiment I, letter classification. On the vast majority of trials, stimuli were presented which made the classification a difficult one; in fact, it was about as difficult as the CE target condition of Experiment I. On occasional trials, however, the classification was quite easy. Thus, if subjects set themselves for a difficult classification based on the majority of trials, and if this set results in a left visual field superiority as in Experiment I, a left field superiority should result for the easy classification as well. This prediction, of course, rests on the reasonable assumption that if the right hemisphere can accurately perform a difficult classification, it can also perform an easy one if called upon to do so (although, as Experiment I demonstrates, it will normally not do so presumably because of the habitual use of verbal codes).

In principle, of course, the experiment could be run in reverse as well—setting subjects for an easy classification and occasionally presenting a difficult one. The problem with this version, however, is that it is likely to result in high error rates for the difficult classifications as described above in the discussion of Experiment I. That is, although the use of a verbal code may be accurate in performing an easy visual classification, it may not at all be accurate in performing a difficult one. Because of this possibility, we chose to create and violate a set only for a difficult classification.

Method

Subjects

Subjects were 12 undergraduates who were paid for participation in one 2-h session. (Due to the fact that there were no reliable interaction of the session effect with visual field in Experiment I we opted to run the present experiment for one session only.) The subjects were screened as in Experiment I and achieved the same criterion of right-handedness.

Apparatus and stimulus materials

The apparatus was identical to that of Experiment I. The trial by trial running procedure differed in that in the present experiment, subjects responded with a keypress by one hand if the target was present, and with a keypress by the other hand if the item presented was not a target. The assignment of hand to response was counterbalanced across subjects.

There were 400 test trials in the session. The trials were constructed using the set of letters C, E, F and T in the same type style used in Experiment I presented at the same exposure duration of 25 ms. The letter F was always the target, and it appeared on 200 of the trials, 50% of the time 2° to the left of centre, 50° of the time 2° to the right. The letters E and T each appeared 84 times, equally divided between left and right occurrences.

Finally, the letter C appeared 32 times also equally divided between left and right presentations. Thus, on the vast majority of trials, subjects were required to make a fairly difficult classification, while on a few (those containing the letter C) the classification was much easier.

The trials were arranged into eight blocks of 50, so that an equal number of target and non-target cards appeared in each block. Of the non-target cards in each block, four contained a C, and the remainder contained either an E or a T.

Fifty practice trials were constructed according to the same principles as the test trials; they were presented at the beginning of the session.

Procedure

Subjects were familiarized with the general procedure as in Experiment I. In addition, they were informed about the unequal appearances of the three non-target items, and about the two-alternative response. Finally, as in Experiment I, they were instructed to respond both quickly and accurately.

Results

Reaction times

Figure 2 displays the mean reaction times for left and right field presentations of the target F, the two difficult-classification non-targets, E and T, and the easy-classification non-target C. As the figure indicates there is an overall effect of item

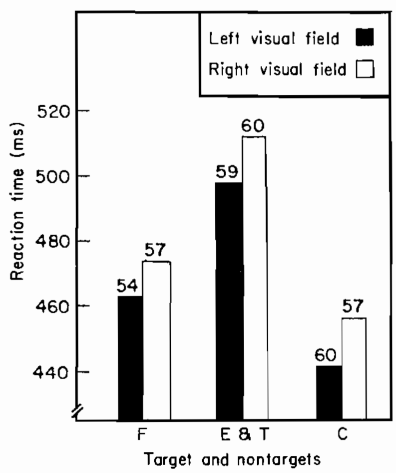

FIGURE 2. Mean reaction times (and standard deviations above the bars) for the target and non-targets of Experiment II as a function of visual field.

that is highly reliable ($F=66{\cdot}64$; $df=2,22$; $P<0{\cdot}001$). *Post hoc* analysis using the Newman–Keuls procedure attributes this main effect to reliable ($P<0{\cdot}01$) differences among all three pairs of comparisons: Responses to F are faster than those to E and T; responses to C are faster than those to F; and responses to C are faster than those to E and T. The first effect is consistent with much research that demonstrates that "presence" responses in visual search tasks (of which this is an example, with a display size of one) are faster than are "absence" responses (e.g. Egeth, Jonides and Wall, 1972). The ease of discriminating the non-target C from the target F overcomes this effect. In fact, responses to C are fastest of all —not surprising, since the experiment was designed with this aim.

The main effect of visual field of presentation is also highly reliable ($F=52 \cdot 06$, $df=1,11$, $P<0 \cdot 001$). More importantly, however, there is no reliable change in the magnitude of the left visual field superiority across the target and non-targets: For F there is a difference of 11·2 ms; for E and T, a difference of 13·8 ms; and for C a difference of 15·1 ms (for the interaction between item and visual field, $F<1$). Apparently, embedding an easy classification in a task that preponderantly requires a difficult classification is sufficient to cause a left field superiority for the easy classification. No other effects reached statistical significance.

Errors

As in Experiment I, errors were few in number. The mean error rates for responses to the target F, to the non-targets E and T, and to the non-target C were 1·5%, 1·0% and 0·9% respectively ($F=2 \cdot 08$, $df=2,22$, $P>0 \cdot 10$). There were 0·9% errors to stimuli presented in the left field, and 1·4% to those presented in the right ($F=2 \cdot 13$, $df=1,11$, $P>0 \cdot 10$). The trends of these error rate effects are consistent with the reaction times reported.

Discussion

The results of Experiments I and II can be summarized as follows. Subjects respond more quickly and more accurately to an easy visual classification when the items are presented in the right rather than the left visual field. When a difficult classification is required, however, the left field shows a performance advantage. Furthermore, this asymmetry in perceptual processing (at least the right field superiority for difficult classifications) is not immutable. Embedding trials that demand an easy classification among ones that demand a difficult classification results in a left field advantage for both the difficult *and* the easy classification trials.

Before drawing conclusions from these effects, we must consider that the procedures of Experiments I and II differed somewhat. In the first place, the one experiment required a Donders c-reaction (go/no go) while the other required a b-reaction (yes/no). In the second place, in Experiment I all subjects responded with only one hand to the target (the non-dominant left) while in Experiment II the assignment of hand to response was counterbalanced across subjects. While it is not immediately clear how these differences might have affected the obtained results, they do render the two experiments somewhat non-comparable. Accordingly, a third experiment was conducted using the same basic procedure of Experiment II to deal with these methodological differences.*

Experiment III

Experiment II demonstrates that in the context of a difficult classification, an easy classification (classifying the non-target C) results in a left visual field reaction time superiority. In the present experiment we hoped to reverse this effect for the non-target C by simply embedding it among trials which also involved easy visual

*I thank Professor Max Coltheart for suggesting this experiment.

classifications. We reasoned that if set for the overall difficulty of the task influences the lateralization of processing for each stimulus, then by using a uniformly easy classification, we should reinstate the right visual field superiority for the letter C that was found in Experiment I (in the EF vs. CG condition). By doing so, we would replicate perhaps the principal result of Experiment I without using a procedure very different from that of Experiment II.

Method

Subjects

Subjects were 18 undergraduates who were paid for participation in a 1-h session. (The present experiment used a different apparatus which, for various reasons, we expected would lead to greater subject variability. Therefore, we increased the size of our subject sample.) Screening for right handedness, followed the procedure of Experiment I.

Apparatus and stimulus materials

Stimuli were presented on the screen of a Tektronix CRT equipped with a P-15 fast phosphor, and controlled by a PDP-8E computer. As in Experiment II, subjects indicated their responses by pressing a key with one hand if the target had been presented, or a different key with the other hand, if a non-target had been presented. Six subjects responded to targets with the dominant hand and six with the non-dominant hand.

The 400 test trials were divided into eight blocks of 50. Each block contained 26 presentations of the target F, 10 presentations of each of the non-targets G and Q, and 4 presentations of the non-target C in randomized order (the letters were each 0·88° in height, and 0·66° in width). The side of presentation of each of the letters (50% of the trials 2° to the left, 50% of the trials 2° to the right) was also randomized within blocks. Three blocks of 50 practice trials were constructed in a manner identical to the test trials, and they were presented at the beginning of the experimental session.

The formal structure of the experiment, then, was virtually identical to that of Experiment II except that all trials in the present experiment involved easier target vs. non-target classifications than were required in Experiment II. Thus, the context in which the non-target C trials appeared should have shifted the lateral field superiority to the right visual field if our interpretation of Experiment II was correct.

Procedure

For the present experiment, the instructions of Experiment II were adopted virtually unchanged except, of course, for a change in instructions about the identities of the non-targets. Due to a change in the apparatus, however, there were slight modifications in the details of the trial-by-trial running procedure.

To begin each trial, subjects fixated a dot in the centre of the screen which remained in view for 1·5 s. This was replaced by a fixation cross that was present for 500 ms and that immediately preceded a 5 ms presentation of the stimulus letter. After the letter was presented, subjects had a 1·5 s window of time in which to respond with a keypress before the fixation cross reappeared on the screen signalling the beginning of another trial. After each block of 50 trials, subjects were given a short break before initiation of the next block.

Results

Reaction times

Figure 3 presents the mean reaction times for the target F, the two high probability non-targets G and Q, and the low probability non-target C. Analysis of variance was performed on these data, as in Experiment II, including the factors of visual field of presentation, item (F vs. G and Q vs. C), and hand of response

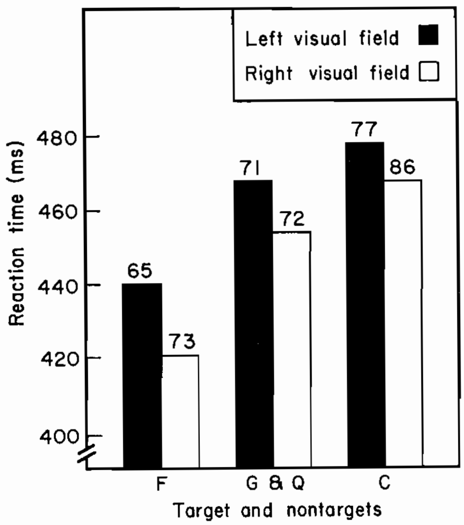

FIGURE 3. Mean reaction times (and standard deviations above the bars) for the target and non-targets of Experiment III as a function of visual field.

to the target (left vs. right). This analysis revealed several reliable effects. To begin with, responses to the target were faster than were those to either non-target. This is indicated by an overall main effect of item ($F=26\cdot96$, $df=2,32$, $P<0\cdot001$), and by subsequent post hoc analysis using the Newman–Keuls procedure to compare F against G and Q ($P<0\cdot01$) and against C ($P<0\cdot01$). There is no reliable difference between the non-targets G and Q and the non-target C ($P>0\cdot05$). As in Experiment II, then, responses to the target were faster than were those to the non-targets, a result to be expected from previous research.

The only other main effect to reach significance in the analysis was that for visual field, with the right field resulting in faster responses by an average of 14 ms ($F=14\cdot86$, $df=1,16$, $P<0\cdot005$). This effect does not reliably differ in magnitude when the target *F* (440 vs. 421), the non-targets G and Q (468 vs. 454) and the non-target C (478 vs. 468) are examined separately, as indicated by a non-significant interaction of item and visual field ($F<1$). Thus, the main hypothesis of this experiment has been confirmed: When the non-target C is presented for classification among other trials which involve a visually easy classification, a right field superiority results. This obviously contrasts sharply with the left field superiority found for C when it was embedded among difficult classification trials in Experiment II.

The only other effect to reach significance was the interaction among visual field, item, and hand of response to the target ($F=7\cdot05$, $df=2,32$, $P<0\cdot01$). Examination of simple effects reveals that the cause of this interaction is an unusually large difference between left and right visual fields (435 ms for the left vs. 393 ms for the right) for the target F for the nine subjects who responded to the target with their right hands. It is not immediately clear why such an effect should have occurred. However, we can speculate that these subjects may have been unusually influenced by the compatibility between the hand of target response and the side on which the target was presented. This would result in unusually fast right hand responses with right field presentations.

Errors

The error rates were quite low for the present experiment; they averaged 2·1% overall. Analysis of variance of these errors revealed no statistically significant trends except the same three-way interaction found for the reaction times among hand, item, and visual field ($F=4{\cdot}69$, $df=2{,}32$, $P<0{\cdot}05$). The reason for this interaction is, again, not completely clear.

Discussion

The purpose of Experiment III was to demonstrate a right visual field superiority for responses to the non-target C in contrast to the left field superiority demonstrated in Experiment II under conditions that were basically identical to those of Experiment II. We succeeded. It now seems reasonable to draw the conclusion that a hemispheric superiority effect for letter classification depends upon the context in which that classification is being performed. When embedded in the context of a difficult classification, a left field superiority is obtained; when embedded in the context of an easy discrimination, the right field is superior.

General discussion

Taken together, the results of these three experiments demand a theory in which there is flexibility in the determination of which hemisphere will be dominant for a particular task—that is, which will assume processing responsibility on each trial.*

How is the dominant hemisphere determined? One possibility is that it is merely the one that first receives the input, the original hemisphere-of-entry. According to this alternative, the lateral asymmetries of Experiment I would be due to the relative efficiency with which each hemisphere can perform each of the classifications. For some reason, an easy classification, by hypothesis, would be more efficiently performed by the left than the right hemisphere, while a difficult one would be better performed by the right than the left. Thus, although each hemisphere would contribute processing to each classification on those trials when it was the hemisphere-of-entry, the hypothesized asymmetries in efficiency would predict asymmetries in performance according to this alternative.

The argument against this hypothesis stems from the results of Experiment II. Here, we demonstrate a *left* field superiority for an easy classification. Only a post hoc and ad hoc revision of the hemisphere-of-entry hypothesis could explain the combined results of Experiments I and II.

We are left with a final alternative: The dominant hemisphere is evidently set by the overall characteristics of the task at hand. According to this hypothesis, subjects develop expectations about such things as the difficulty of a task and the

*This does not, of course, imply that processing is restricted to one hemisphere with each stimulus presentation; it only implies that the response output from one of the hemispheres is the one that dominates a subject's overt response.

optimal strategy for its execution. These expectations cause a "priming" of one of the hemispheres which then maintains dominance for the duration of that task. In this way, even if subjects are presented with some trials that do not accord with the overall expectation for the task, the stimuli on these trials will nevertheless be processed by the hemisphere that is dominant for the remaining trials. This, of course, would only hold if all trials included stimuli that were capable of being processed by the dominant hemisphere.

This sort of flexibility in the locus of processing is supported by the work of Geffen *et al.* (1973), Kinsbourne (1970, 1974, 1975), Levy and her colleagues (Levy *et al.*, 1972; Levy and Trevarthen, 1976), and Patterson and Bradshaw (1975). These investigators have demonstrated hemispheric asymmetries attributable to instructions, to difficulty, and to the influence of competing tasks. The present research, then, taken together with the work of these investigators, outlines the importance of contextual factors and expectations in producing lateral asymmetries in perceptual performance. This is *not* to say that there is flexibility in the *specialization* of each cerebral hemisphere. Neither the present data nor those of others call for this conclusion. What *is* flexible is *where* processing gets accomplished (i.e. dominance), not *what* processes are executed by each hemisphere (i.e. ability).

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