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LETTERS, FACES AND SYMBOLS; STRUCTURAL AND
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MANUAL REACTION TIME TO LATERALIZED WORDS, LETTERS,
FACES AND SYMBOLS: STRUCTURAL AND DYNAMIC
DETERMINANTS OF HEMISPHERIC DOMINANCE

by

Alex Martin Holtzman

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Abstract

MANUAL REACTION TIME TO LATERALIZED WORDS, LETTERS,
FACES, AND SYMBOLS: STRUCTURAL AND DYNAMIC
DETERMINANTS OF HEMISPHERIC DOMINANCE

by

Alex Martin Holtzman

Advisor: Professor Louis D. Costa

The results of studies investigating hemispheric processing difference in normals have most often been interpreted in terms of the direct anatomical access model. Within this conceptual framework, for example, a right visual field superiority on linguistic tasks is attributed to direct access to the language dominant left hemisphere. Based primarily on this conceptualization and the anatomical arrangement through which discrete finger movements are mediated, reaction time models were developed to discriminate between absolute and relative lateralization of function.

In contrast to these structural models there has been some recent evidence that suggests that visual field superiorities may vary as a function of experience with a given task. These findings have been difficult to conceptualize within the framework of a "passive" structural model of hemisphere function.

In order to test the appropriateness of the proposed structural models, four unimanual, two-finger, choice reaction time experiments were designed. Experiments 1 and 2 were designed to explore the linguistic abilities of the normal right hemisphere. In Experiment 3, photographs of faces were used to investigate hemispheric differences in facial recognition, and in Experiment 4 arrays of geometric symbols were employed in an attempt to elicit contrasting modes of processing ("gestalt-wholistic" and "analytic"), expected to produce corresponding right and left hemisphere superiorities, respectively.

For each experiment specific predictions were made as to the ordering of reaction times of each hemisphere-hand condition for each judgment in each experiment. In addition, the data was analyzed over blocks of trials to determine if any significant changes in visual field superiority occurred.

The results of the language tasks provided some support for the structural models. However, in all experiments on-going changes in visual field superiorities were noted, including a right hemisphere advantage during the first block of trials which was found to be somewhat independent of the specific task demands. A more complete and complex model is proposed that attempts to incorporate the structural determinants within a more "active" framework which takes into account the multiple levels of processing required to perform most cognitive tasks, and changes in these processes as a result of experience.

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I

GENERAL INTRODUCTION

Over the last hundred years a great deal of evidence has accumulated which demonstrates that a wide variety of cognitive functions can be localized to either the left or right cerebral hemispheres. The major source of evidence has been clinical observation and behavioral studies of patients who have suffered unilateral cerebral damage either as a result of vascular disease, tumor, or injury (e.g., Luria, 1966; Geschwind, 1970), or surgical intervention for severe epilepsy or tumor (e.g., temporal lobectomy, Milner, 1970; commissurotomy, Gazzaniga, 1970; and hemispherectomy, Smith, 1974). Supporting evidence has also been obtained from studies using direct cortical stimulation (e.g., Penfield & Roberts, 1959) and pharmacological agents (e.g., Wada & Rasmussen, 1960), and morphological differences between the hemispheres have been demonstrated as well (Geschwind & Levitsky, 1968).

There has also been an ever increasing body of literature demonstrating hemispheric processing differences in normal subjects using a wide variety of experimental techniques. The most commonly used procedures have been dichotic listening and tachistoscopic hemiretinal presentation. However, lateralization of function in the normal

brain has been demonstrated by such diverse techniques as recording the direction of eye movements in response to questions (Gur & Gur, 1977; Kinsbourne, 1972), electrophysiological measurements (EEG, Galin & Ornstein, 1972; evoked potential, Davis & Wada, 1974) measuring cerebral blood flow (Risberg, Halsey, Will & Wilson, 1975) and recording changes in heart rate in response to lateralized visual stimulation (Dimond & Farrington, 1977). In spite of this tremendous body of converging evidence, many of the basic questions concerning hemispheric functioning have yet to be adequately answered (see also Kinsbourne, 1978).

Two statements which, at present, based on the above noted converging evidence, seem to be irrefutable are (1) the left and right cerebral hemispheres do subserve different functions, and (2) each hemisphere is capable of some degree of independent functioning. Statement (1) is supported by the vast majority of studies on both pathological and normal populations, while statement (2) is supported primarily by studies of commissurotomy and hemispherectomy patients in whom a relatively isolated hemisphere can be studied with a minimum of facilitory and/or inhibitory influences from the other hemisphere. Given that both statements are true of the normal human brain, one basic question is whether hemispheric differences are relative or absolute. That is, is a particular cognitive process lateralized solely to one hemisphere, or is each hemisphere capable of performing a given task with one being more

efficient, and therefore dominant over the other? As others have pointed out (e.g., Moscovitch, 1973) this question has become increasingly important as a result of certain inconsistencies within the clinical literature. For example, conflicting views concerning the linguistic capabilities of the right hemisphere have developed as a result of apparent discrepancies between the evidence from studies with patients who have suffered unilateral cerebral damage as compared to findings with split-brain and hemispherectomy patients (e.g., Gazzaniga, Glass, Sarno & Posner, 1973; Moscovitch, 1976 a and b; Searleman, 1977; Selnes, 1976). Ideally, in order to settle such a controversy one would need data obtained from normals of the actual ability of each hemisphere to process various types of linguistic stimuli.

One of the most commonly used procedures for exploring hemispheric differences in normals is to present briefly visual stimuli to either the left or right of a centrally located fixation point. It has been commonly found, for example, that subjects are more accurate in recognizing a word presented in the right visual field (RVF), than in the left visual field (LVF). This finding has been attributed at various times to either left-right "directional postexposure scanning" of a rapidly fading iconic memory trace as a result of reading habit (first proposed by Heron, 1957), direct anatomical access to the language dominant left hemisphere (Kimura, 1961), or an attentional bias as a result of selective activation of the language dominant left

hemisphere (Kinsbourne, 1970). The evidence for and against each of these positions has been extensively reviewed elsewhere (e.g., Harcum, 1972; Kinsbourne, 1975; McKeever, 1974; Pirozzolo, 1977; White, 1969 and 1973). Briefly, evidence against the directional scanning hypothesis has come from studies demonstrating that a RVF superiority is found for both Hebrew and English words and letters presented to Hebrew and English speaking subjects (Barton, Goodglass & Shai, 1965; Orbach, 1967; Carmon, Nachson, Isseroff & Kleiner, 1972), for mirror image words (Isseroff, Carmon & Nachson, 1974), and for words presented simultaneously in each visual field (e.g., Hines, 1975, Mackavey, Curcio & Rosen, 1975; McKeever & Huling, 1971). Evidence against Kinsbourne's attentional bias model has come primarily from studies demonstrating opposing visual field superiorities when "verbal" stimuli (words or letters) and "non-verbal" stimuli (faces or geometric forms) have been presented either bilaterally, or randomly to the LVF and RVF to prevent selective hemispheric activation (e.g., Berlucchi, Brizzolara, Marzi, Rizzolatti & Umiltà, 1974; Dee & Hannay, 1973; Pirozzolo & Rayner, 1977). On the other hand, evidence that visual field differences may be at least partially explained by shifts of attention has also been found (e.g., Cohen, 1975; Gur & Gur, 1977; Kinsbourne, 1975; Klein, Moscovitch & Vigna, 1976). To date, the possible contribution that selective attentional shifts may have on the outcome of tachistoscopic laterality tasks has not been

adequately determined. In addition, the possible effects on observed hemifield differences of many of the variables discussed by White (1969) in his review of the literature (e.g., bilateral versus unilateral presentation, stimulus intensity, spacing of the stimulus elements, order or report, ocular dominance) have yet to be clearly specified.

The great majority of the evidence, however, supports the view that perceptual assymetries are primarily determined by direct anatomical access to the functionally specialized cerebral hemispheres (see also Pirozzolo, 1977), and currently almost all studies are done in this conceptual framework. The direct access model is based on the anatomical arrangement of the human visual system. When a subject fixates on the center of the visual field, a briefly presented lateralized stimulus will be initially project to the occipital lobe of the contralateral hemisphere. A significant difference in recognition accuracy is the result of "direct access" for information presented in the visual field contralateral to the hemisphere specialized to process it. The information presented in the field ipsilateral to the specialized hemisphere is assumed to be either processed by the less capable hemisphere or transmitted across the corpus callosum for processing by the specialized hemisphere. In either case, there is assumed to be loss of information which is reflected in the lowered accuracy of report for this visual field.

Assuming that the direct access hypothesis is, in fact, the best explanation of the results from tachistoscopic

laterality studies, there are two major problems that make interpretation of most of the existing data difficult with respect to questions concerned with whether lateralization of function is relative or absolute. Firstly, the neurological data indicates that language functions are localized in the left hemisphere of 90 to 99% of the right handed population (e.g., Goodglas & Geschwind, 1976). However, a review of tachistoscopic studies with normals indicates that in those studies that do find an overall RVF superiority for linguistic material, the effect is found in only about 75% of the subjects (Kinsbourne, 1974; Levy, 1974). This has also been the case for studies that employ "non-verbal" stimuli expected to produce LVF superiorities. Furthermore, many of the studies demonstrating LVF superiorities have been difficult to replicate (Birkett, 1977; Bryden, 1973; White, 1971; White & Barr-Brown, 1972). The second difficulty is that even if appropriate LVF and RVF superiorities could be consistently demonstrated for all right handed subjects, such findings would only indicate the relative superiority of one hemisphere versus the other and, therefore, cannot be used to directly answer questions concerning the ability of the "non-dominant" hemisphere.

Prior to 1970 the most widely used dependent measure in tachistoscopic laterality experiments was accuracy of verbal report. Of all the cognitive functions studies to date, the strongest relationship exists between language functions and the left hemisphere, and the language function

most clearly localized to only the left hemisphere is speech. (see Searleman, 1977, for review). Therefore, by requiring subjects to report verbally, stimuli presented in the LVF necessitates the transmission of some information across the corpus callosum. It is for this reason that split-brain patients cannot verbally report any stimuli presented in the LVF (Gazzaniga, 1970). As White (1972) pointed out, it may be possible to resolve many of the discrepant findings in the literature by employing a response measure that is not dependent on mechanisms lateralized solely to one hemisphere.

Beginning in 1971, a number of studies have appeared using manual reaction time (RT) as the dependent measure. These studies, in contrast to studies that rely on accuracy of report, have found RVF superiorities for verbal material in most subjects tested (usually over 90%) (e.g., Geffen, Bradshaw & Nettleton, 1972; Moscovitch, 1972; Rizzolatti, Umilta & Berlucchi, 1971; Umilta, Frost & Hyman, 1972), and LVF superiorities for face recognition and matching based on physical identity (e.g., Cohen, 1972; Geffen, Bradshaw & Wallace, 1971; Geffen et al., 1972; Rizzolatti et al., 1971).

The cortical control of movement is mediated largely via the pyramidal tract. This pathway is predominantly crossed so that movement of the extremities on each side of the body is controlled by the contralateral hemisphere. Studies with both split-brain monkeys (Brinkman & Kuypers, 1973) and split-brain humans (Gazzaniga, 1970) have demon-

strated that while a gross arm movement can be controlled by either hemisphere, discrete finger movements are controlled exclusively by the contralateral hemisphere.

A number of investigators (e.g., Cohen, 1972; Davis & Schmit, 1971; Geffen et al., 1972; Patterson & Bradshaw, 1975) have measured RT of a gross arm movement to tachistoscopically presented lateralized stimuli. Their rationale has been that by requiring a response that is mediated by both hemispheres in place of one that is controlled by only one hemisphere (i.e., speech), will yield results that are more reflective of hemispheric differences in cognitive processing. As mentioned, this technique has been successful in demonstrating consistent visual field superiorities. However, these authors are then left to speculate about the significance of slower responses to stimuli in one visual field as opposed to the other. The two most likely and common explanations have been that the slower RTs reflect either less efficient processing by the hemisphere contralateral to the "slower" visual field, or the amount of time necessary to transfer the information across the corpus callosum to the "dominant" hemisphere for processing. The alternative strategy is to measure RT of a discrete finger movement. By so doing, a more complete structural model of hemispheric functioning can be developed which should be able to separate out these two alternatives; less efficient processing versus callosal transfer of information.

The paradigm for studying the neural circuitry

underlying simple visuo-motor responses in man was developed by Poffenberger in 1912. By briefly presenting a visual stimulus to either the left or right of fixation and measuring RT for each hand, he found that responses by the hand contralateral to the receiving hemisphere were 5 to 6 msec faster than responses with the ipsilateral hand. Therefore, RT was faster when the same hemisphere that received the stimulus also controlled the response. The time difference between responses by the contralateral hand and ipsilateral hand were assumed to reflect transmission time across the corpus callosum. This finding has been replicated several times using an unpatterned visual stimulus (i.e., a lateralized flash of light) (Anzola, Bertoloni, Buchtel & Rizzolatti, 1977; Berlucchi, Crea, Di Stefano & Tassinari, 1977; Berlucchi, Heron, Hyman, Rizzolatti & Umilta, 1971; Bradshaw & Perriment, 1970; Jeeves, 1969; Jeeves & Dixon, 1970). When, under similar conditions, the motor response could be accomplished by a gross arm movement (i.e., moving a lever) no time difference between the contralateral and ipsilateral hand was found (Filbey & Gazzaniga, 1969). Indirect evidence has also been obtained indicating that when one hemisphere receives the stimulus, but the other hemisphere controls the response, callosal transmission is required. Jeeves (1969) found greatly delayed interhemispheric transmission times in two acallosal subjects, which he assumed reflected the time needed to mediate the response via sub-cortical pathways. Since acallosal subjects, who

should have more efficient sub-cortical pathways than normals, are slower than normals, it is highly unlikely that normal subjects would mediate this response subcortically.

There is then both anatomical and behavioral evidence indicating that this paradigm should provide control over which hemisphere initially receives the stimulus and which hemisphere will control the final response. Based on this assertion, models can be constructed which predict the ordering of the four hemisphere-hand conditions when processing is being accomplished by only one hemisphere versus both hemispheres being able to accomplish the necessary cognitive operations to correctly perform a given task. The models are as follows:

(Key: hemisphere=B; hand=H; left=L; right=R; I=initial registration plus some rudimentary preprocessing time; P=processing time; X=some additional processing time; TM=callosal transmission time of a motor command; TS=callosal transmission time of the stimulus information; MRT=motor response time)

I. Left hemisphere processing only

1. $RT(LB \rightarrow RH) = I + P + MRTRH$
2. $RT(LB \rightarrow LH) = I + P + TM(LB \rightarrow RB) + MRTLH$
3. $RT(RB \rightarrow RH) = I + TS(RB \rightarrow LB) + P + MRTRH$
4. $RT(RB \rightarrow LH) = I + TS(RB \rightarrow LB) + P + TM(LB \rightarrow RB) + MRTLH$

II. Both hemispheres capable; left hemisphere more efficient than the right

1. $RT(LB \rightarrow RH) = I + P + MRTRH$
2. $RT(LB \rightarrow LH) = I + P + TM(LB \rightarrow RB) + MRTLH$
3. $RT(RB \rightarrow LH) = I + P + X + MRTLH$
4. $RT(RB \rightarrow RH) = I + P + X + TM(RB \rightarrow LB) + MRTRH$

III. Right hemisphere processing only

1. $RT(RB \rightarrow LH) = I + P + MRTLH$
2. $RT(RB \rightarrow RH) = I + P + TM(RB \rightarrow LB) + MRTRH$
3. $RT(LB \rightarrow LH) = I + TS(LB \rightarrow RB) + P + MRTLH$
4. $RT(LB \rightarrow RH) = I + TS(LB \rightarrow RB) + P + TM(RB \rightarrow LB) + MRTRH$

IV. Both hemispheres capable; right hemisphere more efficient than the left

1. $RT(RB \rightarrow LH) = I + P + MRTLH$
2. $RT(RB \rightarrow RH) = I + P + TM(RB \rightarrow LB) + MRTRH$
3. $RT(LB \rightarrow RH) = I + P + X + MRTRH$
4. $RT(LB \rightarrow LH) = I + P + X + TM(LB \rightarrow RB) + MRTLH$

If, for example, the processing can be accomplished only by the left hemisphere, the fastest condition should be when stimuli are presented directly to the left hemisphere and the required response is mediated via the most anatomically direct motor pathway (the right hand). The slowest response time should occur when the stimuli are initially presented to the right hemisphere and a response is required by the left hand, thereby necessitating two callosal transfers. The two

ipsilateral conditions (LB-LH and RB-RH) should fall half between the two contralateral hemisphere-hand conditions since both require one callosal transmission.¹ Note that for both models I & II the anatomically direct LB-RH condition should be fastest. The crucial difference between the two models is determined by the relationship of left hand

¹ In those models that specify complete lateralization (I&III) for one of the ipsilateral conditions, transmission should involve only a motor command (LB-LH for Model I and RB-RH for Model III), while the other condition should necessitate the transmission of the stimulus information across the callosum (RB-RH in Model I and LB-LH in Model II). The extent to which transmission of stimulus information proceeds more slowly than the transmission of a motor command should be reflected in the difference between these conditions. There is, in fact, some evidence that callosal transmission time increases as a function of the complexity of the material to be transferred (Umiltà et. al., 1972). On the other hand, several investigators have argued that, physiologically, complete lateralization of function must entail active inhibition of the contralateral hemisphere via the corpus callosum (Gazzaniga, 1974; Pribram, 1971). If so, transmission of the motor command from the "processing" hemisphere to the other may actually take longer than transmission of the stimulus information to the "processing" hemisphere.

The relative position of the two ipsilateral hemisphere-hand conditions when cognitive processes are completely lateralized, should therefore be determined primarily by the interaction of callosal transmission times for motor commands versus transmission of stimulus information and the effect of inhibitory process on both of these transmission times.

To the extent that RT models (those proposed here, or any others which are based on what are assumed to be fixed, structural properties of nervous system function), can accurately discriminate between less efficient processing versus callosal transfer of information, they should also be expected to be at least somewhat sensitive to the properties of callosal transmission.

and right hand responses when stimuli are initially projected to the right hemisphere. If the right hemisphere is unable to process the information, RB-LH should be the overall slowest conditions and should be significantly slower than the RB-RH conditions (Model I). The same should hold true for LB-RH and LB-LH for distinguishing when processing is accomplished solely by the right hemisphere (Model III) versus both hemispheres being capable with the RB relatively more efficient than the LB (Model IV).

The models, although primarily based on the assumption that responses with the hand contralateral to the receiving hemisphere are significantly faster than responses with the ipsilateral hand, require several other assumptions. Specifically, they assume that the time required for each hemisphere to receive a stimulus via the optic pathways and perform some rudimentary precategorical processing (subprocess I), will be more or less equal. In addition, the models assume that response times for each hand are also more or less equal.

The first assumption is supported by studies that fail to find hemispheric superiorities when only simple visual matching is required. For example, in a series of studies on face recognition, Moscovitch, Scullion, and Christie (1976) reported that when subjects were required to determine whether two faces presented simultaneously in the same visual field were identical, no hemispheric superiority was found. However, when the to-be-matched face was presented 100 msec

or more after the first face, or the first face was subjected to backward masking, a right hemisphere superiority emerged. The authors concluded that when a task can be successfully accomplished on the basis of precategorical processing (e.g., discrimination based on brightness, contrast, and contour), each hemisphere will be capable of carrying out the task. Hemispheric differences emerge only when more complex stimulus analysis is required. Similarly, Luria (1973) has stated that the hemispheres are functionally differentiated only at the level of the secondary and tertiary areas; the primary cortical areas "are known to have identical roles" (p. 77, italics his).

Traditionally, it has been believed that there are no differences between the hands for simple reaction time (Seashore & Seashore, 1941; Woodworth, 1938). In the Berlucchi et. al. (1971) study, which replicated Poffenberger's findings, it was noted that left hand responses were faster than right hand responses in 9 out of 14 right-handed subjects; however this difference failed to reach significance. In contrast, Maddess (1975), who found faster RT to stimulation of the crossed, as compared to the uncrossed, optic tracts, also reported that right handed subjects performed better with their right hand while left handed subjects were faster using their left hand. In neither study were any hemispheric differences found. However, both Bradshaw and Perriment (1970) and Jeeves and Dixon (1970), reported a slight, but significant, advantage for the LVF-RB when subjects responded to a lateralized flash

of light. No significant hand differences were found in either study. In addition, Berlucchi et al. (1977) found a tendency towards LVF-RB superiority in response to a flash of light in 10 out of 16 subjects. Responses to the light in the LVF was significantly faster at 5° from fixation but failed to reach significance at 20° and 34° from fixation. Anzola et al. (1977) also reported a LVF-RB superiority to a flash of light at 5° from fixation.

The possibility that there may be a right hemisphere advantage for handling simple sensory-motor responses is also supported by several studies demonstrating significantly impaired auditory and visual simple RT in right hemisphere damaged patients as compared to left hemisphere damaged patients (Berson & Barton, 1970; De Renzi & Faglioni, 1965; Howes & Boller, 1975). The results of the Howes and Boller (1975) study are particularly striking in that the effect could not be attributed to differences in size of lesion (as previously assumed, De Renzi & Faglioni, 1965), fatigue, or practice. In addition, they presented evidence indicating that the RT deficit may actually be localizable. In 11 of the 12 patients with the slowest RTs, the lesion was in either the basal ganglia region or posterior parietal lobe of the right hemisphere.

The available evidence seems to indicate that if any hemispheric differences do exist for mediating simple visual motor responses (I+MRT), they would be in favor of the right hemisphere and/or left hand. It should be noted, however, that in the two recent studies that found a significant LVF speed advantage for responses to a lateralized flash

of light (Anzola et. al., 1977; Berlucchi et. al., 1977) the difference was on the order of only 2 to 3 msec. In order to test the proposed models, such slight differences should not effect hypothesized hemispheric differences in stimulus processing when relatively complex cognitive operations are required.

There are, however, two other variables that must be considered because of their possible effect on the ordering of the hemisphere-hand conditions; stimulus-response compatibility and individual subject differences.

As stated previously, one of the major assumptions that the proposed models are based on is the fact that control of individual finger movements is mediated by the contralateral hemisphere. Although this is an established fact, there is some question over whether the speed advantage for the hand contralateral to the receiving hemisphere as compared to the ipsilateral hand reflects this locus of motor control. Broadbent (1974) has argued that when for example, a subject is required to respond as fast as possible to a lateralized flash of light, responses to the light in the RVF are faster with the right hand than with the left hand, not because the light is projected initially to the left hemisphere, which directly controls the right hand, but because of stimulus-response compatibility. Since both the right hand and the RVF are on the same side of space, the time difference between the right hand and left hand to stimuli presented in the RVF does not represent callosal transmission time, but merely reflects

the advantage of a compatible stimulus-response condition (RVF-RH) over an incompatible stimulus-response condition (RVF-LH). The same reasoning applies to the left hand superiority for LVF stimuli. In order to weaken any alternative explanations of the data based on stimulus-response compatibility arguments, subjects who participated in the following experiments were required to respond with their hands in crossed position (Figure 1). When the subject was responding with his right hand, the hand was placed across the body in line with the LVF. When responding with the left hand, the hand was compatible with the RVF. If the results of measuring manual RT of each hand to lateralized stimuli are determined primarily by stimulus-response compatibility, the ipsilateral hemisphere-hand conditions (LB-LH and RB-RH) should produce faster response times than the anatomically direct contralateral pathways (LB-RH and RB-LH). If, on the other hand, the primary determinants are differences in hemispheric processing ability and locus of motor control, the results should conform to one of the proposed models.

Moscovitch (1973) developed RT models which he proposed could be used to assess the absolute ability of each hemisphere. He maintained that whether only one hemisphere or both hemispheres were capable of accomplishing a given task could be determined by the effect of response hand on the size of the RT differences to stimuli presented in the right or left visual field. If processing is done by only one hemisphere, then RTs should favor one visual field by an equal amount

regardless of response hand. This time difference would represent callosal transmission time. If, on the other hand, both hemispheres are capable of processing, then the difference between the visual fields should vary as a function of responding hand. Therefore, the decision as to whether only one or both hemispheres can accomplish a given task is determined by the presence or absence of a significant hand by visual field interaction. Note that such a model does not place as severe restrictions on the order of the hemisphere-hand conditions as those proposed here. For example, in a study requiring phoneme matching (Moscovitch, 1972), the results supported an interpretation of only left hemisphere processing, the RVF was favored by an equal amount regardless of responding hand. The actual data was as follows: LB-LH = 510 msec; RB-LH = 519 msec; LB-RH = 525 msec; RB-RH = 535 msec. When subjects were required to respond with their left hand, the RVF was favored by 9 msec, and when required to respond with their right hand, the RVF was favored by 10 msec. However, if this data reflects only left hemisphere processing, why should the RB-LH condition be faster than the LB-RH condition? In all of his studies to date (Moscovitch, 1972, 1973, 1976 b; Moscovitch et al., 1976), in which an attempt was made to determine whether one or both hemispheres could accomplish a given task, responding hand was used as a between groups factor. Stimuli were randomly presented to the LVF and RVF and half the subjects responded with their left hand, while

the other half responded with their right hand. Although this design can be used to test whether or not there is a hand by visual field interaction and/or a significant main effect for visual field, it is not appropriate for comparing differences between the four hemisphere-hand conditions, since the data are collected from two separate populations. In addition, there is no way to assess the performance of individual subjects in terms of the main concern of distinguishing between processing solely by one hemisphere versus both hemispheres being capable of performing the task.

Individual differences in hemispheric laterality have been attributed mainly to differences in handedness and family history of handedness (see Hardyck, 1977 for review) and sex (Bradshaw & Gates, 1978; McGlone & Davidson, 1973; Rizzolatti & Buchtel, 1977). In fact, the traditional localization of function model is based primarily on a right handed male population. In order to eliminate the possible effect of these variables on the outcome of the order of the four hemisphere-hand conditions, only strongly right handed males were used as subjects.

Another subject variable that may be of importance, but which cannot be as easily controlled for, is individual differences in cognitive style. It is now generally accepted that hemispheric differences are not related to stimulus characteristics per se (e.g., "verbal" versus "non-verbal") but to the nature of the processing demands necessary to accomplish a given task. For example, right hemisphere

superiorities have been found for experiments employing words (Gibson, Dimond & Gazzaniga, 1972) and letters (Cohen, 1972) on matching tasks that could be accomplished on the basis of physical identity. On the other hand, a left hemisphere superiority has been found for a task requiring the matching of faces that differed on only one critical feature (Patterson & Bradshaw, 1975). As a result of these and similar findings, it has been proposed that the hemispheres are differentiated primarily by mode of processing; the left hemisphere characterized by "analytic" processing, the right hemisphere by "gestalt-wholistic" processing (see Experiment 4). If individuals vary in terms of their preference for one processing style versus the other, these preferences may be reflected as differences in hemispheric superiority. This should be especially so for tasks on which the processing demands are weak enough that idiosyncratic preferences in processing style emerge (see also, Galper & Costa, 1978). If such individual differences do occur, the proposed models should still be applicable, but now only on the level of the individual subject, and not for the group data.

In summary, it has been assumed that by requiring subjects to respond manually to briefly presented lateralized stimuli allows control over which hemisphere initially receives the information and which hemisphere controls the final response. Based primarily on these assumptions, models have been designed to discriminate between relative and

absolute lateralization of function in the normal brain. These models are based on what are assumed to be invariant, structural characteristics of nervous system functioning; the neuroanatomical arrangement through which visual information is received and individual finger movements are mediated. They should, therefore, be applicable to any tachistoscopic RT task and to any subject. The purpose of the following experiments was to provide a strict test of these models. Four different RT experiments were designed. For each experiment specific hypotheses were proposed concerning the expected order of the hemisphere-hand conditions as a function of the particular task required. In addition, the same group of subjects participated in all experiments to see if the expected change in laterality patterns from one experiment to the next would be consistent for each subject.

This outcome is a reasonable expectation if the assumption that RT provides a sensitive measure of the structural determinants of visual asymmetries is valid. However, recently some evidence has been presented that could be interpreted as an indication of some underlying dynamic process which may interact with these structural determinants of visual asymmetries.

In 1964, Kimura demonstrated that normal subjects have a left ear advantage for dichotically presented musical chords. The left ear advantage was interpreted as a reflection of the right hemisphere's superiority on tasks that

require perception of music, which is consistent with clinical findings of impaired musical perception following right hemisphere but not left hemisphere damage (Berlin, Chase, Dill & Hagepanos, 1965; Milner, 1958, 1962). Using monaural presentation, Bever and Chiarello (1974) replicated Kimura's finding of a left ear advantage for "musically naive subjects" for recognition of melodies but found a right ear advantage for trained musicians. The authors interpreted this finding in terms of different processing strategies. They claimed that the experienced musicians used an analytic strategy for melody perception, while non-musicians perceived the melody as a gestalt. The contrasting ear superiorities reflected the assumed left hemisphere superiority for analytic processing and the right hemisphere's superiority for wholistic processing. In addition to providing supporting evidence for the importance of processing strategy for producing laterality effects, Bever and Chiarello's findings carry an additional implication for elucidating hemispheric differences. The fact that a highly trained population (musicians) showed an opposite hemispheric superiority than a naive population (non-musicians) raises the possibility that for a given individual, the relative dominance of one hemisphere over the other may shift as a result of experience.

It has been traditionally maintained that RT paradigms require a large number of trials in order to produce stable performance and a minimum number of errors (usually below 5%). One of the objections raised against the use of RT for studying

cognitive processing has been the fear that since such a large number of trials are run, the results reflect the performance of an "expert" at whatever task the experimenter has devised and may therefore be irrelevant for understanding normal cognitive functioning. If, for example, an experimenter develops a task which he has reason to believe will elicit "gestalt-wholistic" processing, there is no guarantee that subjects will actually maintain this, or any other strategy throughout the course of an experimental session. If subjects do develop new strategies as a result of repeated experience with the task, the possibility exists that this change in processing strategy will be reflected by a change in hemispheric superiority. This dynamic process could, in turn, have disastrous effects for models based on invariant structural characteristics of nervous system functioning when the data base against which they are tested is the mean of a large number of trials.

Recently, several investigators using RT paradigms have attempted to look at hemispheric changes as a result of practice. Davis and Schmidt (1973), and Berlucchi et. al. (1971) noted an overall decrease in response times over experimental sessions (an overall practice effect), but no significant interaction of experimental sessions with visual field. However, Kallman and Corballis (1975) reported changes in auditory laterality patterns as a function of practice. They found a left ear advantage for music stimuli during an initial block of 36 trials, but no ear advantage

during the remaining three trial blocks. Hellige (1976) also reported significant changes in visual field superiority over time. Pairs of letters, one upper case and one lower case, were presented and subjects had to judge whether or not the letters had the same name or different names. RT was measured over a period of three days with three 90-trial blocks per day. Unlike other studies employing a similar paradigm (Cohen, 1972; Davis & Schmit, 1973; Geffen, Bradshaw & Nettelton, 1972), no RVF superiority was found for "same" name responses, but there was a shift towards faster responses to letter pairs in the RVF over trials from day 1 to day 2 which then disappeared by day 3. However, no visual field differences, or significant changes over blocks of trials were found when subjects were required to respond "same" or "different" to pairs of irregular polygons. In addition, when the letter task was replicated with a new group of subjects, although a significant interaction between visual field and blocks of trials was again found, "same" name responses to letter pairs in the LVF were faster than responses to pairs in the RVF over all blocks. Furthermore, Hellige required his subjects to respond with one hand to indicate "same" and the other hand to indicate "different", a response situation that has been shown to produce results that are greatly influenced by stimulus-response compatibility factors (Anzola et al., 1977). Interpretation of the results is, therefore, difficult due to a lack of a clear hemispheric superiority over any block of trials and possible

confounding due to stimulus-response compatibility factors. Finally, contrary to the finding of Kallman and Corballis (1975) and Hellige (1976) that the difference between visual fields decreases after repeated experience, Hardyck, Tzeng & Wang (1977) found that the difference between the visual fields increased as a function of the experience. Subjects were required to make "same-different" judgments to Chinese and English words. When new information was presented on every trial, no visual field superiority was found. When a smaller set of words was used, a significant visual field by trial block interaction was found which the authors maintained was due to an increasing RVF advantage over blocks of trials. They therefore concluded that visual asymmetries do not reflect differences in on-going cognitive processing, but only differences in memory storage locations.

Although based on this previous research it is not at all clear what, if any, relationship exists between the amount of prior experience with a task and hemispheric superiority, the evidence does suggest the possibility of some ongoing dynamic process (differential hemispheric learning, changes in processing strategy?) that may be of importance for understanding hemispheric functioning.

For the experiments presented here, specific predictions were based only on the structural models. However, the data was also analyzed over blocks of trials to determine if, in fact, prior experience does significantly effect any observed differences between the visual fields.

In order to test the usefulness of the proposed models, four RT experiments were designed. Based on a review of the current experimental literature, specific hypotheses were proposed concerning the overall expected visual field superiority and the ordering of the hemisphere-hand conditions. Experiments 1 and 2 were designed to assess the linguistic abilities of the normal right hemisphere. In Experiment 1, subjects were required to judge whether a word was a noun or a verb. It was expected that although both word classes should be processed more efficiently by the left hemisphere, the right hemisphere should be able to process familiar, concrete nouns, but not verbs. Experiment 2 was designed to force subjects to phonemically encode single letters to produce only left hemisphere processing. In Experiment 3, photographs of faces were used in an attempt to produce results consistent with the model for only right hemisphere processing. Finally, in Experiment 4, arrays of geometric symbols were used to elicit "gestalt-wholistic" processing, and, therefore, a right hemisphere superiority in response to a previously memorized "target" array, and the use of an "analytic" strategy, and, therefore, a left hemisphere superiority, for responses to "non-target" arrays.

II

GENERAL METHOD

Subjects

Eight male students at the City College of C.U.N.Y., ranging in age from 18 to 29 years, were paid \$15.00 for participating in all four experiments. All subjects were identified as strongly right handed on the Annett Scale (1972), had no close left-handed relatives, and had normal visual acuity ($20/20 \pm 10$ for each eye tested independently using a Keystone Ophthalmic Telebinocular).

Procedure

Stimuli were presented by means of a Gerbrands 3-channel tachistoscope, Model T-3B-10, at an illumination of $\log 3.5$ mL.

In each experiment a trial consisted of the presentation of a single stimulus about which the subject was required to make a judgment. Depending on the experiment, the subject made a decision based on whether the stimulus matched a previously memorized "target" or whether it belonged to a previously indicated class (e.g., noun or verb). The subject was instructed to indicate his decision by lifting the appropriate finger (either index or middle) off a micro-switch. RT was measured from the onset of the stimulus to the release of the micro-switch by a Gerbrands G1271 digital millisecond timer.

For each experiment, subjects participated in two testing sessions. In the majority of cases, the second session was run 24 hours after the first, and in no cases did the second session follow the first by more than 48 hours. A minimum of 6 days elapsed between experiments. Each subject thus participated in 8 testing sessions over a period of approximately 1 month. A testing session consisted of 24 practice trials and 192 experimental trials, and lasted approximately 45 minutes. The practice trials consisted of two blocks of 12 trials, one block for responses with one hand and one block for responses with the other hand. The experimental trials were run in blocks of 48 trials with the subject switching response hand for each trial block. In each block of trials there was an equal number of RVF and LVF trials and an equal number of trials for each judgment in each visual field. For each block of trials, stimuli were quasi-randomized for field of presentation and required judgment. The only restriction was a maximum of three consecutive trials in the same visual field or requiring the same judgment. Summing over testing sessions, each subject thus received 48 trials for each of the four hemisphere-hand conditions for each judgment in each experiment. Response hand order was counter-balanced within subjects across the two testing sessions for each experiment. Experiment order, response hand order, and which finger was used to indicate each judgment were all counter-balanced across subjects (Table 1).

A trial consisted of the presentation of a black fixation dot centrally located on a white card. The fixation dot was viewed for 2 sec. and was immediately followed by the presentation of a lateralized stimulus for 150 msec. Each stimulus was presented on white cards measuring 102 x 152 mm., lateralized either to the right or left of fixation, and subtending a visual angle of $2^{\circ}24'$ measured from fixation to the geometric center of the stimulus.

Each testing session began with the subject seated in front of the RT apparatus and tachistoscope. After the task requirements of the particular experiment were explained, the subject was familiarized with the response apparatus. The appropriate response hand was positioned on the RT board and his index and middle fingers placed on the appropriate microswitches. The subject was instructed as to the importance of keeping his forearm and non-responding fingers stationary on the board so that each response would be made by only a single finger movement, and was given time to practice the required lift-off response. He was then told that each trial would begin with the presentation of a black dot in the center of the viewing field which would then be followed by the stimulus located either on the left or right of the viewing field. He was further instructed that since for any given trial he would not know which side the stimulus would appear on, the optimum strategy would be to fixate right on the centrally located dot. Throughout the testing sessions, subjects were reminded periodically to maintain fixation

and respond with a discrete finger movement.

Subjects were encouraged to respond as quickly and as accurately as possible. To further ensure speed, accuracy, and low variability of responses, subjects were told that if their responses were incorrect or longer than 900 msec on more than 10% of the trials, they would be dropped from the study (Moscovitch et al., 1976). All subjects were able to meet this criterion. All trials on which an error was committed or on which RT exceeded 900 msec were rerun at the end of each block of 48 trials (Geffen et al., 1971; Patterson & Bradshaw, 1975).

III

EXPERIMENT 1

The predominant view, based on over a century of clinical observation, is that in right handed adults, language functions are localized solely in the left hemisphere. Relatively small, discrete lesions within the language zones of the left hemisphere produce linguistic disturbances, aphasias, with the resulting pattern of deficit related to the locus of the lesion within the hemisphere (Goodglass & Geschwind, 1976; Luria, 1966). Similar lesions in the right hemisphere produce, at most, minimal linguistic deficits. Although there is evidence that linguistic abilities can be subserved by the right hemisphere when critical areas within the left hemisphere have been damaged at an early age (Milner, 1974), and that even in adults some language processes may be taken over by the right hemisphere after left hemisphere damage (Kinsbourne, 1971), the exact role, if any, that the right hemisphere has for normal language functions has remained unclear.

Historically, investigators have speculated about the possible linguistic abilities of the right hemisphere. For example, Broca, who showed that disturbances in speech production resulted from damage to the third frontal convolution of the left, but not the right, hemisphere, also believed that both hemispheres could decode speech (Broca, 1865, cited in Searleman, 1977). Hughlings Jackson (1874) maintained

that although the left hemisphere was responsible for the production of propositional speech, the right hemisphere was capable of producing apropositional speech, such as expletives and overlearned phrases (this belief was later adopted by Henschen (1926), one of the strongest proponents of strict localization). Jackson also stated the propositions were received by the right hemisphere, based on his belief that comprehension, like the production of expletives, is an "automatic" process (Jackson, 1874, p. 132). However, as Jackson stated "the matter of most significance is that damage to but one hemisphere [the left] will make a man speechless." (Jackson, 1874, italics his). Similarly, in a recent review of language disorders resulting from vascular lesions, Goodglass and Geschwind stated that "the left hemisphere alone is responsible for language in the overwhelming majority of right-handed adults" (Goodglass & Geschwind, 1976, pp. 394-395).

Recently there has been increased interest concerning the language capacity of the right hemisphere (e.g., Dennis & Whitaker, 1976; Gazzaniga & Hillyard, 1971; Moscovitch, 1973, 1976 a and b; Searleman, 1977; Selnes, 1976). A controversy has developed primarily as a result of a series of studies aimed at assessing the linguistic competence of the right hemisphere of split-brain patients. Sperry and his co-workers, (Gazzaniga, 1970) demonstrated that these patients are unable to verbally report any words briefly presented in the LVF, supporting the classical position that the function of speech

is localized solely to the left hemisphere. However, using their left hand, they could pick out the correct object, from an array of objects hidden from view, that corresponded to the objects name which had been flashed in the LVF. Therefore, the linguistic competence of the right hemisphere could be tested by allowing the subject to indicate his answer using a response mechanism under the control of that hemisphere.

Using this paradigm, Gazzaniga (1970) reported that the right hemisphere was able to process simple nouns but not verbs of any kind. Subsequent research on this same group of patients reported auditory comprehension of both nouns and verbs (Zaidel, 1976, 1977). In fact, Zaidel, employing a newly developed contact lens technique that supposedly allows a visual stimulus to remain lateralized for long intervals of time, administered a standardized test of auditory vocabulary to two split-brain subjects and one left hemispherectomy patient and reported that the right hemisphere of these patients possessed an auditory lexicon with a mean equivalent age of 11 years 7 months (Zaidel, 1976). These findings have lead to a controversy concerning the extent to which the performance of the disconnected or isolated right hemisphere reflects the capabilities of the normal right hemisphere. If the results from these patients do provide an accurate assessment of right hemisphere abilities, it is necessary to explain why some aphasics with small left hemisphere lesions exhibit less linguistic ability than the right hemisphere of split-brain patients.

Some investigators (e.g., Selnes, 1976) have argued that the linguistic ability of the right hemisphere of split-brain patients does not represent normal right hemisphere function, but instead reflects reorganization as a result of the patients' past history of severe epilepsy. Other investigators (Gazzaniga, et al., 1973; Moscovitch, 1973, 1976 a & b) have argued that the performance of these patients accurately reflects the language abilities of the right hemisphere and have hypothesized that the severe linguistic deficits resulting from a circumscribed left hemisphere lesion are due, in part, to the inhibitory effects that the damaged left hemisphere has upon the right hemisphere. Similarly, the notion of interhemispheric inhibition has been proposed as an alternative explanation for studies that demonstrate subtle linguistic deficits in patients with unilateral right hemisphere lesions as compared to normal controls (Searleman, 1977). In this case it is now the pathological right hemisphere which sends noise over to the left hemisphere thereby causing the subtle linguistic deficits.

Moscovitch (1973) pointed out the importance of obtaining evidence from normal subjects for determining the linguistic ability of the right hemisphere. In a series of studies (Moscovitch, 1972, 1973, 1976 b) he measured manual RT to lateralized letters and analyzed the data according to his model as outlined in the General Introduction. For every task that required phonemic analysis, the results supported the model for only left hemisphere processing. In

order to resolve the apparent discrepancy between the performance of his subjects and the results obtained from split-brain subjects, Moscovitch proposed the model of "functional localization." This model states that the linguistic competence of the right hemisphere is the same in all right-handed subjects, including split-brain subjects, however, in normal subjects the dominant hemisphere interferes or inhibits the verbal behavior of the right hemisphere via the midline commissures and other pathways (Moscovitch, 1973).

It is important to point out that the model of "functional localization" was proposed to explain the inconsistency between the split-brain right hemisphere's ability to comprehend single words and the normal right hemisphere's inability to process nonmeaningful graphemic units (letters). This apparent inconsistency rests on the assumption that the reading of single words cannot be accomplished without phonemic analysis. However, Levy (1974), using tachistoscopic presentation, and Zaidel (1974), using dichotic listening, have presented evidence indicating that the right hemisphere of the split-brain subject is not capable of phonetic analysis. In addition, Saffran and Marin (1977) have demonstrated intact reading of single words in a patient who has lost the ability to phonemically decode as a result of left hemisphere damage. It has also been reported that different aphasic groups are able to read isolated concrete nouns better than other word classes (Gardner & Zurif, 1975). It is, therefore, unlikely that phonemic

decoding is a necessary condition for reading single words, especially familiar concrete nouns.

A more appropriate test of the language capacity of the normal right hemisphere should employ the type of stimuli that the split-brain patients' right hemisphere seems most capable of processing; simple, concrete nouns. Several investigators have attempted to study right hemisphere language processing in normals using accuracy of report of tachistoscopically presented concrete nouns.

Ellis and Shepherd (1974) reasoned that the ability of split-brain patients to process nouns, but not verbs, when presented in the LVF may be due to the concreteness of the words used, not syntactic category. They presented concrete and abstract nouns simultaneously to the left and right visual fields and found that both types of words were identified more accurately when presented in the RVF than in the LVF. In addition, concrete words were recognized better than abstract words when presented in the LVF, whereas there was no significant advantage for processing concrete words better than abstract words when presented in the RVF. Hines (1976) replicated this finding using both simultaneous, bilateral presentation, and unilateral presentation, but found the effect only for high frequency concrete words. Both these studies required verbal report, thereby necessitating the transmission of some information across the corpus callosum for reporting words presented in the LVF. The authors assumed, however, that since there is no reason to

postulate greater transmission loss for abstract than concrete nouns, the right hemisphere must be able to recognize some concrete nouns.

However, other attempts to replicate these results have not been as successful. Orenstein and Meighan (1976), using the same procedure as Ellis and Shephard (1974), reported a LVF superiority for both abstract and concrete nouns which they attributed to left-right scanning habits for word reading. Caplan, Holmes and Marshall (1974) attempted to assess hemispheric differences for three syntactic classes of nouns; "pure" nouns, with no verb component, e.g., river; agentive nouns, derived from an underlying verb, e.g., helper; and category-ambiguous words which can be used as either nouns or verbs, and where the meaning of the two syntactic forms is related, e.g., father. Their results indicated an overall superiority for words presented in the RVF. However, for words presented in the RVF agentive nouns were recognized better than both "pure" nouns and category ambiguous nouns, and for words presented in the LVF recognition of category-ambiguous nouns and agentive nouns was superior to recognition of "pure" nouns. Therefore, syntactically more complex nouns were recognized better when initially presented to the right hemisphere than syntactically simpler ones. As the authors pointed out, it is difficult to reconcile such results with our current knowledge of hemispheric specialization.

These conflicting and unexpected findings may be due

to some of the problems inherent in the use of a verbal response measure for exploring hemispheric differences, as mentioned previously.

In the following experiment, manual RT was measured from both the left and right hands in order to test Gazzaniga's (1970) assertion that the right hemisphere can process visually presented concrete nouns, but not verbs of any kind. Single lateralized words were presented and subjects were required to determine whether the word was a noun or a verb. All words were printed vertically to control for left-right scanning tendencies, and were of equal familiarity.

It was assumed that concrete nouns are the most likely linguistic stimuli to reveal right hemisphere processing based not only on the findings with split-brain patients, but also on the assumption that they should be more suitable than other word classes for "whole-word" reading strategies not dependent on phonemic processing. That is, when presented with a familiar concrete noun it may be possible to go directly from the written word to its image representation without the intermediary step of phonemic decoding.

It was predicted that

1. Response times would be significantly faster for both nouns and verbs in the RVF than in the LVF.
2. For responses to nouns, the hemisphere-hand conditions would conform to order specified by Model II, indicating that both hemispheres are capable of processing these words, the left hemisphere being more efficient than the right hemisphere.

3. For responses to verbs the hemisphere-hand conditions would conform to the order specified by Model I, only left hemisphere processing.

Method

Materials

The stimuli were 12 concrete nouns and 12 verbs (see Table 2). All words were three letters in length and of equal familiarity (100+ per million, Thorndike & Lorge, 1944). The words were constructed using 24-point Helvetica Medium Letraset capital letters and oriented vertically. Each word subtended a visual angle of 1°55' vertically and 0°22' horizontally.

Procedure

The procedure followed the description provided in the General Method section.

Subjects were told that immediately following the fixation dot a word would appear either on the left or right of the viewing field. The words would all be three letters in length written vertically. A given word would either be a noun, referring to an object, or a verb, referring to an action. The subject was instructed to indicate whether the word was a noun or a verb by lifting the appropriate finger off the microswitch. Each block of 48 trials consisted of one presentation of each noun and each verb in each visual field.

Results

The RT data were subjected first to an analysis of variance by the three main factors of Visual Field (left or right), Hand (left or right), and Judgment (noun or verb), plus two additional time factors; Day (first day or second day) and Half (first half of the trials or second half of the trials on each day, 96 trials per half). This analysis of variance, as well as all others to be reported, was with repeated measures on all factors.

Responses on Day 2 were significantly faster than on Day 1 (607 msec vs. 669 msec, respectively). $F(1,7) = 87.336$, $p < .001$. RTs from the second half of each day were significantly faster than from the first half (627 msec vs. 649 msec), $F(1,7) = 15.186$, $p < .01$. There was also a significant Day X Half interaction due to a greater overall decrease in RT on Day 1 (35 msec) than on Day 2 (9 msec), $F(1,7) = 6.926$, $p < .05$. There were no significant interactions of either Hand, Judgment, or Visual Field with either of the time factors (Day or Half).

As predicted, words initially presented in the RVF were responded to faster than those presented in the LVF (RVF = 633 msec, LVF = 644 msec), $F(1,7) = 10.298$, $p < .02$. All other main effects and interactions failed to reach significance.

Since specific predictions were proposed concerning the differential processing of nouns and verbs, separate

analyses were carried out for each word class.

Nouns

Structural Models. The analysis of variance (Day X Hand X Visual Field X Half) yielded significant main effects for Day, $F(1,7) = 34.728$, $p = .001$, and for Half, $F(1,7) = 19.172$, $p < .005$. Nouns presented in the RVF were responded to 16 msec faster than in the LVF (RVF = 622 msec, LVF = 638 msec), $F(1, 7) = 17.817$, $p < .005$.

There was also a significant three-way interaction of Day, Hand, and Half, $F(1,7) = 6.636$, $p < .05$, due to a 25 msec advantage for the right hand on the first half of Day 1 and equal performance of the hands on the three remaining half day segments. There were no other significant main effects or interactions, including any interactions of Hand, Day, or Half with Visual Field.

The mean RTs for each hemisphere-hand condition, over all trials (Day 1 and Day 2) are presented in Table 3. Inspection of the table reveals that the ordering of the conditions does not conform to the order expected if the right hemisphere was able to process nouns since the direct anatomical pathway from the right hemisphere to the left hand (RB - LH) was the slowest condition. However, the ordering does conform to the model for only left hemisphere processing (Model I). Specific comparisons of conditions revealed that the anatomically direct LB - RH was significantly faster than the anatomically direct RB - LH condition. However, although the RB - RH condition was faster than the

RB - LH condition, this difference failed to reach significance. As specified by the model for only left hemisphere processing, if all stimuli initially projected to the right hemisphere must be transferred to the left for processing, the RB - RH condition should be significantly faster than the RB - LH condition.

Mean RTs for each subject over both testing sessions are presented in Table 4 (Day 1 and Day 2). An overall RVF speed advantage was noted in 7 of the 8 subjects. The LB - RH was the fastest condition for 5 subjects and RB - LH was the slowest for 6 subjects.

The overall analysis for nouns did provide fairly strong support for the structural model of hemispheric functioning, as indicated by the overall RVF advantage, which did not interact with either of the time factors (Day or Half), and the ordering of the hemisphere-hand conditions.

Time Dependent Changes. Consideration of the hemisphere-hand conditions on each day separately, however, tended to indicate some change in hemispheric processing over time. As shown in Table 3, on Day 1 the ordering conforms perfectly to the model for only left hemisphere processing, and, unlike the overall data, the RB - RH condition was significantly faster than RB - LH. However, on Day 2 the order has changed in the direction expected if the right hemisphere is able to process concrete nouns; the RB - LH condition has become faster than RB - RH. the time difference between RTs of the RB - RH and RB - LH decreased in 6 of

8 subjects on Day 2 as compared to Day 1 (see Table 4).

Separate analyses of variance for each day (Hand X Visual Field X Half) revealed a significant 13 msec RVF advantage on Day 1, $F(1, 7) = 5.675$, $p < .05$ (6 of 8 subjects), and a significant 18 msec advantage on Day 2, $F(1, 7) = 16.542$, $p < .005$, (8 of 8 subjects). The only other significant finding was for Half on Day 1 indicating an overall practice effect, $F(1, 7) = 17.827$, $p < .005$.

The pattern of change in RT over the course of each day is presented in Figure 2. Each data point represents the mean RT for each visual field over each half day (96 trials) averaged across hands since this factor (Hand) was not significant either as a main effect or in interaction with visual field at any level of analysis (Day or Half).

Inspection of the figure indicates a trend towards increasing difference between the RTs for each visual field (going from Half 1 to Half 2), and, although the visual field X Half interaction did not reach significance on either Day 1, $F(1, 7) = 3.988$, $p = .075$; or on Day 2, $F(1, 7) = .636$, $p = .4$; analysis of each half day separately (Hand X Visual Field) indicated a significant RVF advantage on both the second half of Day 1 and the second half of Day 2 ($F(1, 7)$, $p < .03$ for Half 2 of Day 1, and $F(1, 7) = 6.484$, $p < .04$ for Half 2 of Day 2), but no significant RVF advantage during the first half of either day ($F(1, 7) = .237$, $p > .5$ and $F(1, 7) = 2.126$, $p > .1$, respectively). Therefore, on both

days the expected RVF advantage did not emerge until after 120 trials (96 experimental trials preceded by 24 practice trials).

To determine if there was significant differential hemispheric improvement over the course of each day, percent change scores were computed for each hemisphere-hand condition by subtracting the mean RT of the second half of the day from the mean RT of the first half of the day, dividing by 2 and multiplying by 100 ($\% \text{ change} = \frac{\text{Half 1} - \text{Half 2}}{2} \times 100$). Analysis of variance using these scores (Hand X Visual Field), failed to reveal any significant change on Day 1 or Day 2.

As can be seen in Figure 2, not only was there an apparent trend towards a larger RVF advantage over time, but there was actually a slight (5 msec) advantage for the LVF during the first half of Day 1. To further clarify and substantiate this pattern each half day (96 trials) was divided into equal blocks of 48 trials cutting across all hemisphere-hand conditions (Figure 3). As can be seen, the LVF advantage was even larger, 20 msec, on Block 1, followed by RVF advantages of 10, 29, and 33 msec on Day 1; and RVF advantages of 16, 9, 20 and 30 msec on Day 2.

The finding of a LVF advantage on the first block of Day 1, although failing to reach significance, $F(1, 7) = 4.638$, $p = .069$, was found for 7 of the 8 subjects.

The pattern of response times for the four hemisphere hand conditions on Block 1 revealed that the LVF advantage

was found regardless of responding hand. However, considering only responses to nouns presented in the RVF, right hand responses were faster than left hand responses, tending to indicate left hemisphere processing, whereas for responses to nouns presented in the LVF, the right hand was again faster than the anatomically more direct left hand, arguing against right hemisphere processing of this material.

Returning to the significant three-way interaction of Day X Hand X Half resulting from the right hand advantage during only the first half of Day 1, the right hand advantage was found to be even greater over the first block of Day 1, being significantly faster than the left hand on this block only, $F(1, 7) = 5.662, p < .05$. The pattern for the right hand then mirrors that found for the LVF, both showing a small advantage during the first of Day 1 and both approaching or reaching a significant advantage during an earlier block of trials.

Since it would be unlikely to expect an advantage for processing nouns with the right hemisphere at the beginning of an experiment and then switch to left hemisphere processing, nor is there any reason to expect a significant right hand advantage coupled with a LVF advantage, the most parsimonious explanation is of left hemisphere superiority for nouns throughout the course of the experiment, with the LVF advantage over Block 1 being related to other experimental variables somewhat unrelated to the primary lexical decision task.

In summary, responses to nouns were found to produce an overall RVF superiority across both Days 1 and 2, with the order of the hemisphere-hand combinations in agreement with the model for only left hemisphere processing. This RVF advantage was significant on each day analyzed separately but the hemisphere-hand order was found to be in agreement with the model for only left hemisphere processing on Day 1 with a shift towards some right hemisphere ability by Day 2. In addition, over the course of each day there was a pattern of an increasing superiority of the RVF over the LVF producing a significant RVF advantage on the second half, but not the first half, of each day. Finally, the emergence of the RVF superiority over time was preceded by a LVF advantage on the first block of Day 1 for 7 of 8 subjects.

Verbs

Structural Models. The overall analysis of variance by Day, Hand, Visual Field and Half yielded a significant main effect for Day, $F(1, 7) = 127.712$, $p < .001$, and Half, $F(1, 7) = 11.519$, $p < .02$, as well as a significant Day X Half interaction, $F(1, 7) = 13.580$, $p < .01$. There were no other significant main effects or interactions.

The lack of any significant visual field superiority was also reflected by the ordering of the hemisphere-hand conditions (see Table 5).

Not only did the order fail to conform to the expected model (Model I, left hemisphere processing only) or to any of the other models, but there was a very small

range from the fastest to the slowest brain-hand condition (9 msec vs. 23 msec for nouns).

Time Dependent Changes. Analysis of each day separately was consistent with the overall analysis, yielding only a significant main effect for Half on Day 1, $F(1, 7) = 17.236$, $p = .005$. There were no other significant main effects or interactions on either Day 1 or Day 2.

Similarly, the analysis of variance using the percent change scores also failed to reveal any differential improvement between the visual fields or between hands.

The hemisphere-hand conditions for each day separately (Table 5) again failed to conform to the expected model or to be significantly different from each other.

Finally, the analysis of variance with blocks of trials (Hand, Visual Field and Block (1, 2, 3 & 4)), yielded a significant main effect for Block on both Days 1 and 2 ($F(3, 21) = 13.342$, $p < .001$; $F(3, 21) = 5.589$, $p < .01$, respectively), and a significant Visual Field X Block interaction on Day 2, $F(3, 21) = 3.928$, $p < .03$. Analysis of each Block separately (Hand by Visual Field) revealed a RVF-LB advantage on only Block 3 on both Days 1 and 2; ($F(1, 7) = 6.447$, $p < .04$, $F(1, 7) = 14.924$, $p < .01$). Therefore, on both Days 1 and 2 a small but significant advantage for the RVF-LB emerged after 120 trials (96 experimental trials plus 24 practice trials). Inspection of Figure 3 reveals, however, that this RVF superiority was short-lived. By Block 4 the LVF was faster on both days.

This cross-over from Block 3 to Block 4 was observed in 6 out of the 8 subjects on both Day 1 and Day 2.

The overall results for responses to verbs, in contrast to nouns, yielded no consistent visual field superiorities nor hemisphere-hand orderings consistent with any of the models. As shown in Table 6, there was a great deal of variability in the ordering of the hemisphere-hand conditions between subjects and for each subject from Day 1 to Day 2.

Errors and Slow Responses

The error rate over all trials was low, 3.4%, as was the number of trials reran because RT exceeded 900 msec, 5.8% overall. Both errors and long RTs were subjected to analysis of variance (Hand X Judgment X Visual Field, for each day separately). Since a response was required on every trial, an error consisted of a response with the wrong finger. In this experiment, as well as for the others to be reported, subjects were invariably aware of such mistakes (see also, Moscovitch et al., 1976). These errors, then, most likely reflect motor response errors as opposed to errors in judging the stimuli.

There was a significant Hand X Visual Field interaction for errors on Day 1, $F(1, 7) = 7.631, p < .03$, due to a greater number of errors with the left hand in response to RVF than LVF words, and more right hand errors in response to LVF than to RVF words. Therefore, more errors were committed when the word was received by one hemisphere and the

other hemisphere initiated the response. There were no other significant interactions or main effects for errors or long RTs.

Discussion

Considering only responses to concrete nouns, there was little evidence to suggest that the right hemisphere of normals is able to process these words independently of the left hemisphere. The overall results were most consonant with the model for only left hemisphere processing. This pattern of RTs is consistent with either a strict localization of function model; in order to perform a linguistic task, information initially received by the right hemisphere must be transferred to the left because the neurological mechanisms on which language functions are dependent are located only in the left hemisphere, or with Moscovitch's model of "functional localization": the normal right hemisphere is capable of performing this task, but its language functions are inhibited by the more language efficient left hemisphere. In either case, the results indicate that normals behave as if the ability to identify a word as a noun is mediated solely by the left hemisphere.

The primary rationale for the model of "functional localization" was the apparent discrepancy between the language ability of the right hemisphere of normals and aphasics as compared to split-brain patients. The findings with split-brain patients have also provided the basis for all studies attempting to access the language functions of the right hemisphere in normals.

Out of the original series of 10 split-brain patients only two patients demonstrated an ability to recognize words presented to the right hemisphere. In Gazzaniga's (1970) review of these findings it was pointed out that the other patients were either not studied extensively due to post-operative complication, or had failed these tests, presumably because of right hemisphere damage. All subsequent studies of the language functions of the split-brain patients' right hemisphere (e.g., Levy, 1974; Zaidel, 1976 and 1977) have been carried out on these same two patients from the original series of 10.

Recently, Gazzaniga and his co-workers have studied a new group of 16 patients who have undergone complete sectioning of the corpus callosum. The authors claim that out of this group only one patient has demonstrated any right hemisphere language ability. Therefore, right hemisphere language has been conclusively demonstrated in only three of 26 split-brain patients. Furthermore, there is evidence indicating that each of these three patients suffered early left hemisphere damage (Gazzaniga, LeDoux & Wilson, 1977). Since it has been previously determined that early injury to left hemisphere areas that normally subserve language will lead to the development of language function in the right hemisphere (Lansdell, 1969; Milner, 1974), the split-brain findings are no longer discrepant with the findings with other neurological populations. It therefore appears less reasonable to postulate that the normal right hemisphere of strongly right handed males has a variety of linguistic abilities which

are inhibited by the left hemisphere.

Studies of aphasic patients have provided a great deal of evidence indicating that any description or explanation of language, whether on the anatomical, physiological, psychological or linguistic levels, must proceed from the standpoint that language is not a unitary function, but a variety of functions (e.g., speech production, auditory comprehension, reading, and writing), and that each function is dependent on a number of subprocesses.

The function of auditory comprehension, for example, is not strictly localizable to one specific region in the left hemisphere, but can be disrupted by a lesion in a variety of areas. However, the nature of the comprehension deficit varies as a function of lesion site, presumably because different subprocesses are effected (e.g., Caramazza & Zurif, 1976).

One of the frequent consequences of the selective disruption of specific subprocesses is the reorganization of existing systems to carry out the impaired function (e.g., Marin, Saffran & Schwartz, 1976). For example, almost all models of normal auditory comprehension assume that one necessary subprocess is the ability to accurately discriminate phonemes (Neisser, 1967), yet good comprehension has been demonstrated in patients who cannot discriminate isolated phonemes, while other patients with severe comprehension deficits can perform this task (Blumstein, Baker & Goodglass, 1977). It can be assumed that patients who cannot

discriminate isolated phonemes but who display intact comprehension in a normal setting, mediate this function, in part, by taking advantage of non-linguistic cues (e.g., redundancy and context) (see Boller, Kim & Mack, 1977, for review). When the opportunity to employ this alternative strategy is limited (for example, when comprehension is tested with the Token Test, which was specifically designed to reduce redundancy and contextual cues) comprehension is found to be impaired.

Similarly, as mentioned previously, alternative strategies for word reading have been demonstrated as a result of brain damage. The patient studied by Saffran and Marin (1977), as well as Levy's (1974) analysis of right hemisphere reading ability provided evidence for an alternative strategy not dependent on grapheme-to-phoneme conversion. However, it does not necessarily follow that since an alternative strategy for reading can be demonstrated as a result of brain damage, normal subjects will use this strategy, even under circumstances that may favor that approach; the severe time restraints of tachistoscopic presentation.

Evidence to support this conclusion is provided by a recent series of studies by Rayner and Posnansky (1978) who evaluated three models of word identification; the direct-semantic-access model, the visual-features stage model, and the phonemic-recoding stage model. Out of a total of six separate experiments, they found no evidence whatsoever in support of the direct-semantic-access model, and concluded that this particular model is inappropriate for normal word identification.

Although this experiment was not designed to address questions of reading strategy, it was assumed that any demonstration of right hemisphere reading would be dependent on some non-phonological route from print to meaning. This assumption was based on the lack of evidence for phonemic decoding in those split-brain patients who could read words presented in the LVF, as well as on evidence demonstrating that the right hemisphere employs a "gestalt/wholistic" mode of processing (see Experiment 4).

In this respect, the results indicated that, under the requirements of this task (which required subjects not only to discriminate words, but to do so as accurately and as quickly as possible) a subject will probably rely predominantly on the reading strategy habitually used, and will not employ alternative strategies, even if such alternatives can be demonstrated to be potentially within his cognitive repertoire. Furthermore, regardless of the exact nature of the strategy employed, it is dependent upon functions lateralized to the left hemisphere.

However, although the results for nouns did not provide any evidence that the right hemisphere could independently process these words, there was evidence that the right hemisphere may play a role in normal reading. The pattern of change in the degree of asymmetry over time revealed that right hemisphere functions may be most important during the earliest trials, while the change in the ordering of the hemisphere-hand conditions from Day 1 to Day 2 hints at the emergence of right hemisphere "reading" ability. This

suggests that alternative strategies may emerge when the task demands become sufficiently weakened as a result of repeated experience with a small set of stimuli.

Reading, like all complex cognitive functions, is best viewed as a multistage process. Pirozolla and Rayner (1977) investigated the type of errors made in word recognition by using a forced-choice procedure. They found that words were recognized better in the RVF and that more visual confusion errors (i.e., the choice of a word with the same shape or outline as the one presented) were found for LVF than for RVF words. They concluded that the early stages of word recognition involve visual feature analysis and that the right hemisphere is superior to the left for this process. This interpretation is consistent with the findings of Gibson et al. (1972), who reported a LVF superiority for matching pairs of words, and Bryden and Allard (1976), who reported a RVF superiority for letter recognition when letters were presented in familiar typefaces, but a LVF superiority for unfamiliar, scriptlike typefaces. This finding is particularly striking since the dependent measure was verbal report and, therefore, required participation of the left hemisphere.

The changes in visual field superiority found for nouns would be consistent with a model that assumes that reading is a multistage process, that each hemisphere is superior for some of these processes, but not others (e.g., the right hemisphere is better for the early perceptual stages, the left hemisphere is required for linguistic

analysis), and that the relative importance of a given stage can vary as a result of experience with the task demands and the particular stimuli. Such a model could account for both the importance of right hemisphere processes during the earliest trials and the emergence of right hemisphere ability during later trials.

Because the results of the other experiments revealed similar changes over blocks of trials, these issues will be elaborated upon in the Final Discussion section.

In light of the findings for nouns, the results for verbs were particularly surprising. Although a lack of visual field superiority is often interpreted as evidence for equal processing ability for each hemisphere, the ordering of the hemisphere-hand conditions provided no support for this alternative. Furthermore, there is no reason to believe that verbs should be easier for the right hemisphere to process than concrete nouns, in fact, just the opposite was expected. In comparison to nouns, RTs to verbs were somewhat slower, and showed greater variability both between subjects and for a given subject from day to day. Although it is possible that these results were due to some peculiarity of verbs, as opposed to nouns, it is more likely that these results reflect decision processes that occurred after "word" processing. That is, verbs may have been processed the same way nouns were, but then required some additional processing before a correct response could be made. In addition, this extra processing may have required bihemispheric involvement, resulting in the lack of any significant visual field advantage.

Most experiments that have required a decision, and a separate response to indicate each decision, have been done within a "same-different" framework, with "same" defined along some specified dimension (e.g., same name, physical identity), and "different" defined as "not same". The processes involved in making these judgments have yet to be adequately specified and have often produced confusing results for both foveal presentation (e.g., Egeth & Blecker, 1971), and lateralized presentations (see Moscovitch, 1973, Note 3). Several models have been proposed to account for the processes underlying these judgments. One characteristic that many of these have in common is that "different" judgments, are assumed to require either additional stages of processing, or are carried out by processes that require more time and are somewhat independent of those involved in "same" judgments.

For example, a model proposed by Egeth and Blecker (1971) states that the "sameness detector" is responsive to specific stimulus properties (e.g., familiarity), while the "difference detector is relentlessly featuristic" (p. 325). Davis and Schmit (1971) studied "same-different" judgments to lateralized stimuli and proposed a similar model whereby judgments "different" require multiple comparisons. In addition, their explanation assumes interhemispheric comparisons. Depending on the task, one hemisphere alone can respond "same" but cross-checking with the other hemisphere is always required before a stimulus can be judged "different".

It was assumed that the noun - verb decision required for this experiment would force subjects to process each word according to its semantic class. It is possible, however, that subjects found it easier to approach the task as a noun-non-noun discrimination. Studies employing a lexical decision task in which words had to be discriminated from pronounceable nonwords (Bradshaw, Gates & Nettleton, 1977; Leiber, 1976) have reported a significant RVF superiority for real words, no visual field difference for nonwords, and faster RTs to words. The overall results for nouns and verbs were quite similar to findings for words versus nonwords. The results for verbs in this experiment are also consistent with Davis and Schmit's suggestion that "different" requires inter-hemispheric cross-checking. This is supported by the longer RTs as compared to nouns, and the small range between the fastest and slowest hemisphere-hand conditions. That is, once both hemispheres are involved, the relationship between the hemisphere initially receiving the stimulus and the hemisphere that controls the response is of little consequence.

This interpretation received additional support from the following experiment which was designed within the more traditional "same-different" framework.

IV EXPERIMENT 2

In contrast to words, alphabetic material has been frequently used in manual RT paradigms by investigators who have sought to demonstrate a RVF-LB superiority for "verbal" stimuli.

Rizzolatti et al. (1971) measured manual RT to the presentation of a single lateralized letter. Four different letters were used, two of which were designated as "positive", and the other two as "negative". There was an overall significant speed advantage for "positive" letters in the RVF which was found for 11 out of 12 subjects. In this same paper, the authors reported the results of another study employing the same paradigm with photographs of faces. Using a different group of subjects they found an overall LVF superiority which was also observed in 11 out of 12 subjects. Based on these findings of opposite hemispheric superiorities for tasks that differed only in the nature of the stimuli used, the authors concluded that "the findings are best interpreted in terms of systematic, stimulus-dependent hemispheric differences, favouring the left hemisphere for the recognition of letters and the right hemisphere for the recognition of faces" (p. 436).

Subsequent studies employing letters have demonstrated that hemispheric differences are not stimulus-dependent but are related instead to the processing demands of the

particular task. Klatzky (1970) and Klatzky and Atkinson (1971) used letters in a memory scanning paradigm. At the onset of each trial, the subject was presented with a set of 2 to 5 letters to be memorized. The subject was then presented with either a lateralized letter or a picture, and was required to indicate whether the stimulus was "positive" or "negative" by depressing the proper response key. A "positive" letter was defined as a letter which had appeared in the memory set, and a "positive" picture was one whose name began with a letter in the memory set. They reported an overall LVF-RB superiority for letters. The authors concluded that when letter stimuli are used, the memory scanning task can be performed either on the basis of verbal or spatial stimulus representations. Since a spatial comparison can be accomplished faster than a verbal-acoustic comparison, the right hemisphere is favored. However, the right hemisphere was assumed to be incapable of the necessary linguistic transformation of the picture stimuli, which resulted in a left hemisphere superiority for these stimuli.

Umilta et al. (1972) demonstrated an overall RVF-LB superiority in over 90% of a group of subjects who were required to respond to a previously designated "positive" group of letters. The experiment included three conditions. On a given trial, depending on the condition, the subject was presented with either a one, two, or three-letter display. A significant RVF-LB superiority was found for responses to "positive" two and three letter displays, but, contrary to the

findings of Rizzolatti et al. (1971), not for responses in the single letter condition. While almost every subject had faster RTs to RVF presentations in the two and three letter conditions, in the single letter condition half the subjects responded faster when the letter was presented in the LVF, and half the subjects responded faster to RVF presentations. The authors concluded that the lack of a consistent hemispheric superiority was due to the fact that subjects can process single letter stimuli on either the name level (thereby producing a RVF-LB advantage) or shape level (thereby producing a LVF-RB advantage), or that, based on a hypothesis suggested by Crowder (1971), letters that can only be differentiated by consonant sounds will favor the left hemisphere, while letters that differ in terminal vowel sounds will be processed better by the right hemisphere. The authors devised two additional conditions to determine whether the name-shape distinction or the consonant-vowel distinction was crucial for determining whether a RVF or LVF superiority will be found for single letters. They found an overall RVF-LB superiority for a task in which "positive" and "negative" letters were easily discriminated by shape but all shared the same terminal vowel sound when pronounced, and a LVF-RB superiority when "positive" and "negative" letters differed by both consonant and vowel sounds but were highly similar in shape. They therefore concluded that a left hemisphere superiority will emerge when the terminal vowel sound cannot be used to perform the required task.

Both the Umilta et al. (1972) and Klatzky and Atkinson (1971) studies demonstrated that when single letters are used the task demands of the experiment will determine the direction of the visual field superiority. They differ, however, in the type of processing demands they ascribe to tasks that produce right hemisphere superiorities.

Subsequent research has tended to support Klatzky's position that a LVF-RB advantage will emerge for letter tasks that can be accomplished on the basis of shape while tasks that require the letters to be named will produce a RVF-LB superiority.

This has been most clearly demonstrated by studies that have employed a letter matching task devised by Posner and Mitchell (1967), who demonstrated that when a pair of letters are physically identical (e.g., AA), RT is about 70 msec faster than when the stimuli share the same name but are printed in different cases (e.g., Aa). Cohen (1972), Geffen et al. (1972), and Davis and Schmit (1973) have all used this task and found a speed advantage for RVF presentation when the match required naming, and a LVF advantage for matches that could be accomplished on the level of shape. Moscovitch (1972) required subjects to respond to either "same" or "different" as to whether or not a single lateralized test letter was contained in a set of letters acoustically presented prior to each trial. When the memory set contained six letters a RVF advantage was found. A memory set of only one letter, however, produced a LVF

advantage, presumably because subjects could compare the visually presented test letter against the visual image of the original acoustic set letter. In a later experiment (Moscovitch, 1976 b, Experiment 3), a RVF superiority was produced when a single test letter had to be matched to a previously presented single letter memory set but with "same" defined as any letter that had the same terminal phoneme as the memory set letter.

In all of these RT studies a significant RVF-LB superiority was found only when the task required a verbal transformation of the visually presented letters. Any task that could be accomplished on the basis of physical characteristics of the letters either produced a LVF advantage or no visual field differences.

Evidence from studies with split-brain patients are in agreement with results from studies with normals. Gazzaniga and Sperry (1967) demonstrated that when a letter is flashed in the LVF the split-brain patient can, using his left hand, retrieve the correct letter by palpating an array of letters hidden from view. However, when letters are presented acoustically in a dichotic listening situation, they are unable to indicate the letters presented to the left ear, even when the left hand is used to point out the letters from a multiple-choice array (Zaidel, 1974). Similarly, Levy and Trevarthen (1976) demonstrated that these patients are unable to match a picture of an object (e.g., a bee) whose name rhymed with the name of an object flashed in the LVF (e.g., a key).

Most of the investigators who have studied letter recognition in normals using tasks that required naming of the stimuli, although recognizing that the RVF superiority could reflect either relative or absolute hemispheric specialization, have generally argued for only left hemisphere processing. In the Rizzolatti et al. (1971) study, RT was measured with the left hand and right hand for each subject. Although there was an overall RVF advantage, the order of the hemisphere-hand conditions conformed to the model for both hemispheres being capable to perform the task, the left hemisphere more efficiently than the right (Model II). However, the advantage for the left hand over the right hand for LVF stimuli was only 4 msec. The authors, expecting that the RB - LH condition would produce the slowest RTs, attributed this finding to the possibility that the right hemisphere may have become "primed" as a result of direct visual stimulation, thereby predisposing the motor mechanisms controlling the left hand to respond quickly after the completion of left hemisphere processing. This "priming" effect was assumed to compensate for the time lost during callosal transfer of the motor command from the left to the right hemisphere. However, since the task used in this study could be accomplished by either a verbal strategy or a visual matching strategy, the grouped results may have reflected individual differences in processing strategy. Consideration of the data from each subject lends some support to this interpretation. For 4 of the 12

subjects, RTs with the left hand were slower than RTs with the right hand to LVF stimuli.

In the Umilta et al. (1972) study, in those experiments that produced a left hemisphere superiority (conditions 2, 3, and 4), the grouped data conformed to the model specifying only left hemisphere processing (Model I). In each condition, the LB-RH produced the fastest RTs and the RB-LH the overall slowest times. However, the advantage for the right hand as compared to the left hand in response to LVF letters was again small (from 2 to 9 msec), and since individual data was not presented, it cannot be determined whether this difference was consistent across individual subjects. In addition, in both the Rizzolatti et al. (1971) and the Umilta et al. (1972) experiments, RT trials were blocked by both response hand and visual field. Therefore, since on each trial subjects knew which field the stimulus would be presented in, they may not have always maintained fixation.

In the Moscovitch studies (1972 and 1973), the letter stimuli were randomized for field of presentation and on those tasks that produced a RVF-LB superiority, the data fit his model for only LB processing; a RVF advantage regardless of responding hand. However, as mentioned previously, it is unnecessary for either LB - RH to be the overall fastest condition or for RB - LH to be the slowest in order to satisfy his model for complete lateralization of processing to the left hemisphere.

The following experiment was designed to produce RTs that would conform to the model for only left hemisphere processing (Model I). It was assumed that forcing subjects to verbally encode single letters in order to successfully accomplish a task would require the participation of language mechanisms localized only in the left hemisphere.

On each trial, subjects were presented with a single lateralized letter and were required to indicate whether the letter's name ended with an /i/ sound ("target" letters), or any other sound ("non-target" letters).

It was predicted that:

1. An overall RVF-LB superiority would be found for both judgments.
2. Since, regardless of judgment, each letter must be named, the hemisphere-hand conditions would conform to the order specified for only left hemisphere processing (Model I) for responses to both "target" letters and "non-target" letters analyzed separately.

Method

Materials

The stimuli were 6 "target" letters, all of which, when pronounced, have the same terminal vowel ending /i/, and 6 "non-target" letters which do not end with an /i/ sound when pronounced (see Table 2). The letters were 24-point Helvetica Medium capitol letters. Each letter subtended a visual angle of 0°29' vertically and 0°22' horizontally.

Procedure

The procedure followed the description provided in the General Method section.

Subjects were told that immediately following the fixation dot a single letter would appear either on the left or right of the viewing field. They were instructed that for each trial they should respond by lifting one finger (either index or middle) if the letter ended in an /i/ sound, and respond with the other finger if the letter name ended with any other sound. To insure that subjects understood the task, they were asked to generate some example letters ending with an /i/ sound.

Each block of 48 trials consisted of two presentations of each "target" and "non-target" letter in each visual field.

Results

The overall analysis of variance by Day, Hand, Judgment (target or non-target), Visual Field, and Half, with repeated measures on all factors, yielded a significant main effect for Day (mean RT for Day 1 = 590 msec, Day 2 = 538 msec; $F(1, 7) = 16.737, p < .005$), and for Half (mean RT for the first half of both days = 573, second half of both days = 554 msec; $F(1, 7) = 11.772, p < .02$) as well as a significant Day X Half interaction due to a larger decrease in latencies (overall practice effect) on Day 1 than on Day 2 (34 msec vs. 5 msec; $F(1, 7) = 15.778, p < .007$). In addition, responses to the target letters were significantly faster than responses to non-target letters (543 msec for targets, 584 msec for non-targets; $F(1, 7) = 21.345, p < .004$). There was also a significant Judgment X Visual Field interaction due to an overall 17 msec RVF advantage for target letters and a 6 msec LVF advantage for non-target letters, $F(1, 7) = 11.225, p < .02$.

Structural Models

Separate analysis of variance for each Judgment revealed that, as predicted, the RVF advantage for target letters was significant, $F(1, 7) = 21.115, p < .004$ (8 of 8 subjects). However, the unexpected LVF advantage for non-target letters was not, $F(1, 7) = 1.325, p > .2$ (LVF favored for 5 of 8 subjects).

The order of the hemisphere-hand conditions for each judgment (Table 7) indicates that responses to target letters conformed to the predicted model for only left hemisphere processing. Although the anatomically direct LB - RH condition was significantly faster than the RB - LH, the difference between the right hand and left hand failed to reach significance for LVF letters. Responses to non-target letters (see Table 9) failed to conform to any of the models and produced a much smaller range of reaction times (11 msec vs. 32 msec for target letters).

Time Dependent Changes

Analysis of each Day separately revealed that responses to target letters were significantly faster than responses to non-target letters on both Day 1 and Day 2 ($F(1, 7) = 17.625$, $p < .006$; $F(1, 7) = 22.103$, $p < .004$, respectively). However, the overall Judgment X Visual Field interaction was only significant on Day 1 (RVF < LVF by 21 msec for targets, LVF < RVF by 13 msec for non-targets; $F(1, 7) = 11.076$, $p < .02$, on Day 1; RVF < LVF by 12 msec for targets, RVF = LVF for non-targets; $F(1, 7) = 2.239$, $p > .10$ on Day 2). The only other significant finding was for Half on Day 1, $F(1, 7) = 20.301$, $p < .004$.

Target Letters. Analysis of each judgment separately revealed that the RVF advantage for target letters was significant on Day 1, $F(1, 7) = 25.011$, $p < .003$ (8 of 8 subjects), but failed to reach significance on Day 2, $F(1, 7) = 4.400$, $p > .07$ (6 of 8 subjects). Progressing to the level of each Half day (see Figure 4), the RVF advantage for targets was found on both Half 1 and Half 2 of Day 1

($F(1, 7) = 8.807, p < .03$; $F(1, 7) = 25.999, p < .003$, respectively), and on Half 1, but not Half 2, of Day 2 ($F(1, 7) = 12.837, p < .01$; $F(1, 7) = 0.610, p > .4$, respectively). In addition, the hemisphere-hand orders for each day were found to support the model representative of only left hemisphere processing, but most of the critical comparisons did not reach significance (see Table 7).

Although there was no significant visual Field X Half interaction, nor any evidence of differential improvement using the per cent change scores, both the lack of consistent significant differences between hemisphere-hand conditions and the lack of a RVF advantage on the second half of Day 2 are suggestive of possible changes in hemispheric processing as a function of practice.

Analysis over blocks of trials provided support for the significance of such changes. On Day 1, in addition to the main effects for Visual Field, $F(1, 7) = 24.788, p < .003$, and Block $F(3, 21) = 5.355, p < .008$, there was a significant Visual Field X Block interaction, $F(3, 21) = 3.601, p < .04$. This interaction was also significant on Day 2, $F(3, 21) = 9.132, p < .001$. There was no other significant main effects or interactions on either day. Inspection of the data (see Figure 5), indicates that during the first block there was a slight advantage for the LVF on both days, which then resolved to a RVF superiority across Day 1 and disappeared by the fourth block of Day 2. Consideration of the hemisphere-hand conditions on the first block reveals a pattern reminiscent

of that found for nouns; an overall advantage for the LVF coupled with a RH advantage regardless of visual field.

Non-target Letters. In contrast to the findings for target letters, analysis of responses to non-target stimuli yielded no significant findings on either day except for an overall practice effect on Day 1 (Half, $F(1, 7) = 12.167$, $p < .02$). This lack of any visual field difference was reflected in the ordering of the hemisphere-hand conditions which were not significantly different from each other (see Table 9).

In summary, responses to target letters revealed an overall advantage for the RVF with the hemisphere-hand orders supportive of only left hemisphere processing of these stimuli. Analysis over time revealed that the advantage for the RVF did not emerge until the second block on both days, was maintained across Day 1, but disappeared by the final block on Day 2. Responses to non-targets produced no significant findings and no significant separation of the brain-hand conditions at any level of analysis.

RTs for individual subjects are presented in Tables 8 and 10. In response to target letters, there was a fair amount of agreement between subjects. Overall (Day 1 and Day 2) the LB - RH was the fastest condition for 6 of 8 subjects (Table 8). However, the RB - LH condition was the overall slowest for only 2 of 8 subjects. Comparing Day 1 with Day 2 it can be seen that the RB - LH was slowest for 5 of 8 subjects on the first testing session, but for

only 2 of 8 subjects on Day 2. RTs to non-target letters (Table 10) showed little consistency within subjects from Day 1 to Day 2 or among the subjects.

Both the overall error rate and trials on which RT exceeded 900 msec were low (2.5% and 2% respectively). There were no significant main effects or interaction found for either measure.

Discussion

The overall results for responses to target letters were consistent with the majority of other studies using normal subjects. When confronted with a task that requires linguistic encoding, a speed advantage for RVF presentations will be found. In addition, the hemisphere-hand conditions conformed to the order specifying only left hemisphere processing. These findings then tend to support the structural model and are in agreement with clinical findings. The cognitive operations required to transform graphemes to phonemes and discriminate among the latter appear to be dependent upon mechanisms localized solely to the left hemisphere. If so, then in order to perform such a task, letters initially directed to the right hemisphere must be transferred to the left hemisphere for processing.

However, there were several additional findings that strongly suggest that performance on this task cannot be adequately explained solely in terms of a structural model of hemispheric differences. Firstly, the differences between hemisphere-hand conditions were not statistically significant, and, although a RVF superiority was found for every subject, the orderings of the hemisphere-hand conditions did not show the degree of consistency that would be expected based on this, or any other structural model. Of course, some of this variability can be attributed to measurement error (lapses in attention, fatigue, recovery, expectancy, etc.). However, for most subjects, changes in the ordering of the

conditions followed the same general pattern.

Comparing the results from the first testing session with the second, the most consistent change was reflected in the relative speed increase for responses by the anatomically direct right hemisphere-left hand condition. More revealing was the finding that the overall RVF advantage varied as a function of time.

The overall pattern of change in RT to LVF and RVF target letters was somewhat similar to that found for responses to nouns in the previous experiment. There was slight advantage for the LVF on the first block of trials followed by a significant RVF advantage that was maintained throughout the remaining blocks on the first day of testing. During the second testing session a similar pattern was found, however, the RVF superiority disappeared by the final block of trials. In comparison, responses to nouns showed a larger LVF advantage during the first block of trials which was then also followed by a significant RVF superiority. In contrast to target letters, however, the RVF advantage was maintained throughout the remaining trial blocks on both days of testing, although a shift in the ordering of the hemisphere-hand conditions indicated the emergence of some right hemisphere ability for processing these stimuli. This pattern of change is not unique to the studies reported here. Hellige (1976) found an identical change over blocks of trials for "same" name judgments to different case letter pairs.

It was suggested previously that these changes in visual asymmetry over time can best be explained by a multiple processing model that assumes differential hemispheric ability for certain of the processes, and further assumes that the relative importance of a given process can vary as a function of experience with the task demands and the particular stimuli used. This model will be elaborated upon in the Final Discussion section. However, regardless of the appropriateness of such a model, the finding that a visual field superiority changed with practice is certainly an unexpected one, assuming that perceptual asymmetries for linguistic tasks reflect only direct access to specific neurological mechanisms localized in the left hemisphere.

Another finding difficult to reconcile with a structural model was the failure to observe the predicted RVF superiority for responses to non-target letters. Since it was assumed that every letter must be "named" before a decision as to whether or not it belonged to target class could be made, the results for target and non-target letters were expected to be identical. The fact that no visual field superiority was found is, however, consistent with the lack of findings for "different" judgments and similar to the results for verbs in the preceding experiment.

The results for non-target letters provided stronger support for Davis & Schmit's (1973) suggestion that these judgments may require interhemispheric cross checking. Non-target letters could be processed in the same way as

target letters. Each letter must be "named" and this process is mediated by the left hemisphere. However, while the decision that the letter does belong to the target class can be accomplished by the left hemisphere alone, a judgment indicating that the letter does not belong to the target class may require participation of both hemispheres. Why this additional processing time would be necessary is not at all clear. However, it is likely that it is related to the decision process itself, the act of judging something to be "dissimilar", regardless of the cognitive operations involved in judging "same".

The fact that responses to non-target letters were significantly and consistently slower than responses to target letters provides evidence for the additional processing time assumed to be required to make such judgments. In addition, the lack of any clear visual field superiority and the small range of RTs among the hemisphere-hand conditions for non-target letters is also consistent with this interpretation.

V

EXPERIMENT 3

The first demonstration of a LVF-RB superiority in normals using face stimuli was reported by Rizzolatti et al. (1971). As mentioned previously, the authors consider this result as reflecting a "stimulus-dependent" hemispheric advantage for the recognition of faces. This interpretation is supported by studies that have shown that patients with right cerebral lesions are more impaired on face recognition tasks than patients with left hemisphere lesions (e.g., DeRenzi, Faglioni & Spinnler, 1968; Milner, 1968; Yin, 1970), and by the syndrome of prosopagnosia, a specific inability to recognize faces, which has been associated with posterior lesions of the right hemisphere (Hecaen & Angelergues, 1962).

More recent studies with normal subjects have demonstrated that, as was the case with letter stimuli, the direction of the visual field superiority is dependent on the processing demands of the particular task.

A RVF-LB speed advantage has been reported for both "same" and "different" judgments when subjects were required to match a lateralized schematic face to a previously memorized face when the faces differed on only one feature (Patterson & Bradshaw, 1975, Experiment 3), and Moscovitch et al. (1976, Experiment 3), reported no visual field differences using Identikit faces that differed on all features when the inter-stimulus interval between the to-be-

matched faces was less than 100 msec. In contrast, a significant speed advantage for LVF-RB presentation has been found when face stimuli had to be matched to a previously memorized target face and the stimuli differed on several features. The initial study by Rizzolatti et al. (1971) used this match-to-memory paradigm with photographs of faces. LVF-RB superiorities have subsequently been found by several other investigators using this same paradigm with *IdentiKit* faces that differed on all features (Geffen et al., 1971; Moscovitch et al., 1976, Experiment 2), schematic faces differing on all features (Patterson & Bradshaw, 1975, Experiment 2) and again with photographs of faces (although the effect was found only for males) (Rizzolatti & Buchtel, 1977).

Based on the above results using RT measures, it appears that when subjects have to judge whether or not a briefly presented lateralized face is the same as a previously memorized face, and the stimuli are either photographs of different people or drawings of faces that can be distinguished by several features, a LVF-RB superiority will emerge. This result could reflect either some peculiarity of faces as visual patterns that is more easily processed by specialized right hemisphere mechanisms (Hecaen, 1970), or a consequence of the assumed right hemisphere superiority for "gestalt" analysis (Bogen, 1975; Bradshaw, Gates & Patterson, 1976, Levy, 1974),

When subjects are forced to use an analytic strategy (by varying only one facial feature) a RVF-LB advantage will be found, presumably as a result of left hemisphere super-

iority for this processing mode. Finally, when a face matching task can be accomplished on the basis of lower level perceptual processing, no hemispheric differences will be found.

In the experiments reported by Moscovitch et al. (1976), in which a LVF-RB superiority was found, the RT data conformed to his model for only right hemisphere processing; the LVF was favored regardless of responding hand. The authors, therefore, concluded that the memorized face is "either stored in the right hemisphere or that it is encoded in a form that is compatible with right, but not left, hemisphere processes" (p. 406). Similarly, Rizzolatti and Buchtel (1977) attribute the LVF-RB superiority found in their study to a "neurologically lateralized mechanism for face recognition" (p. 303).

The following experiment was a replication of the above mentioned studies that employed the match-to-memory paradigm. It was assumed that the results would demonstrate an overall right hemisphere superiority on this task. In addition, it was expected that the order of the hemisphere-hand conditions would provide evidence indicating whether performance on this task is, in fact, mediated by mechanisms or processes localized only in the right hemisphere (Model III) or if both hemispheres can perform the task, the right more efficiently than the left hemisphere (Model IV).

Method

Materials

The stimuli consisted of four photographs of female faces matched for clarity, background, pose, and with no obvious distinguishing features (e.g., hair length, expression) (see Table 2). Each face measured 26 mm. X 38 mm. and subtended a visual angle of 1°55' horizontally and 2°54' vertically.

Procedure

The procedure followed the description provided in the General Method section.

Prior to any tachistoscopic trials, the subject was shown the "target" face and was instructed to respond with the appropriate finger (i.e., either index or middle) whenever this face was presented. The subject was then given approximately 2 minutes to study the face. He was then shown all four face stimuli, the "target" face and the three "non-target" faces. He was told that on each trial one of the four faces would be presented and was instructed to indicate the occurrence of the "target" face by responding with the appropriate finger and to respond with the other finger for any of the "non-target" faces.

Each block of 48 trials consisted of 12 presentations of the target face in each visual field and four presentations of each of the three non-target faces in each visual field.

Results

The overall analysis of variance by Day, Hand, Judgment (target or non-target), Visual Field, and Half, yielded a significant main effect for Day, $F(1, 7) = 11.695$, $p < .02$, and a significant Day X Half interaction, $F(1, 7) = 11.810$, $p < .02$, indicating a greater overall practice effect on the first testing session than on the second.

Responses to the target face were significantly faster than responses to non-target faces (488 msec vs. 544 msec). $F(1, 7) = 53.695$, $p < .001$. There was also a significant interaction of Hand and Half, $F(1, 7) = 14.784$, $p < .008$, due to a greater increase in speed for left hand responses (31 msec) than for right hand responses (5 msec) over the last 96 trials (Half 2) as compared to the first 96 trials (Half 1). In addition, there were significant three-way interactions of Day, Hand, and Visual Field, $F(1, 7) = 10.600$, $p < .02$; and of Judgment, Visual Field, and Half, $F(1, 7) = 26.514$, $p < .003$.

Structural Models

The ordering of the hemisphere-hand conditions for RTs to the target face and to non-target faces are presented in Table 11 and Table 13, respectively. In light of the multiple interactions involving both Visual Field and Hand with the time factors of Day and Half, it is not surprising that the overall RTs for each condition were not significantly

different from each other. Inspection of the tables indicates that not only did the order of hemisphere-hand conditions fail to conform to the predicted model for right hemisphere processing only (Model III), or right hemisphere more efficient than left hemisphere (Model IV), for either judgment, but that there was actually a speed advantage for RVF presentations for each judgment both over days and within each day. In fact, the ordering of the conditions for the target face conformed to the model for only left hemisphere processing on Day 2 and over both testing sessions averaged together.

Time Dependent Changes

Although RTs to the target face produced the same ordering of hemisphere-hand conditions found for nouns and target letters, analysis over blocks of trials revealed a pattern of shifting visual field superiorities quite different than that found on the linguistic tasks.

RTs for each visual field averaged over hands for the first and second half of each day are presented in Figure 6. On Day 1 there was a significant Judgment X Visual Field X Half interaction, $F(1, 7) = 17.050$, $p < .005$, due to a small, 8 msec, LVF-RB advantage for targets and a larger, 27 msec, RVF-LB advantage for non-targets during the first half of the day, whereas during the second half of the day the reverse was true; a 17 msec RVF-LB advantage for targets and a 6 msec LVF-RB advantage for non-targets.

It appears that whichever visual field was being responded to more slowly over the first half of trials showed greater improvement over time. This interpretation was supported by the analysis of variance employing percent change scores which revealed a significant Judgment X Visual Field interaction on Day 1, $F(1, 7) = 15.532$, $p < .007$ with the initially slower RVF-LB showing greater improvement than the LVF-RB for responding to the target face, and the initially slower LVF-RB showing greater improvement than the RVF-LB for responding to the non-target stimuli.

Further analyses over blocks of trials (see Figure 7) revealed a highly significant Judgment X Visual Field X Block interaction, $F(3, 21) = 13.753$, $p < .001$, and a significant Visual Field X Block interaction for each judgment separately ($F(3, 21) = 2.996$, $p = .05$ and $F(3, 21) = 6.460$, $p < .004$, for target and non-target faces, respectively).

Note that on the first block of trials there is a 28 msec LVF-RB advantage for responses to the target face and a 48 msec RVF-LB advantage for responses to the non-target faces producing a significant Judgment X Visual Field interaction, $F(1, 7) = 11.409$, $p < .02$; but by block 3 this interaction is in the opposite direction (RVF < LVF by 38 msec for the target face, LVF < RVF by 32 msec for responses to the non-targets, $F(1, 7) = 14.006$, $p < .008$).

Each judgment was further analyzed over each block of trials (Hand X Visual Field). On the first block of trials

the LVF advantage for RTs to target faces was found for 7 of 8 subjects but failed to reach significance, $F(1, 7) = 2.598$, $p = .069$. However, the corresponding RVF-LB advantage for non-target faces was significant, $F(1, 7) = 11.926$, $p < .02$. For the reverse pattern of opposing visual field superiorities on Block 3 the RVF-LB advantage for targets was highly significant, $F(1, 7) = 32.198$, $p = .001$, while the LVF-RB advantage for non-target faces was not, $F(1, 7) = 2.543$, $p > .1$ (6 of 8 subjects). There were no other significant main effects or interactions on any block of trials.

For the majority of subjects, then, RTs to the target face presented in the RVF were initially slower than when presented in the LVF. Over trials, however, RTs to RVF presentations not only equalled, but actually surpassed RTs to LVF presentations. The reverse pattern was found for RTs to the non-target face presentations.

Inspection of Figure 7 not only reveals a complete shift in visual field superiorities over blocks of trials, but also tends to indicate differential treatment of the target face and non-target face depending on which hemisphere initially received the stimuli. On Block 1, RTs to the target face and the non-target faces were relatively the same when presented to the left hemisphere (553 msec and 562 msec, respectively). In contrast, the target face was responded to much faster than the non-target faces when presented to the right hemisphere (525 msec and 610 msec, respectively). To investigate this apparent difference in

response to the required judgment, RTs for each visual field were analyzed separately for each block of trials (Hand X Judgment). It was found (see Table 15) that with the exception of Block 2, the target face was responded to significantly faster than the non-target faces over all blocks of trials on both Day 1 and Day 2 when initially presented to the LVF-right hemisphere. In contrast, for RVF-left hemisphere presentations, a speed advantage for responding to the target face did not emerge until Block 3 of Day 1.

On Day 2 there was also a significant Judgment X Visual Field X Block interaction, $F(3, 21) = 3.843$, $p < .03$. Analysis of RTs to the target face only (Hand X Visual Field X Block) yielded no significant main effects or interactions. Analysis of non-target RTs, however, revealed a significant Visual Field X Block interaction, $F(3, 21) = 4.010$, $p < .03$. The form of this interaction is similar to that found on Day 1, with greater overall improvement by the initially slower LVF-RB. Additional support was provided by the analysis using the percent change scores which revealed a significant decrease in RT for non-target faces presented in the LVF as compared to RVF presentations, $F(1, 7) = 16.568$, $p < .005$. However, although, as was found on Day 1, the RVF is clearly superior to the LVF at the beginning of testing session, and was significantly faster over the first 96 trials (Half 1, $F(1, 7) = 5.876$, $p < .05$), the disappearance of this advantage over time seems to be as much a result of possible left hemisphere

fatigue (the slowing of RT from Block 2 to Block 4) as it is of an increase in speed of response to LVF stimuli.

The overall error rate for this experiment was low (2%), and few trials were rerun because of slow responses (1.25%). There were no significant main effects or interactions found for either measure.

Discussion

In contrast to other studies employing the same paradigm, the overall results (both averaged across sessions and within each session) provided no evidence in support of specific right hemisphere mechanisms or processes for face recognition.

The primary rationale for using face stimuli has been the findings of greater impairment on face recognition tasks in patients with right, as compared to left, hemisphere lesions. It has not, however, been adequately determined whether the superiority of the right hemisphere is related to some particular quality of faces, or to more general perceptual and/or mnemonic demands of these tasks. In comparison to studies of specific language functions, the observed differences between brain damaged groups on these tasks are more open to an interpretation of relative hemispheric superiority. For example, in the often cited study by Milner (1968), although the right temporal lobe group had significantly lower face recognition scores, there was considerable overlap between groups. This was true when there was no time delay between study and test (right temporal range = 5-11, left temporal range = 6-11, normal controls = 6-12; maximum score = 12, Table 9), and with a 90 sec filled delay (right temporal = 6-10, left temporal = 7-12, Table 2).

On the other hand, the syndrome of prosopagnosia has been cited as evidence for a specific neurological face

recognition mechanism lateralized to the right hemisphere. It is not clear, however, what the relationship is between this syndrome and the reported deficit of right hemisphere patients on standardized matching and memory tests of facial recognition. In fact, patients with this syndrome have been reported to perform well on these tests, and to be able to recognize the difference between faces. In addition, although it is generally believed that this disorder can result from a lesion limited to only the right hemisphere, there is not a single anatomical study of a case of unequivocal prosopagnosia to support this claim; bilateral involvement has always been found (see Hecaen & Albert, 1978, for review).

It may be then that face recognition, as tested here, could be accomplished by either hemisphere. This interpretation gains some support in that, compared to the other experiments, this task produced the fastest RTs and fewest errors, suggesting that it may have been accomplished on the basis of lower level perceptual processes (as suggested by Moscovitch et al., 1976, Experiment 1). However, the ordering of the hemisphere-hand conditions failed to provide any support for this alternative.

Another possibility is that the observed lack of conformity to any of the structural models was due to stable individual differences in processing strategy which emerged as a result of the relatively weak demands of this task. This interpretation is supported somewhat by the overall

differences between visual fields for each subject. Averaged across sessions, the RVF was favored for five subjects and the LVF for three subjects. However, these differences were not consistent from one testing session to the other, nor did the hemisphere-hand conditions conform to any of the expected orders for most subjects.

However, in contrast to the lack of findings in the overall data, analyses over blocks of trials revealed consistent hemispheric differences, but that the direction of these differences varied as a result of experience. Firstly, regardless of the nature of the observed shifts in hemispheric superiority, they clearly call into question any explanation of face recognition based solely on fixed, structural hemispheric differences.

For responses to the target face, the predicted LVF superiority was found for seven of the eight subjects. However, in comparison to other studies, this effect was short lived, being followed by a significant RVF advantage by Block 3. Both Rizzolatti et al. (1971) and Moscovitch et al. (1976, Experiment 2) reported significant LVF superiorities, with subjects participating in 656 trials over four days and 240 trials, respectively. One difference between these studies and the one reported here was the level of complexity, and therefore, the strength of the processing demands. Rizzolatti et al. used photographs of faces on which all hair cues were eliminated, and were, consequently, more difficult to discriminate than those

employed in this study. There were also two target faces (and two non-target faces), so that subjects were required to keep at least two separate faces stored in memory. In the study reported by Moscovitch et al., hair cues were also completely eliminated, and, although there was only one target and three non-target faces, two faces were presented on each trial with subjects required to respond "same" if either one or both matched the previously memorized target. Also in support of the importance of task difficulty is the finding reported by Rizzolatti and Buchtel (1977) that the LVF superiority for face recognition increased when stimulus exposure time was decreased. In the studies reported by Geffen et al. (1971) and Patterson and Bradshaw (1975), the task requirements were the same as those used here (one target, three non-targets, single face presentations), but relatively few trials were run (80 and 128, respectively).

Task complexity may suggest why the LVF advantage was relatively weak and declined over trials, but cannot explain the emergence of a left hemisphere advantage. A possible explanation for this shift is suggested by an experiment by Marzi and Berlucchi (1977), who found a RVF, left hemisphere, superiority for recognition of famous faces. The authors argued that this effect was not due to the use of a verbal response measure since, within the framework of a structural model, if face recognition was dependent solely on right hemisphere mechanisms, then the required response would necessitate one callosal transfer for faces presented in the

LVF, and two callosal transfers for faces presented in the RVF, resulting in a LVF superiority. They interpreted the RVF superiority as a result of a "single feature detection strategy" which is more likely to be employed with familiar than unfamiliar faces (p. 755).

In this respect, it can be assumed that a single photograph of a face, which was studied for 2 min. in free vision, and which prior to Block 3 had already been presented tachistoscopically 60 times, can be considered a familiar face.

The contrasting patterns of differential hemispheric improvement and fatigue for each judgment do suggest that each hemisphere was able to accomplish this task, but by relying on somewhat different modes of processing which were differentially effected by practice.

It was found that, overall, the target face was responded to significantly faster than the non-target faces,² but that during the early trials this was true only for LVF presentations. This suggests that during the pretrial study

² In keeping with other studies, face recognition experiments have produced conflicting results in terms of the relationship between RTs to the target and non-targets. Moscovitch et al. (1976) found significantly faster responses to the target face, Patterson and Bradshaw (1975) found no difference, and Geffen et al. (1971) found significantly faster RTs to non-targets. All possibilities are covered in the only three previous studies measuring RTs to both target and non-target stimuli.

period, the target face was, in fact, encoded in some form that was more compatible with right hemisphere processing, so that, from the onset, the target was responded to significantly faster than the non-target faces for LVF presentations. For RVF presentations this speed advantage for responses to the target face did not emerge until an additional 120 trials (24 practice, 96 experimental) were run. This shift may have reflected an on-going search for a critical single feature to distinguish the target from the non-target faces, resulting in the significant advantage for the target face over the non-target faces for RVF presentations, and the superiority of the RVF over the LVF for responses to the target face.

This interpretation is supported by Patterson and Bradshaw's (1975, Experiment 3) finding of a RVF advantage for faces that differed on a single feature, and suggests that, when applicable, single feature analysis is more efficient than a "gestalt-wholistic" approach, or that the left hemisphere is better suited than the right hemisphere for employing an analytic strategy.

This hypothesized single feature detection by the left hemisphere resulted in substantial improvement for responses to the target face, with little improvement over time for responses to the non-target faces, which, presumably, had to be fully analyzed in turn. It appears then that a consequence of focusing in on a single feature is differential improvement in response to the target at the expense of almost no improvement for responding to the non-targets. In contrast, the

the right hemisphere mode (template matching of the memorized target face?) lead to parallel rates of improvement for responses to both target and non-target faces resulting in the differential improvement of the LVF over the RVF for responses to the non-target faces.

The results indicate that the hemispheric differences between naive and trained subjects reported by Bever and Chiarello (1974) on a supposedly "right hemisphere task", can be demonstrated over the course of an experimental session. After repeated experience with a small set of stimuli, subjects become "experts" at selectively responding to a fixed target, reflected by the development of a more efficient strategy (possibly single feature detection) producing a shift from right to left hemispheric superiority. The results are also consistent with the suggestion of Goldberg, Vaughan, and Gerstman (1978) that the left hemisphere excels once a suitable descriptive system has been established.

VI
EXPERIMENT 4

The majority of studies with brain-damaged patients have been done in an attempt to identify and elucidate the relationship between specific symptoms and the locus of cerebral pathology. For example, various types of aphasias (e.g., Broca's aphasia, Wernicke's aphasia, conduction aphasia, isolation aphasia) ideomotor, ideational, and constructional apraxias, and the Gerstmann syndrome, have all been attributed to damage to specific areas within the left hemisphere, while constructional and dressing apraxia, visual-spatial agnosia, and prosopagnosia, are examples of syndromes that have been attributed primarily to lesions within the right hemisphere.

In addition to focusing on specific syndromes, the current interest in hemispheric differences has led to attempts to specify some underlying mechanism or mode of processing that would account for all of the diverse symptomatology associated with damage to each hemisphere. Earlier attempts began from the standpoint of the left hemisphere's superiority for language processes. For example, Geschwind (1965) attempted to account for seemingly non-linguistic disorders resulting from left, as well as right, hemisphere lesions in terms of disconnections from left hemisphere language centers. Other investigators, citing the disruption of visual-spatial processing associated

with right hemisphere lesions, the superiority of the split-brain patient's right hemisphere on tasks requiring visual-spatial analysis, and studies with normals using tachistoscopic presentation, have argued that a language/visuospatial dichotomy is the primary determinant of hemispheric differences.

Many of the studies reviewed so far are consistent with this interpretation; tasks that required a linguistic transformation of the stimuli produced RVF-LB superiorities, while tasks that could be accomplished on the basis of the physical characteristics of the stimuli produced LVF-RB superiorities.

However, as Marshall (1973) has pointed out, the language/visuospatial dichotomy merely describes or labels the observed difference and does not in itself provide an explanation for these differences.

An alternative approach has been to concentrate on differences in simpler sensory and/or motor functions, as opposed to more complex cognitive functions. Semmes (1968) studied the disruption of sensory-motor functions resulting from left and right cerebral lesions and found evidence indicating that the left hemisphere has a more discrete neuronal organization than the right hemisphere. This difference in neuronal organization may, in turn, underlie the observed differences in cognitive functions. Similarly, Kimura has studied the disruption of sequential motor acts and has proposed that the development of language in the left hemisphere is a consequence of the superiority of this hemisphere for all sequential motor behaviors (Kimura, 1976; Kimura & Archibald, 1974).

It has, in fact, become increasingly clear that any description or explanation offered to account for hemispheric differences cannot be based on linguistic processes per se. Firstly, hemispheric differences have been found in infants on the anatomical (Witelson & Pallie, 1973), behavioral (Terkowitz, 1977), and physiological (Davis & Wada, 1977) levels. Secondly, several studies have demonstrated contrasting patterns of hemispheric laterality in normal adults using tasks that do not fit easily into a language/visual-spatial dichotomy (e.g., Bever & Chiarello, 1974; Bradshaw, Gates & Patterson, 1976, Cohen, 1973; Goldberg et al., 1978, Patterson & Bradshaw, 1975). Many of these authors have attributed the observed hemispheric differences to underlying differences in mode of processing. Left hemisphere processing is described as analytic and sequential while right hemisphere processing is described as parallel, gestalt or wholistic. Support for this more general dichotomy has been found in studies with split-brain patients (Bogen, 1975; Bogen, DeZure, Tenhousen & Marsh, 1972; Levy, 1974; Zaidel & Sperry, 1973), and patients with unilateral cerebral lesions (Veroff, 1978; Warrington, 1969), as well as in experiments with normal subjects.

In one of these studies (Bradshaw et al., 1976, Experiment 3), subjects were required to respond "same" to the presentation of a previously memorized "target" array of three geometric shapes, and "different" to any one of three "non-target" arrays that differed from the "target"

on only one feature. They found a significant interaction of visual field with judgment; RTs for "same" favored the LVF-RB, RTs for "different" favored the RVF-LB. They concluded that a judgment based on complete physical identity ("same") constitutes a "gestalt-wholistic" match and is performed more efficiently by the right hemisphere. A judgment based on the appreciation of a change in only one feature ("different") requires an analytic approach and is performed more efficiently by the left hemisphere.

However, there are a number of problems with this interpretation. Firstly, the results conflict with a previous study (Patterson & Bradshaw, 1975, Experiment 3), that found a RVF-LB superiority for both judgments, "same" and "different", using schematic faces that differed on only one feature. The authors attribute this discrepancy to the difference between stimuli that are "seen as faces" and those that are not (p. 678). It is not clear, however, why stimuli that usually produce a LVF-RB superiority (faces) for judgments "same" should produce a RVF-LB advantage when "different" is defined as differing on one feature, while easily nameable stimuli (geometric shapes) produce a LVF-RB advantage for "same" under identical conditions. In addition, using geometric arrays they reported an overall speed advantage for responses "different" as compared to responses "same". To be consistent with the proposed analytic/gestalt dichotomy, this advantage should have been found only for responses to RVF stimuli. If the left hemisphere employs a self terminating

analytic strategy, each element of the presented array must be compared to the elements of the memorized target array, resulting in faster responses to non-target than to target arrays. In comparison, "gestalt-wholistic" processing should not result in a speed advantage for non-target arrays.

However, "different" RTs were faster than "same" RTs in both the RVF (by 74 msec) and LVF (by 51 msec). This implies that either the distinction in processing style is quantitative (e.g., the right hemisphere can also employ an analytic strategy producing faster responses to "different" stimuli than to "same" stimuli, but is more efficient than the left hemisphere in using a "gestalt" strategy) or the distinction is qualitative (e.g., stimuli presented to the LVF that require a "different" judgment must be transferred to the left hemisphere for processing).

The following experiment was a replication of the Bradshaw et al. (1976) study using geometric arrays. Based on their results and the previously cited evidence for ascribing hemispheric differences to different underlying modes of processing, it was expected that:

1. RTs to the "target" array should favor the LVF and RTs to "non-target" arrays should favor the RVF producing a significant Judgment X Visual Field interaction.

2. The ordering of the hemisphere-hand conditions was expected to provide an indication of whether the analytic/gestalt dichotomy is quantitative or qualitative in nature.

If the difference in processing mode is qualitative, responses "same" should conform to the model for only right hemisphere processing (Model III), and responses "different" to the Model for only left hemisphere processing (Model I). If each hemisphere can fully process both "target" and "non-target" stimuli, but each using a qualitatively different processing strategy, then the expected orders should conform to Model IV and Model II for "same" and "different" judgments, respectively, and "different" should be faster than "same" for only RVF presentations. If the difference is only quantitative, the data should conform to Model II and IV and "different" should be faster than "same" for both RVF and LVF presentations.

Method

Materials

The stimuli consisted of four arrays of geometric symbols. Each array consisted of three forms arranged vertically and were constructed using specially prepared templates. Each stimulus measured 45 mm. vertically, subtending a visual angle of $3^{\circ}22'$, and 16 mm. horizontally, subtending a visual angle of $1^{\circ}14'$.

One array was designated as the "target". The three remaining arrays were "non-targets" and each one differed from the target by only one element; either top, middle or bottom (see Table 2).

Procedure

The procedure followed the description in the General Method section.

The subject was shown the target array and instructed to respond with the appropriate finger whenever this array, and only this array, was presented. The subject was then allowed approximately 2 minutes to study this array. He was then shown a card on which all four symbol arrays, the target and the three non-targets, were displayed.

Pilot testing had revealed that the discrimination required on this task was quite difficult, resulting in a large number of errors and slow responses. Consequently, the precise difference between each non-target array and the

target array was carefully pointed out to the subject. The subject was instructed to respond with the appropriate finger whenever the target array was presented, and to respond with the other finger when any of the non-target arrays was presented. He was then allowed an additional 2 minutes to study all four stimuli.

Each block of 48 trials consisted of 12 presentations of the target array in each visual field and four presentations of each of the three non-target arrays in each visual field.

Results

The overall analysis of variance by Day, Hand, Judgment (target or non-target), Visual Field, and Half, yielded significant main effects for Day, $F(1, 7) = 7.907$, $p < .03$, and for Half, $F(1, 7) = 13.869$, $p < .009$, and a significant Day X Half interaction, $F(1, 7) = 10.248$, $p < .02$, indicative of a larger overall practice effect on Day 1 than on Day 2. The only other finding was a significant Judgment X Visual Field X Half interaction, $F(1, 7) = 18.831$, $p < .005$, that took the same form as that found for Faces. Averaged across testing sessions, there was a 23 msec LVF-RB advantage for responses to the target stimulus, and a 23 msec RVF-LB advantage for responses to the non-target arrays on Half 1. By the second Half, however, there was an 11 msec RVF-LB advantage for targets, and an 8 msec LVF-RB advantage for non-target stimuli.

Structural Models

As was the case with Faces, the fact that visual field superiority for each judgment varied as a function of the level of practice precludes the likelihood of finding significant differences between hemisphere-hand conditions over the course of a testing session.

Mean RTs for each condition on each day, and both days averaged together, for responses to the target and non-target arrays are presented in Tables 16 and 18, respectively. Averaged across both days, neither RTs to the target

array nor non-target arrays conformed to any of the models. Note, however, that the overall means for each visual field are in the predicted direction; a LVF advantage for responses to the target array (LVF = 594 msec, RVF = 600.5 msec), and RVF advantage for responses to the non-target arrays (RVF = 581 msec, LVF = 589 msec). In addition, it can be seen that these visual field differences occurred on Day 1 (LVF < RVF by 14 msec for target array, RVF < LVF by 12 msec for non-target array), but not on Day 2 (RVF < LVF by 2 and 4 msec for target and non-target arrays, respectively). It should also be noted that on Day 1 non-target arrays were responded to 29 msec faster than target arrays when presented in the RVF (594 msec vs. 623 msec) but that this difference was only 3 msec for LVF presentations (606 msec vs. 609 msec).

RTs for individual subjects are presented in Tables 17 and 19, for responses to the target and non-target arrays, respectively. There was little agreement in the ordering of conditions for either judgment. Overall visual field differences, however, were somewhat more consistent. On Day 1 the LVF was responded to faster than the RVF for 7 of 8 subjects when the target array was presented, and the RVF was favored for 6 of 8 subjects for presentations of non-target arrays. On Day 2, half the subjects favored one visual field and half the subjects favored the other visual field for each judgment.

Time Dependent Changes

A significant Judgment X Visual Field X Half inter-

action was also found on each day analyzed separately, $F(1, 7) = 11.026$, $p < .02$ on Day 1; $F(1, 7) = 6.076$, $p < .05$ on Day 2. Inspection of Figure 8 indicates that on each day the same pattern of hemispheric change occurred. On the first half of each day there was a LVF-RB advantage for responses to target stimuli and a RVF-LB advantage for responses to non-target arrays. However, by the second half of both days there is no visual field superiority for either judgment. Similar to the findings for Faces, it appears that whichever visual field is initially being responded to more slowly shows the greatest improvement in processing efficiency over the course of the day.

Analyses employing the per cent change scores tended to support this view. On both Day 1 and Day 2 there was a significant Judgment X Visual Field interaction due to a greater decrease in reaction time when the target array was presented to the RVF-LB than to the initially faster LVF-RB, and, concurrently, greater improvement by the LVF-RB than RVF-LB for non-target arrays ($F(1, 7) = 8.544$, $p < .03$; $F(1, 7) = 6.262$, $p < .05$; Day 1 and Day 2 respectively).

Target Array. Analysis of each Judgment separately revealed that for responses to the target array on Day 1 there was an overall LVF-RB superiority, $F(1, 7) = 7.910$, $p < .03$, and a significant Visual Field X Half interaction $F(1, 7) = 10.452$, $p < .02$. The only other significant finding was faster overall RTs on the second half, than on the first half, of the day, $F(1, 7) = 15.046$, $p < .008$.

Analysis for each half day indicated that the LVF-RB was highly significant for the first half of Day 1, $F(1, 7) = 20.460$, $p < .004$, but not on the second half of the day during which there was a slight, 6 msec, RVF advantage, $F(1, 7) = 0.528$, $p > .4$. Finally, analysis of each Block separately (see Figure 9), revealed a LVF-RB advantage on Block 1 only, $F(1, 7) = 6.620$, $p < .04$. There were no other significant main effects or interactions. On Day 2, analysis of responses to the target array yielded no significant main effects or interactions over the day, each Half or each Block, with the exception of a significant LVF-RB superiority on the first block of trials, $F(1, 7) = 8.168$, $p < .03$. In summary, there was significant LVF-RB superiority for targets on Day 1, which was significant over the first half of the day, but not the second half, and over the first block, but no other block of trials analyzed separately. On Day 2, the duration of the LVF-RB advantage was limited to only the first block of trials.

Non-target Arrays. For responses to non-target arrays on Day 1, the analysis revealed a significant Visual Field X Block interaction, $F(3, 21) = 3.136$, $p < .05$. In contrast to responses to targets there was no main effect for Visual Field on the level of Day, Half or Block analyzed separately. On Day 2, however, there was a significant RVF-LB advantage on Block 1, $F(1, 7) = 7.979$, $p < .03$, and by Block 3 there was a significant advantage for the LVF-RB, $F(1, 7) = 15.715$, $p < .007$.

Interaction of Judgment X Visual Field.

On Day 1 the predicted Judgment X Visual Field interaction was found on Half 1 analyzed separately; a 44 msec LVF-RB advantage for the target array, and a 28 msec RVF-LB advantage for non-targets, $F(1, 7) = 12.830$, $p < .01$. By Half 2, however, there were slight, insignificant visual field differences in the opposite direction, a 6 msec RVF-LB advantage for the target array and a 6 msec LVF-RB advantage for the non-target arrays, $F(1, 7) = 0.375$, $p > .5$.

On Day 2, the predicted Judgment X Visual Field interaction was no longer significant over the first half day (12 msec, LVF-RB advantage for the target and a 19 msec RVF-LB advantage for non-targets, $F(1, 7) = 5.013$, $p > .06$), but was significant over an earlier block of trials (Block 1, 31 msec LVF-RB for targets and a 29 msec, RVF-LB advantage for non-targets, $F(1, 7) = 11.453$, $p < .02$), and by Block 3 of Day 2 the Judgment X Visual Field interaction was now found to be significant in the opposite direction (and 8 msec RVF-LB advantage for targets, and a 27 msec LVF-RB advantage for non-targets, $F(1, 7) = 5.909$, $p < .05$).

Inspection of Figure 9 reveals not only shifting visual field superiorities for each judgment over blocks of trials, but also indicates differential treatment of the target and non-target arrays depending on which hemisphere initially received the stimuli.

Separate analysis of each visual field (Table 20) revealed no significant difference between RTs to the target

and non-target arrays when initially presented to the right hemisphere. For RVF, left hemisphere presentations, the non-target arrays were responded to significantly faster than the target array over the first two blocks of trials. For the remaining blocks, no difference was found. It should be noted that this pattern is exactly opposite to that found in the previous face recognition experiment.

Errors and Slow Responses. The overall error rate for all trials was higher for this experiment than any of the preceding experiments (4%), and an additional 4% of the trials had to be rerun because of slow RTs.

Analysis of errors produced no significant main effects or interactions on either Day 1 or Day 2. Analysis of the number of slow responses, however, revealed a significant Judgment X Visual Field interaction, $F(1, 7) = 5.715, p < .05$, on Day 1, (5.7% of the trials). There were a greater number of trials on which RT exceeded 900 msec for RVF presentations of the target array (RVF = 37 trials, LVF = 21), and concurrently, more slow responses to LVF presentations of non-target arrays (LVF = 20, RVF = 10). This finding is in agreement with the overall mean RTs for Day 1, both in terms of the opposite visual field superiorities for each judgment and in finding no difference between responses to the target and non-target arrays for LVF presentations (target array, number of slow RT trials = 21, mean RT = 609 msec, non-target arrays, number of slow RT trials = 20, mean RT = 606 msec).

Discussion

As was the case for face recognition, the most striking finding was the shifting hemispheric superiorities for each judgment as a function of practice.

As predicted, the LVF was favored for responses to the target array and the RVF was favored for responses to the non-target arrays. However, this effect was found only during the first half of Day 1, and was maintained over an even shorter period of time on Day 2 (Block 1).

The results for the first half of Day 1 (96 experimental trials, preceded by 24 practice trials), exactly replicated the findings reported by Bradshaw et al. (1976), who employed this same paradigm and measured RT for 144 trials (preceded by 36 practice trials). The fact that the effect was maintained over a slightly larger number of trials in the Bradshaw et al. study was most probably due to the level of task difficulty. The only difference between their study and the one reported here was the physical characteristics of the elements used to form the arrays. Since their subjects produced substantially longer RTs (mean RT to target = 920 msec, non-target = 857 msec, Table 3, p. 676), than did the subjects in this study (mean RT Half 1, Day 1; target = 636 msec, non-target = 610 msec), it is likely that the arrays they employed were more difficult to discriminate.

The major difference between the results of this study and those reported by Bradshaw et al., was that they found

an overall speed advantage for RTs to the non-target arrays, as compared to the target array, regardless of visual field. In this study the speed advantage for non-targets was found only for RVF presentations. This effect was reflected on Day 1, both by the overall mean RTs, and the number of slow responses. RTs were the same for target and non-target arrays when presented to the right hemisphere, but there was a speed advantage for responding to the non-target arrays, as compared to the target, for RVF, left hemisphere, presentations. This finding is consistent with the proposed differences in mode of processing for the left and right hemispheres. The left employing a sequential-analytic strategy, resulting in faster RTs to non-target arrays, and the right hemisphere employing a parallel-wholistic strategy, resulting in equal processing time for target and non-target arrays.

However, this differential pattern occurred only over the first half of the trials on Day 1. As can be seen in Figure 9, the speed advantage for non-targets over the target for RVF presentations was found on Blocks 1 and 2, but by Block 3 RTs were identical (RVF, target = 585 msec, non-targets = 588 msec). To the extent that the differences in RT to these symbol arrays reflects different modes of processing, the results strongly suggest that the left hemisphere is capable of employing either strategy.

Cohen (1973) reported evidence that sets of letters are processed in parallel by the right hemisphere and serially

by the left hemisphere, but sets of shapes are processed in parallel by both hemispheres. This assumption was based on the fact that RTs to RVF, but not LVF, presentations increased when letter set size was increased, while there was no increase in RT for either the RVF or LVF when shape set size was increased. The results for shapes were based on the mean RT of 320 trials. A similar interpretation would be made of this data based on the overall mean RTs (384 trials); there was no significant difference between RTs to target and non-target arrays for either hemisphere.

However, once the data is analyzed over blocks of trials, a more complete and complex picture emerges. The left hemisphere may indeed have employed an analytic strategy, but, if so, this approach was not fixed. Over time target and non-target arrays were processed with equal efficiency, suggesting a shift towards wholistic-parallel processing.

In comparison to the face recognition experiment, the observed shifts in hemispheric superiority over time were remarkably similar. Overall, this experiment was more difficult than face recognition, as indicated by the overall mean RT across all conditions (Symbol arrays = 591 msec, Faces = 516 msec), per cent errors (4% vs. 2%), and trials on which RT exceeded 900 msec (4% vs. 1.25%). If these shifts represent differential increases in processing efficiency for each hemisphere, they would be expected to occur sooner with "easier" material. In this respect, the visual field cross-overs occurred sooner for Faces than for Symbol arrays on

Day 1, and at the same point for Symbol arrays on Day 2 and Faces on Day 1 (compare Figures 7 and 9), and occurred sooner for Symbol arrays on Day 2 as compared to Day 1.

In contrast to the similar pattern of visual field cross-overs, there were two striking differences between the results of these experiments. Firstly, there was a LVF, right hemisphere superiority for the easily nameable target array which was significant across all of Day 1, whereas there was a LVF advantage for the target face on only the first block of trials on Day 1, which, although observed in 7 of 8 subjects, failed to reach significance. In addition, when each visual field was analyzed separately, a completely opposite pattern for discriminating target and non-target stimuli was found.

It was suggested that during the pretrial study period, the target face was encoded in some form that was most compatible with right hemisphere processing, reflected by the speed advantage for the target face over the non-target faces for LVF presentations, and the advantage for the LVF over the RVF on Block 1. The only procedural difference between these two experiments was that during the pretrial study period, subjects were given ample time to study both the target and non-target arrays, and the difference between them was carefully pointed out and verbalized. The differences between these two studies may, then, reflect differences in the way these stimuli were initially encoded.

The results suggest that, unlike face stimuli, both target and non-target arrays were initially encoded in some form compatible with both a left hemisphere analytic strategy (feature naming), and a right hemisphere wholistic strategy. This resulted in faster responses to non-target than to target arrays for RVF presentations, and equal RTs to target and non-target arrays for LVF presentations, on the initial block of trials.

With increased experience with the target face, it was suggested that a left hemisphere superiority emerged as a result of the development of a "single feature detection" strategy. However, for responses to the target symbol array, the left hemisphere never exceeded the right hemisphere because this strategy was not applicable. Each non-target array differed from the target by only one feature. Therefore, for presentations of the target array there was no single feature that could be used to discriminate this array from the non-targets.

In response to Faces, the left hemisphere shifted towards feature analysis. For Symbol arrays, the salient features were known from the start, and the left hemisphere shifted from feature analysis to a wholistic strategy. The results suggest that this left hemisphere shift occurred because an analytic strategy was particularly inefficient for responding to the target array. On the first block of trials, presentation of this stimulus produced significantly slower RTs (667 msec) than non-target arrays (600 msec), target

faces (553 msec) or non-target faces (562 msec). In contrast, LVF, right hemisphere RTs were significantly faster to the target face (525 msec) than to the non-target faces (610 msec), target arrays (617 msec) and non-target arrays (637 msec). This suggests that right hemisphere processes were particularly well suited for responding to the target face relative to the other non-linguistic stimuli. This also suggests that the stronger LVF, over RVF, superiority found for the easily nameable symbol arrays as compared to the faces, was not due to a right hemisphere advantage for processing symbols better than faces, but was, in fact, a result of the relative inefficiency of the left hemisphere's analytic strategy for processing the target array.

Taken together, the results of both studies indicate that the left hemisphere can employ a wide range of strategies; sequential feature analysis (for target and non-target symbol arrays during early trials), single feature detection (for the target face during later trials), and a wholistic strategy (for target and non-target arrays during later trials), that the strategy initially employed will be determined by the relationship between target and non-target stimuli, and that over time, the strategy will shift to whichever one is most efficient for dealing with the task at hand. In contrast, the right hemisphere appears to employ wholistic processing throughout.

However, although only the left hemisphere shows a change in strategy, this does not necessarily imply that the

left hemisphere alone developed this strategy. In this respect it is interesting to note that, regardless of the assumed nature of the underlying strategy, in terms of only the difference in RTs for each judgment, in both experiments the left hemisphere shifted to the pattern that the right hemisphere had already established (i.e., faster RTs to the target face than to the non-target faces, equal RTs to target and non-target symbol arrays).

VII

ALL EXPERIMENTS

The data from all four experiments was subjected to an analysis of variance by Experiment, Hand, Judgment, Visual Field and Block with repeated measures on all factors. Separate analyses were carried out for Day 1 and Day 2. The complete ANOVA tables may be found in Appendix A. For Experiment 1, nouns were grouped with targets, and verbs with non-targets, because for any given subject, the finger used (index or middle) to respond to target stimuli was also used to indicate nouns, with the other finger used to indicate verbs and non-targets.

There was a significant main effect for Experiment on both Day 1, $F(3, 21) = 14.991, p < .001$; and Day 2, $F(3, 21) = 16.206, p < .001$. Over both days the overall RTs were fastest for Faces (516 msec) followed by Letters (564 msec), Symbol arrays (591 msec) and Words (638 msec). Targets were responded to significantly faster than non-targets on both days, $F(1, 7) = 43.162, p < .001$; and $F(1, 7) = 18.962, p < .005$, Day 1 and 2, respectively. However, as would be expected from the preceding discussions, there was a significant interaction of Experiment X Judgment on both Day 1, $F(3, 21) = 7.231, p < .005$; and Day 2, $F(3, 21) = 6.654, p < .005$.

There were also a number of higher-order interactions, all of which involved Experiment with every possible combination of Judgment, Visual Field, and Block, as well as a

significant interaction of all factors. None of these interactions were highly significant (p range = .03 to .05), and none of them were significant on both days.

The only significant interaction not involving Experiment was a highly significant interaction of Judgment X Visual Field X Block on Day 1, $F(3, 21) = 11.708$, $p < .001$; and Day 2, $F(3, 21) = 8.334$, $p < .001$ (see Figure 10).

The only other significant finding was for Block on Day 1 only, $F(3, 21) = 28.041$, $p < .001$, indicating a greater overall practice effect on Day 1 than on Day 2. There was also a significant RVF superiority on Day 2, $F(1, 7) = 9.076$, $p < .02$. Separate analyses of each judgment indicated that the RVF was superior for targets (including nouns) on Day 2, $F(1, 7) = 12.428$, $p < .01$, but not for non-targets (including verbs), $F = 2.129$, $p > .10$.

Comparison of Figure 10 to the results of all four experiments indicates that the one feature that was common to all was the LVF advantage on the first block of trials on Day 1, whereas on Block 1 of Day 2, there was a smaller LVF advantage averaged across all experiments. This effect tends to indicate that there was a bias towards the right hemisphere on the earliest trials which was somewhat independent of the main cognitive demands of each task, and which was greatly effected by experience. If this was, in fact, true, this LVF advantage would be expected to be larger for the earlier testing sessions for each subject, regardless of the

experiment they were participating in. Since the sequence of experiments was counterbalanced across subjects, a given experiment was the first or second experiment for half of the subjects and the third or fourth experiment for the remaining subjects. As shown in Table 21, the LVF advantage on the first block of trials on Day 1 was larger when the experiment was either the first or second one that subjects participated in than when it was the third or fourth experiment. This was true both averaged across all experiments and for each experiment separately (with the exception of the most difficult task, noun-verb discrimination; words).

VIII

FINAL DISCUSSION

Towards an Active Model

The results indicate the proposed models were relatively unsuccessful for discriminating between absolute and relative lateralization of function. However, the results suggest that this failure cannot be easily attributed to the insensitivity of RT as a dependent measure, stable individual differences in processing style, the overriding effects of stimulus-response compatibility, or to some other uncontrolled experimental variable. Their failure appears, instead, to be directly related to the degree to which the relative superiority of one hemisphere over the other varies as a function of experience. The fact that hemispheric superiority can shift as a result of practice clearly suggests that any model of hemispheric laterality based solely on what are believed to be invariant structural determinants is, at best, incomplete, and possibly inappropriate.

The proposed models were based, in part, on the assumption that visual field asymmetries can be best explained as a reflection of direct anatomical access to the functionally specialized hemispheres. For example, an overall RVF superiority for linguistic tasks occurs because information presented in this field is projected directly to the language dominant left hemisphere. Implicit in this explanation is the assumption that the cognitive processes, and component

subprocesses (P), necessary to carry out this task are all lateralized to the left hemisphere, and the nature of this processing is constant over time.

The results indicate that both of these assumptions are incorrect. They suggest, instead, the need for a more complex model that must allow for the following:

1. that performance of most tasks involves multiple levels of processing;
2. that these processes may differ with respect to degree of lateralization (from relative to absolute) so that the superiority of one hemisphere over the other will be determined by the interaction of these processes;
3. that the relative importance of each process may vary as a result of experience, thereby producing changes in the observed superiority of one visual field over the other.
4. with increased experience, the task may be transformed to such an extent that the type of processing it was originally intended to elicit may no longer be required, allowing the emergence of qualitatively different processes.

Although admittedly speculative, certain similarities in the pattern of RTs to the target stimuli suggest the following model.

Stage 1 - During the earliest trials, a bias towards the LVF, right hemisphere was found on all experiments. This advantage was found to be larger on Block 1 than on Half 1, larger on Day 1 than Day 2, and larger on earlier testing sessions than later testing sessions, regardless of the experiment.

It was previously suggested that this right hemisphere effect on the linguistic tasks may have been related to perceptual processing demands. This assumption was supported by Bryden and Allard's (1976) finding of a LVF superiority for reading scriptlike letters and a greater number of visual confusion errors made to words presented in the LVF (Pirazollo & Rayner, 1977). It is also consistent with the findings of Wilkins and Steward (1974), who reported a LVF superiority for name matching of letter pairs when the second letter of the pair followed the first by 50 msec, but a RVF superiority when the interval was increased to 990 msec.

The degree of perceptual difficulty then, may be one factor which is of increased importance during the early trials. However, the letters used were of a familiar typeface and should not have, by themselves, overtaxed the perceptual systems of the left hemisphere. Another factor that may have been of importance during these early trials was the general unfamiliarity of the experimental task, and, for the linguistic tasks, the stimuli in the noun, verb, and letter sets.

Descriptions of right hemisphere functioning are usually based on its superiority for visuo-spatial processing, which is assumed to reflect an underlying "gestalt-wholistic" mode of processing. However, theories relating hemispheric differences solely to the lateralization of qualitatively different modes of processing have been seriously challenged by the recent demonstration that the right hemisphere superiority for split-brain

patients on a wide variety of spatial tasks (block design, cube drawing, fragmented figures) appears to be totally dependent on the use of manual activities. When the manipulative demands (the performance of the left and right hands) were eliminated, no hemispheric differences were found (Le Doux, Wilson & Gazzaniga, 1977). This finding suggests that the visuo-spatial superiority of the right hemisphere may be dependent on some other processes or mechanisms.

This underlying mechanism may be of a more general "orienting" or "preattentive" nature. Kinsbourne (1974) suggested that the right hemisphere may be specialized for "preattentive" processes. This term was coined by Neisser (1967), who suggested that these processes operate to structure the visual field as a necessary prerequisite to focal attention. "In terms of information processing, the whole is prior to its parts" (1967, p. 91). As Kinsbourne pointed out, "patients with right posterior lesions who suffer from visuo-spatial agnosia behave as though this preattentive structuring had not occurred" (1974, p. 278). A number of other consequences of right hemisphere damage also appear to be consistent with a deficit in some general orienting, "preattentive", or arousal mechanism. For example, patients with right hemisphere damage have been found to be impaired on tests of incidental learning (Luria & Simernitskaya, 1977), to have disturbances in bilateral arousal as evidenced by lowered GSR (Heilman, Schwartz & Watson, 1978), to be impaired on tests of simple reaction time (Howes & Boller,

1975), and to be impaired in the perception of unfamiliar, but not familiar, visual stimuli (Kimura, 1963). In addition, damage limited to the right hemisphere has been reported to produce acute confusional states (Mesulam, Waxman, Geshwind & Sabin, 1976) and more severe cases of unilateral neglect than damage to the left hemisphere (Albert, 1973). In normal subjects, evidence for a LVF superiority on simple reaction time tasks (see, General Introduction) is also consistent with this interpretation.

Taken together, this evidence suggests a bias towards right hemisphere activation as a result of the perceptual demands, unfamiliarity and the importance of "preattentive" processes during the early trials of any tachistoscopic laterality task. These factors should, in turn, interact with the intended task demands (reading words, facial recognition, etc.), detracting from the expected RVF superiority for linguistic tasks and adding to a LVF superiority for visuo-spatial tasks.

Stage 2 - As the stimulus set and task demands become more familiar, the intended processes should come to the fore. For the linguistic tasks this was exemplified by the emergence of a RVF superiority for both Words and Letters after Block 1. It is at this point that the structural models should be most useful, provided that this stage is maintained over a large enough number of trials.

Stage 3 - With repeated experience, a small set of stimuli may become so overlearned that the difference between the visual fields disappears. The task is now a qualitatively different task, and is sufficiently easy that either hemisphere can accomplish it. Alternatively, repeated experience may lead to a qualitatively different form of analysis which may favor processes lateralized to the hemisphere opposite that activated in Stage 2.

In terms of this analysis, the results for nouns are assumed to reflect Stages 1 and 2. The fact that Stage 2 was maintained for a relatively longer time than in any other experiment is consistent with the finding that the structural models were most appropriate for this data. The switch from the model for absolute lateralization (Model I) towards relative lateralization (Model II) may have resulted from a trend towards some new strategy (non-phonological reading?) (Stage 3).

The triangular pattern for target letters on Day 2 (see Figure 5) is assumed to represent Stages 1 through 3. Similar declines in visual field asymmetries over time have been reported (Hellige, 1976; Kailman & Corballis, 1975). In this respect, it is interesting to note that many subjects in this experiment reported that while at first they had to "name" each letter in order to do the task, after a while they could respond "automatically".

Since all of the faces and symbol arrays were known to the subjects prior to any tachistoscopic trials, the

early trials are assumed to reflect primarily Stage 2. The ensuing shifts in visual field superiority (Stage 3) reflect the development of more efficient strategies for performing the required task.

In light of this analysis, it would be predicted that the results for nouns could be made to be similar to the results for letters by running an additional testing session, reducing the number of words in the noun set, or employing a longer exposure time. Similarly, the results for letters could be made to match the results obtained for nouns (both in terms of the larger LVF advantage during early trials and the maintenance of the RVF superiority) by using more script-like letters, shorter exposure time, placing the stimuli further in periphery of the visual field, increasing the number of stimuli in the target letter set. These last three manipulations would also be expected to increase the LVF superiority for faces.

Individual Differences

Individual subjects showed a similar trend as that seen for the grouped data. Confusing orderings of the hemisphere-hand conditions in the grouped data were not traceable to stable individual differences in processing style, which were expected to be reflected by different models fitting the data of different subjects. However, once the data from each subject was broken down over blocks of trials, a much greater amount of between subject consistency emerged

than would be expected based on the overall means from each testing session.

For example, consideration of the results from each subject on each experiment indicates that the greatest amount of variability occurred on the face recognition task. In response to the target face on Day 1, four subjects favored the LVF, four subjects favored the RVF and there was almost no agreement between subjects for the ordering of the hemisphere-hand conditions (see Table 12).

Over blocks of trials, however, 7 of the 8 subjects favored the LVF on Block 1. The one exception was found to have a LVF advantage during the earlier block of 24 practice trials. By Block 3, there was a RVF advantage for all 8 subjects.

Consideration of the pattern of each visual field over blocks of trials also suggested several possible individual difference parameters that occurred within the universal pattern of a LVF to RVF shift.

1. Overall rate of improvement. As can be seen in Figure 7, RTs to the target face on Day 1 decreased by approximately 60 msec, averaged across both visual fields. The range for individual subjects varied from virtually no improvement to a gain of 150 msec. Furthermore, the four subjects who favored the RVF, averaged across all trials on Day 1, averaged approximately 40 msec, while those who favored the LVF averaged 80 msec of improvement. Since all subjects had a RVF advantage by Block 3, this suggests that

those subjects who switched towards the RVF earliest, and therefore favored the RVF overall, developed the more efficient strategy earlier so that less improvement was necessary over the remainder of the trials.

2. Rate of LVF to RVF cross-over. One subject crossed over between practice and Block 1, three subjects between Block 1 and Block 2, and four subjects between Block 2 and Block 3. It would be predicted that those subjects most proficient with an "analytic strategy", (single feature detection), would show the earliest cross-overs.

3. Final outcome. Three subjects still favored the RVF by Block 4. Three subjects again favored the LVF as a result of slower RT on Block 4 as compared to Block 3 in response to RVF presentations. Two subjects had virtually no visual field difference.

Analysis over blocks of trials may also be useful for understanding the confusing finding in some of these experiments, as well as in others, of a complete reversal of visual field superiority from one testing session to another. For example, in the symbol array experiment, subject #3 had a 28 msec LVF advantage for the target array on Day 1, and a 28 msec RVF advantage on Day 2. On Day 1 there was a 28 msec RVF advantage for the non-target arrays, which on Day 2 produced a LVF advantage of 17 msec. As can be seen in Figure 11, the pattern of RTs for each visual field was similar on both days, the primary difference being the earlier visual field cross-overs on Day 2, presumably as a result of the experience gained on Day 1.

In relation to this analysis of individual subjects, it is interesting to note that a LVF superiority was reported for the recognition of single letters, but only for first graders, and not for third, fifth, or seventh graders (Carmon, Nachshon & Starinsky, 1976). This suggests that an analysis over blocks of trials may be useful for differentiating different subgroups of reading disabled children. For example, as compared to normals, some children may have a significantly longer Stage 1, others may never attain Stage 3, etc.

Conclusion

Regardless of the nature of the underlying mechanisms, the observed shifts in hemispheric superiority are difficult to conceptualize within the framework of a passive, direct anatomical access model. It should be pointed out, however, that rejection of this model in no way implies a rejection of any of our current knowledge about the localization of function. The results suggest, instead, that these processes must be recast within a more dynamic, active framework.

The ideal situation would be if these changes were reflected by changes in the ordering of the hemisphere-hand conditions from one model to another. However, inspection of the grouped data, as well as the data of individual subjects, provided little support for this possibility. This was probably so for two reasons. First, as the number of trials decreases, the mean RTs becomes increasingly susceptible to the influences of one or two variable trials, and secondly,

the rate of visual field cross-over varied from one individual to another. By observing the RTs at arbitrarily defined blocks of trials, individuals were "caught" at different stages of on-going change.

Overall, the results were most consistent with a formulation similar to Kinsbourne's selective activation hypothesis, with the additional stipulation that several processes within each hemisphere may be activated at any given point of time, that the relative importance of each process may vary with experience, and that with increased experience qualitatively different processes may be elicited.

Many of the models that have dominated cognition have viewed mind as a collection of somewhat inter-related "passive" systems, through which information "flows" while being subjected to a variety of transformations. The fact that our thinking about hemispheric laterality has been dominated by this "passive" formulation is reflected by the vocabulary used to account for visual field asymmetries. Information is directed or projected to one hemisphere, which then does such and such, or transfers the information to the other hemisphere, and so on. Yet these "passive" models have often failed to account for the diverse performance of individual subjects, especially well practiced subjects (e.g., Hirst, Neisser & Spelke, 1978, Neisser, 1976).

It is suggested that a more appropriate starting point for building models of hemispheric functioning is the individual, who, as Marshall observed, finds himself con-

fronted with "the strange tasks that neuropsychologists set for him" (1973, p. 467). It may be that this quality of "strangeness" alone, produces an initial activation of right hemisphere processes. Subsequent performance, and the resulting hemispheric superiorities, will be determined by an interaction of the strength of the task for eliciting a particular lateralized process, and the individuals ability to weaken these demands through transformation.

TABLE 1

GENERAL PARADIGM

SUBJECT #	RESPONSE FINGER		HAND ORDER	EXPERIMENT
	Targets ¹	Non-Targets ²	Day 1 ³	ORDER ⁴
1	Index	Middle	L-R-L-R	4-1-3-2
2	Index	Middle	R-L-R-L	1-2-4-3
3	Index	Middle	L-R-L-R	3-4-2-1
4	Index	Middle	R-L-R-L	2-3-1-4
5	Middle	Index	L-R-L-R	2-3-1-4
6	Middle	Index	R-L-R-L	3-4-2-1
7	Middle	Index	L-R-L-R	1-2-4-3
8	Middle	Index	R-L-R-L	4-1-3-2

1. nouns, target letters, face, and symbol array
2. verbs, non-target letters, faces, and symbol arrays
3. reverse order on Day 2
4. 1= Words, 2= Letters, 3= Faces, 4= Symbol arrays

TABLE 2
Stimulus Materials

Experiment 1: WORDS

Nouns: DOG, CAT, HAT, KEY, CUP, EAR, LEG, CAR,
SUN, BOY, BED, EGG

Verbs: EAT, RAN, LET, SIT, PUT, SAY, SEE, ASK,
GET, TRY, USE, CRY

Experiment 2: LETTERS

Targets: D, P, G, C, B, T

Non-Targets: L, S, M, N, R, H

Experiment 3: FACES

Target

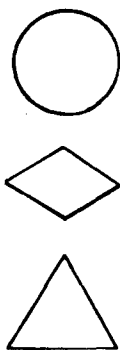


Non-Targets



Experiment 4: SYMBOL ARRAYS

Target



Non-Targets

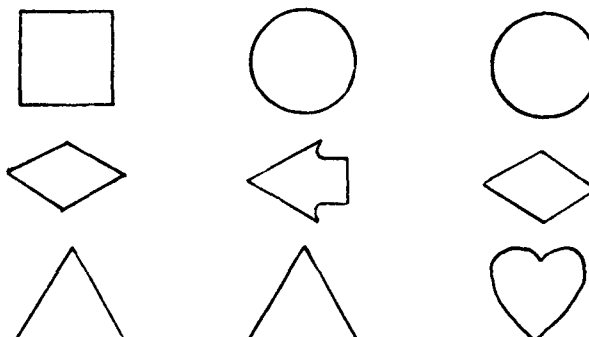


TABLE 3

NOUNS

T-tests of the Significance of the Differences
Between Mean RTs for the Hemisphere-Hand Conditions

	ORDER			p (2-tailed)	df=7
	expected	actual	msec		
DAY 1 & 2	1	LB-RH	619] >.10] <.01
	2	LB-LH	625		
	4	RB-RH	633] >.10	
	3	RB-LH	642		
DAY 1	1	LB RH	649] >.50] <.05
	2	LB LH	653		
	4	RB RH	654] <.05	
	3	RB LH	675		
DAY 2	1	LB RH	589] >.50] <.05
	2	LB LH	596		
	3	RB LH	610] >.50	
	4	RB RH	613		

TABLE 4

Individual Mean RTs: Nouns

Subject#	ORDER												
					RVF		LVF		LB	LB	RB	RB	
	RVF	LVF	LH	RH	LH	RH	LH	RH	RH	LH	RH	LH	
D A Y 1 & 2	1	624	642	634	631	626	622	643	641	1	2	3	4
	2	618	650	631	636	609	626	654	646	2	1	3	4
	3	546	564	555	554	559	533	551	576	1	3	4	2
	4	649	662	668	644	666	633	670	654	1	3	2	4
	5	593	619	612	600	600	585	624	614	1	2	3	4
	6	602	598	608	592	599	605	617	580	3	2	1	4
	7	720	731	738	713	731	708	744	717	1	3	2	4
	8	623	637	622	639	608	638	635	640	3	1	4	2
Mean	622	637	633	626	625	619	642	633					
<hr/>													
D A Y 1 6 7 8	1	633	649	641	641	633	633	649	650	1.5	1.5	4	3
	2	660	684	689	654	667	653	712	656	1	3	2	4
	3	573	588	586	574	590	556	583	593	1	3	4	2
	4	689	681	692	678	691	688	694	668	2	3	1	4
	5	616	648	633	631	614	618	652	645	2	1	3	4
	6	620	608	622	606	613	627	631	585	3	2	1	4
	7	769	782	796	755	795	743	798	767	1	3	2	4
	8	650	674	652	672	625	676	680	668	3	1	2	4
Mean	651	664	664	651	653	649	675	654					
D A Y 2 7 8	1	615	634	628	622	619	612	637	632	1	2	3	4
	2	575	616	573	618	551	600	596	636	3	1	4	2
	3	520	540	524	535	529	511	520	560	1	3	4	2
	4	610	643	643	610	641	579	646	641	1	2.5	2.5	4
	5	570	590	592	568	587	553	597	583	1	3	2	4
	6	585	589	595	579	586	584	604	575	2	3	1	4
	7	670	679	679	670	668	673	690	668	2.5	1	2.5	4
	8	596	601	591	606	592	600	590	612	3	2	4	1
Mean	593	611	603	601	596	589	610	613					

TABLE 5

VERBS

T-tests of the Significance of the Differences Between
Mean RTs for the Hemisphere-Hand Conditions

	<u>expected</u>	<u>actual</u>	<u>msec</u>	p (2-tailed) df=7	
DAY 1 & 2	2	LB-LH	642] >.50] >.10
	1	LB-RH	645		
	3	RB-RH	649] >.50	
	4	RB-LH	651		
<hr/>					
DAY 1	3	RB-RH	676] >.50] >.10
	1	LB-RH	677		
	2	LB-LH	679		
	4	RB-LH	691		
<hr/>					
DAY 2	2	LB-LH	605] >.50] >.10
	4	RB-LH	611		
	1	LB-RH	613		
	3	RB-RH	621		

TABLE 6

Individual Mean RTs: Verbs

Subject#		RVF	LVF	LH	RH	RVF		LVF		ORDER			
						LH	RH	LH	RH	LB	LB	RB	RB
										RH	LH	RH	LH
	1	680	706	689	697	680	681	699	713	2	1	4	3
D	2	623	640	637	626	646	600	628	653	1	3	4	2
A	3	545	532	537	540	536	554	539	526	4	2	1	3
Y	4	663	676	659	680	652	675	667	685	3	1	4	2
	5	630	627	620	637	624	636	616	638	3	2	4	1
1	6	626	616	641	601	639	613	643	590	2	3	1	4
&	7	717	725	719	723	703	732	736	715	3	1	2	4
2	8	660	673	666	667	656	665	677	670	2	1	3	4
Mean		643	650	646	647	642	645	651	649				
<hr/>													
	1	709	750	734	725	713	705	755	746	1	2	3	4
D	2	654	688	692	650	698	611	687	689	1	4	3	2
A	3	574	544	565	552	579	570	554	534	3	4	1	2
Y	4	700	694	682	712	682	718	682	706	4	1.5	3	1.5
	5	665	657	648	679	648	682	648	667	4	1.5	3	1.5
1	6	658	650	691	617	680	637	703	597	2	3	1	4
	7	765	772	764	773	744	786	785	760	4	1	2	3
	8	697	715	703	709	691	704	716	714	2	1	3	4
Mean		678	684	685	677	679	677	691	676				
<hr/>													
	1	653	662	646	670	648	658	644	681	3	2	4	1
D	2	592	594	582	604	594	590	570	618	2	3	4	1
A	3	516	522	509	529	494	539	525	519	4	1	2	3
Y	4	627	659	638	648	623	632	653	665	2	1	4	3
	5	595	597	592	600	600	590	585	610	2	3	4	1
2	6	594	583	591	586	599	589	584	583	3	4	2	1
	7	669	678	674	674	662	679	687	670	3	1	2	4
	8	624	633	630	627	621	627	639	627	2.5	1	2.5	4
Mean		609	616	608	617	605	613	611	621				

TABLE 7
TARGET LETTERS

T-tests of the Significance of the Differences Between
Mean RTs for the Hemisphere-Hand Conditions

	ORDER		msec	p (2-tailed)	
	expected	actual			
DAY 1 & 2	1	LB-RH	530] >.50] <.05
	2	LB-LH	540		
	3	RB-RH	542] >.05	
	4	RB-LH	562		
DAY 1	1	LB-RH	556] >.50] >.05
	2	LB-LH	559		
	3	RB-RH	567] >.10	
	4	RB-LH	588		
DAY 2	1	LB-RH	505] >.10] <.05
	3	RB-RH	515		
	2	LB-LH	520] >.10	
	4	RB-LH	536		

TABLE 8

Individual Mean RTs: Target Letters

Subject#		RVF	LVF	LH	RH	RVF		LVF		LB	ORDER			
						LH	RH	LH	RH		RH	LB	RB	RB	LH
	1	534	566	552	548	539	529	565	567	1	2	4	3	
D	2	494	513	506	502	507	482	505	522	1	3	4	2	
A	3	463	469	480	451	482	494	479	459	1	4	2	3	
Y	4	581	589	594	576	595	567	593	586	1	4	2	3	
	5	542	566	542	566	515	570	570	563	3.5	1	2	3.5	
1	6	558	570	590	538	579	537	602	539	1	3	2	4	
&	7	615	640	655	594	635	595	676	604	1	3	2	4	
2	8	492	497	486	503	465	520	507	487	4	1	2	3	
Mean		535	552	551	536	540	530	562	542					
<hr/>														
	1	553	589	580	563	566	541	595	584	1	2	3	4	
D	2	531	552	546	537	540	523	553	552	1	2	3	4	
A	3	479	486	506	459	502	456	510	462	1	3	2	4	
Y	4	579	602	582	599	570	589	595	610	2	1	4	3	
	5	600	616	587	629	580	621	595	637	3	1	4	2	
1	6	550	636	594	541	555	545	634	538	2	3	1	4	
	7	638	657	676	618	660	616	693	621	1	3	2	4	
	8	528	533	517	545	501	556	533	534	4	1	3	2	
Mean		557	578	574	561	559	556	588	567					
	1	514	543	524	533	512	517	536	550	2	1	4	3	
D	2	458	474	466	467	475	442	457	492	1	3	4	2	
A	3	447	452	456	444	463	432	449	456	1	4	3	2	
Y	4	582	576	605	553	620	545	591	562	1	4	2	3	
	5	485	517	498	505	451	520	545	490	3	1	2	4	
2	6	566	555	587	535	603	530	571	540	1	4	2	3	
	7	592	623	634	581	610	574	659	588	1	3	2	4	
	8	457	461	455	562	430	484	481	441	4	1	2	3	
Mean		513	525	528	510	520	505	536	515					

TABLE 9

NON-TARGET LETTERS

T-tests of the Significance of the Differences
Between Mean RTs for the Hemisphere-Hand Conditions

	ORDER	expected	actual	msec	p (2-tailed)	df=7
DAY 1 & 2	3	RB-RH	579	] >.50	] >.10	
	4	RB-LH	583			
	2	LB-LH	585	] >.50		
	1	LB-RH	590			
<hr/>						
DAY 1	4	RB-LH	604	] >.50	] >.05	
	3	RB-RH	606			
	2	LB-LH	609	] >.10		
	1	LB-RH	628			
<hr/>						
DAY 2	1	LB-RH	552	] >.50	] >.10	] >.10
	3	RB-RH	552			
	2	LB-LH	560	] >.10		
	4	RB-LH	562			

TABLE 10

Individual Mean RTs: Non-Target Letters

Subject#		ORDER											
						RVF		LVF		LB	LB	RB	RB
		RVF	LVF	LH	RH	LH	RH	LH	RH	RH	LH	RH	LH
D	1	558	549	573	534	582	534	565	534	1.5	4	1.5	3
A	2	542	552	545	549	528	557	562	542	3	1	2	4
Y	3	532	528	511	549	509	555	513	544	4	1	3	2
	4	657	662	648	671	643	672	654	671	4	1	3	2
1	5	635	599	635	599	639	631	631	568	2.5	4	1	2.5
&	6	597	582	602	577	611	584	594	570	2	4	1	3
2	7	654	664	644	675	638	671	650	679	3	1	4	2
	8	518	508	509	517	525	512	494	523	2	4	3	1
Mean		587	581	584	584	585	590	583	579				
<hr/>													
	1	586	565	602	549	612	561	593	537	2	4	1	3
D	2	585	586	581	590	578	593	584	588	4	1	3	2
A	3	549	544	528	565	533	565	523	566	3	2	4	1
Y	4	687	671	658	700	657	717	660	682	4	1	3	2
	5	714	644	688	670	697	732	679	609	4	3	1	2
1	6	584	585	595	574	596	573	595	575	1	4	2	3
	7	684	708	667	725	649	719	685	732	3	1	4	2
	8	557	537	533	561	552	562	515	560	4	2	3	1
Mean		618	605	606	617	609	628	604	606				
	1	530	535	545	520	553	508	538	532	1	4	2	3
D	2	500	518	509	508	479	521	540	496	3	1	2	4
A	3	516	513	495	534	486	546	504	522	4	1	3	2
Y	4	628	654	638	644	629	628	648	660	1	2	4	3
	5	556	555	582	529	581	531	583	528	2	3	1	4
2	6	611	579	610	580	627	596	593	565	3	4	1	2
	7	625	621	622	625	628	623	616	627	2	4	1	3
	8	480	480	486	474	498	462	474	486	1	4	2	3
Mean		556	557	561	552	560	552	562	552				

TABLE 11

TARGET FACE

T-tests of the Significance of the Differences Between
the Mean RTs for the Hemisphere-Hand Conditions

DAY 1 & 2	ORDER		msec	p (2-tailed)	df=7
	expected	actual			
	4	LB-RH	477] >.10] >.10] >.10] >.10
	2	RB-RH	486		
	3	LB-LH	489		
	1	RB-LH	497		

DAY 1	4	LB-RH	494] >.50] >.10] >.10] >.10
	2	RB-RH	508		
	1	RB-LH	511		
	3	LB-LH	516		

DAY 2	4	LB-RH	461] >.50] >.05] >.05
	3	LB-LH	462		
	2	RB-RH	464		
	1	RB-LH	484		

TABLE 12
Individual Mean RTs: Target Face

Subject#		RVF	LVF	LH	RH	RVF		LVF		RB	ORDER			
						LH	RH	LH	RH		LH	RH	LB	LB	LH	RH
D A Y 1 & 2	1	508	563	556	514	538	479	575	550	4	3	2	1	
	2	443	427	429	440	460	426	399	454	1	3	4	2	
	3	493	481	502	471	521	464	484	479	3	2	4	1	
	4	490	499	499	490	515	465	483	515	2	3	4	1	
	5	443	473	448	469	421	465	475	471	4	3	1	2	
	6	463	476	481	457	463	463	500	452	4	1	2	3	
	7	556	559	570	544	549	562	591	527	4	1	2	3	
	8	470	459	459	469	445	495	474	443	3	1	2	4	
Mean		483	491	493	481	489	477	497	486					
<hr/>														
D A Y 1 7 8	1	529	593	591	531	582	476	601	586	4	3	2	1	
	2	460	441	439	462	476	444	403	480	1	4	3	2	
	3	555	538	570	523	589	522	551	525	3	2	4	1	
	4	503	515	501	518	525	482	477	554	1	4	3	2	
	5	461	468	445	484	426	497	464	472	2	3	1	4	
	6	487	478	505	460	504	470	507	450	4	1	3	2	
	7	568	597	598	567	565	571	631	564	4	1	2	3	
	8	478	448	462	464	466	490	458	439	2	1	3	4	
Mean		505	510	514	501	516	494	511	508					
D A Y 2 7 8	1	488	532	521	498	494	482	549	515	4	3	2	1	
	2	426	412	419	418	444	408	395	429	1	3	4	2	
	3	430	425	435	420	454	407	417	433	2	3	4	1	
	4	477	482	497	462	506	449	489	476	3	2	4	1	
	5	425	479	452	452	417	433	487	471	4	3	1	2	
	6	439	474	458	456	422	457	494	455	4	2	1	3	
	7	544	521	543	522	534	554	552	491	4	1	2	3	
	8	462	469	458	469	425	500	491	447	3	2	1	4	
Mean		461	474	473	463	462	461	484	464					

TABLE 13

NON-TARGET FACES

T-tests of the Significance of the Differences Between
the Mean RTs for the Hemisphere-Hand Conditions

	ORDER		msec	p (2-tailed)	df=7
	expected	actual			
DAY 1 & 2	3	LB-LH	535] >.50] >.50
	4	LB-RH	540		
	1	RB-LH	547] >.50	
	2	RB-RH	553		
DAY 1	4	LB-RH	558] >.50] >.50
	3	LB-LH	563		
	1	RB-LH	563] >.10	
	2	RB-RH	579		
DAY 2	3	LB-LH	507] >.10] >.10
	4	LB-RH	522		
	2	RB-RH	528] >.50	
	1	RB-LH	532		

TABLE 14

Individual Mean RTs: Non-Target Faces

Subject#		RVF	LVF	LH	RH	RVF		LVF		ORDER			
						LH	RH	LH	RH	RB	RB	LB	LB
D	1	566	606	579	593	563	569	595	617	3	4	1	2
A	2	483	471	478	476	471	495	485	457	3	1	2	4
Y	3	511	554	520	545	489	533	551	558	3	4	1	2
	4	556	540	539	557	543	570	535	545	1	3	2	4
1	5	532	514	515	531	530	535	500	528	2	1	3	4
&	6	586	565	587	565	585	588	589	542	4	1	2	3
2	7	585	625	611	599	594	577	629	622	4	3	2	1
	8	479	528	500	507	504	454	496	560	2	4	3	1
Mean		537	550	541	546	535	540	547	533				
<hr/>													
	1	592	608	588	612	585	600	591	625	2	4	1	3
D	2	495	489	486	498	483	508	490	489	3	2	1	4
A	3	563	618	578	603	546	580	610	627	3	4	1	2
Y	4	586	556	558	584	576	597	541	571	1	2	3	4
	5	560	528	539	549	558	562	521	536	1	2	3	4
1	6	614	597	619	592	618	611	621	574	4	1	3	2
	7	598	643	638	505	508	440	485	571	2	4	3	1
	8	474	528	496	505	508	440	485	571	2	4	3	1
Mean		560	571	563	568	563	558	563	579				
<hr/>													
	1	540	605	571	574	542	539	600	610	3	4	2	1
D	2	471	453	470	454	460	483	481	425	3	1	2	4
A	3	459	490	462	487	433	486	492	489	4	3	1	2
Y	4	527	524	520	531	511	544	529	519	3	2	1	4
	5	505	499	541	514	503	508	479	520	1	4	2	3
2	6	559	534	555	538	553	565	557	511	3	1	2	4
	7	573	608	585	596	558	588	613	604	4	3	1	2
	8	484	528	503	509	500	468	507	550	3	4	2	1
Mean		515	530	520	525	507	522	532	528				

TABLE 15

ANOVAs of the Differences Between Mean RTs to Target and Non-Target FACES in the LVF and RVF at each Block of 48 trials

		LVF	RVF
Day 1 : Block	1	* * *	-
	2	*	-
	3	* *	* * *
	4	* * *	* *
Day 2 : Block	1	* *	* *
	2	* * *	* *
	3	* * *	* * *
	4	* * *	* * *

$p > .10 = -$

$p < .10 = *$

$p < .05 = * *$

$p < .005 = * * *$

TABLE 16
TARGET SYMBOL ARRAY

T-tests of the Significance of the Differences Between
the Mean RTs for the Hemisphere-Hand Conditions

	ORDER		msec	p (2-tailed)	df=7
	expected	actual			
DAY 1 & 2	2	RB-RH	592] >.50] >.50
	1	RB-LH	596		
	3 or 4	LB-RH	598] >.50	
	4 or 3	LB-LH	603		
DAY 1	1	RB-LH	609] >.50] >.10
	2	RB-RH	609		
	4 or 3	LB-LH	622] >.50	
	3 or 4	LB-RH	624		
DAY 2	3 or 4	LB-RH	571] >.50] >.10
	2	RB-RH	576		
	4 or 3	LB-LH	583] >.50	
	1	RB-LH	583		

TABLE 17

Individual Mean RTs: Target Symbol Array

Subject#		RVF	LVF	LH	RH	RVF		LVF		RB	ORDER		LB
						LH	RH	LH	RH	LH	RH	LH	RH
D A Y	1	621	612	626	607	627	614	624	600	3	1	4	2
	2	627	638	635	630	626	629	645	630	4	3	1	2
	3	462	462	455	469	460	463	449	474	1	4	2	3
	4	607	593	606	593	626	587	586	599	1	3	4	2
	5	579	574	574	579	576	582	572	576	1	2.5	2.5	4
	6	649	623	665	608	691	607	638	608	3	2	4	1
	7	643	647	641	649	643	643	640	655	1	4	2.5	2.5
	8	613	605	593	626	572	655	613	597	3	2	1	4
Mean		600	594	599	595	603	598	596	592				
<hr/>													
D A Y	1	656	637	659	635	662	651	656	619	3	1	4	2
	2	617	613	615	615	616	618	614	612	2	1	3	4
	3	495	467	479	482	504	486	455	478	1	2	4	3
	4	632	602	590	643	615	649	566	638	1	3	2	4
	5	621	619	615	624	624	618	607	631	1	4	3	2
	6	681	657	711	627	729	634	694	621	3	1	4	2
	7	669	678	677	670	670	668	685	672	4	2	3	1
	8	613	599	576	636	557	670	596	603	2	3	1	4
Mean		623	609	615	616	622	624	609	609				
D A Y	1	585	586	592	579	593	578	592	581	3	2	4	1
	2	638	662	656	644	636	640	676	649	4	3	1	2
	3	429	457	430	456	417	440	443	471	3	4	1	2
	4	582	584	622	543	638	526	607	561	3	2	4	1
	5	537	529	533	533	529	546	537	521	3	1	2	4
	6	617	589	618	588	654	580	582	596	2	3	4	1
	7	617	616	605	628	616	619	595	638	1	4	2	3
	8	614	611	609	616	587	641	631	592	3	1	2	4
Mean		577	579	583	573	583	571	583	576				

TABLE 18
NON-TARGET SYMBOL ARRAYS

T-tests of the Significance of the Differences Between
the Mean RTs for the Hemisphere-Hand Conditions

	ORDER		msec		p (2-tailed)	df=7
	expected	actual				
DAY 1 & 2	2	LB-LH	573	]	>.10]
	3 or 4	RB-LH	584			
	1	LB-RH	590			
	4 or 3	RB-RH	594			
					>.10	>.50
<hr/>						
DAY 1	2	LB-LH	579	]	>.05]
	3 or 4	RB-LH	595			
	1	LB-RH	609			
	4 or 3	RB-RH	617			
					<.05	>.10
<hr/>						
DAY 2	2	LB-LH	567	]	>.50]
	1	LB-RH	570			
	4 or 3	RB-RH	571	]	>.50	
	3 or 4	RB-LH	574			
<hr/>						

TABLE 19

Individual Mean RTs: Non-Target Symbol Arrays

Subject#		RVF	LVF	LH	RH	RVF		LVF		LB	ORDER		RB
						LH	RH	LH	RH		LH	RH		LH
D	1	631	630	621	640	623	638	619	641	3	2	4	1
A	2	630	619	612	637	615	646	609	629	4	2	3	1
Y	3	516	522	499	539	477	554	521	523	4	1	3	2
	4	600	634	596	637	575	624	617	650	3	1	4	2
1	5	536	550	534	552	543	529	525	574	2	3	4	1
&	6	604	601	616	589	608	600	624	579	2	3	1	4
2	7	571	590	580	581	569	574	592	587	2	1	3	4
	8	563	569	570	562	572	553	568	570	1	4	3	2
Mean		581	589	578	592	573	590	584	594				
<hr/>													
	1	652	652	639	665	639	666	640	664	4	1	3	2
D	2	632	601	592	640	603	661	582	620	4	2	3	1
A	3	497	525	483	538	446	547	521	530	4	1	3	2
Y	4	588	645	599	633	567	609	631	660	2	1	4	3
	5	555	584	556	583	557	553	556	613	1	3	4	2
1	6	636	639	643	631	646	626	641	637	1	4	2	3
	7	610	611	597	624	593	627	601	621	4	1	3	2
	8	582	592	585	590	580	585	590	595	2	1	4	3
Mean		594	606	587	613	579	609	595	617				
	1	609	608	603	614	608	610	598	619	3	2	4	1
D	2	629	637	631	634	627	631	636	638	2	1	4	3
A	3	535	518	514	539	508	562	520	516	4	1	2	3
Y	4	612	624	594	640	584	640	604	641	3	1	4	2
	5	517	515	512	521	529	506	495	536	2	3	4	1
2	6	572	564	589	547	571	574	607	521	3	2	1	4
	7	533	568	564	537	545	521	583	554	1	2	3	4
	8	543	545	555	533	564	522	546	545	1	4	2	3
Mean		568	572	570	570	567	570	574	571				

TABLE 20

ANOVAs of the Difference Between Mean RTs to
Target and Non-Target SYMBOL ARRAYS in the LVF and RVF
at each Block of 48 trials

		LVF	RVF
Day 1 : Block	1	-	* * *
	2	-	* * *
	3	-	-
	4	-	-
Day 2 : Block	1	-	-
	2	-	-
	3	-	-
	4	-	-

$p > .10 = -$

$p < .005 = * * *$

TABLE 21

Right Hemisphere Advantage for Target Stimuli on
Block 1, Day 1. First or Second Experiment versus Third
or Forth

LVF-RVF * in msec

EXPERIMENT	1st or 2nd	3rd or 4th
WORDS -20	-19	-21
LETTERS -3	-19	+13
FACES -28	-40	-16
SYMBOLS -50	-87	-13
ALL -25	-41	-9

* - favors right hemisphere (LVF)
+ favors left hemisphere (RVF)

FIGURE 1

Spatial relationship between visual fields and
response keys for the left and right hand.

REACTION TIME APPARATUS

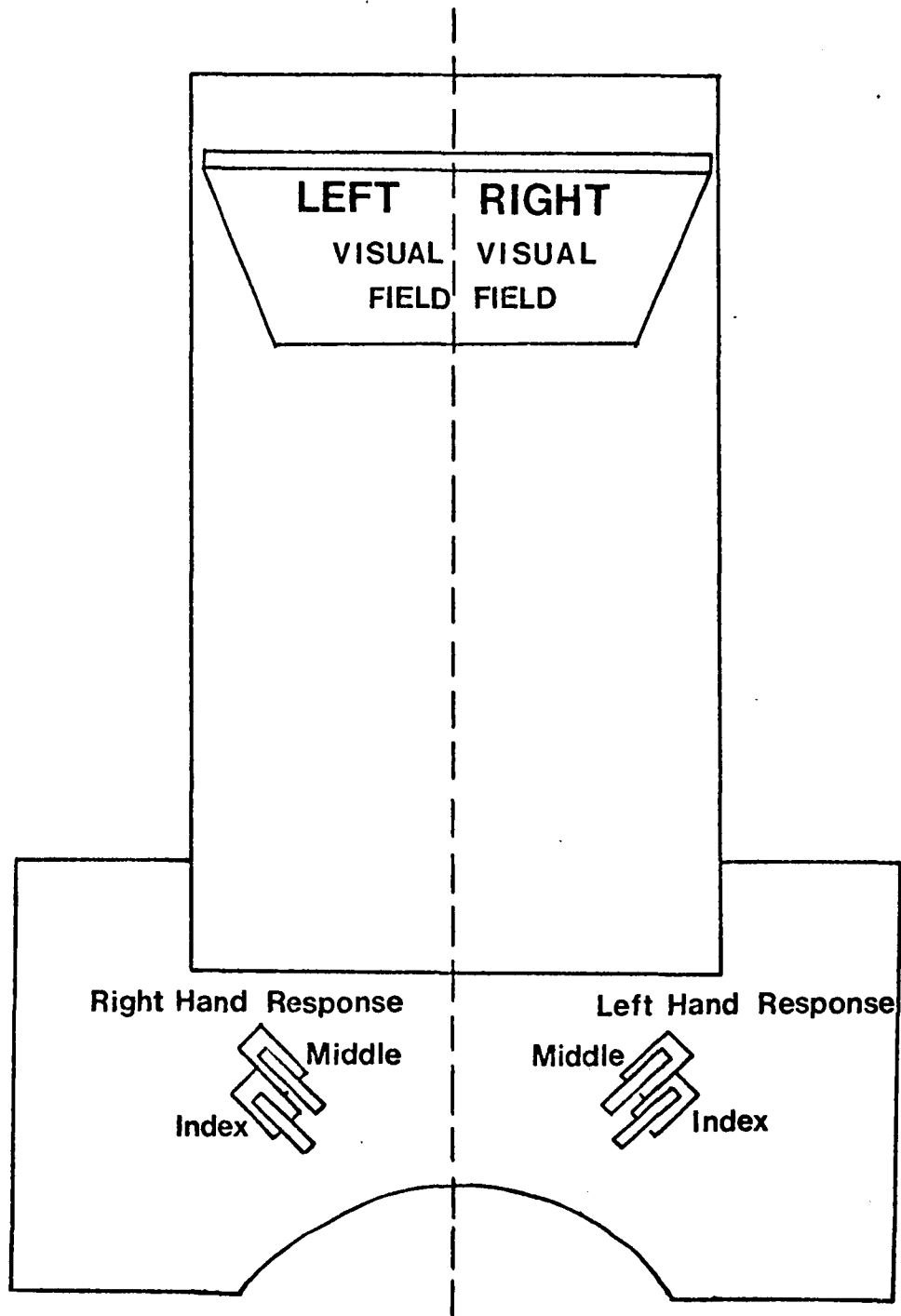


FIGURE 2

Mean RTs to Nouns and Verbs presented in the LVF and RVF for each half day (96 trials) averaged across hands.

WORDS

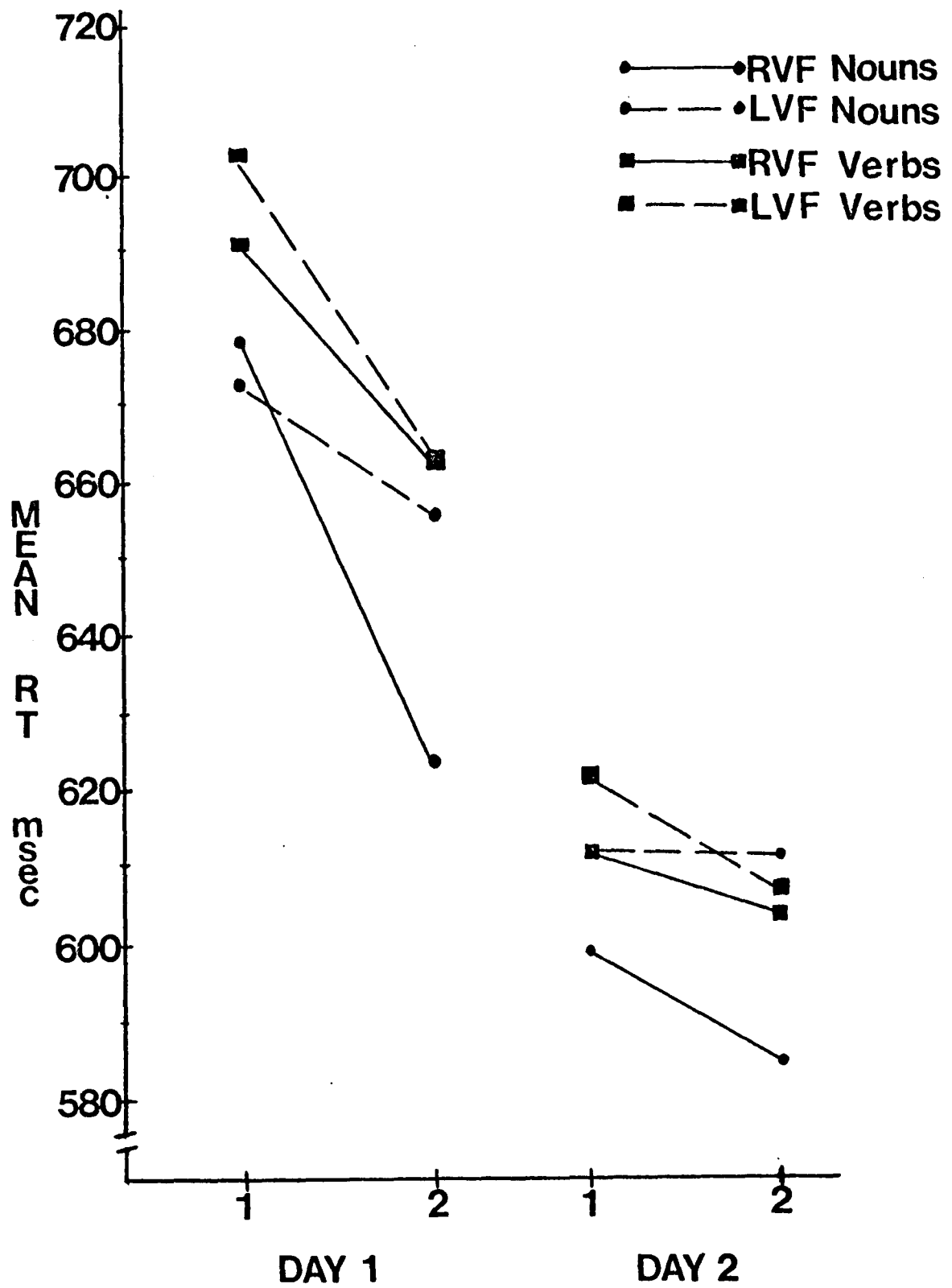


FIGURE 3

Mean RTs to Nouns and Verbs presented in the LVF and RVF for each block of 48 trials averaged across hands.

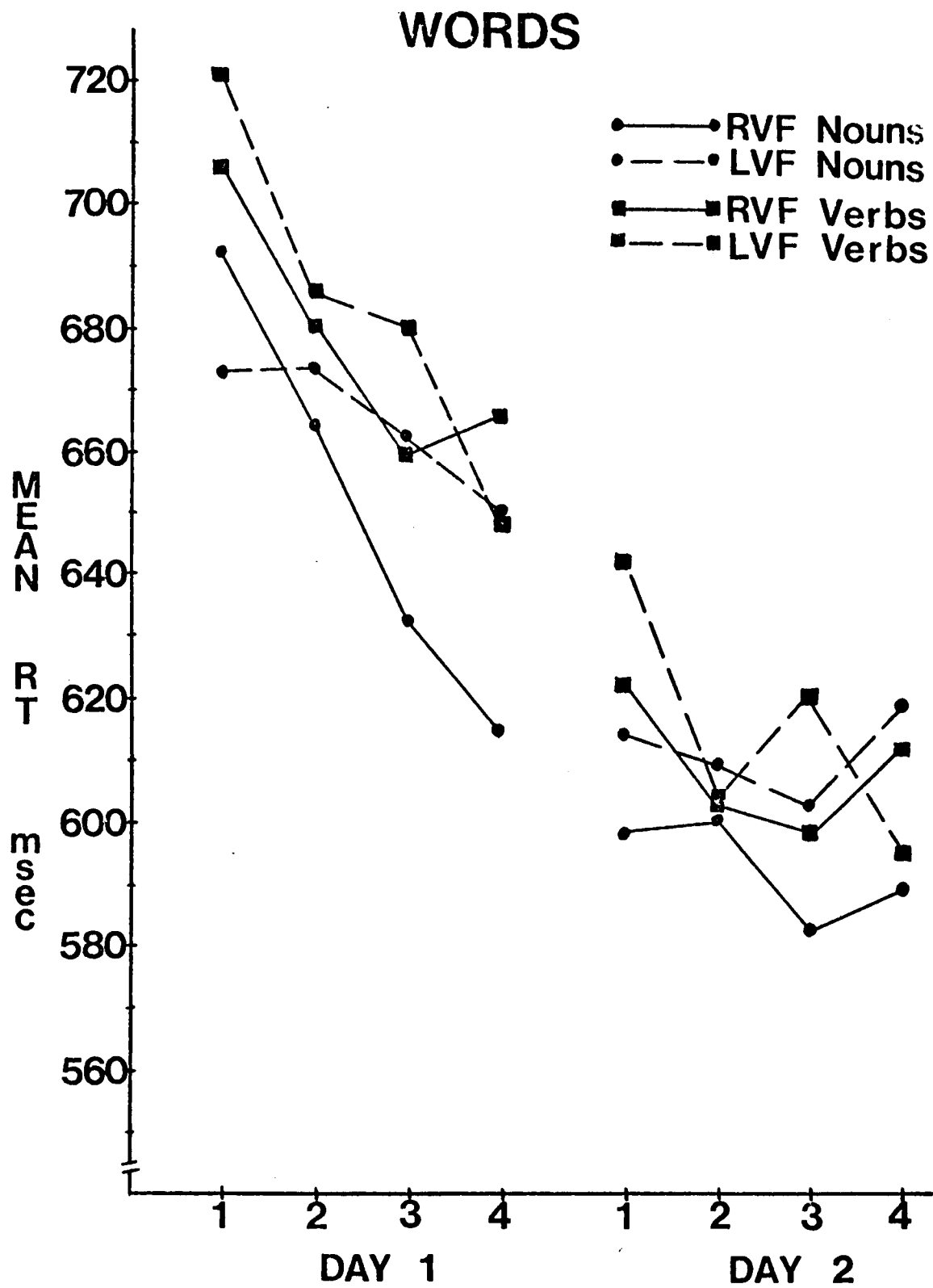


FIGURE 4

Mean RTs to Target and Non-Target Letters
presented in LVF and RVF for each half day (96 trials)
averaged across hands.

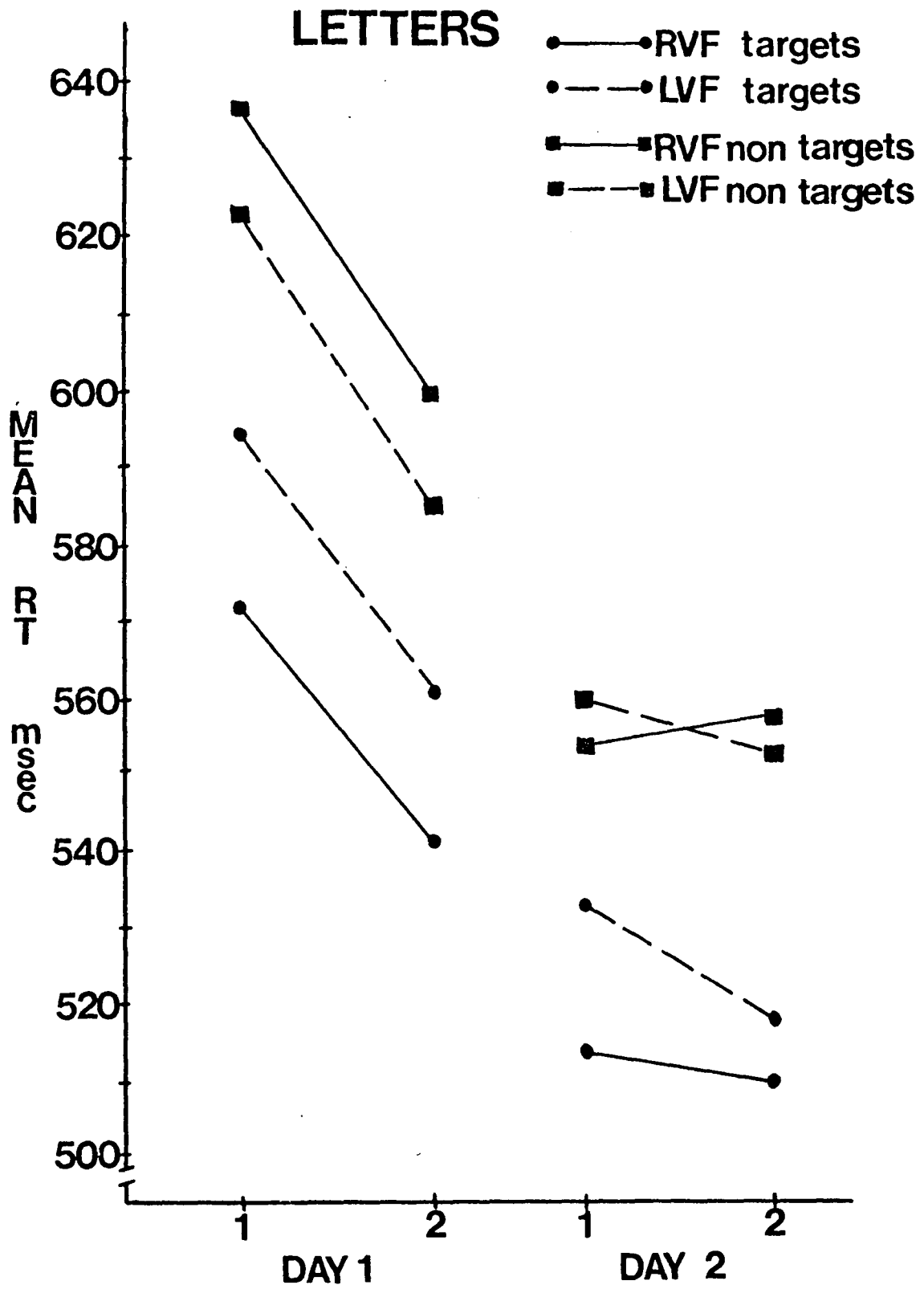


FIGURE 5

Mean RTs to Target and Non-Target Letters
presented in the LVF and RVF for each block of 48
trials averaged across hands.

LETTERS

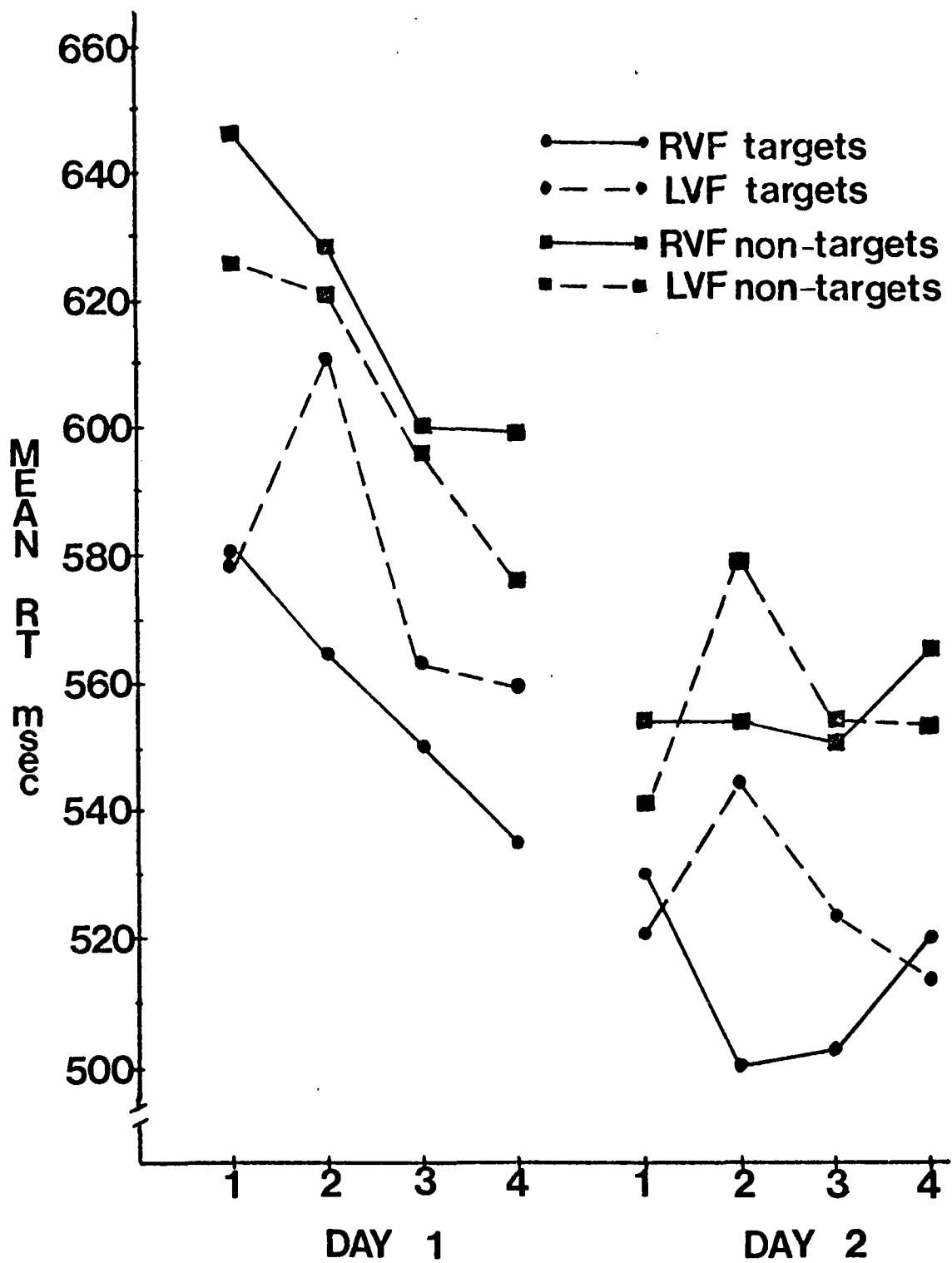


FIGURE 6

Mean RTs to Target and Non-Target Faces
presented in the LVF and RVF for each half day
(96 trials) averaged across hands.

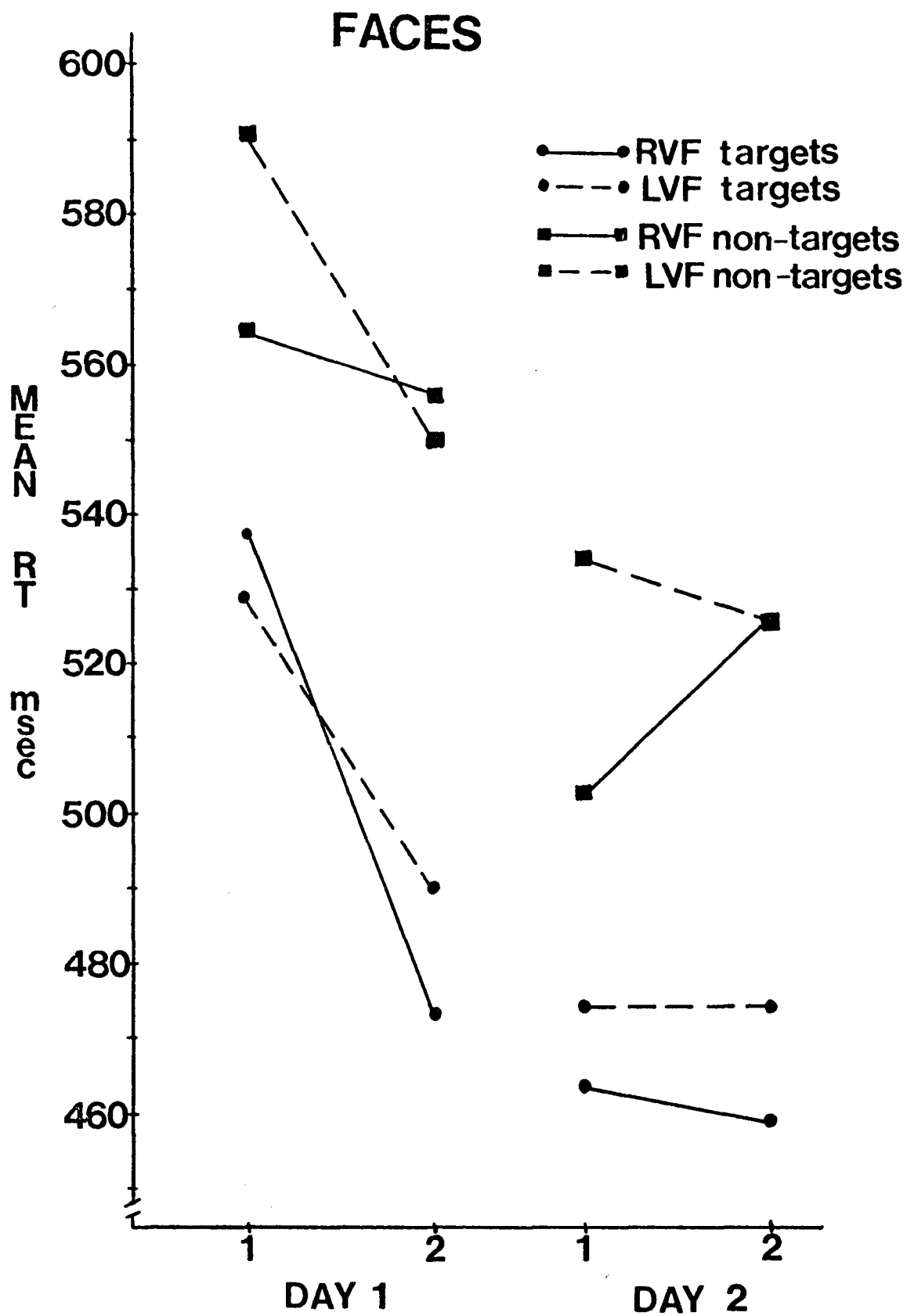


FIGURE 7

Mean RTs to the Target and Non-Target Faces presented in the LVF and RVF for each block of 48 trials averaged across hands.

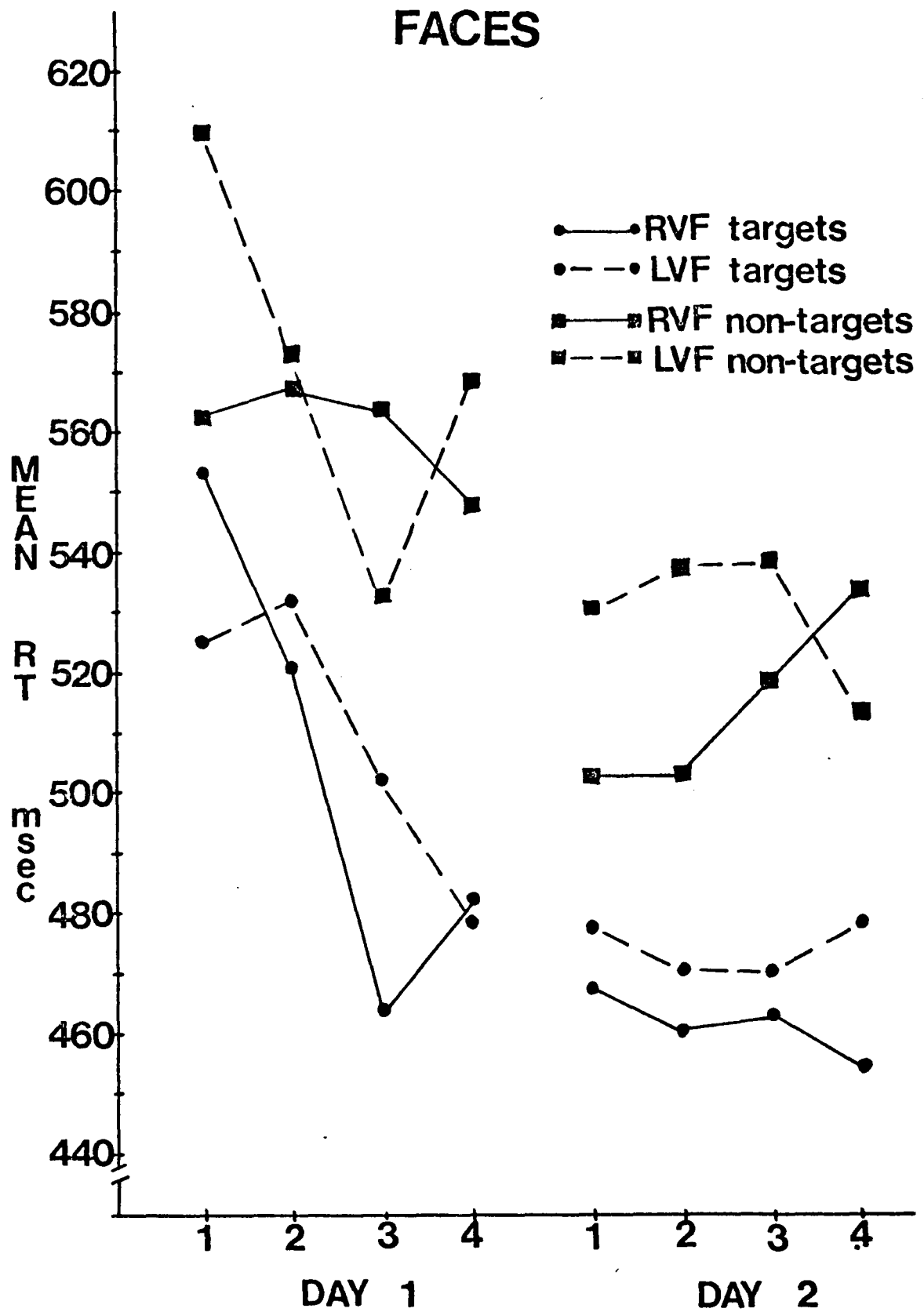


FIGURE 8

Mean RTs to Target and Non-Target Symbol Arrays
presented in the LVF and RVF for each half day (96 trials)
averaged across hands.

SYMBOL ARRAYS

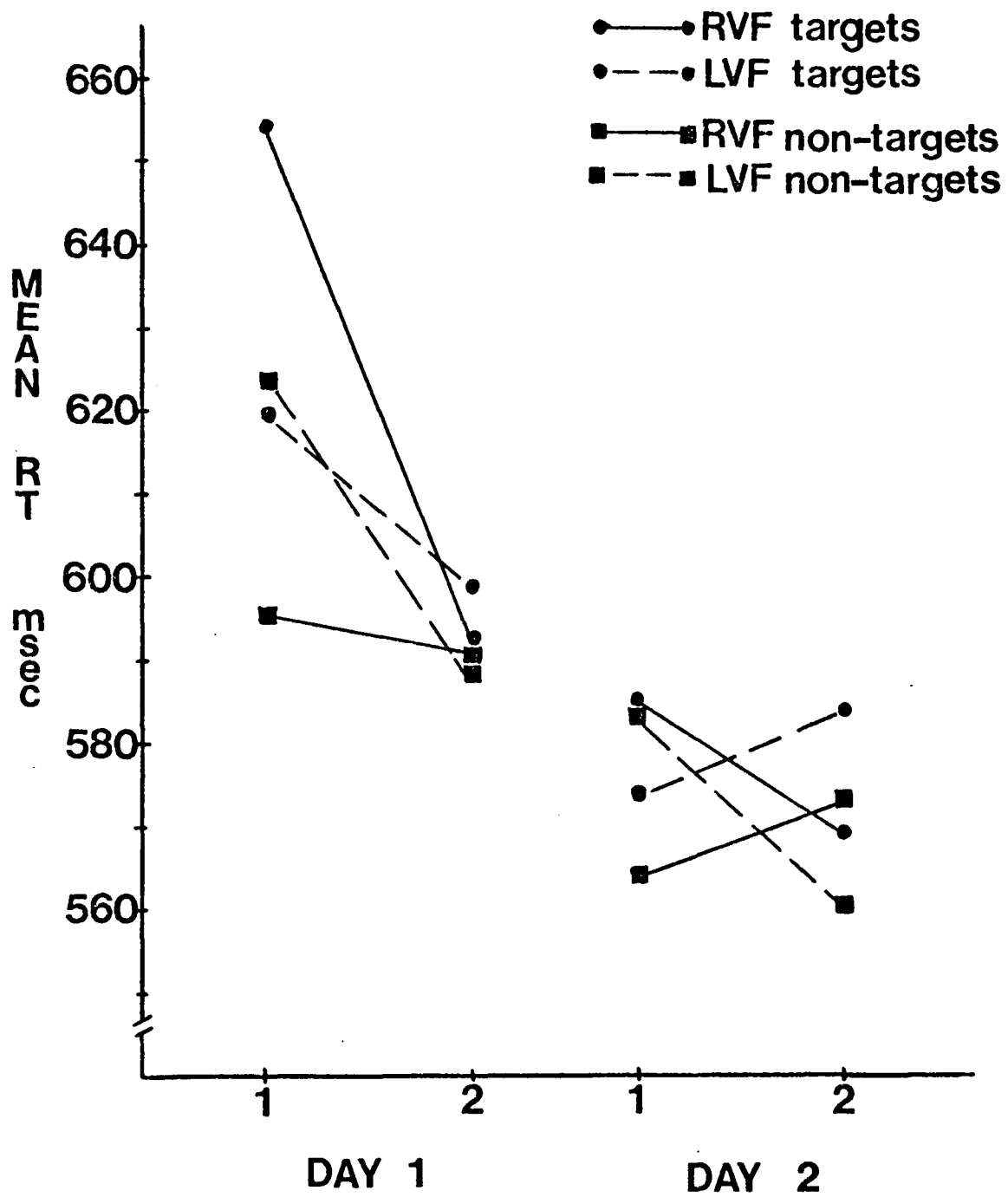


FIGURE 9

Mean RTs to Target and Non-Target Symbol
Arrays presented in the LVF and RVF for each block
of 48 trials averaged across hands.

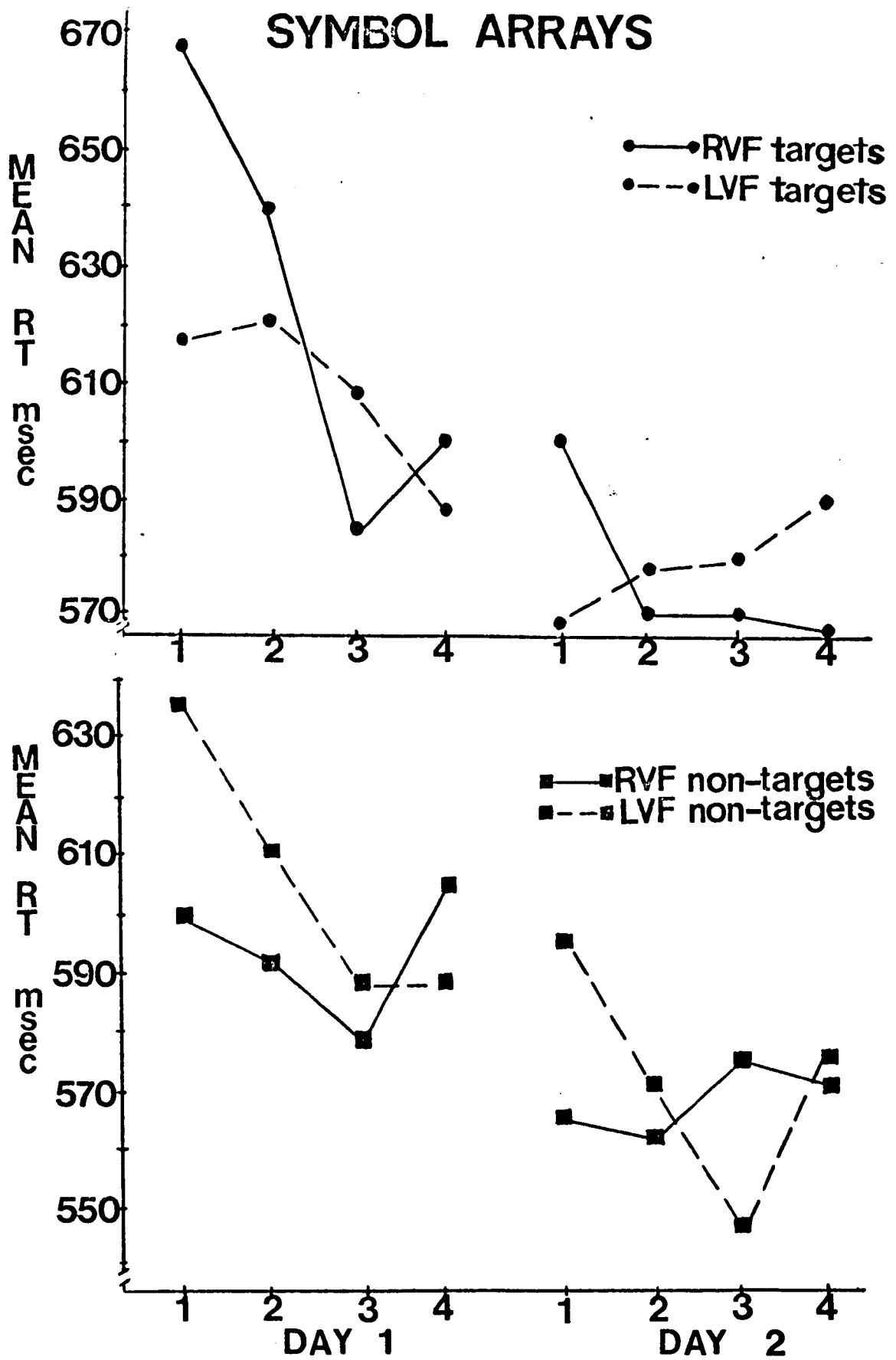


FIGURE 10

Interaction of Judgment, Visual Field, and
Blocks of trials for all experiments.

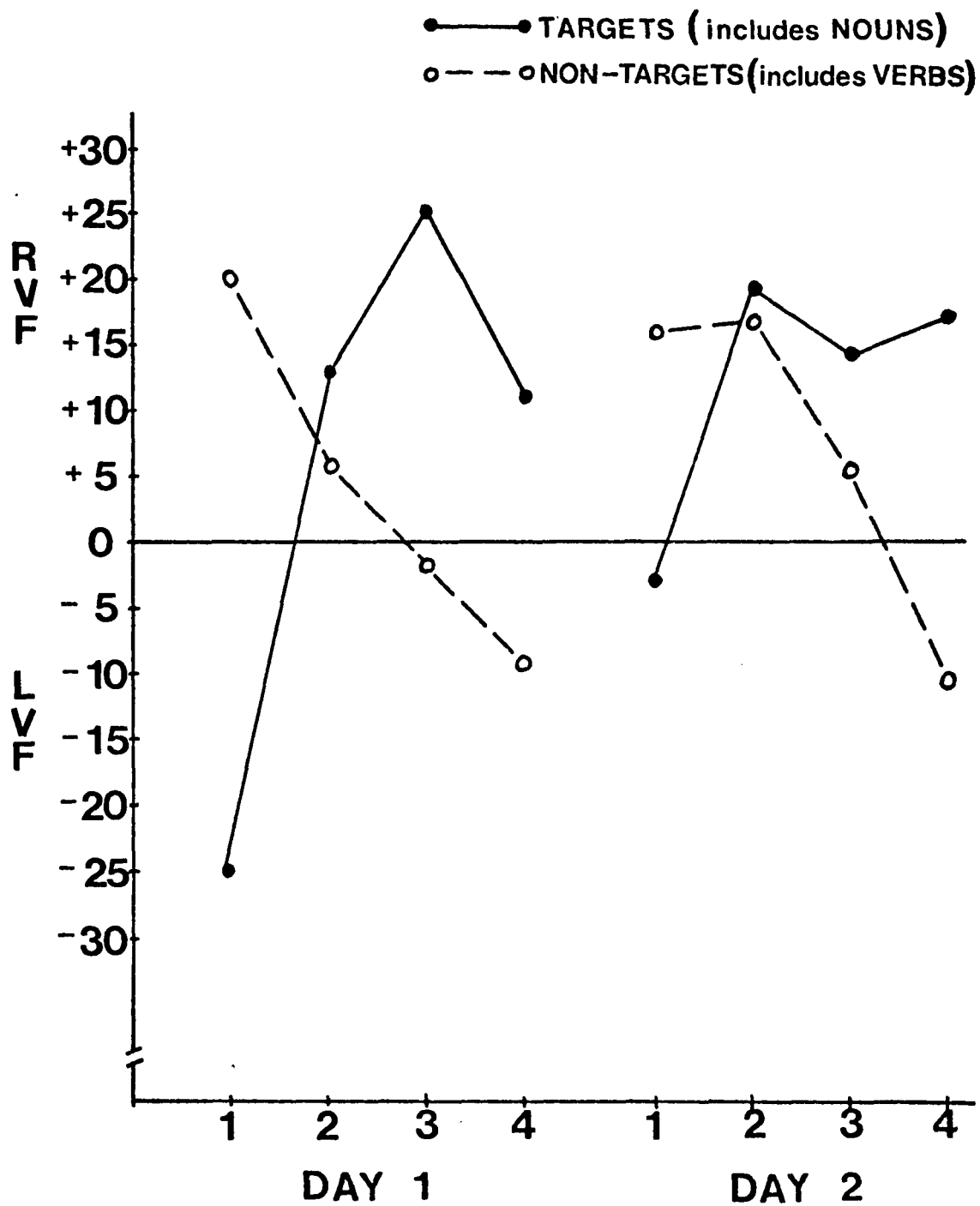
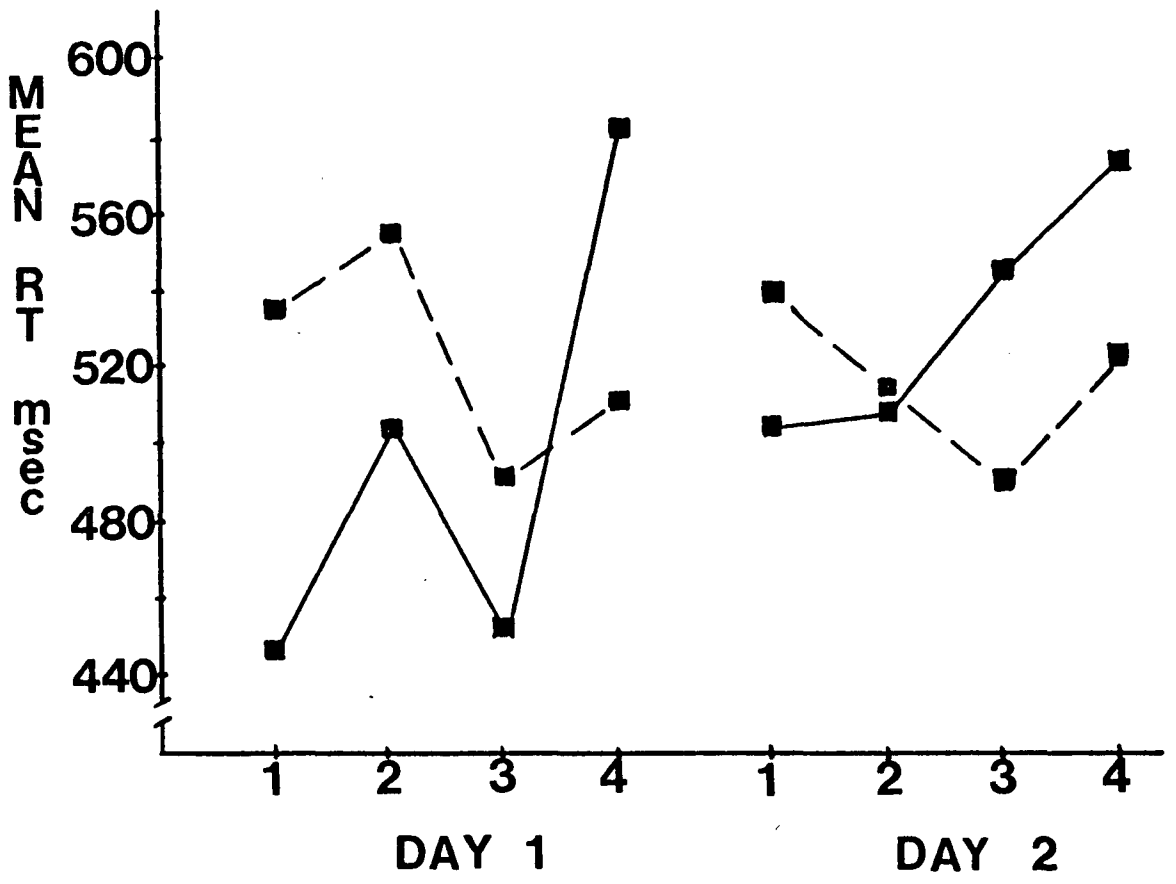
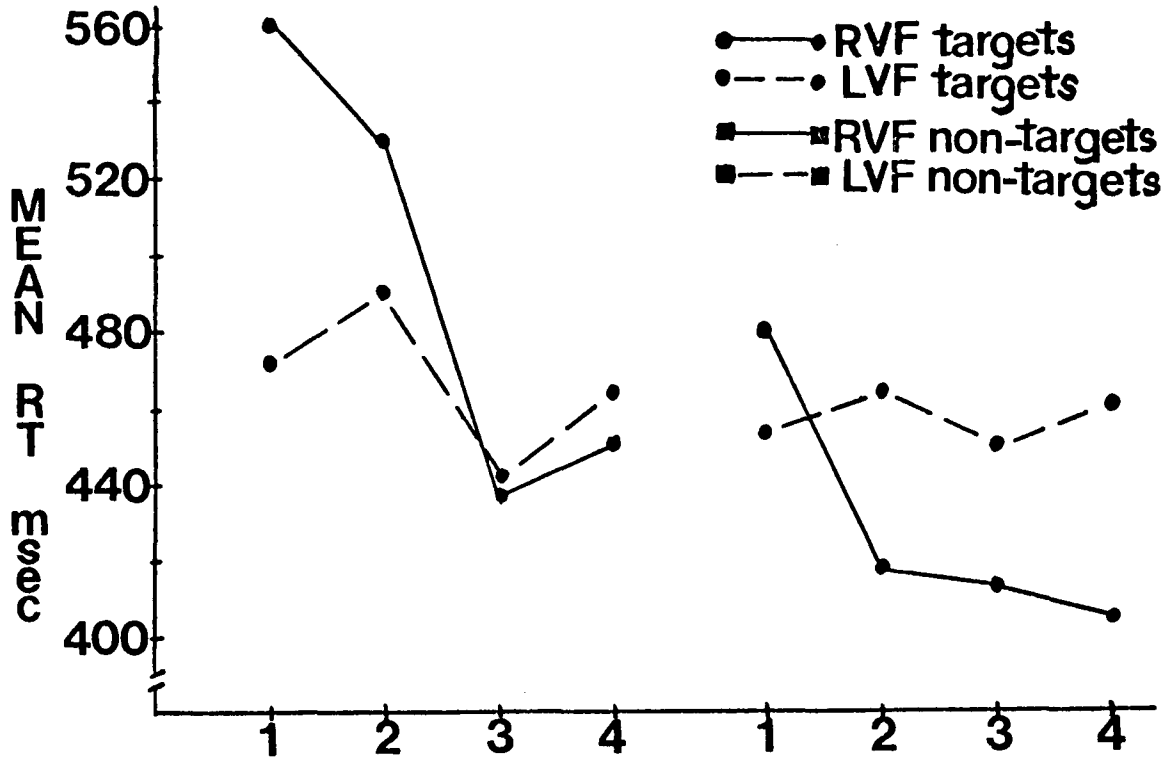
LVF MINUS RVF

FIGURE 11

Mean RTs of Subject #3 to Target and Non-Target Symbol Arrays presented in the LVF and RVF for each block of 48 trials averaged across hands.

SUBJECT 3 SYMBOL ARRAYS



APPENDIX A

Analysis of Variance Table: All Experiments

Factors

Experiment	(E)
Hand	(H)
Judgment	(J)
Visual Field	(VF)
Trial Block	(B)
Subjects	(S)

Repeated measures on all factors

DAY 1

<u>SOURCE</u>	<u>DF</u>	<u>MEAN SQUARE</u>	<u>F-TEST</u>
E	3	767494.313	14.991***
E X S	21	51195.762	
H	1	26.266	0.002
H X S	7	15303.801	
J	1	191953.500	43.162***
J X S	7	4447.270	
VF	1	6084.000	2.621
VF X S	7	2321.219	
B	3	109682.563	28.041***
B X S	21	3911.521	
E X H	3	6853.703	4.311
E X H X S	21	1589.904	
E X J	3	67131.563	7.231**
E X J X S	21	9284.367	
H X J	1	19321.000	4.113
H X J X S	7	4698.055	
E X VF	3	1412.185	0.623
E X VF X S	21	2265.760	

<u>SOURCE</u>	<u>DF</u>	<u>MEAN SQUARE</u>	<u>F-TEST</u>
H X VF	1	1064.391	0.550
H X VF X S	7	1935.567	
J X VF	1	306.250	0.128
J X VF X S	7	2393.378	
E X B	9	1941.641	0.689
E X B X S	63	2818.670	
H X B	3	8788.547	3.110*
H X B X S	21	2826.234	
J X B	3	4546.891	2.329
J X B X S	21	1952.619	
VF X B	3	3052.938	1.886
VF X B X S	21	1618.901	
E X H X J	3	1456.815	0.390
E X H X J X S	21	3733.369	
E X H X VF	3	4776.961	2.644
E X H X VF X S	21	1806.646	
E X J X VF	3	10043.344	3.710*
E X J X VF X S	21	2706.832	
H X J X VF	1	0.016	-----
H X J X VF X S	7	5304.805	
E X H X B	9	1832.744	0.775
E X H X B X S	63	2363.710	
E X J X B	9	1579.207	0.783
E X J X B X S	63	2017.554	
H X J X B	3	1404.844	0.816
H X J X B X S	21	1721.848	
E X VF X B	9	1499.034	1.056
E X VF X B X S	63	1419.900	
H X VF X B	3	1268.484	0.863
H X VF X B X S	21	1469.262	

<u>SOURCE</u>	<u>DF</u>	<u>MEAN SQUARE</u>	<u>F-TEST</u>
J X VF X B	3	17122.102	11.708***
J X VF X B X S	21	1462.449	
E X H X J X VF	3	82.107	0.029
E X H X J X VF X S	21	2880.921	
E X H X J X B	9	842.092	0.537
E X H X J X B X S	63	1568.462	
E X H X VF X B	9	707.575	0.595
E X H X VF X B X S	63	1189.489	
E X J X VF X B	9	4253.156	2.420*
E X J X VF X B X S	63	1757.379	
H X J X VF X B	3	1588.213	1.531
H X J X VF X B X S	21	1037.295	
E X H X J X VF X B	9	3027.705	2.065*
E X H X J X VF X B X S	63	1466.371	
S	7	200886.813	
TOTAL	1023	7704.461	

DAY 2

E	3	594927.000	16.206***
E X S	21	36710.035	
H	1	4497.379	0.964
H X S	7	4665.141	
J	1	143167.625	18.962**
J X S	7	7550.293	
VF	1	21224.844	9.076*
VF X S	7	2338.688	
B	3	3007.273	2.865
B X S	21	1049.759	
E X H	3	3285.255	3.604*
E X H X S	21	911.596	
E X J	3	49472.457	6.654**
E X J X S	21	7434.910	

<u>SOURCE</u>	<u>DF</u>	<u>MEAN SQUARE</u>	<u>F-TEST</u>
H X J	1	8824.250	1.587
H X J X S	7	5558.949	
E X VF	3	1775.052	1.171
E X VF X S	21	1515.230	
H X VF	1	1040.063	0.613
H X VF X S	7	1697.239	
J X VF	1	1458.285	0.840
J X VF X S	7	1735.935	
E X B	9	1861.436	0.631
E X B X S	63	2949.542	
H X B	3	3449.448	1.066
H X B X S	21	3235.006	
J X B	3	164.388	0.105
J X B X S	21	1561.298	
VF X B	3	2404.724	1.789
VF X B X S	21	1343.912	
E X H X J	3	144.147	0.068
E X H X J X S	21	2116.826	
E X H X VF	3	1886.273	1.570
E X H X VF X S	21	1201.774	
E X J X VF	3	999.161	0.641
E X J X VF X S	21	1559.087	
H X J X VF	1	260.016	0.025
H X J X VF X S	7	10232.355	
E X H X B	9	1384.286	0.526
E X H X B X S	63	2630.983	
E X J X B	9	1873.600	2.366*
E X J X B X S	63	791.858	
H X J X B	3	348.428	0.168
H X J X B X S	21	2068.823	
E X VF X B	9	3032.293	2.085*
E X VF X B X S	63	1454.508	

<u>SOURCE</u>	<u>DF</u>	<u>MEAN SQUARE</u>	<u>F-TEST</u>
H X VF X B	3	3524.440	2.257
H X VF X B X S	21	1561.451	
J X VF X B	3	6223.672	8.334***
J X VF X B X S	21	746.814	
E X H X J X VF	3	232.096	0.088
E X H X J X VF X S	21	2639.912	
E X H X J X B	9	824.992	0.828
E X H X J X B X S	63	996.928	
E X H X VF X B	9	1423.857	0.757
E X H X VF X B X S	63	1879.883	
E X J X VF X B	9	2289.678	1.880
E X J X VF X B X S	63	1217.621	
H X J X VF X B	3	1768.174	1.863
H X J X VF X B X S	21	948.902	
E X H X J X VF X B	9	718.682	0.443
E X H X J X VF X B X S	63	1621.799	
S	7	191232.000	
TOTAL	1023	6010.719	

* = $\frac{p}{.05}$
 * * = $\frac{p}{.005}$
 * * * = $\frac{p}{.001}$

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