IMAGINAL PROCESSING IN THE TWO ~~CEREBRAL~~ HEMISPHERES: A COMPUTATIONAL INVESTIGATION

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BY JOAN PAINTER B.Sc., 1995.

Goldsmiths College.

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ABSTRACT

Traditionally theories of cerebral organization have tended to focus on various broad functional dichotomies. However, whilst the identification of dichotomous dimensions distinguishing the hemispheres provides useful approximations of their functional properties, such dichotomies fail to account for the many diverse manifestations of hemispheric asymmetry. Recent research in cognitive psychology, however, indicates that mental faculties previously treated as undifferentiated phenomena are better described and understood as being composed of distinct processing units that perform specific operations. This evidence has led to the development of new computational models of functional cerebral lateralization. The phenomenon of visual mental imagery has achieved particular prominence in this respect as evidence has been produced in support of the claim that the generation component of the imagery system is lateralized to the left hemisphere (LH). Given these findings the question naturally arises as to whether other components of the imagery system are lateralized to the LH or whether both hemispheres are involved in different aspects of imagery performance.

The thesis initially presents a review of the literature pertaining to the above, including methodological and theoretical issues related to the localization of function in the brain, models of hemispheric interaction, computational models of imagery developed within cognitive psychology, the relationship between imagery and perception and the evidence in support of the LH image generation hypothesis. A series of experiments is then reported which was designed to investigate the possible lateralization of additional imaginal components. The first five experiments investigated the putative LH localization of the image scanning component of the imagery system. A further three experiments are then presented designed to investigate the possibility that the two hemispheres are specialized for the generation of different forms of visual images. The implications of these findings for specific models of cerebral lateralization of the imagery system are then discussed, as are the implications for a general theory of cerebral organization.

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CHAPTER 1

INTRODUCTION

1.1 HEMISPHERE SPECIALIZATION: THEORY AND METHOD

1.1.1 Introduction

Asymmetries in hemispheric function were first documented in the nineteenth century by observers who noted the tendency for language disorders to occur following left hemisphere (LH) damage and visuo-spatial disorders to occur following right hemisphere (RH) damage (e.g. Broca, 1865; Jackson, 1874). In the ensuing years clinical investigators have reported additional consistent differences in the behavioural consequences of unilateral injuries, and it is now generally accepted that the cerebral hemispheres are functionally dissimilar. The optimum way of conceptualizing these differences, however, remains controversial, and there is as yet no fully articulated, general model of hemispheric specialization.

For example, over the last thirty years investigators in the area of laterality research have periodically attempted to reduce the multiple specializations of each hemisphere to a single more encompassing function. Thus at various points in time the LH has been described as being specialized for such things as verbal, analytic and serial processing, whereas the RH has been characterized as being specialized for nonverbal, holistic and parallel processing. Moreover, these global processing dichotomies have unfortunately paved the way for ever more abstract notions of the relationship between mental function and the hemispheres. The concept of hemisphericity, for instance, asserts that the two hemispheres are specialized for qualitatively different modes of thought, and in consequence individuals will exhibit a preferred left or right cognitive style depending on which hemisphere they tend to rely on. This notion has spawned many outlandish claims. For example, differential utilization of RH and LH modes of thought has been purported to account for the differences between Western and Oriental philosophies, our political ideologies, the generation gap and, perhaps most intriguingly, the supposed failure of the European-based educational system (e.g. Ornstein, 1970).

Active investigators in the area of laterality research understandably dismiss these imaginative notions as totally unwarranted speculations which have no basis in fact. Indeed the very concept of hemisphericity has been called into question (Beaumont, Young and McManus, 1984). Cognitive styles, implying predominant activity by one or other hemisphere, do not appear to reliably characterize individuals any more than they reliably characterize particular populations or cultures. Nevertheless, it also has to be acknowledged that the more empirically based processing dichotomies have not fared particularly well either. Many of these global abstractions were derived from attempts to discern regularities across empirical observations following retrospective analyses of the literature. This form of post-hoc inductive reasoning, however, inevitably led to the identification of opposing conglomerates of only partly related attributes. Thus, while these global dichotomies may sometimes provide useful approximations of the respective competencies of the two hemispheres, they have little predictive and explanatory power and consequently fail to account for the many diverse manifestations of hemispheric asymmetry.

Moreover, it is questionable whether any new global processing dichotomy would be any more successful in integrating the wide variety of diverse functions attributed to each hemisphere. In recent years, for example, a number of studies have tested for such a dimension empirically. Various statistical techniques lend themselves to such an analysis, but one strategy which has been employed in this respect involves the investigation of the relationship between different cognitive tasks which are known to reliably produce similar laterality effects. If the observed hemispheric superiority occurs because both tasks tap into the same aspect of some fundamental dichotomy, then one would expect the asymmetries for the two tasks to be positively correlated. The multi-task studies which have been carried out, however, have found only weak or no relationships between the asymmetries for the tasks (e.g. Dagenbach, 1986; Hellige, Bloch and Taylor, 1988). It would, therefore, appear unlikely on empirical grounds that there is a single processing dimension which can account for all hemispheric asymmetries. Thus the complexity of the present picture may not, as has been suggested, be due to conceptual limitations, but may instead reflect the true multifactorial nature of the underlying processes.

Considerations such as these have led many investigators to conclude that any attempt to subsume all the essential aspects of hemispheric functioning under some perfect dichotomy is an exercise in futility. Indeed some researchers have argued that the theoretical and epistemological problems which afflict this area are so great that it is no longer a viable field of research (e.g. Efron, 1990). However, while the traditional dichotomous approach to hemispheric specialization is undoubtedly deficient, it is possible that new theoretical paradigms may yet provide insight into the nature of cerebral organization.

In recent years, for example, there has been a continuing and highly productive interaction between the clinical neurological tradition and the functionalist information processing approach of contemporary cognitive psychology. In particular, the development of sophisticated cognitive theories of visual mental imagery have provided a theoretical foundation on which to base explicit questions about the neural distribution of the imagery system (e.g. Kosslyn, 1980). Moreover, this area has served as a testing ground for the formulation of new computational models of functional cerebral lateralization (Farah, 1984; Kosslyn, 1987). The recency of these developments is understandable, as it is only in the last two to three decades that mental imagery has been considered a bona fide subject of scientific investigation in cognitive psychology. Nevertheless, the prominence currently accorded to visual mental imagery in the area of laterality research is remarkable, given that prior to the early 1980s the issue of the cerebral localization of imagery was seldom explicitly discussed.

Before discussing the implications of these developments, however, it is perhaps appropriate initially to briefly review the methodologies and theoretical assumptions that have traditionally characterized the area of laterality research.

1.1.2 Sources of Evidence

Prior to the 1960s the primary source of evidence regarding hemisphere function came from observations of brain-damaged patients. Damage to one hemisphere leads to disabilities different from those arising from damage to the other hemisphere, and it is this relationship between the side of the lesion and the type of disorder which is thought to provide evidence regarding the functional specialization of the hemispheres. The straightforward nature of this definition, however, belies the true complexity underlying interpretations of these observations. In many cases the nature, locus and extent of the damage cannot be very accurately ascertained. Moreover, even if the precise site of damage can be established, the lesion may sometimes "disconnect" processes rather than impairing them per se.

Additional problems arise if the injury was incurred early in life as research appears to indicate that the plasticity of cerebral organization diminishes with age. Clinical reports of cases where damage was sustained in childhood, for example, suggest that each hemisphere can assume at least some of the opposite hemisphere's functions (e.g. Milner, 1975; Dennis and Whitaker, 1976; Woods, 1980). This potential for cerebral reorganization, however, does not appear to be present in patients whose damage was sustained in adulthood. In cases where injury was incurred early in life, therefore, the observed deficits cannot be assumed to necessarily reflect normal brain organization.

Furthermore, factors such as the time elapsed since the injury was incurred, the degree of recovery of function achieved, the age of the patient, the sex of the patient and whether they are right- or left-handed all have to be taken into account. Nevertheless, in spite of these difficulties, the clinical evidence has yielded a sizable body of information about hemispheric function. However, its limitations prevent definitive conclusions being drawn about cerebral organization, and it is therefore necessary to look for converging evidence from other sources.

Split-brain patients first began to be studied extensively in the 1960s. These patients have undergone neurosurgery which involves complete sectioning of the corpus callosum, as well as several smaller forebrain commissures, so that the two hemispheres are disconnected. By testing their response capacities when sensory inputs have been limited to one hemisphere, it is assumed that it is possible to examine the functions of each hemisphere independently. In general, the data reported from such studies appear to be consistent with the picture of hemispheric differences that has emerged from studies of brain-damaged patients (Springer and Deutsch, 1989; Hellige, 1990). However, again there are limitations to such data. For example, as noted previously, the commissurotomy operation in its full form involves complete section of the forebrain commissures. The midbrain commissures, however, are not sectioned, and it is possible that some information may be transmitted from one hemisphere to the other via these remaining pathways. Furthermore, information may also be passed between the hemispheres via cross-cuing strategies, whereby subjects use bodily gestures and orienting responses to facilitate the lateral transfer of information (e.g. Gazzaniga and Hillyard, 1971).

An additional and potentially more serious problem is that neurosurgical intervention in these cases is necessitated by the presence of long-standing, intractable epilepsy, and this may have produced major changes in brain organization. For example, Whitaker and Ojemann (1977), in a review of the ten commissurotomized patients who have been the focus of research, observed that split-brain patients differed considerably from one another and from the general population in terms of both their performance and their neurological status.

Furthermore, they also observed that the majority of these patients appeared to have sustained their lesions in infancy and childhood, and more recently Geschwind (1985) has claimed that some of the patients may even have sustained their lesions in utero. The significance of this claim is that such prenatal lesions have been shown to result in a reorganization of cerebral lateralization that differs from that which occurs following lesions in infancy or childhood. This could, therefore, go some way towards accounting for the variability in performance that is found between these patients. Moreover, it would also appear to suggest that patterns of cerebral lateralization demonstrated in commissurotomy patients may not easily generalize to the developmentally normal adult brain. Thus, while split-brain data can perhaps serve to strengthen evidence from other sources, the above considerations would appear to suggest that it is inappropriate to draw firm conclusions from these studies in isolation.

Finally, studies of cerebral organization have not been limited to clinical populations. Indeed the popularity of hemispheric specialization as a research topic is probably due to a large extent to the development of techniques which facilitate the investigation of cerebral organization in normal intact subjects. Reviews of this area generally conclude that the data from normal subjects are in overall broad agreement with the clinical and split-brain evidence (Springer and Deutsch, 1989; Hellige, 1990). Indeed it is this convergence of results from a wide variety of different sources which has led to the consensus that different cognitive processes are subserved by different hemispheres.

It is, however, also acknowledged that many of the asymmetries which are found in experiments with normal subjects appear to be extremely labile. There has, for example, been a disproportionately large number of failures to replicate reported experimental results (e.g. Boles, 1983, 1984). Moreover, a wide range of individual performance differences have been observed on tasks that are supposed to be lateralized, even among populations thought to be relatively homogenous in terms of lateral organization. It also appears that seemingly trivial procedural differences between experimental paradigms can influence results. In fact the apparent ease with which relatively superficial changes in stimuli, instructions or other task parameters can eliminate or even reverse a performance asymmetry serves to illustrate the inherently unsatisfactory nature of much of the normative laterality literature. It would, therefore, appear to be appropriate to briefly consider some of the factors which may have contributed to this variability.

1.1.3 Techniques

It is possible that the labile nature of asymmetries found in experiments with normal subjects may in part be due to lack of precision in the techniques of testing. These techniques generally involve channelling sensory inputs so that they are projected primarily to one or other hemisphere, and subsequent task performance is then analyzed in order to ascertain if accuracy or response latency vary as a function of the hemisphere of initial reception. For example, in dichotic listening tasks material presented to the left ear is thought to be projected primarily to the RH, whereas material presented to the right ear is thought to be projected primarily to the LH (Kimura, 1961). Tests of lateralized tactile presentations are based on a similar form of contralateral mapping for voluntary motor control.

Alternatively, there are some more specialized techniques which attempt to provide more direct physiological measures of hemispheric activity. Electroencephalographic (EEG) studies, for example, involve recording electrical activity at certain sites in the brain while subjects engage in psychological tasks. Similarly, regional cerebral blood flow (rCBF) studies monitor the increased blood flow which occurs at certain regions within the brain during task engagement.

By far the most popular technique employed to study cerebral organization in normals, however, is the divided visual field study, and as this is the procedure which is employed in the studies reported subsequently the methodological difficulties associated with this technique will be described in detail. It should perhaps be noted, however, that all of the alternative procedures have methodological and theoretical complications (Beaumont, 1982a; Bradshaw, 1989a), and none can be regarded as being inherently superior to the divided visual field technique.

The divided visual field procedure rests upon the fact that the anatomy of the visual pathways means that it is possible to direct information initially to a particular cerebral hemisphere: if the subject maintains central fixation and a visual stimulus is presented briefly in the left visual field (LVF) then it is projected initially only to the RH, if presented briefly in the right visual field (RVF) it is projected initially only to the LH. When the technique is used to test commissurotomized patients the presented visual information is confined to the hemisphere of original reception. In normal individuals, however, the brain obviously functions as an integrated whole: information to one hemisphere being immediately transferred to the other via the corpus callosum. Nevertheless, it is possible to detect performance differences on certain tasks, depending on whether the stimulus was presented to the RVF or LVF, and these differences are thought to reflect functional asymmetry.

It should perhaps be noted, however, that there are two alternative explanations of performance differences between the visual fields in lateralization studies with normals. For example, visual field performance asymmetries may arise because one cerebral hemisphere is relatively inefficient at processing the stimulus material presented. Alternatively, one hemisphere may be unable to fully process the information and it would, therefore, have to be transferred via the commissural fibres to the opposite hemisphere before processing could take place. Transmission across the corpus callosum necessitates some delay, during which the information is assumed to undergo some degree of transformation such that it arrives at the second hemisphere in a comparatively degraded state. Unfortunately experimental data do not normally allow discrimination between these alternatives.

It is clear from this brief description that the divided visual field technique is in principle simple and elegant. However, consideration of the methodological and theoretical bases of visual hemifield studies indicates that there are a number of procedural factors which, if not adequately controlled, can influence the outcome of such studies. For example, there is some evidence which appears to suggest that the retinal cells adjacent to the visual midline are bilaterally represented in the visual cortex (e.g. Stone, Leicester and Sherman, 1973; Koerner and Teuber, 1973). Not all investigators agree with this interpretation (Bradshaw, 1989a), but given the uncertainty surrounding this issue it is generally thought appropriate to avoid presenting stimuli in this area. Unfortunately the precise extent of the region has not been clearly established, but in practice it is thought prudent to avoid presenting stimuli in the central 3° of vision. Conversely, as acuity along the horizontal meridian of the visual field diminishes with distance from fixation (Alpern, 1962), it is also thought wise to restrict the outer limit of stimulus presentation to 5° from the fixation point.

A further factor which needs to be carefully controlled is stimulus presentation time. After stimulus onset eye movements may bring a laterally presented stimulus into foveal vision and exposure durations, therefore, should be limited to a time less than the latency of such movements. Estimates of the time taken to initiate eye movements vary between 180 ms and 200 ms (Cohen, 1983). These are, however, mean latency times, and as the standard deviations are mostly of the order of 20 ms to 25 ms it is generally recommended that a more conservative estimate of 150 ms be adopted (Young, 1982; Bradshaw, 1989a). However, Young (1982) also observes that the saccadic movements themselves will take some 20 ms to 30 ms to execute, and there may then have to be some adjustments in convergence and accommodation. Furthermore, perceptual sensitivity is apparently substantially reduced for some 40 ms to 50 ms after the movement is initiated (Volkmann, Schick and Riggs, 1968). For these reasons, therefore, Young feels that stimulus exposure durations of up to 200 ms can be acceptable.

The divided visual field technique obviously also relies on accurate control of fixation in order to ensure that the stimuli are presented in the required retinal positions. Unfortunately, there is no commonly agreed method for ensuring that fixation is maintained. Some investigators have used video or electro-oculographic monitoring of eye movements in order to control fixation (Young, Bion and Ellis, 1980; Dimond and Beaumont, 1972), but the technical investment involved in such procedures has prevented their widespread use. Alternatively, McKeever and Huling (1971) developed a technique whereby subjects had to report a neutral stimulus presented centrally prior to the presentation of the lateralized stimulus. The procedure has the advantage of not requiring complex and expensive equipment, but concern has been expressed regarding the possibility that the central stimulus might influence the subsequent perception of the lateralized stimulus (e.g. Hines, 1972). In consequence, the popularity of the procedure has declined.

More recently, some investigators have advocated random presentation of both central and purely peripheral trials (e.g. Kosslyn, Koenig, Barrett and Cave, 1989), and it is possible that such a procedure might help to ensure that central fixation is maintained. However, this method may not easily generalize to all experimental designs. The majority of investigators, therefore, rely on instructing subjects to fixate centrally, and guard against the loss of central fixation by presenting stimuli unilaterally and in a random sequence. It has to be acknowledged, however, that the reliability of such a procedure can be questioned. Although this concern can perhaps be mitigated to a certain extent by emphasizing to subjects the importance of maintaining central fixation not only in the initial instructions but throughout the trials themselves.

It has also been claimed in recent years that factors which influence the sensory quality of the lateralized stimulus may bias performance in visual-hemifield studies. For example, there is evidence which appears to indicate that the RH makes more effective use of lower quality information than the LH (Sergent and Hellige, 1986; Christman, 1987). Specifically, the RH appears to be at an advantage with highly degraded stimuli, brief exposure durations, large eccentricities and reduced levels of stimulus luminance. An observed performance asymmetry, therefore, may perhaps be due to the particular viewing conditions prevailing in an experiment rather than to the respective competencies of the cerebral hemispheres at carrying out the task under consideration. It should perhaps be noted in this respect, that a number of investigators have claimed that lateralization is not characteristic of peripheral sensory processes (e.g. Moscovitch, 1986). Nevertheless, given the above evidence it would seem prudent to attempt to control for these factors if at all possible.

Finally, it should perhaps be noted that Sergent (1983) has also argued that the effects of certain stimulus parameters may vary as a function of task demands. The precise nature of this relationship, however, has not been clearly specified. Moreover, irrespective of any interactive component, the evidence relating to the influence of factors imposed by task demands, such as familiarity, practice, set size, etc., is rather inconsistent, and it is not possible therefore to draw any general conclusions with respect to this issue.

It is clear from the above brief review that there are methodological problems associated with this technique, and inadequate control of these factors could obviously influence results. It is possible, therefore, that the somewhat confused findings which have emerged from this area may in part be due to methodological laxity. Beaumont (1983a, p. 184), for example, suggested that inconsistencies in the normative literature may have arisen "partly because of the indifferent scientific quality of many of the studies". Similarly, Bradshaw (1989b, p. 74) claimed that the contradictions in the literature often stemmed from "inadequacies of experimental control". Nevertheless, it is important to note that Beaumont (1983a) also maintains that there is sufficient consistency overall to suggest that despite its limitations the technique is robust and generally reliable. Indeed it does appear to be widely accepted as a valid method of investigating cerebral organization in normals.

1.1.4 Individual Differences

An additional factor which may have contributed to the variability in performance asymmetries often found in experiments with normal subjects is individual differences in cerebral organization. There are, of course, a wide range of factors which could potentially be of relevance to this issue, but two particular characteristics have been the focus of extensive research: handedness and sex.

An overwhelming majority of individuals perform skilled actions preferentially with the right hand. Cross-cultural surveys, for instance, suggest that in the majority of contemporary cultures only about 10% of the population are left-handed, and a variety of indirect evidence suggests that this may even have been the case in prehistoric times (e.g. Porac and Coren, 1981). Numerous theories have been postulated regarding the origins of left handedness (e.g. Levy and Nagylaki, 1972; Bakan, 1977; Annett, 1985), but ever since asymmetries in the nervous system were first documented it has been assumed that cerebral organization is directly related to hand preference. One of the earliest accounts, for example, regarding this relationship was provided by the contralateral rule (e.g. Wernicke, 1874). In essence this view states that speech dominance is always located in the hemisphere contralateral to the preferred hand. Right-handed individuals should, therefore, show LH dominance for language, whereas left-handed individuals should show the opposite pattern. For the vast majority of right-handers this "rule" undoubtedly applies, but evidence would appear to suggest that left-handers do not conform to this general principle.

Data relating to this issue have emerged from studies utilizing the Wada technique and electro-convulsive therapy (ECT). The Wada technique is a procedure in which sodium amytal is introduced into the carotid artery, so interrupting functions in the hemisphere on the same side as the injection for a brief period. Using this technique, Rasmussen and Milner (1975) provided data showing that of the left-handers studied about 70% had LH speech, 15% RH speech and 15% bilateral representation. Similarly, studies investigating the effects of unilateral ECT also suggest that left-sided speech is to be found in about 70% of left-handers (Warrington and Pratt, 1973). Furthermore, the results obtained using these techniques are in good agreement with a number of reviews which have investigated the incidence of aphasia in right- and left-handers following unilateral lesions (Segalowitz and Bryden, 1983; Kimura, 1983). It should perhaps be noted, however, that the data are not wholly consistent. For example, in a review of the frequency and severity of aphasia following unilateral lesions, Carter, Hoheneggar and Satz (1980) produced estimates suggesting that 24% of left-handers have left-sided speech, none right-sided speech and 76% bilateral speech. Nevertheless, notwithstanding this ambiguity, all of the evidence clearly supports the view that there is a higher incidence of RH and bilateral language organization in sinistrals.

The situation regarding the relationship between handedness and cerebral lateralization of visuo-spatial abilities is unfortunately less clear. It has, for example, frequently been suggested that the dominance relationship between the two hemispheres is one of causal complementarity. That is, the localization of language representation in the LH is thought to usurp some of the neural space that would otherwise be dedicated to visuo-spatial processing, thus creating a RH bias for this ability (e.g. Corballis, 1983). However, there often fails to be a good negative correlation between laterality effects for verbal and spatial processing, and this lack of association has led some investigators to conclude that the LH specialization for language functions and the RH specialization for visuo-spatial functions are causally independent of each other (e.g. Bryden, Hecaen and DeAgostini, 1983). It cannot be assumed, therefore, that the pattern of cerebral organization for visuo-spatial abilities in sinistrals and dextrals will simply be the inverse of that found for language functions.

More recently, however, Bryden and MacDonald (1989) have reviewed the evidence relating to this issue and they concluded that left-handers do display greater heterogeneity of cerebral lateralization for visuo-spatial abilities than right-handers. For example, they estimated that approximately 68% of right-handers are RH dominant for visuo-spatial abilities whereas 32% are LH dominant. In contrast, they suggest that only 38% of left-handers have right-sided dominance, 30% have left-sided dominance and 32% have bilateral representation. Thus the evidence would again appear to support the view that sinistrals are a less homogenous group than dextrals with respect to cerebral organization.

The greater variability observed among left-handers has led to the search for additional variables that might indicate which left-handers show the pattern of hemispheric asymmetry characteristic of right-handers and which do not. Levy and Reid (1976), for example, claimed that the pattern of brain lateralization in left-handers could be reliably inferred from hand posture in writing. Similarly, it has been suggested that the variability between left-handers may be accounted for by determining whether there is a history of familial sinistrality (Hécaen and Sauget, 1971). Unfortunately neither of these variables have proved to be a reliable indicator of brain organization. Thus, as there is as yet no simple method for assessing cerebral organization in sinistrals, it is generally accepted that only right-handed subjects should be used in studies in which handedness is not included as a variable.

The evidence relating to sex differences in cerebral organization, however, is somewhat more problematic. Gender is, of course, one of the most obvious sources of individual variation in behaviour, and the question of whether there are any differences in cognitive behaviour between males and females has been investigated extensively. In general, the evidence regarding this issue has pointed to a male superiority for spatial and mechanical skills, and a female superiority for verbal skills (Maccoby and Jacklin, 1974). Obviously identifying sex differences such as these does not necessarily reveal anything about the origins of the differences. Nevertheless, there have been several attempts to relate these differences in cognitive ability to differences in the pattern of cerebral organization. In particular, in recent years it has been argued that male brains are more lateralized, both for language and visuo-spatial ability, than female brains.

Evidence consistent with this interpretation emerged from a series of clinical lesion studies carried out by McGlone (1980). The results of this research indicated that the incidence of aphasia after LH damage was three times higher in males than in females. Furthermore, there appeared to be a double dissociation of the effects of

LH and RH lesions in males on the performance of the verbal and nonverbal subtests of the WAIS. Specifically, LH lesions were associated with a decline in verbal IQ, whereas RH lesions were correlated with a decline in nonverbal IQ. In contrast, verbal and nonverbal IQ scores in females did not appear to vary as a function of the side of the lesion. These data, therefore, would appear to support the view that both language and spatial abilities are represented more bilaterally in females than in males, and in consequence it has frequently been recommended that studies in which sex differences are not included as a variable should only use male subjects.

McGlone's hypothesis, however, has been challenged. For example, Inglis and Lawson (1982) in a review of the literature that reported the effects of unilateral lesions on the subscales of the WAIS, found an equivalent effect for males and females of LH lesions on verbal IQ scores. It also appears that, aside from performance IQ, there is little evidence of a decreased incidence in females relative to males of nonverbal deficits commonly associated with RH damage (Hier, Mondlock and Caplan, 1983). Such a difference, however, might be expected if female brains were less lateralized. Furthermore, reviews of the evidence relating to this issue suggest that support for the hypothesis from studies using neurologically normal individuals is, at best, equivocal (Fairweather, 1982; Bradshaw and Nettleton, 1983).

Finally, Kimura (1987) has recently argued that LH lesions may be more likely to produce aphasia in males than in females because of intrahemispheric sex differences in the location of the language areas, rather than because of sex differences in language laterality. She claims that females are more likely to experience language impairment and apraxia after damage to the anterior region of the LH. Males, on the other hand, are likely to experience aphasia and apraxia after either anterior or posterior lesions of the LH. Consequently, Kimura argues that in females speech and manual praxis are more focally represented in the anterior regions of the LH. Since vascular accidents causing restricted damage tend to affect posterior regions more than anterior, this could account for the higher incidence of aphasia in males than in females.

Kimura's data await replication by others, and it is therefore difficult to draw any firm conclusions from the above evidence regarding cerebral organization in males and females. Moreover, the picture is complicated further by the possibility of complex interactions between sex and handedness. Geschwind and Galaburda (1985), for example, have formulated a far-reaching theory of lateralization which attempts to account for, among other things, the positive correlation between left-handedness, being male, spatial superiority and disorders of the immune system. In essence, the theory proposes that fetal testosterone delays the maturation of regions of the LH, and this consequently enhances growth of corresponding regions in the RH. Males, who are exposed to higher levels of fetal testosterone than females, will therefore show a greater degree of shift to RH participation in handedness and language and are more likely to have superior RH skills. Furthermore, as testosterone is also known to retard the growth of the thymus gland and other structures of the immune system, it will also contribute to a greater vulnerability in males to a variety of disorders.

Geschwind and Galaburda's hypothesis is a provocative one. There is some indirect evidence in support of this view (Thatcher, Walker and Giudice, 1987; Benbow, 1987, 1988), but there have also been detailed critiques of particular aspects of the theory (e.g. Bishop, 1990). Moreover, McManus and Bryden (1991) have recently observed that the richness and complexity of the theory has to date prevented any serious attempt to evaluate the model as a whole. On the basis of the evidence considered thus far, therefore, it would appear that there is as yet insufficient evidence to merit exclusion of either sex from experimental participation.

1.1.5 Models of Hemispheric Specialization

A final potential source of variability, and one which has enjoyed increasing attention in the last decade, concerns the theoretical paradigm within which researchers are working. Data and interpretation are inevitably constrained by theory and in evaluating previous research it is therefore essential to take into account the part that theoretical assumptions have played in determining these findings. Reviews in this area have typically focused on the disposing factors, such as language, handedness, sex, etc., presumed responsible for cerebral organization. Less emphasis, however, has been placed on the precise nature of the underlying organizational principles of hemispheric functioning postulated by the various models.

In recent years, however, there has been a growing awareness of the need to pay greater attention to what the hemispheres are actually presumed to be doing, irrespective of the factors thought to be responsible for the basic configuration. Moreover, by de-emphasizing the exact role of the disposing factors and concentrating upon the underlying hemispheric organization some progress appears to have been made towards developing a more general theoretical account of the nature of hemispheric specialization. For example, in an insightful discussion of this issue Allen (1983) observed that in the majority of theoretical formulations regarding cerebral organization the basic unit of analysis was the hemisphere. He, however, presented cogent arguments for a reformulation of the concept of hemispheric specialization in terms of smaller neural processing entities.

Support for Allen's suggestion comes from research in cognitive psychology indicating that mental faculties previously treated as undifferentiated phenomena are better described and understood as being composed of distinct processing units or modules (e.g. Marr, 1982; Fodor, 1983), each of which are thought to perform specific operations and whose separate activation is required for the realization of such functions. This new perspective has led to the elaboration of numerous computational models of information processing that specify the various steps necessary to carry out a particular task. Traditionally these computational models have not been concerned with neural "hardware", but in line with Allen's proposals it is clear that computational models of cerebral lateralization can be formulated in which the processing modules are differentially lateralized to one or other hemisphere.

This perspective can perhaps go some way towards accounting for the labile nature of the asymmetries which have been found in experiments with normal subjects. For instance, according to this view even simple tasks will involve a number of different processing subsystems, and there is no reason to expect that the hemisphere that is superior for one of the subsystems will be superior for all of them. The functional superiority of any one hemisphere for a particular task, therefore, will depend upon a set of variables whose effects summate to determine the observable asymmetry. Consequently, studies with normals may have frequently generated contradictory findings because of a diversity of subtly varying procedures and tasks which called upon different mixes of differentially lateralized subprocessors.

The perspective is also consistent with reviews that have addressed the issue of whether the degree of specialization is absolute or relative. Absolute models of hemispheric specialization imply that the cerebral structures subserving particular functions are completely lateralized to one or other of the cerebral hemispheres, whereas relative specialization implies that both hemispheres are capable of performing most functions but at different levels of efficiency. In a review of this area Cohen (1982) concluded that in general the evidence was more supportive of relative than absolute specialization, and the computational perspective is consistent with this view to the extent that the processing modules involved in a particular function are presumed to be localized in both hemispheres.

However, while there may be relative specialization at the macro level, this does not entirely solve the problem of relative versus absolute specialization. Rather it merely succeeds in shifting the issue to a different level of the model. That is, it is necessary to consider if there is absolute or relative specialization at the subprocessor level, and one way of attempting to evaluate these two opposing ideas is to consider how the two hemispheres might interact. Traditionally theories of hemispheric interaction have been formulated using the hemisphere as the basic unit of analysis. However, since a hemisphere may be viewed as a collection or set of subprocessors, there is no particular conceptual barrier to moving from a hemisphere level of analysis to a subprocessor level.

Although numerous models of hemispheric interaction have been put forward over the years, Allen (1983) observed that it was possible to group all the various theories into a small number of categories defined by the nature of hemispheric interaction proposed. First, a number of cooperative interaction models have been formulated which propose that the two hemispheres perform exactly the same function simultaneously (e.g. Ellenberg and Sperry, 1980). Overall performance of the given task is some form of interactive vector of the two hemisphere's activity, with the necessary communication taking place via the commissural fibres. Each hemisphere, however, is not thought to make an equal contribution since one may lead or predominate and, therefore, contribute more to overall performance. A somewhat more extreme version of this approach is provided by the parallel processing model (Moscovitch, Scullion and Christie, 1976). Here both hemispheres are operating simultaneously but independently of each other. Overall performance, therefore, does not reflect an interactive vector but is dependent, presumably, on speed of output. A third general approach to relative specialization is provided by the allocation model (e.g. Levy, 1974). Here it is assumed that both hemispheres are in principle capable of performing a given task, but in practice only one does so at a time. In essence, tasks are thought to be allocated on the basis of some form of analysis to the appropriate hemisphere.

Unfortunately there are problems with all of these approaches. The allocation model, for instance, relies on some form of sorting mechanism in order to determine whether or not information is to be transferred to the opposite hemisphere. The proposed mechanisms in such accounts, however, are often rather vague and little evidence is cited in support of the various postulates. The cooperative interaction model and the parallel processing model, on the other hand, seem implausible and wasteful. In either case one hemisphere is presumed to duplicate what is already happening in the other hemisphere, implying a very inefficient use of processing space.

There are, however, two further models of hemispheric interaction which to a certain extent avoid these problems. According to the subprocessor view, while there is relative specialization at the macro level, there is absolute specialization at the subprocessor level. Each subprocessor is thought to accept particular information as input, perform some specialized operation on it, and then pass the transformed information along to other subprocessors. Unfortunately it is not clear how the subprocessors are to be sequenced and coordinated. Although it should perhaps be noted that this issue is not without its precursor in the traditional approach, as no solution to hemispheric integration was forthcoming when the unit of analysis was the hemisphere. Nevertheless, it is apparent that specifying the subprocessors involved in a task can only be regarded as a first step.

An alternative model which has been put forward does propose some form of bilateral representation at the subprocessor level. According to this perspective both hemispheres have the capacity to perform a given function but they inhibit or suppress each other's activity via the commissural fibres. Such an approach has, of course, been suggested in the past, most notably by Kinsbourne (1974). All previous inhibitory models, however, have suggested a gross "switching off" of whole cognitive systems in the other hemisphere. In contrast, according to Cook (1984, 1986), this inhibition occurs between the subprocessors in a complementary fashion. He observed that the corpus callosum connected largely homotopic regions in the association cortex on each side, and in accordance with this basic fact he suggested that activation of a group of cells in one hemisphere suppresses the exact same neural pattern of activity in the other hemisphere. At the same time, however, this allows activity to develop in surrounding neurons which represent complementary aspects of information. Thus, for example, excitation of a pattern of cortical cells which mean "cat" in the LH would imply inhibition of "cat" in the RH, together with excitation in the RH of peripheral cat-related information, such as kitten, purr, and so on.

Bradshaw (1989b) has suggested that we should perhaps not regard the subprocessor model and the negative inhibition model as necessarily incompatible. He argues that a composite model is most attractive. According to this view there is a finite number of uniquely specialized subprocessors. In addition, however, there is also mirror-image negative connectivity, with subprocessors in each hemisphere taking major responsibility for different aspects of complementary information. It should perhaps be noted in this respect, however, that many researchers argue strongly against the notion of bilateral representation (e.g. McCarthy and Warrington, 1990). Clinical investigators in particular note that unilateral injuries may often produce devastating effects upon higher cognitive functions, and they therefore tend to stress the absolute nature of hemispheric specialization.

It would appear, therefore, that as yet no firm conclusions can be drawn with respect to models of subprocessor interaction. Nevertheless, notwithstanding this ambiguity, the computational perspective has provided a much needed analytic focus to research in hemisphere specialization. It is also clear, however, that the successful application of this approach rests ultimately on the validity of the cognitive model from which it is partly derived. It would appear appropriate, therefore, to next consider in detail the theoretical formulations of visual imagery which have been advanced over the years in cognitive psychology.

1.2 COGNITIVE THEORIES OF VISUAL MENTAL IMAGERY

1.2.1 Introduction

Imagery phenomena first became the focus of psychological research over one hundred years ago when Galton (1883) carried out a survey on the vividness of imagery and reported that there were substantial individual differences. Indeed some subjects claimed that they had no conscious mental imagery at all. Nevertheless, despite this early research interest, visual mental imagery was then almost totally neglected as a topic for study during the first half-century or more of experimental psychology.

This neglect was primarily due to the fact that from the 1920s until the early 1960s behaviourism was the major influence on psychological theorizing. The approach forbade any mention whatsoever of inner mental processes and insisted on dealing only with externally observable events. Mental phenomena, therefore, were reduced to the behavioural evidence from which they were inferred, and investigators were expected to remain close to the data and to spurn abstract mentalistic theory. In consequence, imagery came to be regarded as "a mental luxury (even if it really exists) without any functional significance whatever" (Watson, 1913, p. 174).

However, to every such dogma there comes in time an equal and opposite reaction, and with the rise of the information processing approach in cognitive psychology the study of mental phenomena once again came to be regarded as an appropriate topic for scientific investigation. For example, in 1964 in an article entitled "Imagery: the return of the ostracized" Holt reviewed some of the historical reasons why the study of mental imagery was long ignored in psychology. He also urged investigators to return to the study of imagery, and shortly after the publication of this article the topic became a fashionable area of cognitive research. Moreover, much of its increase in popularity during this early period was attributable to the work of Allen

Paivio, who attempted to formulate a theory describing how imaginal representations were related to other forms of knowledge representation in the cognitive system.

1.2.2 Dual Coding Theory

According to Paivio's dual coding hypothesis cognition is served by two functionally independent but partially interconnected symbolic systems, verbal and imaginal, operating in parallel (Paivio, 1969, 1971, 1986). The imaginal system is said to be specialized for processing nonverbal objects and events, whereas the verbal system is said to be specialized for processing linguistic information. Paivio, however, claims that this symbolic distinction is conceptually orthogonal to distinctions in sensory modality. Thus, nonverbal imagery can involve vision, audition, taste, smell and haptic components, and verbal processes can include both visual and haptic aspects along with a primary auditory-motor component. Both symbolic systems, therefore, are thought to be composed of a number of modality-specific sensorimotor subsystems.

Furthermore, within each subsystem are basic representational units, termed logogens in the verbal system and imagens in the nonverbal system, which can be activated by relevant stimuli. The term logogen was originally formulated by Morton (1969, 1979) and refers to the verbal representational units in long-term memory. The parallel term, imagen, refers to the imaginal representations that correspond to objects or their parts in long-term memory. Finally, each symbolic system is thought to be able to activate the other through associative connections between imagens and logogens.

There would appear to be some evidence in support of Paivio's proposal that there are two separate but interdependent symbolic systems. For example, Paivio's dual coding hypothesis helps to explain why pictures as a rule are much easier to remember than words (Shepard, 1967; Standing, 1973). Pictures are said to be more likely than words to be processed both verbally and imaginally, and consequently recall is thought to be improved by the availability of two alternative traces (Paivio and Csapo, 1973). The hypothesis is also supported by studies reviewed by Richardson (1980) in which memory for pictures was compared when subjects either were or were not explicitly instructed to verbally label the objects represented in the pictures during the learning phase. The results indicated that verbal labelling instructions typically enhanced retrieval, suggesting that a combination of imaginal and verbal processing improves long-term retention.

It has also been claimed that dual coding theory can account for the finding that concrete words are typically more easily retrieved during recall than abstract words (e.g. Paivio, Yuille and Madigan, 1968). The greater image-evoking quality of concrete words is thought to increase the probability of the item being encoded both verbally and imaginally. A number of researchers, however, have observed that this is not the only possible explanation of these results since concrete and abstract words do not differ only in image-evoking potential. For example, some abstract words are more lexically complex in terms of derivation and morphemic structure, and some evidence suggests that this increased complexity may make them harder to learn (Kintsch, 1972). Similarly, abstract words are typically acquired at a later stage of development than concrete words, and it has been suggested that the earlier a word is acquired the more easily it will be retained (Carroll and White, 1973). Because of these additional confounding factors, therefore, it is not possible to conclude unequivocally that the better recall of concrete material is due to imagery.

Moreover, the results of studies which have attempted to test for a causal relationship would also appear to pose some difficulties for dual coding theory. For example, when subjects either are or are not explicitly instructed to imagine interactions among pairs of objects, the interactive imagery instructions are typically found to enhance recall of concrete but not abstract words (Richardson, 1980). A similar effect, however, is obtained when subjects are instructed to use verbal mediation strategies, and Bower (1970, 1972) has provided evidence which suggests that these effects occur because both mnemonic strategies lead to an increase in the cohesiveness and organization of the material. For example, he established that recall of pairs of concrete words was much better when subjects were told to imagine the two objects interacting than when they were told to form separate images of the objects or simply to use rote rehearsal. This suggests, therefore, that the effect is due to enhanced relational organization rather than to the image-evoking quality of concrete words.

These findings undoubtedly pose some problems for Paivio's dual coding theory, and alternative theoretical accounts of how imaginal representations might be related to other forms of knowledge representation in the cognitive system have been formulated (e.g. Marschark, Richman, Yuille and Hunt, 1987). Nevertheless, it should be noted that Paivio (1986) has modified his theory by incorporating additional organizational assumptions within each symbolic system in order to attempt to accommodate the above results. The debate on the role of imagery in the recall of concrete and abstract words, therefore, cannot be regarded as being fully resolved. Moreover, notwithstanding the controversy surrounding this particular area of research, the theory does seem to account for picture-word differences found in free recall studies. Thus, there is some evidence in support of the view that verbal and visual or imaginal memory codes can be distinguished in studies of long-term memory.

However, a further and perhaps more important criticism which is commonly advanced against Paivio's dual coding theory is that it pays insufficient attention to the properties of images. The internal workings of the proposed representational units, for example, are not clearly specified, since no consideration is given to precisely how images are represented and what sort of processes operate upon them. In order to establish that images makes an independent and distinctive contribution to cognition, however, it is necessary to demonstrate that images possess special properties which distinguish them from other modes of conscious thought. In consequence, a number of investigators have concentrated their research efforts on the nature of visual imagery, and have attempted to specify its properties and infer its functions from these properties.

1.2.3. The Nature of Imagery

Before discussing the empirical literature, however, it is necessary to consider some problems concerning the definition of visual mental imagery. The informal meaning of the word "image" relies heavily on the notion of a picture in the mind, and given the overwhelming introspective evidence the existence of such images has never been questioned. However, while the existence of mental imagery has never been in doubt, its theoretical status remained equivocal until relatively recently. Indeed the tumultuous history of the concept of imagery in both philosophy and psychology attests to the difficulties this issue has raised. In particular, what is problematical is the ultimate nature of images as mental representations. Clearly they cannot simply be "pictures in the mind", since if an image is an entity to be perceived then a "mind's eye" or homonculus is required. This then introduces an infinite regress as it is then necessary to account for the form of representation in the "mind's eye's mind", and so on. However, if one adopts a computational approach, whereby cognition is characterized as computations over data structures or representations, then this problem disappears since there is no more of a conceptual problem in positing mechanistic operations that could access imaginal representations than there is in positing mechanistic operations that could access other forms of mental representation. Nevertheless, this still leaves open the question as to the precise nature of images as mental representations, and in this respect psychologists have tended to divide into two opposing schools of thought.

During the 1970s, for example, a number of theorists, in a similar vein to Watson, claimed that visual images had no independent functional role and no status as an explanatory concept. Pylyshyn (1973), for instance, asserted that an adequate characterization of human knowledge required an emphasis on the importance of abstract mental structures to which there was no conscious access and which were language-like in nature, as opposed to pictorial and sensory. Therefore, according to this view, all information, visual and verbal, was thought to be represented internally by means of propositions, i.e. abstract, language-like representations that assert facts about the world. The structure of these representations, therefore, was not thought to be analogous to the structure of the objects they represented. Moreover, visual cognition was thought to constitute activation and manipulation of these propositional representations, and mental images were held to be merely epiphenomena of this process.

In contrast, imagery theorists claimed that images had a functional role in cognition and were subserved by representational codes that differed in important ways from codes underlying other types of information. Specifically, it was claimed that mental imagery involved the use of representations and processes that were ordinarily dedicated to visual perception, rather than abstract conceptual structures subserving thought in general. Moreover, while the majority of imagery theorists explicitly disavowed the picture metaphor, images were still endowed with many pictorial qualities. Kosslyn, Pinker, Smith and Schwartz (1979), for instance, proposed that images were quasi-pictorial representations which occurred in a spatial medium. Furthermore, they observed that if an image depicts an object in this way, as opposed to describing information discursively, then the size, orientation, and location of an object must be instantiated in the image because these properties are inextricably linked in the quasi-pictorial format. Thus, it is possible to hypothesize that if images do have a functional role in cognition then spatial properties should affect information processing when images are used.

Evidence which is consistent with this position appears to have been provided by experiments investigating spatial transformations of visual images, as these studies appear to demonstrate that when people operate on mental images they go through a process analogous to actually operating on a physical object.

1.2.3.1 Spatial Transformations

The most widely cited evidence in support of the view that mental images can be transformed in ways that are parallel to the kinds of transformations that occur in their physical counterparts has arisen from studies investigating mental rotation. Shepard and Metzler (1971), for example, found that the time taken to judge whether two objects seen at different orientations were identical was linearly related to the angular distance between them. This appeared to indicate that the image of one object was mentally rotated until it was in a corresponding orientation to the other. A subsequent study by Cooper and Shepard (1973) which explored the use of mental rotation in identifying rotated letters and numbers produced similar results. Moreover, in one condition in this study the subjects were given advance information about the test character to be presented and its degree of rotation, and in this instance the subjects' reaction time functions were essentially flat suggesting that they had been able to complete the imagined rotations before the character appeared. These findings have subsequently been replicated in a number of experiments using a variety of different objects, and it has also been demonstrated that rotation can occur through the depth plane as well as the surface plane (e.g. Cooper and Shepard, 1975; Carpenter and Just, 1978; see Finke and Shepard, 1986, for a review). It would appear, therefore, that mental rotation resembles the actual rotation of concrete objects or patterns.

Furthermore, the proposal that imagined transformations and their physical counterparts are governed by the same laws of motion leads to a number of predictions that have been tested using the mental rotation paradigm. For example, physical rotations do not slow up or break down because of the visual complexity of the object or pattern. Thus, by analogy, the same should be true of mental rotations. Similarly, imagined rotations should be of the whole form as opposed to being carried out in a fragmented fashion whereby specific portions are rotated. Finally, mental transformations should be continuous. That is, imagined rotations, like physical rotations, should pass through all the intermediate points along the transformational path. Evidence which is consistent with all of these predictions has been obtained (Cooper, 1975; Cooper and Podgorny, 1976; Cooper, 1976), and it would appear, therefore, that studies carried out within the mental rotation paradigm provide strong support for the claims of imagery theorists.

Nevertheless, it should be noted that there is some evidence which conflicts with this interpretation. Pylyshyn (1979), for example, found that complexity did influence speed of rotation when the subjects' task was to judge whether a rotated figure comprised a part of a complex initial stimulus. However, as Shepard and Cooper (1982) observed, mental rotation will be influenced by complexity when perceptual learning of the particular objects has not progressed to the point where the subjects can readily imagine them transformed as a whole. Cooper (1975) and Cooper and Podgorny (1976), who found that mental rotation rates were independent of the visual complexity of the patterns, used extensive training procedures. In Pylyshyn's study, on the other hand, the stimuli used were unfamiliar to the subjects. Furthermore, recently Bethell-Fox and Shepard (1988) have demonstrated that the effect of pattern complexity does decrease with the amount of experience the subjects have with the particular forms used.

A further issue which has been raised relates to the large range in reported rates of mental rotation. Shepard and Metzler (1971), for example, estimated rates of the order of 60° per second, whereas Cooper and Podgorny (1976) estimated rates of the order of 500° per second. Pylyshyn (1978, 1981) has claimed that this inconsistency casts doubt on the conventional interpretation of mental rotation experiments. However, more recently Shepard and Metzler (1988) have provided evidence that the inconsistency is simply due to differences in procedure, i.e. simultaneous versus successive presentations of the stimuli to be compared.

Given the above evidence, therefore, it would appear that the findings favour an analogue view of visual mental imagery, rather than a propositional account. Furthermore, the results of other investigations suggest that individuals can imagine additional, nonrotational, transformations. For example, mental transformations appear to be used to compare objects that are presented at different sizes, different shapes and even different colours (e.g. Bundesen and Larsen, 1975; Shepard and Feng, 1972; Dixon and Just, 1978).

Nevertheless, it should be noted that it is possible to provide a propositional account of mental rotation by assuming that a series of stepwise transformations are carried out, converting the propositional representation successively to each intermediate state until it reaches the upright form. As Eysenck and Keane (1990) observe, however, this explanation is somewhat ad hoc and seems far less plausible and parsimonious than one stemming from imagery theory. Thus, at this point, it seems reasonable to conclude that in general the evidence arising from studies investigating spatial transformations of images appears to favour the imagery account rather than the propositional perspective.

1.2.3.2 Image Scanning

Further evidence in support of the notion that there is a close correspondence between the processes of perceiving and imagining arises from the phenomena of mental image scanning which has occupied a central position in the empirical and theoretical study of imagery for many years. In a comprehensive series of experiments, for example, Kosslyn and his colleagues have shown that when people are asked to scan mentally between the remembered locations of objects on imagined displays, the time required to do so increases linearly with increasing distance between the objects (Kosslyn, 1973; Kosslyn, Ball and Reiser, 1978). Furthermore, this relationship between scanning distance and reaction time has been found with both two and three dimensional arrays, indicating that the effect operates within the depth plane as well as the picture plane (Pinker, 1980). Interestingly, Pinker and Kosslyn (1978) also found that the reaction times for mental scanning in depth were still proportional to the three dimensional separation distances even after subjects were instructed to imagine moving one or more of the objects in the initial configuration. This suggests, therefore, that images can preserve information about relative three dimensional distances even after the subjects have mentally rearranged the objects.

A related effect to mental scanning is demonstrated by findings indicating that reaction times to report on the presence of a named property vary inversely with the size of the image. Thus, for example, it takes longer to verify whether a rabbit has whiskers if the animal has been imaged next to an elephant than if it has been imaged next to a fly (Kosslyn, 1975). Kosslyn argued that this effect is due to a "grain" limitation, because when a rabbit is imagined next to an elephant it is depicted as being relatively smaller and its features are therefore harder to resolve. Furthermore, he also observed that the subjects' introspective reports suggested that they were "zooming in" in order to clearly see the specified properties of the smaller images.

Findings such as these have been interpreted as evidence that mental images preserve information about the spatial and perspective properties of objects and visual scenes, and that subjects operate upon them in much the same way as they would operate upon an external sensory stimulus. However, it should be noted that a propositional account of both of the above effects can be formulated. For example, propositionalists can explain the findings regarding the effect of distance by proposing that the arrays are represented by a network of propositions in which distance is symbolized by degrees of relatedness. Similarly the effects of size can be accounted for by proposing that subjects activate fewer propositions when asked to construct small images, so that detailed information is not readily available (Anderson, 1978). There would, however, appear to be evidence which casts doubt on both of these interpretations.

For example, Kosslyn (1976) compared the effect of varying the size of the parts of imagined animals with the effect of varying the association strength between the animals and their specified properties. The results indicated that when subjects were not instructed to use imagery verification times varied as a function of conjoint frequency. With imagery instructions, on the other hand, verification times were governed by size and not by strength of association. Similarly, Kosslyn (1980) demonstrated that if subjects were not explicitly instructed to perform imagined scanning then verification times were not related to distance. Thus it would appear that the effects only occur when subjects are operating upon images. Nevertheless, it should be noted that the fact that the effects appear only to be apparent when subjects are explicitly instructed to form images, renders the imagery account vulnerable to certain other criticisms.

1.2.4 The Imagery-Propositional Debate

Notwithstanding the evidence arising from studies investigating mental rotation and image scanning, the question of whether images have an independent functional role in cognition continued to be the object of spirited debate throughout the 1970s and early 1980s. Numerous criticisms of the imagists' position were advanced, but some of these now appear to be somewhat ill-conceived. For example, Pylyshyn (1973) claimed that as individuals can easily translate information from a verbal to a nonverbal code, and vice versa, there must be some common format or interlingua, which is propositional in nature, to intervene between the two different codes. However, as Anderson (1978) observed, this argument leads to an infinite regress, since it therefore seems necessary to assume that there is also another code which intervenes between the verbal code and the propositional code, and so on. There are, however, two further criticisms which have been advanced which warrant greater consideration, as they appear to provide alternative explanations of the apparent relationship between mental imagery and perceptual representations revealed in mental rotation and mental scanning experiments.

First, Intons-Peterson has contended that the experimental paradigms used to study the visual properties of imagery are sufficiently vulnerable to experimenter expectancy that much, if not all, of the data showing visual properties of images could be artifactual (Intons-Peterson and White, 1981; Intons-Peterson, 1983). In support of this claim she manipulated the expectations of research assistants regarding the outcome of a series of experiments on the relation of imagery to perception and found that this systematically affected the results of the experiments. Second, Pylyshyn (1979, 1981) views image-percept equivalence as a form of demand characteristic. He proposes that subjects of imagery experiments may interpret instructions to use imagery as meaning that they should simulate the use of their visual systems. Several studies have shown that naive experimental subjects are quite capable of predicting the linear relationship between distance and reaction time (e.g. Mitchell and Richman, 1980). It is, therefore, not unreasonable to think that when subjects are told that their primary task is to form and to scan mental images they would simply try to alter their response times according to their knowledge about distances between the imagined objects. As Pylyshyn (1981) observed, such tendencies need not be of conscious origin but could be based on tacit knowledge of relationships between physical distance and scanning time.

There is, however, evidence which casts doubt on these alternative explanations. With respect to the findings regarding experimenter expectancy effects, for example, it is important to note that the results reported by Intons-Peterson consisted of simple increases or decreases of imagery performance relative to perceptual performance. What has not been demonstrated, however, is that experimenter bias can influence the form of an imagery function, and there is in fact evidence to suggest that the form of such functions may be impervious to these influences. For example, Jolicoeur and Kosslyn (1985) replicated the Kosslyn, Ball and Reiser scanning experiment, except that the experimenters were led to expect that the relation between reaction time and distance should resemble a U-shaped function instead of a linear function. Despite having these misleading expectations the experimenters obtained the usual linear increase in reaction time with increasing scanning distance. This would appear to suggest, therefore, that experimenter bias is not a crucial factor in determining the general outcome of these experiments.

Similarly, with respect to demand characteristics, Finke and Pinker (1982) carried out an image scanning experiment using a task which required no explicit instructions to form or to scan mental images. Subjects were presented with simple dot patterns and allowed to inspect them. The patterns were then removed and an arrow was presented at an unpredictable location. Subjects were required to respond as quickly and as accurately as possible as to whether or not the arrow pointed to a location previously occupied by a dot. The results indicated that reaction times were directly proportional to the distances separating the dots and the arrows. Furthermore, most of the subjects reported that they formed images of the patterns and scanned along these images in the direction indicated by the arrow in order to make their judgements. Thus the experiment demonstrates that mental images are formed and scanned spontaneously in the absence of any instructions to that effect. Further, because the arrows were always presented at unexpected locations, the subjects would not have known in advance the proper scanning distances and thus could not have planned to delay their response times by proportional amounts in accordance with their tacit knowledge.

These findings were replicated and extended in another series of experiments in which whether or not subjects were given advance information about where the arrow would appear was manipulated (Finke and Pinker, 1983). The results indicated that when subjects were uncertain about the arrow's location their reaction times increased with increasing distance. In contrast, when they were given advance information about the arrow's location their reaction times were not significantly related to the arrow-dot distance. This suggests, therefore, that the observed effects of image scanning are not dependent on whether or not subjects are explicitly instructed to use imagery. Rather image scanning appears to be the strategy of choice when individuals have to judge directions among items whose relative positions have not been explicitly encoded.

Nevertheless, while this series of studies strongly suggests that image scanning is not an artifact of explicit demand characteristics, the effects of implicit task demands cannot be ruled out. Pylyshyn (1979, 1980, 1981), for example, has argued that people may mentally simulate physical events when solving geometric problems even when task instructions do not explicitly state that such simulation is called for. According to this argument, individuals simply simulate physical events out of sheer "habit" in response to the implicit demands of the experiment.

Furthermore, it has to be acknowledged that there was a complication in the results of Finke and Pinker (1983) in that the error data revealed a departure from linearity, with subjects making far more errors for the shortest arrow-dot distances than for the other distances. Finke and Pinker explained this apparent anomaly by arguing that dot positions are unlikely to be recorded in memory with perfect accuracy. Therefore, each imagined dot will fall into a circular region of uncertainty. Given a constant angular range within which the scanning process is directed, it is more likely that the imagined dot will fall outside of the critical sector the closer it is to the arrow. Evidence which was consistent with this interpretation was provided by Pinker, Choate and Finke (1984). They reasoned that if Finke and Pinker's explanation of the elevated error rate for the shortest arrow-dot distance was a consequence of inaccuracy in remembered dot location, then any manipulation that served to increase that uncertainty, such as increasing the retention level, should enhance the effect. As predicted, the results revealed that when the retention interval was very long and the arrow-dot distance was small there was an increase in both reaction times and errors resulting in a departure from the otherwise linear trend.

More interestingly, however, Pinker and his colleagues also found that this effect was not predicted by control subjects who were given a description of the task and were instructed to estimate how the response times and errors would vary with distance. Similarly, in an experiment carried out by Reed, Hock and Lockhead (1983) the scan path consisted of diagonal lines, curved spirals and bent spirals of varying length. When asked to predict the scanning times, control subjects correctly guessed that times would increase with increasing distance, but they could not guess the more subtle effects of the shape of the path on the scanning times. This discrepancy between estimated and actual data patterns casts doubt on the tacit knowledge hypothesis, as do the results of the preceding experiments given that there is no obvious type of physical movement whose duration is a linear function for all distances except small ones and whose duration is independent of distance when the source of the journey is known beforehand.

There is, however, one final argument which has been put forward by Pylyshyn (1981, 1984) in support of the view that images are mere epiphenomena. Specifically, he has proposed that according to the assumptions underlying cognitive science, the primitive processing modules comprising the mental architecture should have the property of what he calls "cognitive impenetrability". That is, they should always operate in the same way and therefore the phenomena they yield should not be influenced by beliefs, goals or any other high-level aspects of cognition. According to Pylyshyn, if images operate in a special medium then they must be part of the functional architecture of the mind and therefore they should not be modified by high level beliefs and goals because primitive architecture can only be sensitive to the syntactic form of representations not their content. There is evidence, however, which indicates that in certain instances high-level aspects of cognition can influence imaginal processing.

Intons-Peterson and Roskos-Ewoldsen (1988), for example, found that their subjects took longer to imagine traversing a familiar route when told they were carrying a cannonball than when told they were carrying a balloon. Similarly, Hinton and Parsons (1981) provided evidence which appeared to demonstrate that people's capacity to imagine objects can sometimes depend on an erroneous structural description of an object that they have implicitly adopted in accordance with their beliefs. This sensitivity to the contents of beliefs is put forward by Pylyshyn as evidence in support of the view that the process in question cannot represent a primitive component of the cognitive architecture. It must, therefore, be a manifestation of whatever mechanisms manipulate the representations underlying knowledge in general.

There are, however, a number of counter-arguments which can be advanced against this objection. First, Johnson-Laird (1988) observes that beliefs, goals and other high-level aspects of cognition must themselves depend on mental architecture and, by definition, they are cognitively penetrable, although presumably Pylyshyn would not regard them as mere epiphenomena. Second, Pinker (1984) observes that the penetrability criterion pertains to information processing components, but researchers can only gather direct evidence that beliefs are penetrating individual tasks involving many components. Thus, if a person's beliefs do influence an imagery task, it could simply be due to the fact that the executive has access to certain parameters which can be set prior to the operation of a particular component, such as rotation or scanning.

It would appear from the above brief review of the imagery-propositional debate that there are no particularly compelling arguments in support of the view that images have no explanatory value in psychological theorizing. Indeed there appears to be a consensus among contemporary researchers that the whole debate was not only overly protracted, but also meaningless. Some investigators, for example, have claimed that the issue cannot be decided on behavioural evidence alone. Anderson (1978), for instance, has argued that it is impossible to resolve the debate empirically because propositional representations and pictorial representations do not have distinct properties from which distinct behavioural consequences can be predicted. Not all investigators, however, agree with this conclusion. For instance, Johnson-Laird (1985) observes that a propositional representation can handle both determinate and indeterminate spatial relations, such as "next to", with equal ease. In contrast, we cannot imagine two objects side by side without the relation being either to the "left of" or to the "right of". Similarly, we cannot imagine a shape whose orientation, location and size are indeterminate, since each image must make commitments to particular values of these parameters. Thus, according to this reasoning, images and propositions are functionally and structurally distinguishable from one another.

Moreover, these constraints contrast with the optionality of other properties in imagery. For example, properties such as surface texture, colour, and so on, are often reported as being totally unspecified in images. Interestingly, however, the constraints on which geometric properties are optional in images and which are obligatory are not predictable from physical and geometric constraints on objects in the world, since just as an object must have an orientation when viewed it must also have a certain colour and texture. Pinker (1984), therefore, argues that as the constraints on images are not just constraints on which properties are defined in the world, then this can be regarded as evidence in support of the view that imagery is represented by special mechanisms since if imagery was nothing more than the use of tacit knowledge then the only constraints on what images could represent would stem from what we know can or cannot occur in the world.

Considerations such as these have resulted in recent years in a shift in emphasis in research away from attempting to prove that images are a vacuous representational construct. Rather there now appears to be a growing consensus that different representational constructs are needed to characterize the richness of human cognition. Boden (1988) and Johnson-Laird (1983), for example, have both argued that even the dichotomy between imaginal and propositional representations is too simplistic. Rather they claim that it is more correct to posit a three-fold division between propositions, analogue representations and mental models. Johnson-Laird defines mental models as representations which can be wholly analogical, or partly analogical and partly propositional. According to this view, mental models are thought to correspond to structural analogues of the world and images are the perceptual correlates of models from a particular point of view.

It is important to note that the distinction between the three types of representation is a high level one. As Johnson-Laird (1988) observes, there is a trivial sense in which Pylyshyn is bound to be right in his belief that everything can be reduced to a uniform code in the language of the brain. However, he claims that such a level of description is not one which serves any useful role in cognition. Rather it is proposed that the functional organization of these primitive symbols may make explicit high-level relations, such as the three-dimensional structure of an object or its visual appearance from a particular point of view. What is important, therefore, is not what the representations really are but what functions they serve. Such a perspective, therefore, makes it perfectly legitimate to investigate the functional properties of such representations and how they are accessed and generated.

1.2.5 Kosslyn's Theory of Visual Mental Imagery

While in many ways the imagery-propositional debate was prolonged and infertile one positive aspect of the controversy was that it spurred imagery theorists to clarify the concept of imagery in a far more rigorous way, and consequently a number of investigators attempted to formulate detailed and precise theoretical accounts of the structures and processes involved in imaginal processing (e.g. Shepard, 1981; Hinton, 1979). By far the most important contribution, however, both theoretically and empirically, was Kosslyn's computational model of visual mental imagery (Kosslyn 1980, 1981, 1983).

Kosslyn's theory proposes that imagery uses representations and processes that are ordinarily dedicated to visual perception, rather than abstract structures subserving thought in general. For example, according to this account the experience of an image corresponds to a pattern of activation in an array-like structure known as the visual buffer which is used in both imaging and perceiving. This array consists of units or cells, and the position of cells within the array corresponds to position within the visual field. Cells, when activated, represent patches of the surface of a represented shape, so that the pattern of activation within the buffer is isomorphic to the shape of the visible surfaces of the object. It is also posited that the characteristics of the visual buffer are innately determined and fixed, and consequently these characteristics will influence all representations, both imaginal and perceptual, that occur within it. For example, the visual buffer is said to have a limited extent and specific shape and hence can only support representations depicting a limited visual arc. It is also claimed to have a limited resolution which is highest in the centre but falls off towards the periphery. Finally, representations within the buffer are said to be transient and begin to fade as soon as they are activated, so complexity is also limited because parts of a complex image may decay before other parts have been activated.

According to the model the representation in the visual buffer can be activated in two ways. First, cells can be activated by information arriving from the visual system during perceptual processing. Second, during imaginal processing a "surface image" in the visual buffer can be generated from "deep representations" stored in long-term memory. Kosslyn assumes that there are at least two distinct kinds of deep representation. Abstract propositional representations, for example, are thought to store information regarding the properties of an object, including descriptions about the locations of parts of an object. Literal encodings, on the other hand, are said to depict the actual appearance of an object. Specifically, every object is thought to be represented by a "skeletal encoding" which represents the global shape or central part, and detailed parts of the object may also be stored as additional separate literal encodings.

The theory of the properties of the long-term memory structures emerges directly from Kosslyn's theoretical postulates regarding the various processes that use this information as input. Image generation, for example, is said to be accomplished by three subprocessing components, PICTURE, PUT and FIND, which are coordinated by an executive IMAGE processing component. The PICTURE processing module activates the stored literal encodings of parts of an object, creating a pattern in the visual buffer. The PUT processing module coordinates these separate encodings such that they form a single composite image. This is achieved by using the description of the locations of parts of an object encoded in the propositional representations to set the PICTURE module so that the parts are imaged in the correct relative positions. This process is sequential and, therefore a FIND module is also invoked by the PUT module to locate the "foundation part" where a new part should be added to previously imaged material. Finally, the theory also proposes that once an image is formed in the visual buffer it can be used in various kinds of processing. For example, to maintain images a REGENERATE processing module, which purportedly refreshes units one at a time, is used. Alternatively a set of specific modules are posited, such as ZOOM, PAN, ROTATE and SCAN, which enable the images to be inspected and transformed in various ways.

Kosslyn's model represented a major contribution to the study of imagery. The detailed specifications of representations and processes enabled predictions to be tested and consequences examined, and many of the theoretical postulates are supported by empirical evidence. Moreover, the model reconciled many conflicting experimental results by allowing a functional role to abstract propositional representations as well as to quasi-pictorial images. Nevertheless, notwithstanding Kosslyn's efforts, the progress that had been made to this point was almost entirely within the theoretical confines of the information processing paradigm, which eschews all concerns with neural "hardware". However, in recent years some of the most interesting findings in imagery research have arisen from studies which have attempted to form a bridge between the theoretical constructs of cognitive theories of imagery and neurological phenomena. Before reviewing this evidence, however, it would appear appropriate initially to consider the traditional view of the neural basis of imagery which prevailed prior to the early 1980s.

1.3 THE CEREBRAL LOCUS OF VISUAL MENTAL IMAGERY: HISTORICAL OVERVIEW

1.3.1 Introduction

The issue of the cerebral locus of visual mental imagery was rarely explicitly discussed prior to the mid 1980s. Reviews of hemispheric specialization, for example, typically did not discuss the lateralization of imagery in great detail (e.g. Bradshaw and Nettleton, 1981; Springer and Deutsch, 1981; Beaton, 1985), and studies specifically intended to study differential hemispheric involvement in imaginal processes were relatively infrequent. Paradoxically, however, despite the relative absence of explicit statements regarding this issue, there appeared to be a widespread implicit assumption pervading much of the literature that imagery was a RH function. Ehrlichman and Barrett (1983), for example, in a review of this area cited numerous statements by various authors which indicated an a priori assumption of RH superiority. The proposed relationship between the RH and imagery, however, appeared to be largely inferential as typically no studies were cited to justify this assumption. Nevertheless, the notion of RH superiority was so deeply ingrained that a left visual field advantage on an imagery task was often viewed as proof of the validity of the paradigm (e.g. Bradshaw and Nettleton, 1983, p. 90).

Consideration of the historical evidence relating to the neuropsychological mechanisms underlying imagery, however, would appear to suggest that such a view was inappropriate as none of the findings can be described as unequivocally supporting the RH hypothesis. Moreover, it appears that some of the studies directly contradicted such a formulation.

1.3.2 Clinical Evidence

Published reports of loss of imagery are relatively rare compared with reports of other cognitive disabilities, although whether this is because such loss is uncommon or whether it is because it evades detection is difficult to judge. Nevertheless, periodically cases have appeared in the literature. For example, in the nineteenth century Charcot (1883) described the case of a male patient who had no visual memory of shapes and colours. He apparently knew, for instance, that certain colours were associated with certain objects, but could not visualize these colours. Wilbrand (1887) also described a similar case in which a female patient was unable to image familiar objects and scenes. He reported, for example, that the patient could not "visualize the streets of Hamburg where she had been born and brought up; nor even her own house" (translated by Critchley, 1953).

Reports such as this led to the formulation of the term "Charcot-Wilbrand syndrome" which Critchley (1953) defined as the loss of the ability to conjure up visual images or memories. It should be noted, however, that in both of these cases the imaginal deficit occurred in the context of other quite widespread recognition impairments. Indeed reports in the literature of loss of imagery independent of visual agnosia have been relatively rare. Nevertheless, this did not prevent certain authors from attempting to generalize about the critical lesion site.

For example, Nielsen (1946) observed that occipital lobe damage was associated with loss of what he termed "visual reminiscence" and claimed that, although both hemispheres were implicated, the dominant area was usually located in the hemisphere specialized for language. However, he also noted that lateralization tended to be slight and variable, and in a later report he asserted that individual variation was in fact so great that the critical area could be lateralized to either the

LH, the RH or, alternatively, be bilaterally represented (Nielsen, 1955).

This view was echoed to some extent by Humphrey and Zangwill (1951) who described three patients with loss of both dreaming and waking imagery. One case had a right posterior parietal lesion, the second a bilateral parieto-occipital lesion with predominant damage on the left, and the third, who was left-handed, a right posterior parietal lesion. The authors therefore concluded that deficits of visual imagery appeared liable to follow lesions on either side. Critchley (1953) also voiced a similar opinion, arguing that imaginal impairments were associated with both RH and LH lesions. On the other hand, Luria (1973) described two types of disrupted ability to form visual images independently of perceptual difficulties which he claimed generally resulted from damage to the hemisphere specialized for language.

Over the next few years additional case reports were published but they failed to clarify the position. Indeed at various times parietal lobe, occipital lobe and temporal lobe damage have all been associated with loss or severe deficit of visual imagery and both hemispheres have been implicated. It would appear, therefore, that no firm conclusions regarding the cerebral locus of visual mental imagery could be drawn from the above evidence.

Furthermore, systematic studies of patients grouped according to locus of brain lesion appear to have been equally indeterminate. Many of these studies were carried out within the theoretical framework provided by the dual coding hypothesis (Paivio, 1969). As noted earlier, this theory postulates two interconnected memory systems, verbal and imaginal, operating in parallel. Given the wealth of evidence implicating the LH and RH respectively in certain aspects of verbal and visual processing, it was hypothesized that the verbal system might be lateralized to the LH and the imaginal system lateralized to the RH. If this was the case, then it should be possible to demonstrate an impairment in RH damaged patients on tasks that fostered the use of imagery. The results of these studies, however, provided no unambiguous support for the RH hypothesis.

For example, Jones (1974) compared the effectiveness of imagery mnemonics for paired-associate learning of lists of concrete and abstract words in patients with either left or right temporal lobe lesions. The lists were learned using either no mnemonic strategy or relational imagery for the concrete word pairs. The results indicated that left temporal lobe subjects were generally inferior to normal controls and patients with right temporal lobe lesions. In fact the latter two groups performed virtually equivalently. All of the groups, however, benefited to some extent from the use of imagery mnemonics. Since LH damaged patients are almost certain to show poor performance on such a task due to verbal-linguistic deficits, it would appear that the most parsimonious conclusion is that imagery effects were unqualified by the locus of damage.

Subsequent studies, however, did demonstrate a RH deficit. For example, Jones-Gotman and Milner (1978), using a slightly more difficult version of the task employed by Jones (1974), produced evidence that right temporal lobectomy patients were significantly impaired in the use of imagery mnemonics relative to normal controls. Moreover, Jones-Gotman (1979) showed a similar selective impairment of visual imagery in right temporal patients in a study testing incidental learning of image-mediated or pronounced words. However, while in both of these studies RH damaged patients performed significantly worse than normal controls, they also still performed significantly better than patients with LH damage. Of course, the deficit of the left-lesioned patients might exclusively reflect their verbal impairment, but the possibility that imaginal impairments also exist cannot be ruled out. These studies, therefore, merely serve to illustrate the inherent ambiguity that is inevitably introduced when verbal tasks are used to study imagery.

There is one study, however, which purports to show a specific imaginal deficit in RH damaged patients. Whitehouse (1981, exp. 2) compared the effects of pictorial distractors on a picture recognition task in patients with left and right anterior damage. The distractors were either verbally similar or visually similar to the target picture. Whitehouse reasoned that if the imaginal system was lateralized to the RH then right-lesioned patients would tend to rely primarily on the verbal system and should, therefore, be relatively unaffected by the visually similar distractors. Conversely, left-lesioned patients would tend to rely on the imaginal system and should, therefore, be less affected by the verbally similar distractors. The predicted interaction was significant and Whitehouse interpreted this as supporting the hypothesis that the verbal and imaginal systems were differentially lateralized. There are, however, reasons to question this conclusion. No simple effects analysis was carried out on the significant interaction, and consideration of the reported data suggests that the variation between the two groups was predominantly concentrated in the verbal similarity condition. It is not clear, therefore, whether the effect of visual similarity varied significantly as a function of side of lesion.

Clearly none of the systematic studies of groups of brain-damaged patients unequivocally supports the hypothesis of RH specialization for visual mental imagery. Indeed on the basis of the clinical evidence reviewed thus far it would appear that no firm conclusions could be drawn regarding the neural locus of the imagery system.

1.3.3 Commissurotomized Patients

Studies of commissurotomized patients have been an important source of information regarding hemispheric function. However, prior to the early 1980s there was relatively little systematic investigation of imaginal processing in this area. Nevertheless, there were some reports in the literature which appeared to be incompatible with the RH hypothesis. For example, Hoppe (1977) conducted retrospective interviews with twelve split-brain patients concerning their recollections of dreams. Eight of the patients could not recall any postsurgical dreams, but four could. Similarly, Greenwood, Wilson and Gazzaniga (1977) reported that one completely commissurotomized patient reported dreams from two out of four rapid eye movement (REM) awakenings and none from four non-REM awakenings. Of course, in the absence of baseline data collected prior to surgery for comparison, these dream reports are difficult to interpret. Nevertheless, as patients with complete commissurotomies cannot report RH experiences, these studies would appear to suggest that in some instances the LH can independently generate and experience visual mental imagery.

Moreover, commissurotomized patients are apparently also capable of reporting waking as well as dreaming imagery. Gazzaniga and Le Doux (1978), for example, described an investigation in which a split-brain patient was asked to form a mental image of a visually obscured object placed in their right hand. The patient reported that they were able to form the image, and this therefore would again appear to suggest that imagery is not the exclusive province of the RH. Nevertheless, as noted in Section 1.1.2, the possibility of atypical patterns of neurological organization in these patients suggests that any inferences drawn regarding patterns of normal lateralization require converging support from other populations.

1.3.4 Studies with Normal Subjects

Studies designed to investigate differential hemispheric involvement in imaginal processes were not limited to clinical populations. Indeed during the 1970s and early 1980s a number of relevant investigations were carried out with normal subjects. The results of these experiments, however, failed to clarify the position. For example, a number of tachistoscopic and dichotic listening studies have demonstrated that perceptual asymmetries in word recognition may be qualified by the concreteness-abstractness and imageability of the stimuli. Although the results are not wholly consistent (Bradshaw and Gates, 1978; Gross, 1972; Schmuller and Goodman, 1979; Young and Ellis, 1980; Boles, 1983; Lambert and Beaumont, 1981, 1982), it appears that the usual right visual field superiority for word recognition can be reduced or absent when high imagery concrete words are used (e.g. Ellis and

Shepard, 1974; Day, 1977; Hines, 1976; Kelly and Orton, 1979; McFarland, McFarland, Bain and Ashton, 1978). These findings, therefore, have been interpreted as indicating a RH superiority for imaginal processing.

Unfortunately, however, demonstrating that the RH is better able to process high imagery concrete words than low imagery abstract words is not evidence of a RH specialization for imagery. In order to demonstrate RH superiority it would be necessary to show that the RH performed better than the LH when stimuli were high imagery words, and no such evidence appears to exist. Moreover, it is questionable whether the results of these studies are actually indicative of asymmetries in imaginal processing. For example, the differential asymmetry for high and low imagery words could simply reflect differential availability of lexical representations in the two hemispheres rather than imagery processes per se.

There is, however, one further tachistoscopic study which appears to provide support for the claim that the RH mediates imagery. Seamon and Gazzaniga (1973) instructed subjects to remember a set of words by rehearsing each individually or by generating a relational image of objects represented in the word set. A lateralized picture probe was then presented and subjects were required to indicate whether or not the picture corresponded with an object in the word set. The results indicated that the verbally rehearsed items were more quickly recognized in right visual field presentations, whereas the imaginally encoded items were more quickly recognized in left visual field presentations.

However, although these results are consistent with the RH hypothesis, there is an alternative explanation for these findings. As Seamon and Gazzaniga noted, the RH may simply have been faster than the LH at carrying out a comparison between two "visual stimuli". It is not possible, therefore, to unequivocally attribute the left visual field advantage to imaginal processing. Moreover, it should be noted that attempts to replicate these results have not always been successful (Longoni, Zoccolatti and Speranza, 1980), and it is therefore not clear how robust these findings are.

One final source of evidence regarding the cerebral lateralization of imagery concerns the findings of EEG studies with normal subjects. Robbins and McAdam (1974), for example, produced evidence for greater LH involvement during verbal subvocalization and greater RH involvement during visual imagery. Similarly, Ehrlichman and Wiener (1980) found that ratings of verbal and imaginal activity were positively correlated respectively with relatively greater LH and RH activation. However, as Ehrlichman and Wiener observed, such a pattern could be interpreted as reflecting changes only in verbal activity. That is, if LH activation is proportional to the amount of verbal activity then the apparent increase in RH activation may simply be due to a relative decrease in verbal activity, and hence LH involvement, during imagery. Studies which attempted to control for this potential confound by holding verbal activity constant and varying the degree of imagery required found no evidence which was consistent with the RH hypothesis (Haynes and Moore, 1981; Barrett and Ehrlichman, 1982).

Clearly none of the above findings provide unambiguous support for the claim that the RH is specialized for imagery. Given this evidence, therefore, it is perhaps somewhat surprising that the notion of RH superiority was so deeply ingrained at the beginning of the 1980s. This apparent paradox, however, becomes somewhat more understandable if one considers that at this time theories of cerebral organization focused almost exclusively on broad functional dichotomies. In consequence, the visual, non-verbal nature of imagery suggested greater involvement of the RH, given its specialization in visuo-spatial functions. As is clear from the findings described in the preceding pages, however, this view was based more on the properties of imagery than empirical evidence, and gradually the assumption began to be challenged.

Doubts regarding the validity of the hypothesis were first expressed by Paivio and te Linde (1982). They reviewed the evidence pertaining to the brain mechanisms underlying episodic and semantic memory functions of nonverbal imagery and observed that, contrary to received wisdom, the LH appeared to be implicated in certain aspects of image generation. The full extent of the tenuous nature of the RH hypothesis, however, was finally fully exposed by Ehrlichman and Barrett (1983) who in a review of much of the evidence described in the preceding pages concluded that there was clearly an insufficient empirical basis for considering imagery a RH function.

1.3.5 Farah's Computational Model

Whilst attempts to localize the imagery system as an undifferentiated whole to one neural locus have not been successful, a computational approach to the understanding of cerebral organization has been more fruitful. As noted in Section 1.1.5, computational models of cerebral lateralization propose that the processing modules involved in a particular function may be differentially lateralized to one or other hemisphere. A consistent picture, therefore, will only emerge if investigators look for the brain areas associated with each component individually.

Farah (1984) applied this reasoning to a review of single-case studies of brain-damaged patients displaying loss of visual imagery. In accordance with Kosslyn's (1980) theory she proposed that mental imagery involves a number of separate modules, some of which are shared with perception and some of which are specific to imaginal processes. Given this analysis of the imagery system, Farah reasoned that one would expect to find cases of loss of imagery that corresponded to losses of different processing components of imagery. In order to identify which component or components of the imagery system must have been damaged Farah produced an analysis of the cognitive processing required to carry out a series of complementary imaginal and perceptual tasks. If the literature indicated that a patient could perform a task then it was inferred that all of the cognitive components required by that task were intact. It was possible, therefore, to infer that a component was damaged if it was the only component in the task analysis of a failed task that did not also occur in the task analysis of a successfully performed task.

Thirty-seven cases describing loss of imagery were initially included in the analysis. Five of these cases, however, involved patients who had extensive bilateral damage and their performance on virtually all of the tasks was impaired. In consequence, there were very few components that could be ruled out by virtue of occurring in a successfully performed task. Details of these cases are summarized in Table 1.3.1.

Table 1.3.1: Cases with extensive damage categorized by primary topic of case report, etiology and anatomical site of cortical damage.

Case	**Primary Topic**	**Etiology**	**Lesion Site**
Adler (1944)	Visual agnosia	Anoxia	Diffuse
Brain (1941)	Visual agnosia	Infection	Diffuse
Brown (1972) Case 13	Visual agnosia	Anoxia	Diffuse
Levine (1978)	Visual agnosia	Surgical trauma	Bilateral temporal, parietal and occipital
Nielsen (1946) p. 188	Simultanagnosia	Cerebrovascular accident	Bilateral parietal and occipital

The remaining cases fell into two distinct groups. First, thirteen patients were unable to carry out visual recognition tasks or to answer questions requiring imagery. Moreover, when the recognition deficit was content-specific it was paralleled by a content-specific imagery deficit. Farah therefore suggested that this implied damage to one of the representational components of long-term visual memory. These cases are summarized in Table 1.3.2, and consideration of the area of cortical damage listed for each case appears to indicate that there is no clear trend either in laterality or in region within the posterior lobes. It should be noted, however, that this lack of anatomical regularity may reflect the need for a more fine grained componential analysis in relation to long-term visual memory representations.

Table 1.3.2: Cases displaying long-term visual memory deficit categorized by primary topic of case report, etiology and anatomical site of cortical damage.

Case	**Topic**	**Etiology**	**Lesion site**
Albert et al (1975)	Visual agnosia	Cerebrovascular accident	Right anterior, bilateral posterior
Basso et al (1980)	Loss of imagery	Cerebrovascular accident	Left temporal and occipital
Beyn and Knyazeva (1962)	Prosopagnosia and agnosia	Cerebrovascular accident	Bilateral posterior
Boyle and Nielsen (1954)	Visual agnosia	Neoplasm and surgical trauma	Bilateral occipital
Epstein (1979) Case 1	Loss of dreaming	Cerebrovascular accident	Left posterior (left-handed)
Humphrey and Zangwill (1951) Case 1	Loss of dreaming	Penetrating head wound	Right parietal
Macrae and Trolle (1956)	Visual agnosia	Head injury	Bilateral temporal and parietal
Nielsen (1946) p. 176	Visual agnosia	Cerebrovascular accident	Right occipital, left temporal and parietal
Ratcliff and Newcombe (1982)	Visual agnosia	Cerebrovascular accident	Bilateral occipital, parietal, temporal
Shuttleworth et al (1982) Case 2	Prosopagnosia	Head injury	Bilateral posterior
Taylor and Warrington (1971)	Visual agnosia	Cortical atrophy	Diffuse
Wapner, Judd and Gardner (1978)	Visual agnosia	Cerebrovascular accident	Left temporal, bilateral occipital
Wilbrand (1887, translated Critchley, 1953)	Visual agnosia	Cerebrovascular accident	Bilateral posterior

Table 1.3.3 details a further four cases in which patients were also reported as experiencing agnosia and imagery deficits. In these cases, however, the original reports contained insufficient evidence relating to the behavioural deficits to enable full task analyses to be carried out. These cases, therefore, had to be excluded from the main analysis.

Table 1.3.3: Cases reporting both agnosic and imaginal impairments which were excluded from the main analysis. The cases are categorized according to the primary topic of the case report, the etiology and the anatomical area of cortical damage.

Case	**Topic**	**Etiology**	**Lesion Site**
Brown (1972) Case 11	Apperceptive visual agnosia	Anoxia	Bilateral posterior
Brown (1972) Case 12	Apperceptive visual agnosia	Cerebrovascular accident	Bilateral posterior
Holmes (1944) p. 359	Colour agnosia	Cerebrovascular accident	Left occipital
Nielsen (1946) p. 203	Visual agnosia	Cerebrovascular accident	Right occipital

Finally, and most importantly, the analysis identified a group of eight patients who were unable to answer questions requiring imagery but were able to answer similar questions about visible stimuli and carry out visual recognition tasks (see Table 1.3.4). Farah reported that the only component in the failed tasks that did not occur in the successful tasks was the image generation process. Moreover, she also observed that consideration of the lesion sites in this group indicated that six of the eight cases had damage predominantly or exclusively in the posterior regions of the hemisphere dominant for language. In contrast, therefore, to the prevailing implicit assumption that imagery was a RH function, Farah claimed that a region of the posterior LH was critical for the image generation process.

Table 1.3.4: Cases displaying an image generation process deficit categorized by primary topic of case report, etiology and anatomical area of cortical damage.

Case	Topic	Etiology	Lesion Site
Brain (1954) Case 1	Loss of imagery	Head injury	Left posterior
Brain (1954) Case 2	Loss of imagery	Head injury	Unspecified
Brownell et al (1984)	Loss of imagery	Cerebrovascular accident	Bilateral parietal, left frontal
Humphrey and Zangwill (1951) Case 3	Loss of dreaming	Penetrating head wound	Right posterior parietal (left-handed and aphasic)
Lyman et al (1938)	Alexia and agraphia	Neoplasm	Left parieto-occipital
Nielsen (1946) p. 200	Topographic disorientation	Cerebrovascular accident	Left posterior
Nielsen (1946) p. 227	Gerstmann's syndrome	Neoplasm	Left parietal and occipital
Spalding and Zangwill (1950)	Loss of "number form"	Penetrating head wound	Bilateral, greatest in left parieto-occipital

Furthermore, Farah identified a further six cases in which the authors had again reported the occurrence of imaginal deficits independently of visual agnosia. These patients all had left posterior damage, but it was not possible to include them in the main analysis as insufficient evidence regarding the behavioural deficits had been reported to enable full task analyses to be carried out. Details of these cases are summarized in Table 1.3.5.

Table 1.3.5: Further cases excluded from the analysis categorized according to the primary topic of the case report, the etiology and the anatomical area of cortical damage.

Case	**Topic**	**Etiology**	**Lesion Site**
Arbuse (1947)	Gertstmann's syndrome	Neoplasm	Left parieto-occipital
Nielsen (1946) p. 230	Gerstmann's syndrome	Cerebrovascular accident	Left parieto-occipital
Nielsen (1955) Case 7	Loss of imagery	Neoplasm	Left occipital
Nielsen (1955) postscript Case 1	Loss of imagery and dreaming	Neoplasm	Left occipital
Nielsen (1955) postscript Case 2	Loss of imagery and dreaming	Neoplasm	Left occipital
Wilbrand (1887) described by Nielsen, 1955.	Loss of imagery	Cerebrovascular accident	Left posterior

For the sake of completeness it should be noted that it was not possible to allocate one final case unequivocally to either the long-term memory group or the image generation process group. The case investigated loss of dreaming in a patient with parieto-occipital damage, predominantly on the left, following a penetrating head wound (Humphrey and Zangwill, 1951, Case 2). No reference was made in the report to recognition difficulties, but there was mention of a visual memory loss. Unfortunately it is not clear whether this statement referred to a deficit of recognition memory or an inability to recall visual information. Nevertheless, notwithstanding this ambiguity, it is clear that Farah's evidence directly challenged the prevailing view that imagery was linked to the right hemisphere.

Farah's work, perhaps partly because of the apparently heretical nature of this claim, had an enormous impact and served as the primary impetus for a surge of research activity in this area. This activity, which will be reviewed in the next two sections, has focused on three main questions. First, what is the nature of the relationship between imagery and perception and do they share common underlying structures? Second, does image generation constitute a separable process within the imagery system, and third, what are the respective roles of the two cerebral hemispheres in this process?

1.4 IMAGERY AND PERCEPTION: FUNCTIONAL EQUIVALENCE

1.4.1 Introduction

It is clear from the previous discussion that one of the fundamental assumptions underlying Farah's approach is that the representations and processes underlying visual perception are in many instances the same as those underlying visual imagery. This idea has a long history and can be traced from the philosophical writings of Hume (1739/1969), through theoretical discussions of perception at the neurophysiological level (e.g. Hebb, 1968), to the more recent information processing approaches. However, theorists seem to have favoured the assumption of a single representational system well in advance of any convincing objective empirical data. Indeed in some instances the assumption appears to have been based on little more than the introspective impression that perception and imagination are experientially similar. In the last two decades, however, research has attempted to clarify the relationship between imagery and perception, and in consequence our theoretical understanding of imagery has been considerably advanced.

Before discussing the empirical evidence relating to this issue, however, it is worth noting explicitly that this evidence has no direct implications for the debate relating to the format of mental images which was discussed in Section 1.2.4. As Block (1983) observes, it has often been assumed that demonstrations of equivalence between imaginal and perceptual representations imply that imagery is pictorial as opposed to descriptive. This assumption appears to stem from the fact that many people appear to find it difficult to understand the possibility that the representations of visual perception might not be pictorial. As noted previously, however, many investigators are committed to the view that the representations underlying visual perception are descriptive. Therefore, the claim that the representations of imagery and perception are of the same format is irrelevant to the imagery-propositional controversy since both might be descriptive or, alternatively, both might be pictorial.

1.4.2 Research in Cognitive Psychology

The findings arising from mental rotation and mental scanning experiments indicate an analogous operational process between visual percepts and mental images, but the issue of how close the similarity is between a mental image and a visual percept is left open. In recent years, however, several research programmes within cognitive psychology have investigated this issue and have gathered evidence in support of the view that mental images and visual percepts share certain characteristics in common.

Only a few representative examples of this large literature will be presented here, but a comprehensive review of this work may be found in Finke (1985).

A typical example of studies in this area is provided by an experiment carried out by Finke and Kosslyn (1980). Subjects were presented with dots six, twelve and eighteen millimetres apart and were then instructed to indicate how far out into the visual periphery the dots could move until it was no longer possible to tell that the dots were separate. The findings indicated that there was a strong similarity between the field of resolution in imagery and perception. Similarly, Finke (1979) found that mental images functioned equivalently to visual percepts in producing visual motor adaptation. Pennington and Kosslyn (reported in Kosslyn, 1980) also provided evidence indicating that images show the visual "oblique effect", whereby lines in bar gratings are more difficult to resolve when they are oriented diagonally than when they are oriented horizontally or vertically. Finally, Podgorny and Shepard (1978) demonstrated the functional equivalence of mental images and visual percepts in a dot localization task. In this study subjects were presented with a grid in which they either imagined or were briefly presented with a block letter. A dot was then presented in one of the squares and the subjects had to report whether or not it fell on or off the letter. The results indicated that latencies were unaffected by whether the letter was real or imagined, and Podgorny and Shepard therefore concluded that the representations arising out of images and visual percepts were functionally equivalent.

However, while the above findings would appear to demonstrate some equivalence between images and percepts it is perhaps important to note that our own experience indicates that there are also differences. Percepts are usually more detailed and vivid and, as they depend heavily on the current stimulus situation, are typically less susceptible to internal control than are images. Moreover, there is evidence which suggests that the equivalences between imagery and perception do not extend to the earliest stages of information processing in the visual system. For example, in a review of this area Finke (1980) concluded that whilst mental images and physical objects can be functionally equivalent at levels of the visual system where pattern information is processed, such equivalences do not extend to the retinal or precortical levels which are primarily responsible for chromatic after-effects. Thus, even if it is accepted that the above evidence supports the principle of perceptual equivalence, there are clearly limitations.

Furthermore, it should be noted that the evidence is not wholly consistent. There have, for example, been failures to replicate some of the findings relating to functional equivalence (Broerse and Crassini, 1980, 1981, 1984; Intons-Peterson and White, 1981). Moreover, evidence which appears to suggest that visual information is not an essential aspect of imagery has arisen from studies investigating modality-specific interference. It has been demonstrated on numerous occasions, for instance, that the formation and retention of visual images is disrupted by a concurrent visual perception task (e.g. Segal and Fusella, 1970), thereby suggesting that certain mechanisms are involved in both vision and visual imagery. Baddeley and Lieberman (1980), however, provided evidence in support of the claim that the conflict in these interference experiments was spatial not visual per se, and in consequence a number of investigators have claimed that images are not tied to the visual modality (e.g. Anderson, 1985). Rather they are viewed as abstract, amodal representations which depict spatial and continuously varying information.

This claim appears to be supported by a number of experiments which have compared the imagery processes of sighted and congenitally blind subjects. Marmor and Zabeck (1976), for example, gave a mental rotation task to congenitally blind subjects using normal and mirror-reversed patterns that were presented at different orientations on a raised surface, and found that the linear relationship of reaction time to angular displacement was still evident. Carpenter and Eisenberg (1978) also reported a similar finding using haptically presented letters. Further studies investigating mental scanning tasks, imagery mnemonic tasks and semantic information retrieval under imagery instructions have all produced evidence suggesting that congenitally blind subjects are able to perform these tasks, and that their patterns of response time are qualitatively similar to those of sighted subjects (Kerr, 1983; Jonides, Kahn and Rozin, 1975; Zimler and Keenan, 1983).

The above evidence clearly suggests that visual information is not an essential aspect of imagery and it perhaps seems reasonable to conclude, therefore, that the findings in sighted subjects are also due to the use of nonvisual spatial representations. Moreover, evidence which is consistent with the notion that images are spatial and not visual has arisen from studies concerned with colour effects in imagery. Colour effects would provide a clear case for visual rather than nonvisual spatial representations, given that this property can only be encoded visually. However, as noted previously, a number of studies have failed to find such effects. Finke and Schmidt (1977, 1978), for example, provided evidence of image-percept equivalence for an orientation-specific colour adaptation known as the McCollough effect. However, the imagery induced effect was only obtained for imaged lines on a real colour background, not for imaged colour on a real black and white grating.

In contrast, it should perhaps be noted that Intons-Peterson (1987) found that subjects require less time to form an image when the colour of the image matches the colour of the perceptual surface on which the image is projected. Similarly, Kerr (1983) in an attempt to replicate Kosslyn's (1975) image inspection task, found that congenitally blind subjects were unable to answer animal body-part imagery questions, but could perform the task when asked to image familiar household objects either next to a car or next to a paper clip. She attributed the failure on the animal body-part questions to the fact that such information was unlikely to have been encoded any other way than visually. Such evidence suggests, therefore, that sighted individuals are not exclusively reliant on nonvisual spatial representations, and it could perhaps be taken as implying that normal subjects may have a choice of using visual or nonvisual spatial representations for performing imagery tasks.

Nevertheless, notwithstanding the above evidence, it has to be acknowledged that the findings reviewed thus far do not provide compelling support for the view that imagery and perception share some common underlying components. Moreover, it is important to note that the research of imagery theorists in this area is ultimately based on the inference that we would not expect imagery and perception to function in highly similar ways if they did not share some processing components. It is in fact possible, however, to formulate a relatively plausible argument in support of the view of image-percept equivalence without invoking the concept of shared representational mechanisms. If we hypothesize, for example, that the imagery system evolved partly as a means of planning behaviour through simulation of anticipated events, then it is reasonable to expect that the imagery system will mimic input from the visual system. Thus, similarities would be expected irrespective of whether or not imagery and perception share a common system. The existence of similarities does not therefore imply, in any strict sense, that imagery and perception necessarily share components.

Given the above considerations, it would appear that it is not possible to draw any firm conclusions regarding the relation between imagery and perception. However, a somewhat different perspective on this issue arises if consideration is not limited exclusively to research carried out within cognitive psychology.

1.4.3 Neuropsychological Findings

Despite the long-standing interest of psychologists in the question of the relation between imagery and perception, it is only relatively recently that a coherent attempt has been made to review the empirical findings from neuropsychology that are directly relevant to this issue. The importance of this evidence was first highlighted in an article by Farah (1988), and the following discussion owes a great deal to this insightful review.

1.4.3.1 Psychophysiological Studies

One source of information about the neural structures that subserve imagery representation arises from studies utilizing brain imaging techniques with normal subjects. For example, Roland and Friberg (1985) examined regional cerebral blood flow during three types of cognitive processes: verbal rehearsal of a familiar jingle, mental arithmetic in which subjects subtracted threes starting at fifty and a visual imagery task in which subjects were required to visualize themselves walking through a familiar location. The results indicated that the pattern of regional blood flow for the imagery task differed from those of the other tasks. Specifically, the imagery task produced a massive increase in blood flow in the occipital lobes and the posterior superior parietal and posterior inferior temporal areas. Given that these are precisely the same areas that have been found to show increased activation during visual perceptual processing (e.g. Roland, 1982), the results support the claim that the visual cortex participates in visual imagery.

A similar pattern of results has also been reported in two studies carried out by Goldenberg and his colleagues. In the first study normal subjects were required to learn auditorily presented lists of concrete words (Goldenberg, Podreka, Steiner and Willmes, 1987). One group of subjects was instructed to use imagery and the other was not, and the results revealed that there was relatively more blood flow to the occipital lobes during the imagery condition than during the non-imagery condition. Similarly, in the second study Goldenberg, Podreka, Steiner, Willmes, Suess and Deecke (1989) required subjects to verify the truth of auditorily presented sentences, originally constructed by Eddy and Glass (1981), that either required or did not require the use of visual imagery. Once again a greater occipital blood flow was found for the imagery than for the non-imagery condition. Moreover, activity of this region was found to be positively correlated with self-ratings of the vividness of the images.

Further evidence which is consistent with the notion that mental imagery evokes visual sensory activity has arisen from electrophysiological studies. For example, when subjects' eyes are closed a pattern of electrical activity known as the alpha rhythm occurs in the visual areas of the brain, and it has been well established that this rhythm can be attenuated when subjects open their eyes or form visual images (e.g. Brown, 1966). In an elegant extension of this basic finding, Davidson and Schwartz (1977) measured EEG alpha rhythm simultaneously over the occipital and parietal areas of the brain under three conditions: during visual imagery (imagining a flashing light), tactile imagery (imagining a regular tap on the arm) and combined visual and tactile imagery (imagining the flashing light and the arm tap together). It was found that imaging the light suppressed the rhythm in the occipital lobe and imaging touch inhibited activity in the parietal lobe. The combined condition, on the other hand, was found to produce attenuated activity in both areas.

More recently event-related potential techniques have also been used to examine regional brain activity during imagery. Farah, Peronnet, Weisberg and Perrin (1987), for example, studied the responses evoked by visually presenting words which the subjects were instructed either simply to read or to read and form a visual image of the meaning of the word. In the imagery condition there was a highly localized increase in the occipital ERP relative to the non-imagery condition. In order to ensure that the effect was not simply due to greater cognitive load, a further study was also carried out in which the reading-only of correctly spelled words was compared with the detection of misspelled words. The misspelling detection condition was found to produce an ERP that was different in both polarity and pattern from that evoked by the imagery instructions.

In a second study Farah, Peronnet, Gonon and Giard (1988) examined the effects of imagery on the ERP to visual stimuli. This study was based on an experiment originally carried out by Farah (1985) in which subjects were shown the letters H or T after being instructed to form a mental image of one of them. The results indicated that a matching image led to better detection than a non-matching image, and Farah therefore concluded that the interaction between imagery and perception implied a common locus of activity. Moreover, the content-specific nature of the interaction suggested that the common locus consisted of representational structures. Farah et al. (1988) repeated this experiment while recording ERPs to stimuli, and the results indicated that imagery had a content-specific effect on the visual evoked potential which was maximal at the occipital recording sites. The authors concluded, therefore, that the finding supported the claim that imagery and perception share representations in the occipital lobe.

Finally, researchers have recently employed electrophysiological techniques to investigate the cerebral correlates of different types of visual images. Uhl, Goldenberg, Lang, Lindinger, Steiner and Deecke (1990), for example, measured cortical potential (DC) shifts while subjects imagined either single colours completely filling the visual field, static achromatic images of faces or the shape of contours between two points on previously memorized patterns. These images were classified respectively as low-information visual images, high-information visual images and spatial images, and the results revealed maximal parietal (DC) shifts during performance of the contour task. This finding, therefore, appears to imply that the parietal regions are involved in spatial imagery.

To summarize, the psychophysiological evidence, whether from blood flow studies, EEG or ERP experiments, is consistent in suggesting that instructions to image give rise to increased activity in the occipital lobes and in posterior parietal and temporal areas associated with visual perception. As such, the findings would appear to favour the claim that there is a single representational system underlying visual imagery and visual perception. Furthermore, there is also some support for the view that different areas subserve different types of visual images.

Nevertheless, it should be noted that there are some difficulties associated with some of the studies that have been discussed. For example, the Goldenberg, Podreka, Steiner and Wilmes (1987) study used a between-subjects design, such that the resting, imagery and non-imagery condition were performed by different groups of subjects, and this greatly limits the inferences which can be drawn from the comparisons between conditions. Moreover, a further possible confound in relation to this evidence is that the increased activity in the visual cortex during the imagery tasks may merely have reflected greater cognitive effort on the part of the subjects.

Farah rejected this explanation on the grounds that the imagery task in the Goldenberg, Podreka, Steiner, Willmes, Suess and Deecke (1989) study produced a lower error rate than the non-imagery task. However, it is possible to argue that greater cognitive effort would be expected to produce a lower rather than a higher error rate. Nevertheless, it should perhaps be noted that previous research findings suggest that task effortfulness is usually associated with blood flow changes to the frontal lobes not the occipital lobes (e.g. Lassen, Ingvar and Skinhoj, 1978).

A further difficulty arises from the fact that Goldenberg and his colleagues used multi-dimensional scaling to analyze the patterns of cerebral blood flow. As this procedure is descriptive rather than statistical, the reliability of the findings await support through replication. Finally, it is also appropriate to note that while the Uhl, Goldenberg, Lang, Lindinger, Steiner and Deecke (1990) study appeared to provide evidence of the involvement of the parietal regions in spatial images, a regional cerebral blood flow study by Goldenberg, Podreka, Uhl, Steiner, Willmes and Deecke (1989) using exactly the same tasks found no differences in the patterns of activation between the colour and the contour task. Furthermore, it is likely that some investigators would object to the classification of the face task in these studies as a visual rather than a spatial task.

In addition to difficulties with specific studies, it is also necessary to consider the methodological limitations of psychophysiological techniques. For instance, the temporal correlation of increased blood flow with psychological events is somewhat crude, as the radioactive elements which facilitate detection of increased activity take some time to pass through the head. Similarly, inferences from scalp topography to brain locations are necessarily indirect and therefore subject to error. The greatest difficulty, however, arises from the fact that the indirect nature of these techniques means that it is not possible to refute unequivocally the possibility that the observed activity in the visual areas of the brain is epiphenomenal with respect to the functions of imagery. According to this account, visual images are not visual representations, they are merely accompanied by occipital activity but such activity is not necessary for the processing of images to occur. However, while the psychophysiological evidence does not allow us to distinguish between a functional and epiphenomenal role for the visual system in imagery, the clinical evidence does.

1.4.3.2 Lesion Studies

If visual imagery and visual perception are subserved by the same representational machinery then lesions should produce parallel impairments in imagery and perception, and there is in fact a great deal of evidence indicating that perceptual and imaginal deficits frequently co-occur following brain damage. For example, since Farah's initial review further single-case studies of patients with imagery deficits associated with disorders of visual recognition have been reported (Davidoff and Wilson, 1985; Gomori and Hawryluk, 1984; Benke, 1988; Goldenberg, 1992; Trojano and Grossi, 1992). What is perhaps of more interest, however, is that in a number of cases selective disturbances of single aspects of visual recognition have been associated with an equally selective imagery deficit.

It has been known for many years, for example, that damage to the occipital lobes may result in colour blindness (see Cowey, 1982; Meadows, 1974), and research suggests that such patients also lose the capacity to form colour images (e.g. Stengel, 1948; Beauvois and Saillant, 1985, case 2; Sacks and Wasserman, 1987). Humphreys and Riddoch (1987), for instance, provide a detailed account of the patient HJA who, in addition to various other problems, had impaired colour vision and was also extremely poor at imaging colour information about objects. When questioned about the colour of animals, for example, he stated that an elephant was green and that a polar bear was grey. More recently De Vreese (1991, case 2) has reported a similar pattern of deficits in the patient MA. Furthermore, equivalent evidence has also arisen from group studies. DeRenzi and Spinnler (1967), for instance, tested a large group of patients with colour-related perceptual deficits and found that colour vision impairment was significantly correlated with colour imagery impairment. Findings such as these, therefore, would appear to suggest that the colour of mental images is represented in the same neural substrates as the colour of visual percepts.

Further evidence which is consistent with this claim arises from a case reported by Beauvois and Saillant (1985, case 1). The visual areas of the brain were intact in this patient, but there appeared to have been a neuroanatomical disconnection between her language and vision areas following a stroke. Thus, while she performed normally on colour tasks that were purely visual, she performed extremely poorly on tests which required coordination of visual and verbal information. She could not, for example, name a visually presented colour although she was able to sort objects on the basis of colour. What is of interest, however, is that the patient displayed a parallel impairment on various colour memory tasks. Thus, she could distinguish between correctly and incorrectly coloured drawings of objects, but was unable to answer questions such as "What colour is a gherkin?". A parallel pattern of deficits was observed in a case described by De Vreese (1991, case 1). In terms of interactions with visual and verbal task components, therefore, visual images and visual percepts were equivalent in these cases, supporting the claim that colour perception and colour imagery depend upon the same neural substrates of colour representation.

Evidence of parallel deficits in imagery and perception has also emerged from investigations concerned with two distinct aspects of the visual system. It has been found in primates, for example, that there is a marked contrast between the effects of parietal and temporal lesions on visual discrimination tasks (e.g. Pohl, 1973; Iwai and Mishkin, 1968; Brody and Pribram, 1978). Specifically, monkeys with lesions to the inferior temporal lobe appear to be impaired at learning to discriminate between different forms and patterns, whereas monkeys with lesions to the parietal lobe appear to be grossly impaired on tasks requiring assessment of spatial relations between objects. Moreover, a similar pattern has arisen from data from single neuron recordings. Temporal recordings, for instance, have revealed that neurons selectively respond to variations in shape, colour or texture (e.g. Desimone, Albright, Gross and Bruce, 1984). Parietal recordings, on the other hand, suggest more sensitivity to the motion of a stimulus and its position relative to eye fixation (e.g. Sakata, Shibutani and Kawano, 1983).

Ungerleider and Mishkin (1982) attempted to summarize this evidence by coining the term "two cortical systems" to capture the distinction between two functionally and anatomically distinct systems of visual representation of stimuli in perception. They argued that the temporal system appeared to be concerned with the visual appearance of stimuli, whereas the parietal system appeared to be concerned with the spatial location of stimuli. Consequently they called the system that represents object properties the "what" system, and the system that represents spatial location the "where" system, and it is relevant to note that this dissociation between what and where has also been found in humans following damage to different areas of the brain.

Patients with bilateral parieto-occipital damage, for example, often have difficulty locating objects in the visual field, but are quite capable of recognizing them (DeRenzi, 1982). On the other hand, the converse pattern of visual processing deficit also occurs in which patients with bilateral temporo-occipital damage are able to localize an object accurately, but are not able to recognize it (e.g. Bauer and Rubens, 1985). Thus there exists evidence from both animals and humans that the visual appearance of objects and their spatial relations are represented separately and independently by two different perceptual systems. What is of more interest, however, is that recent evidence suggests that the same distinction exists in mental imagery.

Levine, Warach and Farah (1985), for example, described two patients with impaired visual perception. The first had recognition difficulties following bilateral temporo-occipital damage, and the second had localizational difficulties following a parieto-occipital lesion. A series of tests revealed that the first patient was unable to draw or describe objects from memory, but showed good retention of the capacity to locate items in space from memory. In contrast, the second patient was unable to perform tasks requiring the coding of relative spatial locations in images, but could give detailed descriptions from memory of the appearances of objects. Levine and his colleagues also reviewed similar cases of perceptual deficits which had been previously reported in the literature, and found that when the appropriate imagery abilities had been tested they showed parallel patterns of impairment.

More recently Farah, Hammond, Levine and Calvanio (1988) have described a patient who, following bilateral temporo-occipital and right temporal and right frontal damage, was unable to perform visual imagery tasks which involved information retrieval and image generation, but was able to perform spatial imagery tasks which involved image maintenance and manipulation. As the patient also displayed some impairment on perceptual analogues of the visual imagery tasks Farah and her colleagues concluded that the dissociation between visual and spatial imagery tasks could not have been due to differential image generation demands of the two types of task. They therefore argued that different kinds of mental imagery tasks called upon different kinds of imagery representations, some of which are visual and some of which are spatial.

The above evidence supports the view that the functional and anatomical distinction between what and where in the perceptual system also exists in the imagery system.

Furthermore, there appears to be a parallel dissociation in perception and imagery between object recognition abilities within the "what" system. It has been known for many years, for example, that visual agnosia can be category-specific, and Farah (1984) in her initial review observed that within the group of agnosic patients reported to have accompanying imagery deficits the particular stimulus categories that were difficult for patients to recognize were also more likely to be difficult to image. Moreover, further evidence of category-specific parallelism has been reported in more recent cases.

For example, one frequently reported finding is that individuals often experience difficulty in recognizing living, animate objects but have preserved recognition of inanimate objects (McCarthy and Warrington, 1990). It is of interest to note, therefore, that Farah, Hammond, Mehta and Ratcliff (1989) reported that a visually agnosic patient with this type of category-specific deficit was significantly more impaired at recalling the appearances of living than non-living objects from memory. In contrast, his ability to recall nonvisual information was normal for both animate and inanimate objects. Similar findings of recognition difficulties accompanied by imagery deficits restricted to the same classes of visual entities have been reported by Shuttleworth, Syring and Allen (1982, case 2), Sartori and Job (1988) and Mehta Newcombe and De Haan (1992). Furthermore, it is perhaps worth noting a previous report in the literature in which Beyn and Knyazeva (1962), in an item by item comparison, found that an agnosic patient could recognize thirteen out of sixteen objects that he claimed he could image. In contrast, he only recognized three out of sixteen objects that he claimed he could not image. Again, therefore, the findings appear to imply that visual imagery depends on structures that normally subserve object recognition.

There is also a recent report which suggests that the parallelism between imagery and perception may exist at the level of feature-integration. Visual integrative agnosia was first documented by Riddoch and Humphreys (1987) and refers to the inability to integrate elementary features in object representations. Their patient, therefore, was reported to resort to a piecemeal strategy in matching and copying, and to focus on details when attempting to visually identify objects. More recently Grailet, Seron, Bruyer, Coyette and Frederix (1990) have documented a similar pattern of impairments in the patient HG. However, in contrast to the patient described by Riddoch and Humphreys, HG also performed poorly on imagery tasks and spontaneous drawings of objects, suggesting that his knowledge for entire objects was also impaired. Grailet and his colleagues therefore proposed that the evidence favoured a common integration process for both visual perception and imagery, damage of which resulted in the inability to derive correct percepts or images of whole objects.

One final area of potentially relevant neuropsychological evidence considered by Farah (1988) relates to research on the hemispatial neglect syndrome. Patients with visual neglect fail to detect stimuli presented in the half of space opposite their lesion (e.g. Heilman, Watson and Valenstein, 1985), and research indicates that neglect for mental images appears to accompany visual neglect (Bisiach, Capitani, Luzzatti and Perani, 1981; Bisiach and Luzzatti, 1978; Bisiach, Luzzatti and Perani, 1979;

Meador, Loring, Bowers and Heilman, 1987; Barbut and Gazzaniga, 1987). However, while this evidence constitutes a strong demonstration of common mechanisms underlying imagery and perception, it is a moot point which particular component of imagery and perception this evidence implies is shared.

Bisiach, for example, interprets these findings in terms of the loss of half of a spatially mapped representational schema. However, it is also possible that the locus of the common imaginal and perceptual deficit is not impaired representational structures, but rather impaired attentional processes, and indeed more recent evidence gathered by Ogden (1985) is somewhat more compatible with this interpretation than the representational account. Nevertheless, the evidence does suggest that the two sides of the image depend on the same attentional resources as the two sides of perceptual space. Furthermore, it is perhaps appropriate to note that recently Farah, Soso and Dasheiff (1992), using a technique developed by Kosslyn (1978), reported that the visual angle of the "mind's eye" was reduced following unilateral occipital lobectomy in much the same way as the visual angle of visual perception is reduced. Such evidence is consistent with the claim that imagery occurs in a spatially mapped representational medium dependent on occipital cortex.

1.4.4 Summary

To summarize, the neuropsychological evidence appears to demonstrate visual cortical involvement in imagery, and is consistent with the old and intuitively appealing idea, first expressed by Hume, that mental images are reactivations of perceptual experiences. Nevertheless, while this parallelism suggests a relationship between the neural structures involved in perception and imagery, it is obvious that the two systems cannot be identical. If they were, seeing and imaging would be indistinguishable.

Moreover, it is important to stress that selective disturbances of single aspects of visual recognition do not always associate with an equally selective imagery deficit. For example, the patient suffering from visual integrative agnosia described by Riddoch and Humphreys (1987) was extensively tested but showed no imagery problems. Similarly, Grossi, Angelini, Pecchinenda and Pizzamiglio (1993) found that ten hemineglect patients showed poor performance in left hemispace on an imaginal task, but showed no left neglect on a perceptual control task.

Conversely, close parallelism has not been verified in all cases in which imagery and perceptual deficits co-occur. For example, a case report of an associative visual agnosic patient by Goldenberg (1992) documented a discrepancy between his knowledge about the shapes of objects as manifested by recognition and his ability to imagine these objects as assessed by drawing or verbal description from memory. Similarly, Trojano and Grossi (1992) observed that the patient MP was unable to draw from memory objects which he could recognize and define semantically. This impairment could not, however, be attributed to an image generation deficit, as the patient was able to perform imagery tasks not requiring visual mental images of objects (e.g. letter imaginal tasks).

Findings such as these are, of course, inconsistent with Farah's (1984) claim that impairment in these cases is due to the loss of long-term visual memory representations common to both imagery and perception. Indeed evidence such as this has led Goldenberg (1992) to suggest that the representations activated in mental imagery are not the same as those involved in visual perceptual recognition. However, as noted by Trojano and Grossi (1994) in a review of this area, it is of course possible that these apparent inconsistencies merely reflect functionally heterogeneous imagery impairments. Moreover, although imagery deficits cannot be predicted on the sole basis of recognition problems, the relatively high frequency of such an association suggests that it is not unreasonable to assume that certain neural structures are shared in common.

Furthermore, it is worth reiterating that the findings also appear to suggest that imaginal representation, like perceptual representation, is not an undifferentiated faculty, but rather consists of at least two independent sets of representational abilities, visual and spatial. Indeed in a recent review of research relating to this issue Logie and Baddeley (1990) concluded that the evidence suggests that imagery has related but separable visual and spatial components. Such a conclusion clearly goes some way toward accounting for the imaginal abilities observed in peripherally blind subjects which were documented in Section 1.4.2.

Of course, the difficulties associated with drawing inferences regarding normal functioning from studies of brain-damaged patients should not be underestimated. Nevertheless, the consistency of the findings about the neural substrates of visual imagery across a range of different methods and subjects strengthens the evidence both qualitatively and quantitatively, and therefore provides strong support for the view that some of the representations and processes underlying visual perception are the same as those underlying visual imagery.

1.5 THE CEREBRAL LOCUS OF VISUAL MENTAL IMAGERY: CONTEMPORARY OVERVIEW

1.5.1 Introduction

It would appear from the previous section that a great deal of progress has been made in providing evidence in support of the assumption underlying Farah's approach that imagery and perception share representations and processes in common. Farah's claim that the LH is specialized for the generation of visual mental images, however, has been somewhat more contentious, and a number of authors have expressed reservations as to how well founded this view is (Sergent, 1990; Goldenberg, 1989; Paivio, 1989). It would appear necessary, therefore, to evaluate the evidence and criticisms relating to this issue in greater detail.

1.5.2 The Laterality of Image Generation

1.5.2.1 Single-Case Studies

Whilst Farah's initial review article was enormously influential it must be acknowledged that it was not without problems. Sergent (1990), for example, in a review of the evidence bearing on the cerebral lateralization of the image generation process provided a detailed critical review of Farah's interpretation of the localizing evidence reported in the cases identified as being consistent with her hypothesis. Indeed Sergent claimed that out of the fourteen cases presented by Farah in support of LH specialization for image generation, only one, described by Nielsen (1946, pp. 227-230), appeared to be relevant if "stringent scientific criteria" were applied (Sergent, 1990, p. 103). Similar concerns were voiced by Goldenberg (1989), although according to his inclusion criteria the only relevant cases were the ones described by Brain (1954).

These criticisms are in fact difficult to refute categorically as Farah herself observed that there were some difficulties with the quality of the information regarding the precise location of the lesion site in some of the cases that she cited. Moreover, there are undoubtedly problems associated with interpreting data in this post hoc fashion. Any retrospective analysis of published case studies, for example, is obviously limited by the information reported by the original authors, and loss of visual imagery was often not the major focus of the initial investigations. It is, therefore, unclear how extensively or systematically the original investigators explored this particular deficit.

However, since Farah's initial review further single-case studies of patients with unilateral brain damage have provided evidence of a loss of imagery following LH damage. Trojano and Grossi (1994), for example, in a review of this area identified a further three cases of patients who displayed relatively "pure" imagery deficits. Grossi and his colleagues, for instance, described a patient (AP) with a left occipital lesion who was unable to carry out a number of imaginal tasks (Grossi, Orsini, Modafferi and Liotti, 1986; Grossi, Modafferi, Polosi and Trojano, 1989). He displayed, for example, an inability to describe familiar places from memory and he also produced unrecognizable freehand drawings of objects. On the other hand, he displayed no impairment in copying pictures or in recognizing visually presented objects, although he did experience some difficulty in describing complex pictures. Similarly, he displayed an inability to judge the angle formed by the hands of a clock which had to be imaged after being told a given time verbally, but performed the task correctly in a perceptual condition.

Given that AP was unable to perform tasks requiring imagery but was able to perform similar tasks on visible stimuli, Grossi and his colleagues concluded that he was impaired in constructing adequate mental images. One possible criticism of this conclusion, however, was raised by Sergent (1990) who noted that AP had a severe memory deficit. She claimed, therefore, that the imagery tasks may simply have been too difficult for this patient. It is not possible to refute this suggestion categorically, but it is perhaps worth noting in this respect that AP's memory span was within normal limits.

Farah, Levine and Calvanio (1988) described a further patient (RM) with a left occipital and medial temporal infarct who displayed a similar pattern of selective imagery deficits. He was, for instance, deficient at generating images of objects and colours and was also impaired at verifying high imagery sentences and completing pictures. Moreover, Farah and her colleagues used this case to investigate a further criticism which had been put forward by Sergent (1990). In her review of this area

Sergent had observed that failure by LH damaged patients to verbally report subjective experience of visual imagery was not necessarily indicative of an inability to generate images, given that such patients are susceptible to verbal comprehension and/or production deficits. Sergent suggested, therefore, that loss of imagery in such cases might simply reflect a functional disconnection that isolates imagery processes from language.

In order to investigate this issue Farah and her colleagues tested RM on two imagery tasks, a colouring task and a drawing completion task, in which neither the stimuli nor the response were verbal. The patient was also tested on perceptual analogues of the two tasks. Unfortunately the results of the drawing tasks were inconclusive as, although RM's performance in the imagery condition was extremely poor, he refused to complete more than two items on the perceptual control task. Nevertheless, on the colouring tasks his performance was significantly worse in the imagery condition than in the perceptual condition, and this suggests that the underlying deficit in this patient was an impairment of imagery ability and not merely a disconnection of imagery processes from language. It should perhaps be noted that this conclusion was challenged by Sergent (1990) as no formal test of colour perception and discrimination was administered. Nevertheless, the patient was reported to name seven out of eight colours correctly at the end of research testing.

More recently a third case has been reported by Riddoch (1990). This patient (DW) had a left temporo-parietal lesion and showed poor performance on a number of imaginal tasks. He was, for example, unable to decide whether or not the uppercase version of a verbally presented letter contained any curved segments, whereas he performed perfectly on a perceptual analogue of this task in which the letter was presented visually. One possible confound in relation to this finding is that the failure on the imagery task may simply have reflected an inability to link letter shape with the sound of the letter. However, DW was also impaired on a task which required him to judge whether the visually presented incomplete (without a tail) body of an animal had a short or long tail in relation to its body. On the other hand, he could make this judgement when presented with complete line drawings of the animals. Riddoch therefore concluded that DW's overall performance was consistent with an image generation deficit resulting from a lesion in the posterior regions of the LH.

For the sake of completeness there are two further single-case studies which warrant consideration. Botez, Olivier, Vezina, Botez and Kaufman (1985) described the case of a left-handed teacher with congenital damage which had resulted in hypoplasia of the RH and flattening of the posterior third of the corpus callosum. The patient showed poor performance on a number of imaginal tasks and Botez and his colleagues interpreted these findings in terms of the componential model of imagery, concluding that there was a deficit in the image generation component. However, as Trojano and Grossi (1994) observe, it is questionable how useful these findings are for localization purposes given that the subject was left handed and had inborn disorders.

Finally, another case of loss of visual imagery in a patient with a left tempero-occipital infarct was reported by Pena-Casanova, Roig-Rovira, Bermudez and Tolosa-Sarro (1985). This patient failed to perform adequately on a number of image generation tasks, and consequently Farah (1989) cited the case as evidence in support of the LH hypothesis. However, Sergent (1990) observed that while this patient did indeed perform poorly on image generation tasks he also showed associated deficits pointing to visuo-verbal and visuo-gestural disconnection. Thus, although the authors' description was highly suggestive of an image generation deficit, it is questionable whether in this case the imagery deficits were sufficiently "pure" to enable failure on the tasks to be unequivocally attributed to the image generation component.

Nevertheless, notwithstanding these latter two cases and the various criticisms raised by Sergent (1990), it would appear that overall the findings of the more recent reports are consistent with Farah's claims. Moreover, it should be noted that Sergent's approach can also in turn be criticized. By applying very stringent criteria Sergent was in effect considering and criticizing each case in isolation. However, as Tippett (1992) observed in a review of this area, while it is undoubtedly important to be critical, this sort of case-by-case deconstruction of a trend observed across a widely dispersed literature can itself be questioned. A full picture can sometimes provide more information than looking stringently at the individual parts of which the evidence is composed. Furthermore, Tippett (1992) also noted that what was striking about the area was the pervasiveness of findings that seemed to implicate the LH in the image generation process. Indeed on the basis of such findings Tippett concluded that the LH had a direct role of some kind in the generation of visual images.

Trojano and Grossi (1994) reached a broadly similar conclusion following their review of this area, although they added two important provisos. First, whilst they acknowledged that the neuroanatomical data pointed to the posterior regions of the LH as the critical area for loss of imagery, they suggested that on the basis of the evidence it was inappropriate to attribute an exclusive role in this respect to the occipital lobe. Second, they observed that if damage to a single specific component was responsible for the behavioural deficits displayed by these patients then one would expect homogenous findings across the cases. However, while the subjects had some features in common there were also qualitative differences in their performance in other respects. For example, AP's freehand drawings from memory contained all the appropriate elements of the objects he had been asked to depict, but the spatial relations between the various elements were incorrect. RM and DW, on the other hand, displayed a different pattern of drawing production deficits.

As Trojano and Grossi observe, these inconsistencies could reflect additional cognitive damage attributable to the different anatomical lesions of these patients. Conversely, they could also be accounted for by assuming deployment of different compensatory strategies on the part of the patients. However, it is also possible that the image generation component may be further subdivided and that these inconsistencies reflect damage to different subcomponents. If this is the case then a more fine-grained componential model of the imagery system is clearly required.

This last point will be discussed in further detail in Section 1.6, but suffice to say for now that overall it would appear that the evidence from single-case studies is in broad agreement with Farah's claims. The situation with regard to group studies of brain-damaged patients, however, is somewhat more equivocal.

1.5.2.2 Group Studies of Brain-Damaged Patients

Since the initial review of Ehrlichman and Barrett (1983) a number of group studies have been cited in the literature in relation to this issue, but unfortunately none of these have produced definitive findings with respect to the contribution of the cerebral hemispheres to the image generation process. For example, Read (1981) compared the performance of right and left temporal lobectomy patients and normal control subjects on their capacity to solve three-term series problems (e.g. A is taller than B, B is taller than C. Which one is the tallest?). The left temporal lobectomy patients produced a significantly poorer overall performance than right lobectomy patients and control subjects. Indeed the latter two groups performed virtually equivalently. Given that it has been claimed that visual imagery is used in the solution of such logical problems Read suggested that the results might reflect a deficit in image generation, an inference which was supported by the normal performance of these patients on the Token Test and IQ tests. Nevertheless, the subjects were not tested on a control task without imagery and it is not therefore possible to unequivocally attribute the deficit to the image generation processing component.

Some group studies, however, have incorporated perceptual control tasks into the design. For example, Morrow, Ratcliff and Johnston (1985) compared the performance of RH stroke patients and controls on tasks which required the estimation of distances between pairs of cities from either perceived or imagined maps of the United States. The results indicated that the RH group was significantly worse than the controls in the imagery condition but not in the perceptual condition. Unfortunately, however, Morrow and his colleagues did not test LH damaged patients, and it is of course possible that they may have been even more impaired than the RH group. It is not possible, therefore, to draw any firm conclusions from these results.

Findings from group studies which have used drawing from memory to evaluate imaginal abilities have also proved to be somewhat equivocal. Gainotti, Silveri, Villa and Caltagirone (1983), for example, found that aphasic LH damaged patients were significantly more impaired in producing freehand drawings from memory than non-aphasic LH damaged patients, RH damaged patients and controls. On the other hand, Grossman (1988) reported that RH damaged patients produced freehand drawings that were less recognizable than those produced by LH damaged patients, both aphasic and non-aphasic, and controls. However, Grossman also observed that the only patient who consistently drew unrecognizable objects was an aphasic with LH damage, and he suggested that the impairment displayed by this patient could be construed as implying an image generation deficit. Once again, however, there were no perceptual control tasks, and therefore it is not possible to determine precisely what deficits underpinned performance in these groups.

A further attempt to specify the role of the cerebral hemispheres in visual image generation was made by Goldenberg (1989), who investigated the ability of patients with unilateral brain damage, patients with Parkinsons disease and normal controls to form visual images. The subjects' performance on verbal and visuo-spatial imagery tasks was compared with their performance on perceptual control tasks in the same modality, and the results provided no evidence to support the view that the capacity to form mental images varied as a function of lesion site. Furthermore, Goldenberg also used multidimensional scaling in order to assess the structure of correlations between test scores, and this failed to reveal any separation between imagery and non-imagery tasks. There was, however, a separation of the verbal tasks from the visuo-spatial tasks, and in addition visuo-spatial imagery tasks were separated from visuo-spatial perceptual tasks. On the basis of these findings, therefore, Goldenberg suggested that the separations pointed towards different underlying operations in verbal and visuo-spatial imagery tasks. Moreover, as these distinctions obtained irrespective of the site of the lesion, he suggested that this implied that neither hemisphere made an exclusive contribution to image generation.

The question of whether the qualitative nature of the information in images might determine the involvement of different processing components is an interesting one and will subsequently be discussed in greater detail. However, contrary to Goldenberg's suggestions, it is questionable whether this evidence can also be interpreted as supporting the view that neither hemisphere makes an exclusive contribution to image generation. This is because the subjects in the study who had localized brain damage showed great diversity of lesion site. Indeed of the seventyfour patients with focal damage only five, four LH patients and one RH patient, had damage in the occipito-temporal region. If this area is critical to the image generation process then it follows that the majority of data in the analysis came from patients in whom this region was intact, and this obviously limits any inferences that can be drawn from the findings. Nevertheless, it is perhaps worth noting that the four patients who had left occipito-temporal lesions appeared to be selectively impaired in their capacity to use imagery to enhance verbal memory. In contrast, the patient who had a right temporo-occipital lesion performed poorly on the visuo-spatial imagery tasks.

A further study comparing patients with RH and LH damage was carried out by Bowers, Blonder, Feinberg and Heilman (1991). This investigation was concerned with exploring the capacity of these patients to identify and image objects and facial expressions of emotions. The findings indicated that RH damaged patients were more impaired in the identification and imaging of facial expressions, whereas LH damaged patients performed more poorly on tasks requiring the identification and imaging of objects. Furthermore, Bowers and his colleagues observed that whereas the RH patients generally displayed parallel impairments on the imagery and perceptual facial expression tasks, there was one RH patient who was selectively impaired at imaging emotional expressions and another who was selectively impaired at identifying emotional expressions. This pattern suggested the possibility of a double dissociation and Bowers and his colleagues therefore claimed that this could perhaps imply a RH contribution to the generation of images of emotional expressions. However, as Trojano and Grossi (1994) observed, what is perhaps also worthy of note is that two patients with LH damage showed a global imagery deficit for both objects and emotional expressions, in the absence of any perceptual difficulties. Thus, while the evidence could perhaps be regarded as implying a relationship between right posterior lesions and emotion-related visual imagery deficits, it is questionable whether it is appropriate to link these deficits specifically to the image generation component.

One final group study which is of relevance to the issue of the laterality of image generation was carried out by Goldenberg and Artner (1991). They compared the performance of patients with left posterior lesions, patients with right posterior lesions and control subjects on the verification of high and low imagery sentences and the verification of pictorial representations of the predicates of the high-imagery sentences. The results indicated that patients with left posterior lesions performed poorly on the high imagery sentences. The size and reliability of this effect, however, was not particularly compelling and was in fact only evident when the high and low imagery sentences were analyzed separately. Moreover, while the LH patients performed relatively poorly on the imagery task, they performed even more poorly on the pictorial verification task. The performance of patients with right posterior lesions, on the other hand, did not differ significantly from that of the control subjects. Goldenberg and Artner, therefore, concluded that the most parsimonious explanation for this pattern of results was that the patients with left posterior lesions had impoverished knowledge about visual properties of objects. Their ability to convert visual knowledge into mental images, however, was said to be unimpaired.

There are, however, a number of points which need to be considered in relation to these conclusions. First, the pictorial perceptual control task used in this study required subjects to decide which of two visually presented figures was the more typical version of an item, and Trojano and Grossi suggest that this task may actually require the generation of visual images. Second, Tippett observes that as subjects were selected solely on the basis of lesion sites it is possible that none of the subjects had a severe deficit in visual image generation.

Thus, given these concerns, it again does not appear possible to draw definitive conclusions from these findings. Indeed, in contrast to the findings of single-case reports, the evidence arising from group studies of brain-damaged patients provides little unequivocal support either for or against Farah's claims regarding the LH's role in image generation.

1.5.2.3 Split-Brain Patients

As noted in Section 1.3.3, prior to the early 1980s there was relatively little systematic investigation of imaginal processing in commissurotomized patients. However, once Farah's initial review had been completed she attempted to obtain confirmation of her findings with split-brain patients. With her colleagues she carried out a divided visual field study with the split-brain patient JW (Farah, Gazzaniga, Holtzman and Kosslyn, 1985). The task used was one in which JW was presented with an uppercase version of a letter. He then had to decide whether or not the lowercase version of the letter was relatively small, as with the lowercase version of the letter "a", or relatively tall, as with the lowercase version of the letter "t". A perceptual analogue of the task in which the lowercase letter was presented directly was also incorporated into the design. The results indicated that JW's hemispheres performed equivalently on the perceptual task. On the imagery task, however, JW's RH was unable to make the decision and performed at chance level, whereas his LH had no difficulty carrying out the task.

A further more detailed study of JW was also carried out by Kosslyn, Holtzman, Farah and Gazzaniga (1985). The results of this investigation will be described in greater detail in Section 1.6.2, but suffice to say for now that the findings again appeared to imply that JW was unable to perform tasks that required him to generate detailed images of letters and animals in his RH. The evidence, therefore, appeared to support the view of an exclusive contribution of the LH to the generation of images.

However, further investigations with other commissurotomized patients have produced conflicting findings to those detailed above. Kosslyn, Holtzman, Gazzaniga and Farah (1985), for example, tested a second split-brain patient (VP) and found that while she displayed an initial deficit on the image generation letter classification task, she was subsequently able to perform the task when information was presented to her RH. Similarly, Corballis and Sergent (1988) tested the commissurotomized patient LB on the same task and found that both hemispheres performed significantly above chance, with the RH being faster but less accurate than the LH. Unfortunately no perceptual control tasks were incorporated into this design, but in a follow-up study with LB in which both perceptual and imagery tasks were used it was found that both hemispheres could perform at above chance level and with equal accuracy in the imagery condition (Sergent and Corballis, 1990).

These conflicting results serve to illustrate the well documented idiosyncrasies of commissurotomized patients. As noted in Section 1.1.2, split-brain patients differ considerably from one another in terms of their performance and their neurological status. Indeed in this respect, it is perhaps worth noting that it was subsequently found that VP had an incomplete section of her corpus callosum, with spared fibres in the rostrum and splenium. Factors such as this could account for the different patterns of performance observed in these patients. Nevertheless, notwithstanding the reasons for the variability, the discrepancies only serve to confirm the risks researchers run in generalizing from results of commissurotomized patients to the general population.

Furthermore, on a purely methodological note, caution in generalizing from these results to localization in normal subjects is also dictated by the fact that the statistical techniques used to analyze the data may have been inappropriate. In all of the above studies data were analyzed by analysis of variance. However, one of the fundamental assumptions of this technique is that the observations must be independent from one another, an assumption which is clearly likely to be violated when all of the data are provided by a single subject. Unfortunately recent research suggests that even a relatively minor violation of this assumption can produce a substantial effect on the level of significance. Scarino and Davenport (1987), for example, demonstrated that a small amount of dependence among the observations may cause the actual alpha to be considerably greater than the nominal alpha of .05. Consequently a number of statisticians have argued strongly against the use of this technique when dependence of observations is present (e.g. Stevens, 1992).

Thus, given all of the above considerations, it seems reasonable to exercise great caution in drawing any inferences from these results regarding the laterality of image generation in normal subjects.

1.5.2.4 Behavioural Studies with Normal Subjects

Unfortunately relatively few studies have examined the lateralized performance of normal subjects in image generation tasks. Farah (1986) asked subjects to use imagery as a prime in a task that required discriminating among various symbols. The imaged primes were more effective in the right visual field than the left visual field, and Farah interpreted this evidence as being consistent with the view that the LH is better able to generate images. However, as Sergent (1990) observed, the design of this study was actually inappropriate to test image generation per se as the subjects were presented at the beginning of each trial with the shape to be imaged. The representation of the mental image was, therefore, dependent on sensory stimulation rather than on activation of stored information in long term memory.

Nevertheless, Cohen (1975) obtained very similar results to Farah in an experiment in which normal subjects were required to form an image from long-term memory in preparation for making a normal/mirror reversal judgement about letters presented at different orientations. The results revealed a LH superiority in the use of images on those trials where mental rotation was not required. Cohen interpreted this finding in terms of hemispheric differences in the use of advance information, but Farah (1986) suggested that the finding may actually have reflected hemispheric differences in image generation ability. This claim could be correct, although it should be noted that a positive finding arising from a subset of trials in an experiment not specifically designed to investigate image generation cannot be regarded as providing strong evidence in support of the LH hypothesis.

Two further studies of relevance to the hemispheric locus of image generation were reported by Lempert (1987, 1989). In the first experiment in the 1987 study the effects of imaging, overtly rehearsing and silently rehearsing concrete sentences on unimanual hand-tapping rates were examined, and the results indicated that the imagery condition was associated with greater tapping decrement on the right side than on the left side. The effect, however, was only apparent in female subjects, but in a replication of this experiment the effect of imagery on right-sided tapping was found to be significant in both males and females (Lempert, 1989). Both of these experiments, however, employed a between-subjects design, and the evaluation of hemisphere asymmetry is of course better served by within-subject designs. Moreover, a repeated measures design was employed in the second experiment in the 1987 study to compare the effect of high and low imagery sentences on tapping rates, and in this case the interaction between hand and imagery failed to reach significance.

One final study designed to investigate the cerebral locus of image generation using normal subjects was reported by Sergent (1989). Subjects carried out a letter classification task with the decision being made either directly on a lowercase letter in one experiment (perceptual task) or on the generated image of a lowercase letter in the other experiment (imagery task). In addition the quality of the letters (clear or blurred) and the retinal eccentricity of stimulus presentation (small or large) were manipulated. The results revealed that whereas both hemispheres were equally efficient at performing the perceptual task with clear letters there was a significant advantage for the left visual field in the image generation condition, suggesting a superiority of the RH over the LH.

However, as Sergent herself observed, performance in divided visual field studies is extremely sensitive to a multitude of variables, and a slight modification of the procedure may yield a different pattern of results. Thus, despite the RH superiority in the imagery condition, Sergent concluded that the most appropriate inference to draw from these results was that both hemispheres were equipped with the processing structures necessary for image generation. This was perhaps not an unreasonable conclusion, given that the RH appears to be at an advantage with degraded stimuli and large eccentricities (Sergent and Hellige, 1986; Christman, 1987).

Nevertheless, notwithstanding Sergent's conclusions, the conflicting findings arising from this area of research appear to provide little compelling support for the LH hypothesis.

1.5.2.5 Psychophysiological Studies

Unfortunately psychophysiological studies also appear to have produced discrepant results. Mazziotta, Phelps, Carson and Kuhl (1982), for example, obtained information about regional cerebral metabolic activity associated with imagery in a study in which subjects had to judge two successive sequences of tones as "same" or "different". In a post-experiment interview subjects were questioned about the cognitive strategies they had used for retention of the tone sequence, and it was observed that all of the subjects who reported using a visual imagery strategy also displayed evidence of increased LH activity. The remaining subjects, on the other hand, showed greater RH than LH activation. However, it is important to note that the subjects who employed a visual imagery strategy actually displayed no increased activation in the temporo-occipital or occipital areas. Indeed the only significant asymmetry was located in auditory rather than visual areas of the cortex.

Some of the regional cerebral blood flow studies described in Section 1.3.3.1 have also been cited in the literature as being of relevance to this issue. The experiment carried out by Roland and Friberg (1985), for example, comparing metabolic activity during verbal rehearsal, mental arithmetic and imaging, revealed that the highest mean increases in blood flow occurred in posterior areas of the LH during the imagery condition. However, given the absence of an appropriate control task in this design, it is not possible to unequivocally attribute this increase to the image generation component.

The series of studies carried out by Goldenberg and his colleagues have also yielded inconclusive findings. Goldenberg, Podreka, Steiner and Willmes (1987), for example, reported an experiment in which subjects had to memorize concrete words. One group of subjects was instructed to use imagery and the other was not, and the results revealed a marked shift in LH activity during the imagery condition relative to the resting condition. However, there was no significant difference in overall hemisphere activation between the two conditions, nor was there any significant difference between regions of the posterior LH and posterior RH.

In a second experiment Goldenberg, Podreka, Steiner, Willmes, Suess and Deecke (1989) studied the blood flow correlates of verification of high and low imagery sentences. Once again there was no overall hemispheric asymmetry between the two conditions, but the LH did show higher inferior occipital activation in the imagery condition than the RH. However, this experiment employed a between-subjects design, and a second experiment using a repeated measures design in which subjects were required to count the number of corners of imaged letters (imagery condition) or to silently rehearse the alphabet (no-imagery condition) found no asymmetry in the activation of inferior occipital or indeed inferior temporal regions.

In a third study Goldenberg, Podreka, Uhl, Steiner, Wilmes and Deecke (1989) attempted to investigate the blood flow correlates of different types of visual images, i.e. low-information images (single colours filling visual field), high-information images (static achromatic images of faces) and spatial images (contours between two points on memorized map). Only one task produced evidence of lateralization, there being an association between the face task and higher left inferior occipital activation. However, Goldenberg and his colleagues also reported that there was an overall rightward shift of hemispheric activity from the rest condition to imagery.

Finally a fourth study compared the blood flow patterns which were elicited by the generation of either visual or acoustic images (Goldenberg, Podreka, Steiner, Franzen and Deecke, 1991). Unfortunately, contrary to instruction, twelve out of the fourteen subjects experienced visual images during the acoustic imagery condition. Increased activity in the left inferior occipital regions was found for both imagery conditions relative to the control condition, and as visual imagery had been experienced in both conditions Goldenberg and his colleagues concluded that this supported the claim that this area was important for modality specific components of visual mental imagery.

Similar findings to the above have also arisen from electrophysiological studies. For example, Farah, Weisberg, Monheit and Peronnet (1990) studied the responses of subjects who were instructed to generate mental images of the meaning of either visually or auditorially presented words. In the control condition subjects merely listened to words. The findings indicated that the generation of visual mental images in both the visual and auditory conditions was accompanied by greater electrophysiological activity over the LH than the RH. Furthermore, the effect was greatest over modality-specific visual cortex.

Nevertheless, notwithstanding the positive findings reported in the latter two cases, the variability in the results would appear to preclude drawing any firm inferences regarding the laterality of image generation. Furthermore, it is perhaps appropriate to note that the picture is further complicated by the fact that the designs of all the psychophysiological studies reported above are such that any observed asymmetries cannot be unequivocally attributed to the image generation component.

1.5.3 Summary

To summarize, it would appear that the evidence arising from single-case studies provides strong support for the claim that the LH has a direct role of some kind in the generation of visual images. However, as noted in Section 1.1.2, there are certain limitations associated with drawing inferences regarding hemispheric function from observations of brain-damaged patients, and in order to draw definitive conclusions it is therefore necessary to look for converging evidence from other sources. Unfortunately, as is apparent from the above brief review, the findings arising from the alternative sources of evidence are at best equivocal.

It is clear, however, that methodological difficulties beset much of the evidence arising from group studies of brain-damaged patients and normal subjects. The investigation of image generation is a complex process, and its isolation for experimental purposes requires an exhaustive and systematic examination of the various operations that underlie an image generation task. The computational approach to the experimental investigation of this process would allow such an isolation, but the power of this approach has not yet been used to its full potential. Indeed the experiments which have produced equivocal evidence are to a large extent those whose designs prevented attribution of the observed asymmetry/deficit to the image generation component.

Thus, while the absence of converging evidence from other sources is a matter for concern, it would appear inappropriate to disregard the positive findings arising from single-case reports given that much of the conflicting evidence arises from methodologically inadequate studies. Nevertheless, in this respect it should perhaps be acknowledged that there are a number of researchers who consider single-case reports an inappropriate paradigm for investigating the cerebral locus of a given process.

Sergent (1990), for example, argues strongly against the use of single-case studies in investigations of the cerebral localization of cognitive processes. This is because in such an approach the anatomical locus of damage is initially relatively unimportant as subject selection is determined by the nature of the impairment rather than by the site of the lesion (see Caramazza, 1986; Caramazza and Badecker, 1989). This, Sergent feels, is inappropriate. Rather group studies in which patients with damage invading the specific locus under consideration are compared with patients suffering from lesions in other cerebral areas are deemed to be the most suitable approach. Thus, if Sergent is correct, it could be argued that it would be inappropriate to give any weight to the positive findings arising from single-case reports.

Without wishing to enter into the general debate of single cases versus group studies, it does seem reasonable to question some of the above assertions. First, merely because subjects are selected on the basis of impairment does not seem in any way to prevent investigators from attempting to establish the anatomical correlates of the deficits by examining consecutive cases. Second, grouping together subjects with damage invading the specific locus under consideration is only feasible if sufficient information exists to precisely specify where the cerebral locus is. Unfortunately phrases such as "posterior areas of the LH" would appear to be too broad to facilitate identification of precise neuroanatomical correlates. Finally, group studies represent a probabilistic approach, and given the rarity of patients displaying a selective loss of imagery it is questionable whether this type of approach is suitable for this area of research. Indeed the group studies reviewed previously could be interpreted as demonstrating nothing more than the relative infrequency of such deficits. Consequently, it would appear inappropriate to regard this criticism as casting serious doubt on the deterministic inferences drawn from single-case reports.

Thus, although the lack of converging evidence is obviously a matter of concern, the prevailing consensus among researchers in this area appears to be that the evidence from single-case reports is sufficiently strong to support the view that the LH has a direct role of some kind in the generation of visual mental images.

1.6 THEORETICAL CONSIDERATIONS

1.6.1 Introduction

The above conclusions demonstrate that during the last decade there has been a significant shift in beliefs regarding the involvement of the LH in imagery processes. Nevertheless, despite this consensus, there is still debate amongst researchers regarding the precise nature of the LH's contribution. For example, contrary to earlier claims, it is no longer the case that the sole view is that image generation is the exclusive domain of the LH. Indeed a number of prominent investigators have claimed that both hemispheres can generate visual images, but that they do so in different ways. These differing interpretations of the data have been primarily determined by the different theoretical perspectives adopted by these investigators. It is necessary, therefore, to briefly consider some of the major theoretical models of hemispheric specialization for imaginal processes which have been formulated in concert with the reporting of the above data.

1.6.2 Kosslyn's Model

Kosslyn (e.g. Kosslyn, 1987; 1988; Kosslyn, Flynn, Amsterdam, and Wang, 1990) in a series of reviews and articles has developed a far-reaching theory of lateralization based on neuroanatomical, neurophysiological and computational considerations regarding the functional organization of high level vision. His starting point was consideration of the way that information about the appearance of objects might be represented in long-term visual memory, and how such representations might function during recognition.

Numerous theories of object recognition have been put forward over the years, but all of the various perspectives have been in agreement that in order to recognize an object there must be some form of match between the object and a stored representation. Some objects, however, are subject to a near infinite number of transformations, and it seems unlikely that separate representations can be stored for all the possible configurations that mutable objects can adopt. It has been suggested, therefore, that there must be some form of stored representation that can match up with such objects across a wide range of transformations. Accordingly, a number of theorists have proposed that recognition is achieved by decomposing the object to be recognized into simpler parts (Marr, 1982; Biederman, 1987). These parts are then said to be matched up with a stored description in the brain detailing the component parts and the spatial relations among the parts, and it is the nature of these spatial relations which forms the crux of Kosslyn's theory.

According to this theoretical formulation the brain is capable of computing two different types of representation. Categorical representations make use of abstract, generalized spatial relations which are said to capture what is stable across instances that may differ in terms of metric units. Thus, for example, the categorical spatial relation "connected to" could be used to describe the relationship between the human arm and shoulder since this remains constant under all of the different positions the arm can adopt. These spatial relations, therefore, would facilitate recognition of mutable objects. However, Kosslyn also observed that there are some objects that would not be usefully represented for recognition using these types of representations. Some objects, such as the human face for example, do not vary much from instance to instance, and generalized spatial relations such as "next to" or "above" would not facilitate recognition of particular exemplars of such objects. It is suggested, therefore, that there is a second type of representation which makes use of coordinate spatial relations which specify the precise locations of objects or parts in space in terms of metric units. Such representations are said to be important when recognition is contingent on precise spatial relations, and they are also thought to facilitate navigation when it is necessary to know precisely where an obstacle is located.

As regards lateralization, Kosslyn argues that the LH makes more effective use of categorical representations, whereas the RH makes more effective use of coordinate representations. These predictions are based on a number of assumptions about different innate predispositions of the left and right hemispheres for the control of speech output and search control respectively, and a "snowball" mechanism that biases the lateralization of specific processing subsystems to one side or the other. Specifically, it is claimed that categorical representations will be more easily labelled and interpreted by a system specialized for language. The innate predisposition of the LH, therefore, means that subsystems in this hemisphere that produce or use categorical representations will receive more effective feedback than subsystems in the RH because of the absence of transhemispheric degradation. Consequently, these subsystems will also become stronger and more effective in the LH. Similarly, these initially lateralized subsystems then serve as second-order "seeds" by providing more effective feedback to subsystems on the same side that send them input, and the effect is compounded. Precisely the same procedure is purported to occur in the RH, but here the innate predisposition for unilateral control of systematic visual search patterns over space is said to lead to more effective feedback for subsystems making use of coordinate representations.

These theoretical claims enabled Kosslyn to make predictions about the lateralization of specific components of the imagery system. For example, image generation that required access to coordinate representations should be more effective in the RH, whereas image generation that required access to categorical representations should be more effective in the LH. Similarly, image scanning should only require the use of coordinate representations and would be expected therefore to be lateralized to the RH. On the other hand, mental rotation of complex forms is claimed to require both categorical and coordinate information, which in consequence suggests bilateral involvement. It should perhaps also be noted that Kosslyn claims that relatively low-resolution patterns of overall shape can be encoded as a single perceptual unit. As the two hemispheres are deemed to be equivalent in this respect it is also possible to predict that no difference should be found between the hemispheres on image generation tasks which do not require the construction of multipart images, e.g. imaging the overall shape of an object.

There are in fact numerous other hypotheses which can be generated, but the above examples perhaps serve to illustrate the innovative and comprehensive nature of the theory. Nevertheless, it must be acknowledged that the theoretical formulations incorporate numerous assumptions, and it is obviously necessary, therefore, to consider whether or not any of the predictions generated by the theory have received empirical support.

The first data of relevance to this issue were reported in an article by Kosslyn and his colleagues detailing a series of experiments carried out with the split-brain patient JW (Kosslyn, Holtzman, Gazzaniga and Farah, 1985). As noted in the previous section, it was established that JW was unable to generate detailed images in his RH. However, it was also discovered that both of JW's hemispheres could perform tasks requiring the imaging of the outline of objects. Kosslyn (1987) subsequently interpreted these results as indicating that JW's LH had a specialized role in the generation of categorical representations, whereas both hemispheres were equivalent in terms of generating "skeletal" images representing overall shape. Unfortunately, as detailed previously, the doubts relating to the validity of such evidence prevent any inferences being drawn from these findings.

However, Kosslyn has also identified some studies of brain-damaged patients in the literature which he claims provide evidence in support of the purported lateralization of categorical and coordinate relations. Unfortunately, some of these cases are not entirely compelling as the evidence fails to address the basic premise regarding asymmetries in spatial relations (Farah, 1984; Levine, Warach and Farah, 1985; Farah, Levine and Calvanio, 1988). Nevertheless, there are some positive findings. Deleval, De Mol and Noterman (1983), for example, reported the case of a patient with LH damage who was able to generate images of parts of objects but not their respective places. Furthermore, the previously described case study reported by Grossi, Orsini, Modafferi and Liotti (1986) of a patient with a left temporo-occipital lesion who produced pictures with elements in the wrong relation to each other also appears to be consistent with Kosslyn's claims.

Studies with normal subjects have also provided some positive findings. Kosslyn

(1988), for example, reported evidence consistent with the view that the LH is specialized for generating images from categorically stored information, whereas both hemispheres are equally adept at generating images from information which has been globally stored. Nevertheless, it should perhaps be noted that this evidence was presented without detailed report of the procedures and analyses necessary for rigorous evaluation. More recently, however, similar findings have also been reported by Findlay, Ashton and McFarland (1994) in a study designed to assess hemispheric differences in image generation from categorical and global information input via the haptic modality.

Finally, a number of studies have addressed the issue of asymmetries in spatial relations at a perceptual level. Kosslyn, Koenig, Barrett, Cave, Tang and Gabrieli (1989), for example, carried out a series of divided visual field studies with normal subjects in which they were required to make categorical judgements (e.g. was a dot above or below a line) and metric distance judgements (e.g. was a dot within or beyond 3 mm from a line). The authors reported that the results indicated that subjects responded significantly faster on categorical judgements when they were presented in the right visual field, whereas they responded more quickly on coordinate judgements when they were presented in the left visual field. However, it should perhaps be noted that in three out of the four experiments only the RH advantages in the metric distance tasks were significant. Moreover, this pattern of results has been replicated in a number of other studies (Hellige and Michimata, 1989; Koenig, Reiss and Kosslyn, 1990; Sergent, 1991; Rybash and Hoyer, 1992; Cowin and Hellige, 1994). Thus, while overall the evidence would appear to support the claim that the RH is specialized for coordinate representations, the situation with regard to a LH specialization for categorical representations is somewhat equivocal.

Kosslyn, Chabris, Marsolek and Koenig (1992) have responded to these concerns by arguing that while a LH advantage for categorical relations is seldom significant in a single experiment, there is a trend towards such an advantage. Indeed the authors calculated that the probability of such a trend occurring by chance across seven of the experiments reported in four of the studies was .06 (Hellige and Michimata, 1989; Kosslyn, Koenig, Barrett, Cave, Tang and Gabrieli, 1989, Exp. 1, 2, 3, 4; Koenig, Reiss and Kosslyn, 1990; Sergent, 1991, Exp. 4).

It is of course possible that Kosslyn and his colleagues are correct and the effect is sufficiently small to only be detectable over a number of studies. Nevertheless, caution perhaps dictates that too much weight should not be placed on an explanation that proves to be only marginally significant over seven experiments. However, notwithstanding the quality of evidence in support of Kosslyn's ideas regarding LH specialization for categorical relations, it is undoubtedly the case that his work has stimulated a great deal of ongoing research. Moreover, his stance has led other investigators to consider the possibility of the two hemispheres being differentially specialized for the generation of images.

1.6.3 Paivio's Model

Paivio (1986, 1989), for example, has given consideration to the respective contribution of the two hemispheres to image generation within the context of dual coding theory. According to this formulation there are three distinct ways in which the representational units termed imagens can be activated. First, representational processing is said to occur during recognition when there is relatively direct activation of the imagen via a matching process between this stored information and a familiar external stimulus. Second, activation can occur via referential processing which is when there is cross-system activation between verbal and nonverbal representations, as for example when an image is generated in response to a word. Finally, associative processing refers to activation via units within each system. Thus, for example, the environmental nonverbal sound of an engine could, via the process of spreading activation, trigger the generation of an image of a car within the nonverbal system.

According to Paivio the representational units and processes necessary for recognition of visual objects are equally available in both hemispheres. The LH, however, is said to dominate on tasks which require referential processing, whereas the RH is thought to perhaps predominate on tasks involving associative processing. Consequently, Paivio claims that asymmetries found during visual imagery will relate to the verbal and/or nonverbal aspects of the task. Unfortunately the evidence presented in support of this view is not entirely compelling (e.g. Paivio and Ernest, 1971; Luria, 1973; Curry, 1976). Nevertheless, the influence of this perspective is still apparent in contemporary research. Goldenberg (e.g. 1989), for example, who has been primarily influenced by the conceptual framework provided by dual coding theory, has suggested that a distinction should be drawn between verbal imagery tasks and visuospatial imagery tasks.

It must be acknowledged, however, that this theoretical perspective does not have widespread acceptance in the area of laterality research. One point of concern relates to the fact that dichotomous dimensions formulated in terms of task demands have proved to be singularly unsuccessful in the past. A second point of concern relates to the standard research paradigm of dual coding theory in which the concreteness of words is varied. Within this conceptual framework such a manipulation is, of course, regarded as valid since referential processing is thought to facilitate the generation of images in response to high imagery words. It is, however, possible to question whether the results of such studies are actually indicative of asymmetries in imaginal processing. As noted in Section 1.2.2, for example, concrete and abstract words do not only differ in image evoking potential, and it is not possible, therefore, to demonstrate unequivocally that differential hemispheric performance in such tasks is due to imagery. The differential asymmetry for high and low imagery words, for instance, could simply reflect the greater lexical complexity of some abstract words, or alternatively the differential availability of lexical representations in the two hemispheres. Thus, notwithstanding the work of Goldenberg and his colleagues, this theoretical perspective has had relatively little impact.

1.6.4 Corballis's Model

Finally, an alternative approach has been put forward by Corballis (1989, 1991). This theoretical formulation represents an attempt to develop a model of human laterality within an evolutionary context, and, as such, it primarily focuses on the marked human population bias in favour of right handedness and left cerebral representation of language. The evolutionary link between these two has long been a matter of speculation, but a number of authors have suggested that the early manufacture and use of tools may have favoured the subsequent evolution of a hand skilled at sequential manipulations. The LH, therefore, is said to have established cerebral mechanisms specialized for fine motor control, and these adaptations are thought to have subsequently provided a platform for the mediation of speech (e.g. MacNeilage, Studdert-Kennedy and Lindblom, 1987).

Furthermore, according to Corballis these adaptations also provided a basis for the subsequent emergence of a distinctively human mode of cognition which he terms "generativity". Specifically, these early adaptations are said to subserve the ability to internally manipulate or generate sequentially organized actions. LH activity, therefore, is thought to be characterized by the ability to combine elements in accordance with a set of rules in order to generate novel assemblages. Moreover, the characteristic of generativity is said to underlie not only skilled manual actions and language, but also aspects of visual perception.

As regards the latter, Corballis adopts a similar stance to Kosslyn in that he takes into consideration the theories of Marr (1982) and Biederman (1987) and argues for two distinct forms of representation: one that facilitates recognition of mutable objects and one that represents objects whose recognition is contingent on precise spatial relations. According to Corballis, however, the solution to the former is a mode of representation based on partwise analysis and storage, whereas the solution to the latter is a holistic, template-based mode of recognition. Specifically, it is claimed that early in our evolutionary history visual perception was subserved by an analogue mode of representation which preserved the precise metric properties of objects. This mode of representation was initially represented bilaterally, but the subsequent evolution of the generative mode in the LH usurped some of the neural space that would otherwise be dedicated to analogue representation, thus creating a RH bias. Conversely, the LH characteristic of generativity facilitated the evolution of a mode of visual perception based on the segmentation of objects into simple geometric components. According to Corballis, stored representations of these primitive components can be assembled to form an infinite array of objects. Thus, given this analysis, it also follows that the LH will be specialized for the generation of multipart images, whereas the RH will be specialized for the generation of holistic images.

Corballis's theory is noteworthy in that it attempts to integrate information from several domains. Nevertheless, it must be acknowledged that the evidence presented in support of these claims is not particularly compelling. For example, in support of the theory Corballis cited a review of patterns of agnosia in brain-damaged individuals which was reported in the literature by Farah (1991). In this review Farah claimed that the failure to recognize objects which occurs in conjunction with alexia was due to the disruption of partwise representations of shape. Moreover, she argued that these cases resulted predominantly from LH damage. In contrast, the failure to recognize objects which occurs in conjunction with prosopagnosia was associated with RH damage and was due to the disruption of holistic or unified picture representations. It should perhaps be noted, however, that while this evidence is consistent with Corballis's hypothesis Farah did note in this article that there were a number of alternative explanations for this pattern of data. Furthermore, the data do not address the issue of whether or not the two cerebral hemispheres generate images in different ways.

Corballis also cites evidence from some divided visual field studies with split-brain patients (e.g. Corballis and Sergent, 1988; Sergent and Corballis, 1990). The difficulties with such evidence, however, have been well documented previously. Finally, Corballis observed that Kirk and Kertesz (1989) reported characteristic deficits in drawing from memory following unilateral injury. Patients with LH damage tended to oversimplify drawings by leaving out details, whereas patients with RH damage produced drawings that contained details but lacked spatial organization. According to Corballis this supports his theory about hemispheric specialization of image generation. However, no control task was included in this study and previous research suggests that the effect also occurs when subjects copy drawings (Gainotti and Tiacci, 1970).

Thus, although the above evidence could be construed as being consistent with Corballis's claims regarding two different modes of representation, it does not permit any inferences to be drawn about differential hemispheric involvement in image generation.

1.6.5 New Dichotomies for Old?

The above brief summary serves to highlight the different theoretical approaches and methodologies adopted by the major contributors to this field. Furthermore, it also illustrates the degree of overlap in their respective positions in that, while they disagree about the nature of specialization of image generation in the two hemispheres, they all view imagery as a multicomponent process and the LH as having a role of some kind in the generation of images. What is perhaps most striking, however, is that all of the theorists have attempted to integrate the various findings into models which propose an all encompassing dichotomy that purportedly characterizes all manifestations of hemispheric specialization.

Given the comments in the very first section of this chapter regarding the doubts relating to the validity of such global dichotomies, however, it seems reasonable to question whether replacing old dichotomies with new ones is necessarily a fruitful exercise. In Section 1.1, for example, it was observed that many investigators feel that any attempt to subsume all the essential aspects of hemispheric functioning under some perfect dichotomy is a futile activity. Moreover, evidence was presented which appeared to suggest that it was unlikely on empirical grounds that there was a single processing dimension which could account for all hemispheric asymmetries.

Perhaps a more pertinent question to ask, therefore, is why it is that we should expect hemispheric differences to be reducible to one single principle? One possible justification which has been advanced is the desirability of parsimonious theoretical constructs within which all of the various findings can be incorporated. However, in isolation mere conceptual tidiness is not sufficient reason to impose a global dichotomy, since such considerations must always ultimately defer to the need for explanatory adequacy.

A stronger justification in support of the need to seek some unifying principle is perhaps provided by the argument that it makes evolutionary sense to do so. According to this view evolutionary considerations suggest that there was a fundamental, antecedent mode of specialization which favoured evolution away from symmetrical organization and provided a platform for the subsequent evolution of other asymmetries. This is, of course, the argument advanced by Corballis. Moreover, Kosslyn's model also ultimately rests on the assumption that there is a fundamental innate duality underlying hemispheric specialization.

Without wishing to enter into the general debate regarding the biological origins of hemispheric dissociation, it must be acknowledged that the concept of a fundamental, antecedent mode appears quite plausible and is in fact supported by a number of prominent investigators. What is perhaps more important, however, is that it is a moot point whether this fundamental mode would still be manifest today. As Bertelson (1981) observed, any new capacity which appears under a particular environmental pressure can then produce other effects which in turn can guide further evolution. Moreover, organs can change functions and also serve many at the same time. In other words, irrespective of whether or not there was some fundamental mode of specialization which acted as a precursor for all subsequent dissociations, the nature of hemispheric specialization today may be multifactorial. There seems to be no compelling reason, therefore, to assume that there must be some unifying principle underlying all manifestations of laterality.

Of course, if the empirical evidence strongly supported the theoretical claims made in the previous sections then many of the above comments would be redundant. However, it is clear that the evidence in support of Corballis's and Paivio's models is weak. Moreover, while the findings relating to Kosslyn's model appear to be more substantive, it is important to emphasize that even here there are problems. Kosslyn (1987) developed his theory to account for the evidence in the literature relating to the LH's role in image generation. Consequently, many of its explanatory successes are a posteriori. To justify itself, however, the proposed dichotomy should not only help to explain existing asymmetries, but also predict those as yet undiscovered. Unfortunately, the empirical consequences have proved hard to specify a priori, as evidenced by the somewhat ambiguous findings arising from the series of studies designed to investigate perceptual asymmetries in categorical and coordinate relations.

Nevertheless, notwithstanding the unsatisfactory nature of Kosslyn's model of hemispheric specialization, it should perhaps be emphasized that these criticisms do not in any way detract from the validity of adopting a computational perspective. Many of the problems discussed above appear to derive primarily from the fact that these theoretical formulations have taken the hemisphere rather than smaller neural processing entities as the basic unit of analysis. Moreover, irrespective of theoretical considerations, it is still the case that a hemispheric advantage was shown for a specific processing subsystem that had been proposed independently of data on hemispheric asymmetry.

It is, however, also worth noting in this respect that all of the evidence discussed thus far relates to a single processing component within the imagery system. Thus, it seems somewhat premature to attempt to derive general principles that purportedly apply to all other imaginal processing components. Indeed it seems reasonable to argue that a more appropriate way to proceed is to explore the lateralization of other components within the system. For example, are other components of imagery performance lateralized to the LH? Alternatively are some components lateralized to the RH or perhaps bilaterally represented? Only by attempting to answer questions such as these will it be possible to make general statements regarding the neural distribution of the imagery system.

As an initial step towards achieving the above goal, therefore, it was decided to carry out a series of studies investigating the possible lateralization of an additional component within the imagery system. Given the multifactorial nature of imagery performance there were obviously a number of possible candidates. However, one component, image scanning, had already been the subject of some preliminary investigations. It was decided, therefore, to explore the lateralization of this particular component in greater detail.

CHAPTER TWO

2. EXPERIMENT ONE

2.1 Introduction

In Section 1.2.3.2 it was noted that one aspect of imagery performance which has been extensively researched is that of image scanning, and it now appears to be firmly established that subjects are able to mentally scan from one location to another of an internally maintained image in much the same way as they would scan an external stimulus. The vast majority of this research, however, was carried out within the theoretical confines of the information processing approach, and, as such, little consideration was given to the neurological "hardware" underpinning this phenomena. There is one study to date, however, which has attempted to investigate image scanning in relation to hemisphere function.

French and Brightwell (1989), using a modification of a technique employed by Finke and Pinker (1982), produced evidence suggesting a LH superiority for image scanning. Simple dot patterns were presented tachistoscopically for five seconds in free vision, followed by a three second fixation field. Subsequently an arrow was presented briefly at an unpredictable location in either the RVF or the LVF and subjects were required to indicate via a manual response whether or not the arrow pointed to a location previously occupied by a dot. As predicted, reaction times were found to be directly proportional to the distance between dot and arrow. Of more interest, however, was the finding that RVF presentation led to superior performance of the task, significantly so at longer dot-arrow separations, suggesting a LH superiority for image scanning.

One possible confound, however, was that the task employed by French and Brightwell involved not only image scanning but also image maintenance and the extraction of spatial information from the image. It was not clear, therefore, which of these components was responsible for the LH advantage. In a follow-up study, however, French and Painter (1991) investigated whether or not these other aspects of imagery performance could have been responsible for the LH advantage found in the French and Brightwell study by modifying the task further in order to remove the scanning component. Once again simple dot patterns were presented for five seconds in free vision, followed by a three second fixation field. However, a circle stimulus was then briefly presented at an unpredictable location in either the RVF or LVF, and subjects were required to indicate whether or not the circle surrounded a location previously occupied by a dot. A perceptual analogue of this task, in which each dot pattern remained on the screen throughout the trial, was also incorporated into the design.

Although no performance asymmetry was found on the perceptual task, subjects responded faster on the imagery task when the stimulus circle was presented in the

LVF than when it was presented in the RVF. As the hemispheres performed equivalently on the perceptual task but demonstrated a visual field advantage on the imagery task, the asymmetry could not be attributed to the lateralization of cognitive processing components which were involved in both tasks. Therefore, the results suggested a RH superiority for either image maintenance or the extraction of spatial information from images, and provided support for the claim that the LH superiority found by French and Brightwell (1989) was due to the image scanning component.

Unfortunately, however, the French and Painter study did not by itself allow inferences to be drawn regarding which of the components, image maintenance or the extraction of spatial information from images, was lateralized to the RH. Indeed the findings appeared to be consistent with at least three alternative explanations. First, the RH might simply be better at maintaining the visual image in terms of clarity and stability. Second, the RH might simply be more adept at extracting information of any kind from a degraded image. Finally, both hemispheres may be equally proficient at image maintenance but the RH may be better able to extract specific types of spatial information from an image.

Unfortunately it was not possible to distinguish between these alternative accounts on the basis of past research. The first two interpretations, for example, are consistent with a great deal of evidence indicating more effective use of lower quality information by the RH than by the LH (e.g. Sergent and Hellige, 1986). On the other hand, the alternative view, that the LVF advantage reflected a RH superiority for a spatial processing component specific to the imagery system, accords well with the established role of the RH in spatial processing (De Renzi, 1982).

The primary aim of the current study, therefore, was to investigate whether or not the quality of the representation on which the evaluations were performed could have been responsible for the RH advantage found in the French and Painter (1991) study. Precisely the same imagery task as employed by French and Painter was used in this study, but the quality of the image was manipulated by varying the delay between pattern offset and presentation of the circle stimulus. In the short-delay condition the circle stimulus was presented one second after pattern offset, whereas in the long-delay condition the circle stimulus was presented six seconds after pattern offset. The image begins to fade as soon as it is encoded into the visual buffer (Kosslyn, 1980), and, therefore, the longer the time the image is maintained the lower its degree of resolution. Thus, if the RH advantage found by French and Painter was simply due to the quality of the maintained image then one would expect hemisphere competence to vary as a function of image maintenance duration. It was predicted, therefore, that the long-delay condition would have a more detrimental effect on LH performance than RH performance.

2.2 Method

2.2.1 Subjects

Forty subjects, thirteen males and twenty-seven females, participated in the experiment. They were all undergraduates aged between twenty and fifty years of age (mean age 28.9 years, SD 9.17), and all were right-handed by self-report with normal or corrected to normal vision. Data from an additional nine subjects were not analyzed as described below.

2.2.2 Apparatus

Stimuli were generated by an IBM XT286 microcomputer and presented on a 24.5 cm x 17.5 cm visual display screen. Subjects viewed the display from a chin rest positioned 75 cm in front of the screen. The visual angle subtended at the eye by the viewing area at this distance was 18.7° horizontally and 13.4° vertically. Subjects responded to stimuli via two buttons of a mouse and a warning tone was emitted when an incorrect response was made. The computer was programmed to treat as errors any trials on which the reaction time exceeded three seconds. Exposure duration, recording of reaction times and response type, randomization of the trials and counterbalancing of the order of presentation of the conditions were all controlled by the computer.

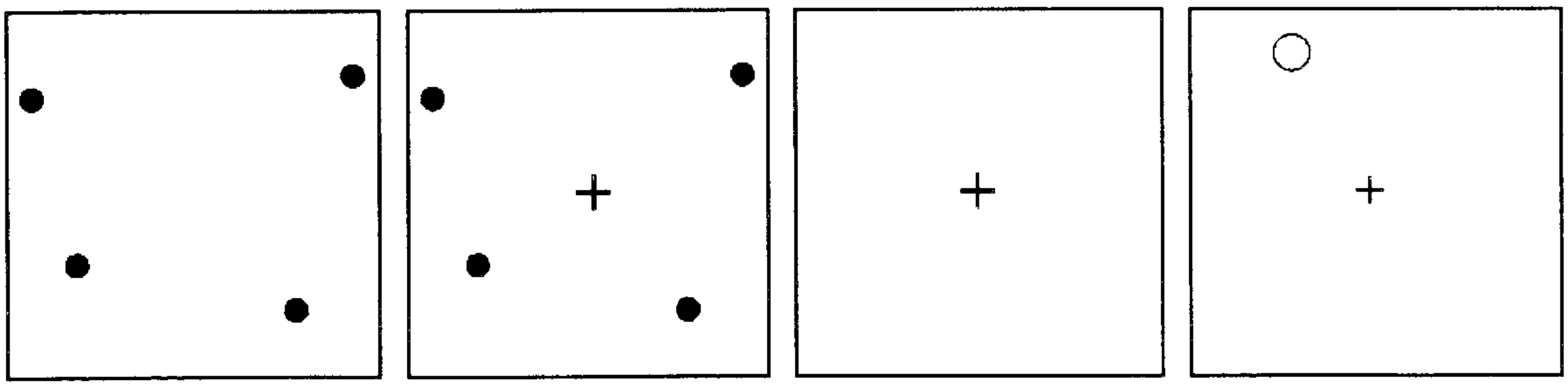
2.2.3 Stimuli

The computer generated different dot patterns for each subject within the constraints outlined below. The patterns consisted of four black dots, 3 mm in diameter, on a white background. Each dot subtended a visual angle of 0.23°. Dot locations were restricted to an area between 3 cm and 8.25 cm from the centre of the screen.

Furthermore, dots never appeared within 2 cm of the vertical midline or within 2 cm of the horizontal midline of the field. Within these constraints, one dot was located in each quadrant of the screen in a randomly determined position.

On each trial the dot patterns were presented in free vision for five seconds. A fixation point, which consisted of a black cross at the centre of the screen, was presented one second before pattern offset. In the short-delay condition the fixation point was presented for an additional one second after pattern offset, whereas in the long-delay condition it was presented for an additional six seconds after pattern offset. A black circle stimulus 12 mm in diameter, subtending a visual angle at the eye of approximately 0.9°, was subsequently presented in the right or left visual field. The width of the outline comprising the circle stimulus was approximately 1 mm. (A graphical illustration of the sequence of stimulus presentation is presented in Figure 2.2.3.1).

Figure 2.2.3.1. Illustration of the sequence of stimulus presentation on each trial. (N.B. not drawn to scale).



Each dot pattern was presented on sixteen trials, eight in the short-delay condition and eight in the long-delay condition. Within these eight trials the circle was presented twice in each quadrant, once surrounding a location previously occupied by a dot and once clearly not doing so. In these latter trials the circle was always presented at least 4 cm away from the dot location in the quadrant. This distance corresponds to a visual angle of 3°. The program was so written that every dot pattern/circle combination presented had a mirror-image equivalent which was also presented. This ensured that any hemifield differences obtained could not simply be a reflection of unintentional biases in favour of one or other visual field. The order of presentation of the trials was randomized within each condition.

2.2.4 Procedure

Subjects were run individually. Prior to the commencement of each condition subjects read the instructions for the task which were presented on the display screen. Throughout the experiment subjects sat viewing the display screen from a chin rest positioned directly in front of the screen, with their response hand resting on two buttons of a mouse and their non-response hand resting on the space bar of the keyboard. Half of the subjects responded with their left hand and half with their right hand. Furthermore, within each response hand half of the subjects used their index finger for a positive response and their middle finger for a negative response, with this pattern being reversed for the other half of the subjects. Subjects initiated trials by pressing the space-bar with their non-response hand, and a warning tone was emitted when an incorrect response was made in order that subjects could monitor their performance. The order of presentation of the two conditions was counterbalanced, and after completion of the first condition subjects were allowed to take a short rest if they so wished. The sessions lasted approximately forty minutes.

Subjects were instructed that they were to try to remember the position of each dot by forming an image of the pattern exactly as it appeared on the screen. The pattern was presented for five seconds in free vision. After four seconds of the presentation period had elapsed a black cross was presented at the centre of the field, and this was the cue for subjects to fixate centrally by staring directly at the centre of the black cross. The dot pattern then disappeared from the screen. In the short-delay condition the fixation cross was presented for an additional one second, whereas in the long delay condition it was presented for an additional six seconds.

At the end of this period a circle stimulus was presented for 167 ms in either the right or left visual field. The circle either surrounded a location previously occupied by a dot or else clearly did not. Subjects were instructed to press the YES button if the circle was surrounding a location that was previously occupied by a dot, or the NO button if it was not. It was stressed in the instructions to the subjects that on those trials where the circle was not surrounding a location previously occupied by a dot this would be quite clear, as on such trials the circle would always appear well away from any dot location in the pattern. (See Appendix I for verbatim instructions to subjects).

Thirty-two practice trials were given prior to the commencement of each condition.

The dot patterns used in the practice trials were not used in the experimental trials of which there were eighty in each condition. The same trials were used in the short-delay and long-delay conditions, the only difference being the timing of the onset of the circle stimulus. The trials, however, were presented in different random orders in each condition.

For both conditions the subjects were instructed to respond as quickly and as accurately as possible. Furthermore, the importance of maintaining central fixation was emphasized not only in the initial instructions but throughout the trials themselves. At the end of the experiment subjects were debriefed and questioned concerning the strategies that they had employed. One subject who reported using an image generation strategy was excluded from the final analysis, as were eight subjects who responded correctly to less than 70% of the trials. All of these excluded subjects were replaced in order to ensure that complete counterbalancing, with respect to order of presentation of the conditions, response hand and fingers, was maintained.

2.3 Results

Mean reaction times for correct responses and mean number of errors for each subject comprised the data upon which the statistical analyses reported below were performed. Trials on which reaction times exceeded three seconds were treated as errors. These data, averaged across subjects, are presented in Table 2.3.1 with standard deviations.

Table 2.3.1. Mean RTs (ms) and mean number of errors with standard deviations, as a function of type of response for each visual field for the short-delay and long-delay conditions.

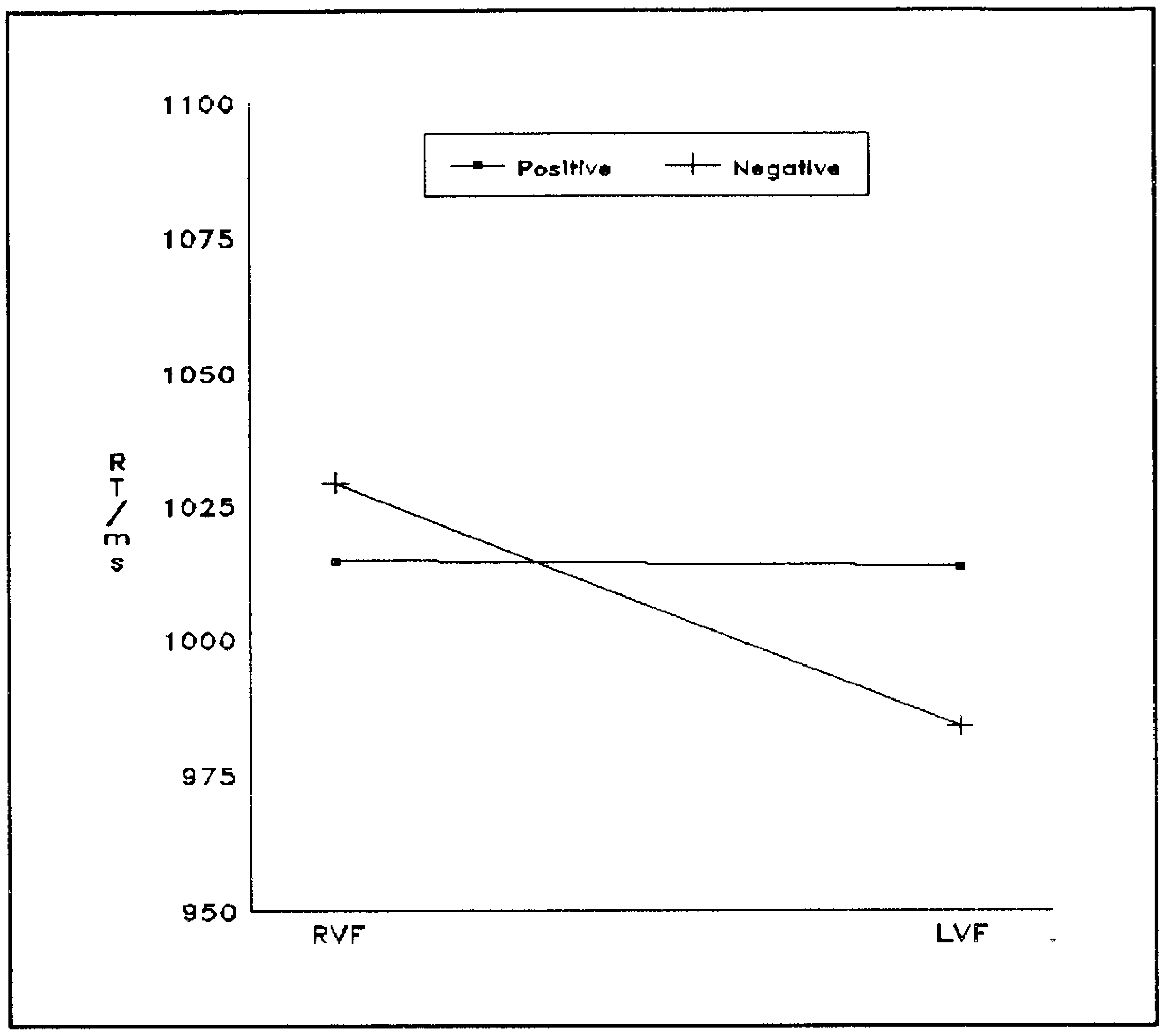
SHORT-DELAY	RVF		LVF	
	YES	NO	YES	NO
Mean RTs	926	968	925	918
SD	186	220	196	186
Mean Errors	1.65	1.45	1.65	1.02
SD	1.58	1.48	1.76	1.19
LONG-DELAY	RVF		LVF	
	YES	NO	YES	NO
Mean RTs	1103	1090	1101	1049
SD	277	249	322	249
Mean Errors	2.65	2.70	2.35	2.02
SD	1.80	1.73	2.17	1.72

Reaction Times

Initially data were analyzed using a three-way repeated measures ANOVA, with delay (long vs. short), visual field of circle presentation (RVF vs. LVF) and type of trial (positive vs. negative) as factors. A significant main effect was found for the short-delay and long-delay conditions, $F(1,39) = 33.35$, $p < .001$, with subjects producing significantly longer RTs in the long-delay condition (mean RT 1085 ms) than in the short-delay condition (mean RT 934 ms). A significant main effect was also found for visual field, $F(1,39) = 4.23$, $p < .05$, with subjects producing significantly slower RTs when the circle stimulus was presented in the RVF (mean RT 1021 ms) than when it was presented in the LVF (mean RT 998 ms).

This main effect, however, was modified by a significant interaction which was obtained between visual field and type of trial, F(1,39) = 5.18, p < .05. (See Figure 2.3.1 for graphical illustration). The mean RTs for positive trials in the RVF and LVF were 1014 ms and 1013 ms respectively, whereas for negative trials in the RVF and LVF they were 1029 ms and 983 ms respectively. Simple effects analysis, with the criterion value for statistical significance set at .0125 in order to control the familywise error rate[1], revealed that the RTs on the negative trials differed significantly between the visual fields, F(1,39) = 17.29, p < .001. No other simple main effects reached significance.

Figure 2.3.1. Graphical illustration of the significant interaction between Visual Field and Type of Trial



A significant interaction was also obtained between positive and negative trials as a function of length of delay, F(1,39) = 5.51, p < .025. (See Figure 2.3.2 for graphical illustration). The mean RTs for positive trials in the short-delay and long-delay

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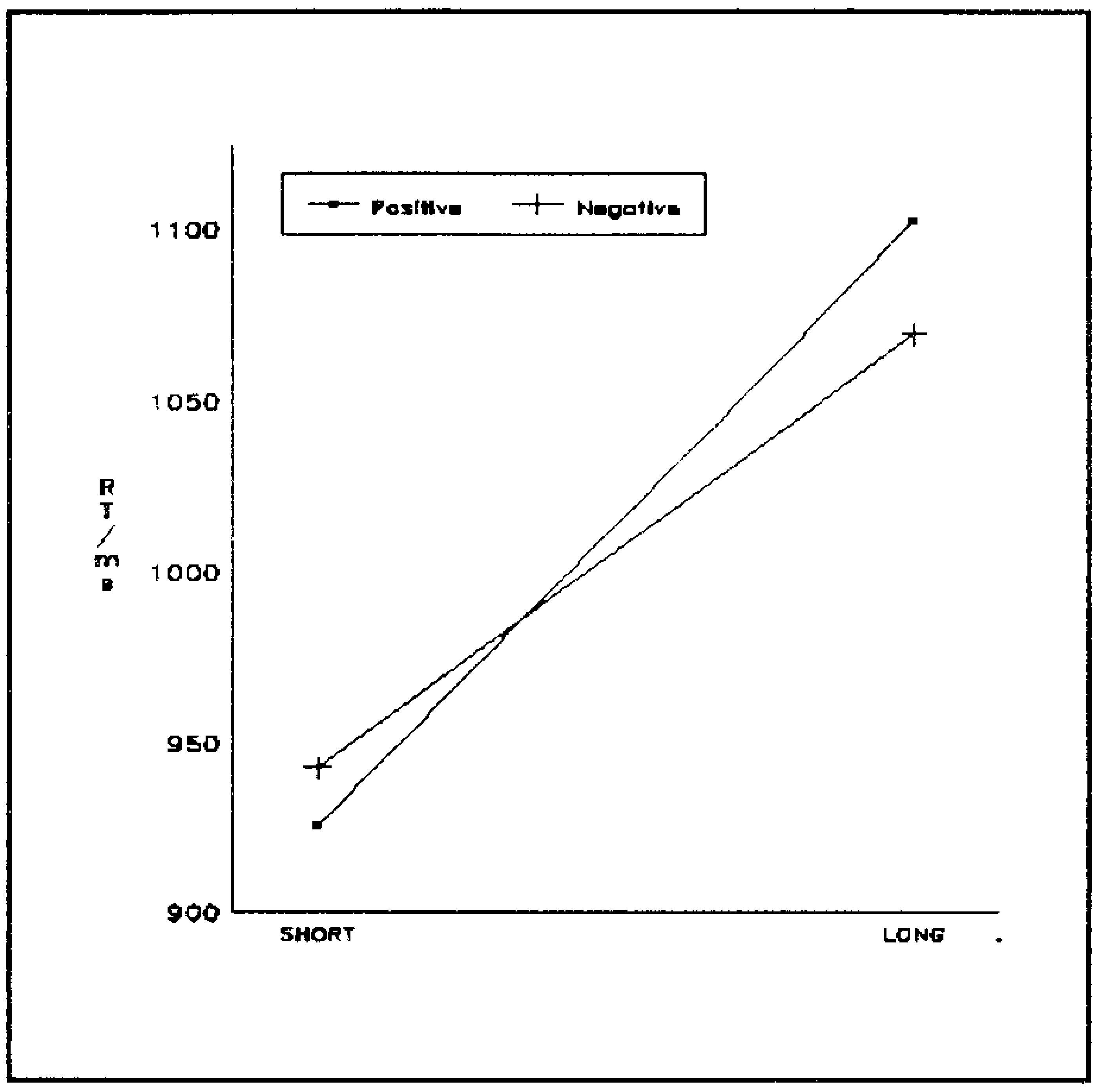
[1] A Bonferroni adjustment, whereby the criterion value for statistical significance is set at alpha/number of comparisons, was applied in order to ensure that the familywise error rate for the set of comparisons was < .05. This adjustment is used, when necessary, in all following analyses.

conditions were 925 ms and 1102 ms respectively, whereas those for negative trials in the short-delay and long-delay conditions were 943 ms and 1069 ms respectively. Simple effects analysis, with the criterion value for statistical significance set at .0125, revealed that both positive trials, F(1,39) = 29.78, p < .001, and negative trials, F(1,39) = 28.52, p < .001, differed significantly as a function of the length of delay. No other simple main effects reached significance.

Figure 2.3.2. Graphical illustration of the significant interaction between Delay and Type of Trial



A further analysis, however, contrasting the difference scores between the long-delay and short-delay condition for both types of trial revealed that these differed significantly, F(1,39) = 5.551, p < .025, with the difference between the long-delay and short-delay conditions being greater for positive trials (mean difference score 176 ms) than negative trials (mean difference score 126 ms).

No significant main effect was found for type of response and no other interactions reached significance.

Errors

Initially data were analyzed using a three-way repeated measures ANOVA, with delay (long vs. short), visual field of circle presentation (RVF vs. LVF) and type of trial (positive vs. negative) as factors. A significant main effect was found for the short-delay and long-delay conditions, F(1,39) = 43.16, $p < .001$, with subjects making significantly more errors in the long-delay condition (mean number of errors 2.43) than in the short-delay condition (mean number of errors 1.44).

No other main effects or interactions reached significance.

2.4 Discussion

Initial analyses of the data revealed that mean reaction times and mean number of errors were significantly greater for the long-delay condition than for the short-delay condition, as would be expected on the basis of task difficulty. Furthermore, with respect to the reaction time data, it was found that type of trial interacted significantly with length of delay, with positive trials appearing to be more adversely affected by the length of delay than negative trials. Of most interest, however, was the finding of a significant main effect for visual field, with subjects responding significantly faster when the stimulus circle was presented in the LVF than when it was presented in the RVF. Furthermore, the visual fields differed significantly as a function of type of trial. Although no performance asymmetry was found on positive trials, subjects made significantly faster responses on negative trials when the circle stimulus was presented in the LVF than when it was presented in the RVF.

The principal aim of this study was to examine the respective competence of the two hemispheres when operating upon representations of varying quality. One aspect of the results, therefore, which is of particular importance is the absence of a visual field asymmetry as a function of delay. If the RH advantage in the French and Painter study was in fact determined by the quality of the representations on which the evaluations were performed then one would have expected the reduced quality of the image in the long-delay condition to have a more detrimental effect on the LH than on the RH. However, while a LVF advantage prevailed overall, thus replicating the results found by French and Painter (1991), there was no evidence to support the view that hemisphere competence differs as a function of the quality of the image.

The above evidence can also be viewed as providing support for the claim that the RH superiority in both this experiment and the previous study by French and Painter can be attributed to a spatial processing component specific to the imagery system. This leaves open, however, the question of the nature of the spatial processing component. The RH, for example, might simply be more adept at representing or processing all forms of spatial information in images. Alternatively, the RH may be better at representing or processing specific types of spatial information in images.

One aspect of the data, however, which warrants further consideration in this respect is the interaction between visual field and type of response. As noted previously, although no performance asymmetry was found on positive trials, subjects made significantly faster responses on negative trials when the circle stimulus was presented in the LVF than when it was presented in the RVF. Furthermore, it is perhaps worthy of note that a similar pattern was found in the error data in the French and Painter study, with subjects making significantly fewer errors on negative trials in the imagery task following LVF presentation than following RVF presentation. As it seems unlikely that spatial processing was not required when making a positive judgement the most parsimonious explanation would appear to be that the RH was more adept at representing or processing some form of spatial information specific to the negative judgement.

Unfortunately the current study does not permit inferences to be drawn regarding the possible nature of this spatial information, since consideration of the two responses suggests a number of potential computational differences between the two types of evaluation. For example, in line with Kosslyn's (Kosslyn, 1987; Kosslyn et al., 1990) suggestions, it could perhaps be claimed that negative responses called for some evaluation of the distance separating the dots and the circle whereas positive judgements did not. On the other hand, in line with Corballis's (1989, 1991) suggestions, it is also possible to claim that negative responses perhaps required some evaluation of the circle's position in relation to the pattern as a whole whereas positive judgements did not. However, these considerations are clearly somewhat speculative and it is, therefore, perhaps more appropriate to simply conclude that the evidence appears to support the view that the RH is specialized for representing or processing specific types of spatial information in images.

On a methodological note, there is an additional aspect of the data which warrants further consideration. It has frequently been pointed out that if tasks vary in difficulty, different patterns of results from them do not necessarily imply different processing components. A single processing subsystem, for example, could operate differently at different levels of difficulty. This point was of relevance in the French and Painter (1991) study as, not surprisingly, the perceptual task was considerably easier than the imagery task, and this raised the possibility that the difference in the pattern of lateralization between the two versions of the task was due to task difficulty rather than a shift to the use of imagery in one task. However, as noted earlier, both the reaction time and error data in the present study demonstrate that the long-delay condition was significantly more difficult than the short-delay condition. The absence of a visual field asymmetry as a function of delay, however, would appear to indicate that hemisphere performance was not differentially influenced by task difficulty. Nevertheless, it should perhaps be noted in this respect that it could still be argued that the level of difficulty associated with the short-delay condition was sufficient to obscure any differences in the pattern of lateralization between the two versions of the task.

In conclusion, the absence of a visual field asymmetry as a function of delay suggests that the RH superiority found in this study can be attributed to a spatial processing component specific to the imagery system. Furthermore, as the LVF advantage was specific to a particular type of evaluation, this can be taken as evidence in support of the view that the RH is specialized for the representation or processing of a specific form of spatial information in images.

CHAPTER THREE

3. EXPERIMENT TWO

3.1 Introduction

The findings reported in the previous chapter replicate and extend those in the French and Painter (1991) article, by demonstrating that differential hemispheric involvement on the experimental task appeared to be determined by a form of spatial processing specific to the imagery system. What is perhaps of more interest, however, is the implications of these findings for the French and Brightwell (1989) study. Specifically, the results appear to demonstrate that when the scanning component of the task is removed the effects of the remaining components summate to determine a RH superiority. This then would appear to provide further support for the claim that the LH superiority found by French and Brightwell was due to the image scanning component of the task.

Such a conclusion would be noteworthy since it would appear to cast doubt on Kosslyn's (1987, 1990) theoretical speculations regarding the neural distribution of the imagery system. As noted in Section 1.6.2, Kosslyn has argued that subsystems that make use of categorical representations will be stronger and more effective in the LH, whereas subsystems that make use of coordinate representations will be stronger and more effective in the RH. Furthermore, Kosslyn also states that "scanning should not require use of categorical representations" (Kosslyn, 1987,

p. 167). Thus, according to this view, the image scanning component should be lateralized to the RH. Evidence supporting a LH superiority would, therefore, cast doubt on Kosslyn's claims regarding image scanning and perhaps also on the validity of particular aspects of the model.

Unfortunately, however, it is not possible to conclude unequivocally that the image scanning component is lateralized to the LH as there are still two further alternative explanations which could account for the pattern of results obtained by French and Brightwell (1989). As noted previously, the task used in this study involved presenting simple dot patterns tachistoscopically for five seconds in free vision followed by a three second fixation field. Subsequently an arrow stimulus was presented briefly in the RVF or LVF, and this was either pointing at one of the previous dot locations from a distance of 4 cm, 6 cm or 8 cm or else clearly not pointing at any. The results revealed that RVF presentation led to superior task performance, significantly so at longer dot-arrow separations, and this was interpreted as suggesting a LH superiority for image scanning.

However, one possible confound with respect to this conclusion is that the restricted viewing area of the tachistoscope that was used meant that the distance from the central fixation point to the arrow increased in proportion to the distance between the dot and the arrow. Thus, it is possible that the findings may simply have reflected the extent to which the lateralized stimulus was offset from the central fixation point.

It should perhaps be noted that previous research suggests that this alternative account is unlikely since a number of studies have found no laterality effects relating to eccentricity (e.g. Beaton and Blakemore, 1981). Moreover, those which have found hemifield differences appear to demonstrate that it is the RH which is at an advantage with large eccentricities (Kitterle, 1991). Nevertheless, given Sergent's (1983) claims that the effects of certain stimulus parameters may vary as a function of task demands, this alternative explanation cannot be rejected unequivocally. Moreover, a further problem relates to the fact that the French and Brightwell study did not include a perceptual analogue of the scanning task. It is not possible, therefore, to conclude that the effect was specific to image scanning since it could perhaps be due to processes involved in scanning generally.

The primary aim of the current study, therefore, was to attempt to determine whether either of the above two explanations could account for the pattern of results found in the French and Brightwell study. The imagery task used in this study was the same as that employed by French and Brightwell apart from the following two exceptions. First, the arrow was always either pointing at one of the previous dot locations from a distance of 6 cm or else clearly not pointing at any. Second, in order to investigate whether variations in eccentricity could have been responsible for the previous finding, the extent to which the arrow stimulus was offset from the central fixation point was manipulated.

One problem with respect to this manipulation, however, is that previous research on image scanning has shown that when advance information regarding the arrow's location is made available, reaction time is found to be uncorrelated with distance (Finke and Pinker, 1983). In such circumstances it appears that subjects use a different strategy for making their judgements based on an internal comparison between anticipated correct directions and test directions specified by the arrow. Thus, in order to ensure that subjects used an image scanning as opposed to a vector-matching strategy, it was necessary to manipulate stimulus offset whilst at the same time maintaining unpredictability in arrow location. This was achieved by fixing the location of the arrow on the horizontal axis, but varying it on the vertical axis. In the small eccentricity condition the arrow was located 2 cm to the right or left of the vertical midline, whereas in the large eccentricity condition it was located 10 cm to the right or left of the vertical midline.

Finally, in order to assess whether performance asymmetries were specific to the imagery system, a perceptual analogue of the above task was also incorporated into the design in which the dot pattern was presented for two seconds in free vision and then continued to be presented through the presentation of the fixation stimulus and arrow stimulus. (It should perhaps be noted that it was necessary to present the dot pattern for different periods of time in the imagery and perceptual conditions, since previous research had indicated that if the dot pattern was presented for five seconds in the perceptual condition subjects simply became bored with this unnecessarily lengthy exposure.)

In line with the reasoning underlying the claims made by French and Brightwell, it was predicted that a LH advantage would be found only on the imagery task.

3.2 Method

3.2.1 Subjects

Forty subjects, 18 males and 22 females, took part in the experiment. They were all undergraduates who were right-handed by self-report with normal or corrected to normal vision, and they were aged between 19 and 43 years of age (mean age 35.1 years, SD 6.935). Data from a further five subjects were not analyzed as detailed below.

3.2.2 Apparatus

Details for this section are identical to those reported in Chapter 2, apart from the following two exceptions. First, the stimuli in this study were generated using the Micro Experimental Laboratory software package. Second, subjects viewed the screen from a distance of 50 cm. This corresponds to a visual angle subtended at the eye by the viewing area of 28.1° horizontally and 20° vertically.

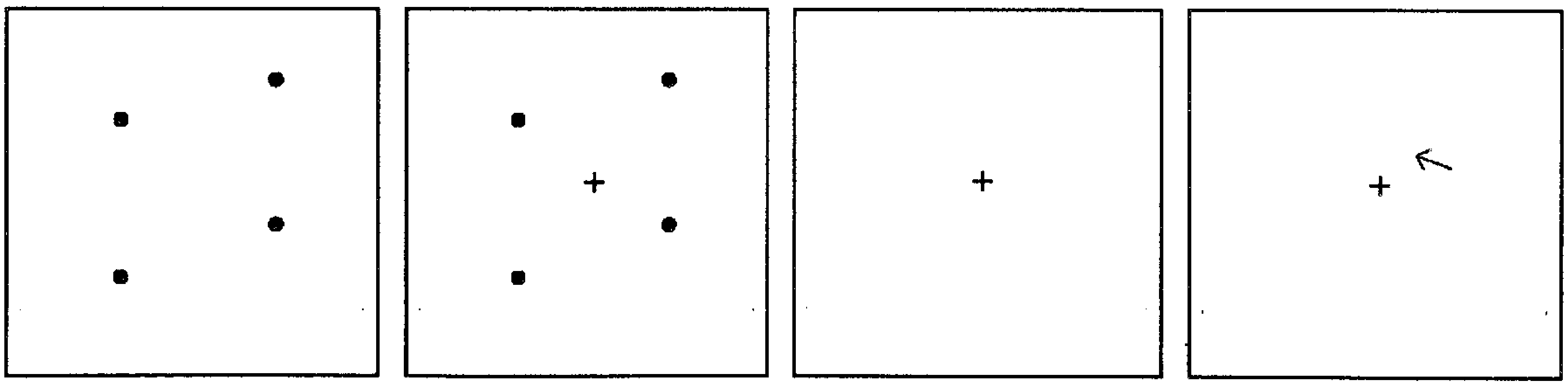
3.2.3 Stimuli

The computer generated different dot patterns for each subject within the following constraints. The patterns consisted of four black dots, 6 mm in diameter on a white background. Each dot subtended a visual angle of 0.7°. On the vertical axis dots never appeared within 2 cm of the top or bottom of the screen or within 2 cm of the horizontal midline of the field. Within these constraints, one dot was located in each

quadrant of the screen in a randomly determined position on the vertical axis. Dot location on the horizontal axis, however, was fixed, with two dots appearing 4 cm to the left of the vertical midline and two dots appearing 4 cm to the right of the vertical midline.

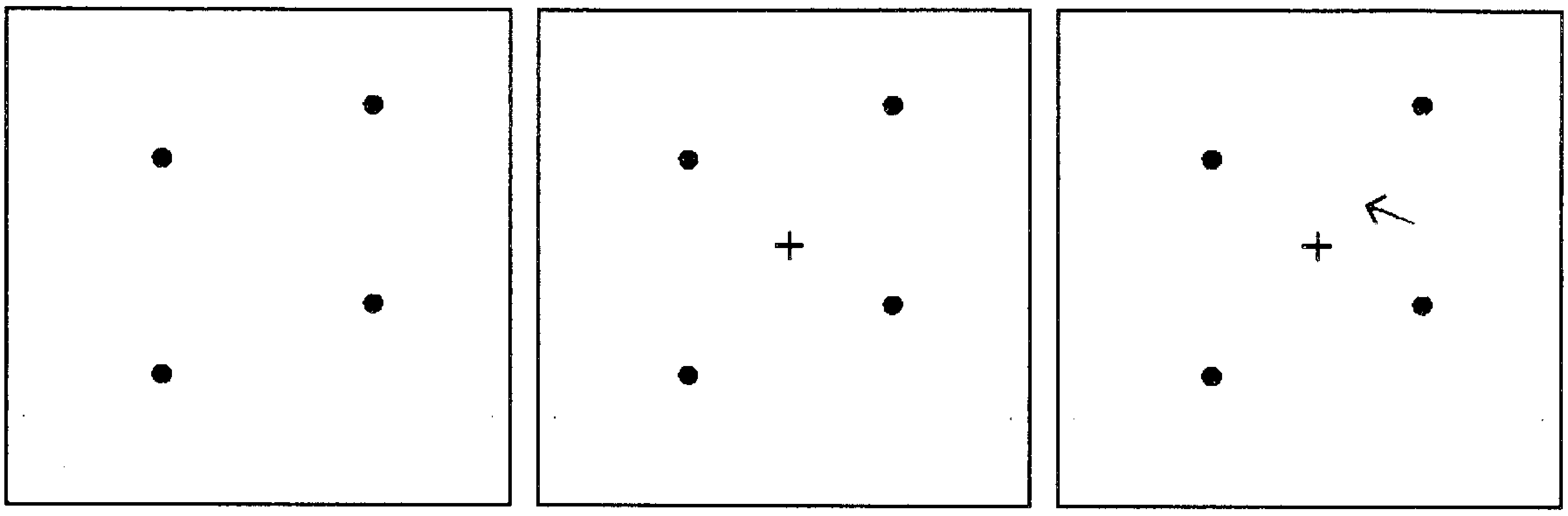
In the imagery condition the dot pattern disappeared from the screen one second after the presentation of the fixation point which consisted of a black cross at the centre of the screen. Subsequently the cross disappeared and a black arrow stimulus 18 mm in length, subtending a visual angle of 2.1°, was presented briefly in either the right visual field or left visual field. It was either pointing to one of the locations previously occupied by a dot, or else clearly not pointing at any of them. This sequence is graphically illustrated in Figure 3.2.3.1.

Figure 3.2.3.1. Illustration of the sequence of stimulus presentation on trials in the Imagery Condition. (N.B. not drawn to scale).



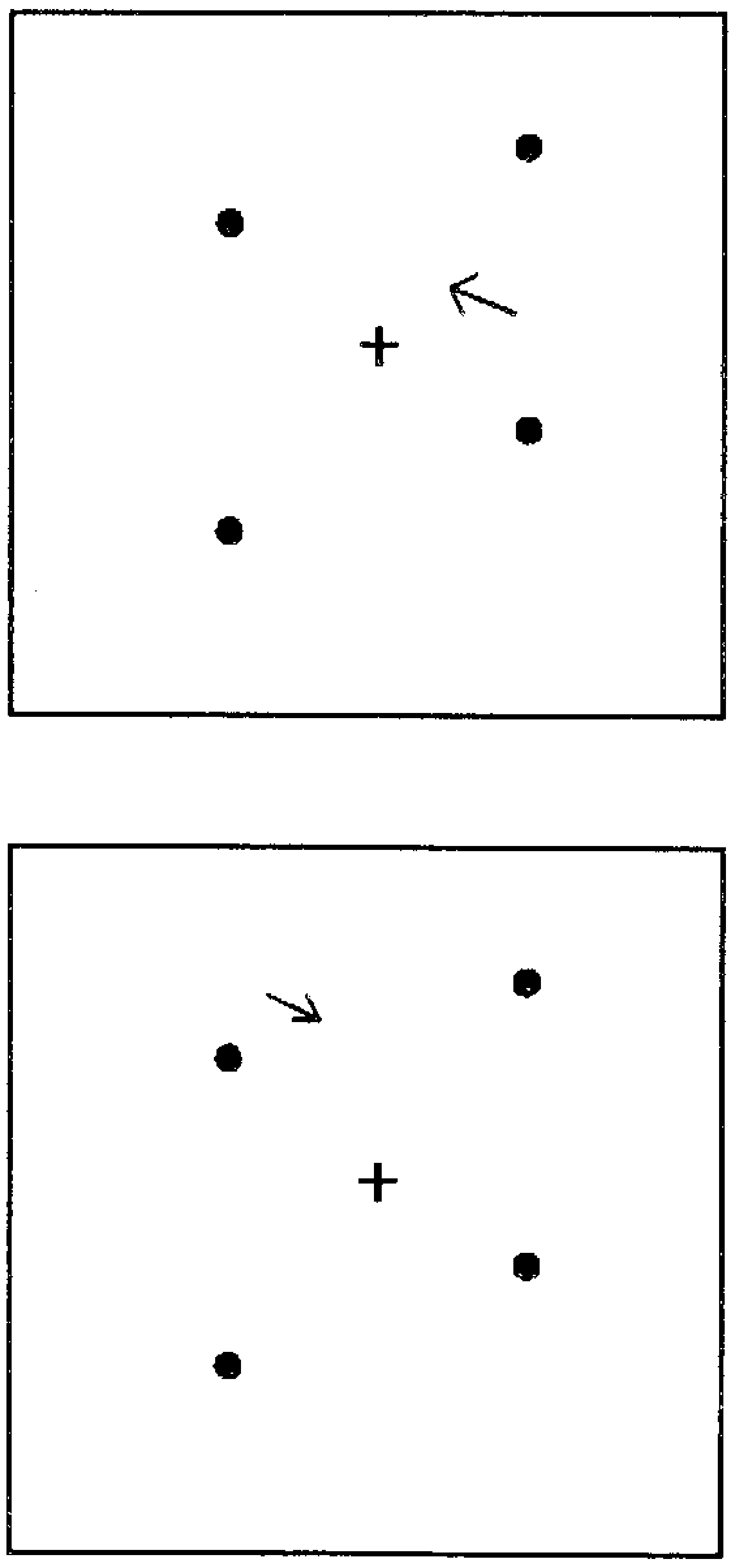
In the perceptual condition the dot patterns remained on the screen throughout the trial. This sequence is graphically illustrated in Figure 3.2.3.2.

Figure 3.2.3.2. Illustration of the sequence of stimulus presentation on trials in the Perceptual Condition. (N.B. not drawn to scale).



The location of the arrow was subject to the following constraints. On the positive trials in the small eccentricity condition the arrow was pointing, from a distance of 6 cm (6.7°), at a dot location in the opposite visual field. On the negative trials the arrow was pointing, from a distance of 6 cm, at a point not occupied by a dot in the opposite visual field 4 cm away from the vertical midline (henceforth, referred to as a "negative target location"). On such trials the arrow pointed at the midpoint of whichever of the following was the largest: the distance between the dot in the uppermost quadrant and the top of the screen; the distance between the dot in the lower quadrant and the bottom of the screen; the distance separating the two dots. A graphical illustration of a positive and negative trial in the small eccentricity condition are presented in Figure 3.2.3.3.

Figure 3.2.3.3. Illustration of positive (top) and negative (bottom) trials in the small eccentricity condition. (N.B. not drawn to scale).



On the positive trials in the large eccentricity condition the arrow was located on the periphery of the field and was pointing, from a distance of 6 cm, at a dot location in the same visual field.

On the negative trials the arrow was again located on the periphery of the field and was pointing, from a distance of 6 cm, at a location in the same visual field 4 cm away from the vertical midline. In this instance, however, selection of the negative target location was restricted to points above the uppermost dot or below the lower dot. This ensured that on such trials the scan path clearly missed all dots in the pattern. A graphical illustration of a positive and negative trial in the large eccentricity condition are presented in Figure 3.2.3.4.

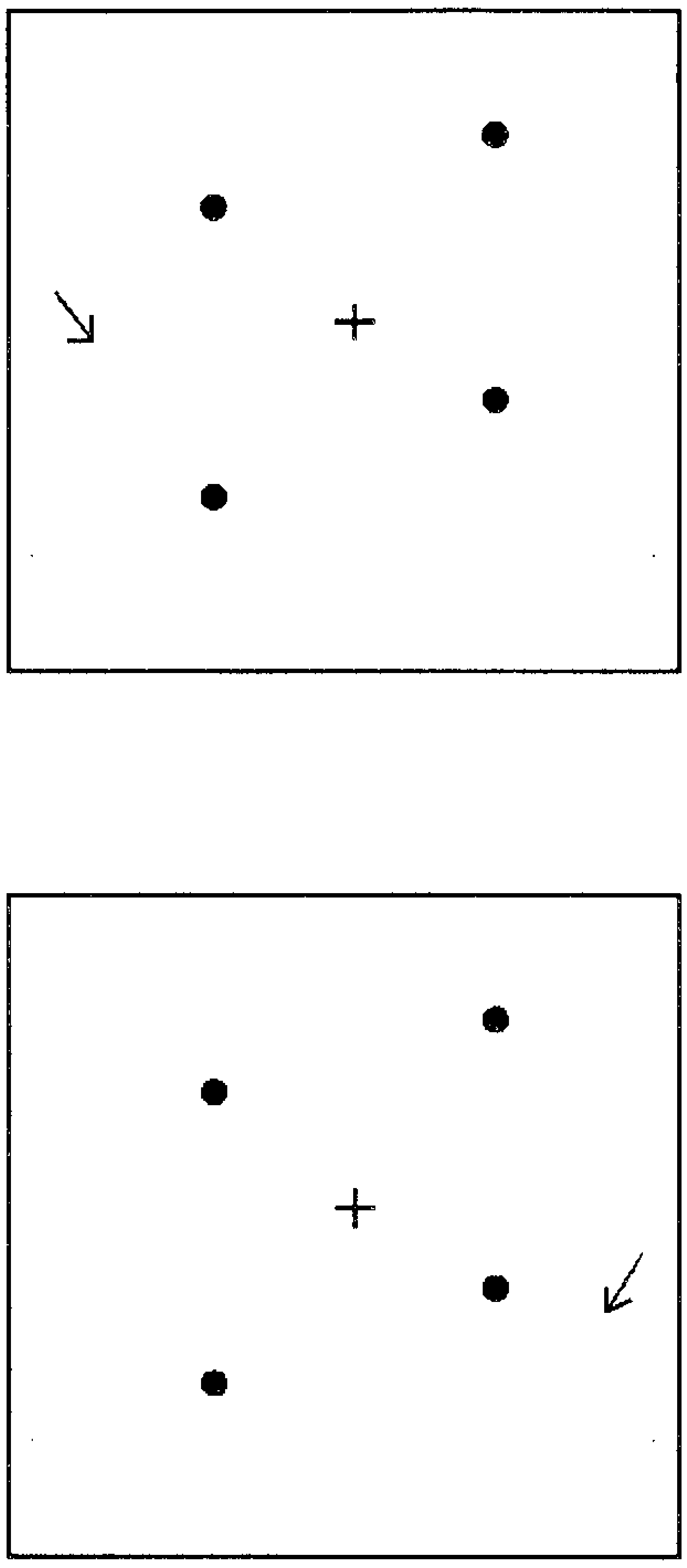


Figure 3.2.3.4. Illustration of positive (top) and negative (bottom) trials in the large eccentricity condition. (N.B. not drawn to scale).

Finally, the arrow never appeared within 2 cm of the top or bottom of the screen, or within 1 cm of a dot location. Within these constraints the angular orientation of the arrow was randomly determined from within a range of 70° to 110° for RVF presentation and 250° to 290° for LVF presentation. The mean displacement of the arrow from the fixation point across subjects was 3.1 cm (3.4°) in the small eccentricity condition, and 10.3 cm (11.8°) in the large eccentricity condition.

Each dot pattern was presented on sixty-four trials, thirty-two in the imagery condition and thirty-two in the perceptual condition. Each pattern was used in its original orientation on sixteen trials in each condition. Within these sixteen trials each dot location was pointed at twice, once from within the same visual field (large eccentricity) and once from the opposite visual field (small eccentricity). On the remaining eight trials the arrow pointed at a negative location in either the same (large eccentricity) or opposite (small eccentricity) visual field. The exact mirror image of each of these trials was also presented, thus ensuring that any hemifield differences could not be due to unintentional biases in favour of one or other visual field. Once the trials had been generated the order of presentation was randomized within each condition.

3.2.4 Procedure

Viewing conditions, presentation of instructions, mode of response and counterbalancing of the order of presentation of the conditions and response hand and fingers were identical in all respects to the details reported in the first paragraph of the procedure section in Chapter 2.

In the imagery condition subjects were instructed to try to remember the position of each dot by forming an image of the pattern exactly as it appeared on the screen. After four seconds of the presentation period had elapsed a black cross was presented at the centre of the field. This was the cue for subjects to fixate centrally by staring directly at the centre of the black cross. The dot pattern then disappeared from the screen and the fixation point was presented for an additional three seconds.

At the end of this period an arrow stimulus was presented for 183 ms in either the RVF or the LVF. The arrow either pointed at a location previously occupied by a dot, or else clearly did not. Subjects were instructed to press the YES button if the arrow was pointing at a location that was previously occupied by a dot, or the NO button if it was not. It was stressed in the instructions to the subjects that on those trials where the arrow was not pointing at a location previously occupied by a dot this would be quite clear, as on such trials the arrow would point well away from any dot location in the pattern.

The perceptual condition differed in that each dot pattern remained on the screen throughout the trial. Each pattern was presented for a period of two seconds prior to the presentation of the black cross at the centre of the field, and subjects were instructed to fixate on the cross as soon as it appeared. The fixation cross was presented for two seconds and the arrow stimulus was presented for 183 ms in either the RVF or the LVF. The arrow either pointed at a dot, or else clearly did not. Subjects, therefore, had to press the YES button if the arrow was pointing at a dot, or the NO button if it was not. (See Appendix II for verbatim instructions to subjects).

Feedback was given at the end of each trial to enable subjects to monitor their performance. When a correct response was made a display appeared informing the subjects of their reaction time and their average percentage of correct trials for the block. When an incorrect response was made the subjects were informed of this visually and a warning tone was also emitted. Sixteen practice trials were also given prior to the commencement of the sixty-four experimental trials in each condition. One dot pattern was generated in both its original and mirror image orientation for the practice blocks, and sixteen trials were then randomly selected.

For both conditions the subjects were instructed to respond as quickly and as accurately as possible, and the importance of maintaining central fixation was emphasized not only in the initial instructions but throughout the trials themselves. At the end of the experiment subjects were debriefed and questioned concerning the strategies that they had employed. All subjects reported using an image scanning strategy, but five subjects who responded correctly to less than 70% of the trials were excluded from the analysis. These excluded subjects were replaced in order to ensure that the final subject pool was completely counterbalanced.

3.3 Results

Mean reaction times for correct responses and mean number of errors for each subject comprised the data upon which the statistical analyses reported below were performed. Trials on which reaction times exceeded three seconds were treated as errors. These data, averaged across subjects, are presented in Table 3.3.1 and 3.3.2 with standard deviations.

Table 3.3.1. Mean RTs (ms) and mean number of errors with standard deviations in the Imagery condition, as a function of type of response for each visual field for the small eccentricity (SE) and large eccentricity (LE) conditions.

IMAGERY - POSITIVE	**RVF**		**LVF**	
	SE	**LE**	**SE**	**LE**
Mean RTs	944	949	939	950
SD	350	329	355	351
Mean Errors	1.75	1.62	1.72	1.75
SD	1.15	1.12	1.41	1.37

IMAGERY - NEGATIVE	**RVF**		**LVF**	
	SE	**LE**	**SE**	**LE**
Mean RTs	939	989	936	1017
SD	265	284	279	277
Mean Errors	1.40	2.05	1.47	1.70
SD	1.28	1.30	1.28	1.38

Table 3.3.2. Mean RTs (ms) and mean number of errors with standard deviations in the Perceptual condition, as a function of type of response for each visual field for the small eccentricity (SE) and large eccentricity (LE) conditions.

PERCEPTUAL POSITIVE	**RVF**		**LVF**	
	SE	**LE**	**SE**	**LE**
Mean RTs	622	649	644	691
SD	265	241	292	284
Mean Errors	0.85	0.70	0.92	0.95
SD	1.27	0.82	1.07	1.04

PERCEPTUAL NEGATIVE	**RVF**		**LVF**	
	SE	**LE**	**SE**	**LE**
Mean RTs	697	696	710	692
SD	171	199	235	211
Mean Errors	0.87	1.02	0.67	1.15
SD	0.94	1.00	0.86	1.21

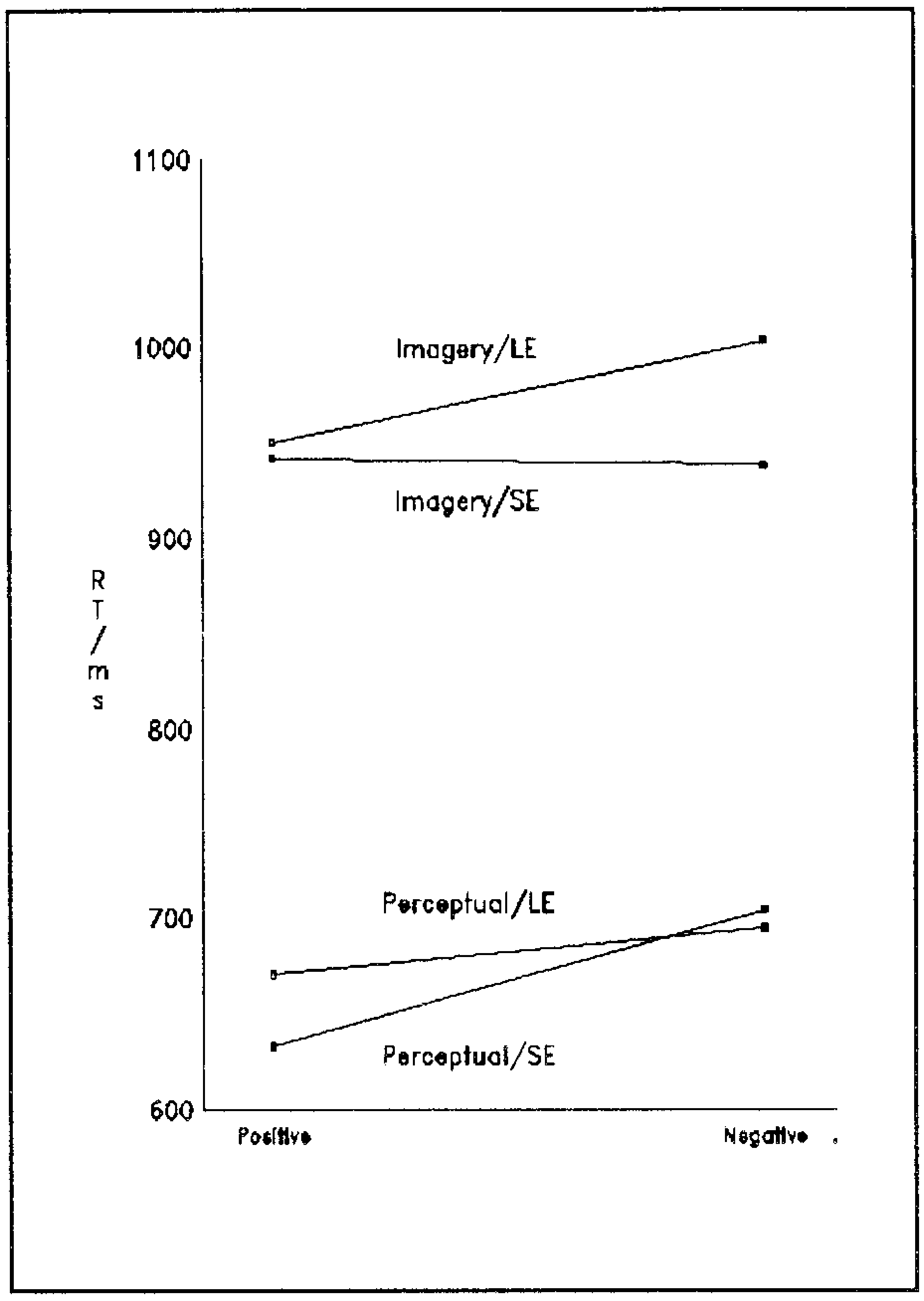
Reaction Times

Initially data were analyzed using a four-way repeated measures ANOVA, with condition (imagery vs. perceptual), visual field of arrow presentation (RVF vs. LVF), extent of eccentricity (small vs. large) and type of trial (positive vs. negative) as factors. A significant main effect was found for the imagery and perceptual conditions, $F(1,39) = 52.02$, $p < .001$, with subjects producing significantly longer RTs in the imagery condition (mean RT 957 ms) than in the perceptual condition (mean RT 675 ms).

In addition, a marginally significant main effect was found for the small eccentricity and large eccentricity conditions ($F(1,39) = 3.87$, $p < .06$), with subjects producing shorter RTs in the small eccentricity condition (mean RT 803 ms) than in the large eccentricity condition (mean RT 829 ms). Finally, a marginally significant main effect was also found for the type of response factor ($F(1,39) = 3.82$, $p < .06$), with subjects producing longer RTs in the negative response condition (mean RT 834 ms) than in the positive response condition (mean RT 798 ms).

These main effects, however, were modified by a significant interaction which was obtained between condition, eccentricity and type of trial, ($F(1,39) = 7.14$, $p < .025$). (See Figure 3.3.1 for graphical illustration). The mean RTs in the imagery condition for small eccentricity presentation were 941 ms for positive responses and 937 ms for negative responses, whereas for large eccentricity presentation the mean RT was 949 ms for positive responses and 1003 ms for negative responses. In the perceptual condition for small eccentricity presentation the mean RTs were 633 ms for positive responses and 703 ms for negative responses, whereas for large eccentricity presentation the mean RT was 670 ms for positive responses and 694 ms for negative responses. Simple effects analysis, with the criterion value for statistical significance set at .0125 in order to control the familywise error rate[1], revealed that only the RTs in the perceptual condition for small eccentricity presentations for positive and negative responses differed significantly, $F(1,39) = 14.77$, $p < .001$.

Figure 3.3.1. Graphical illustration of the significant interaction between type of response, eccentricity and condition.



No significant main effect was found for visual field and no other interactions reached significance.

Errors

A four-way repeated measures ANOVA, with condition (imagery vs. perceptual), visual field of arrow presentation (RVF vs. LVF), extent of eccentricity (small vs.

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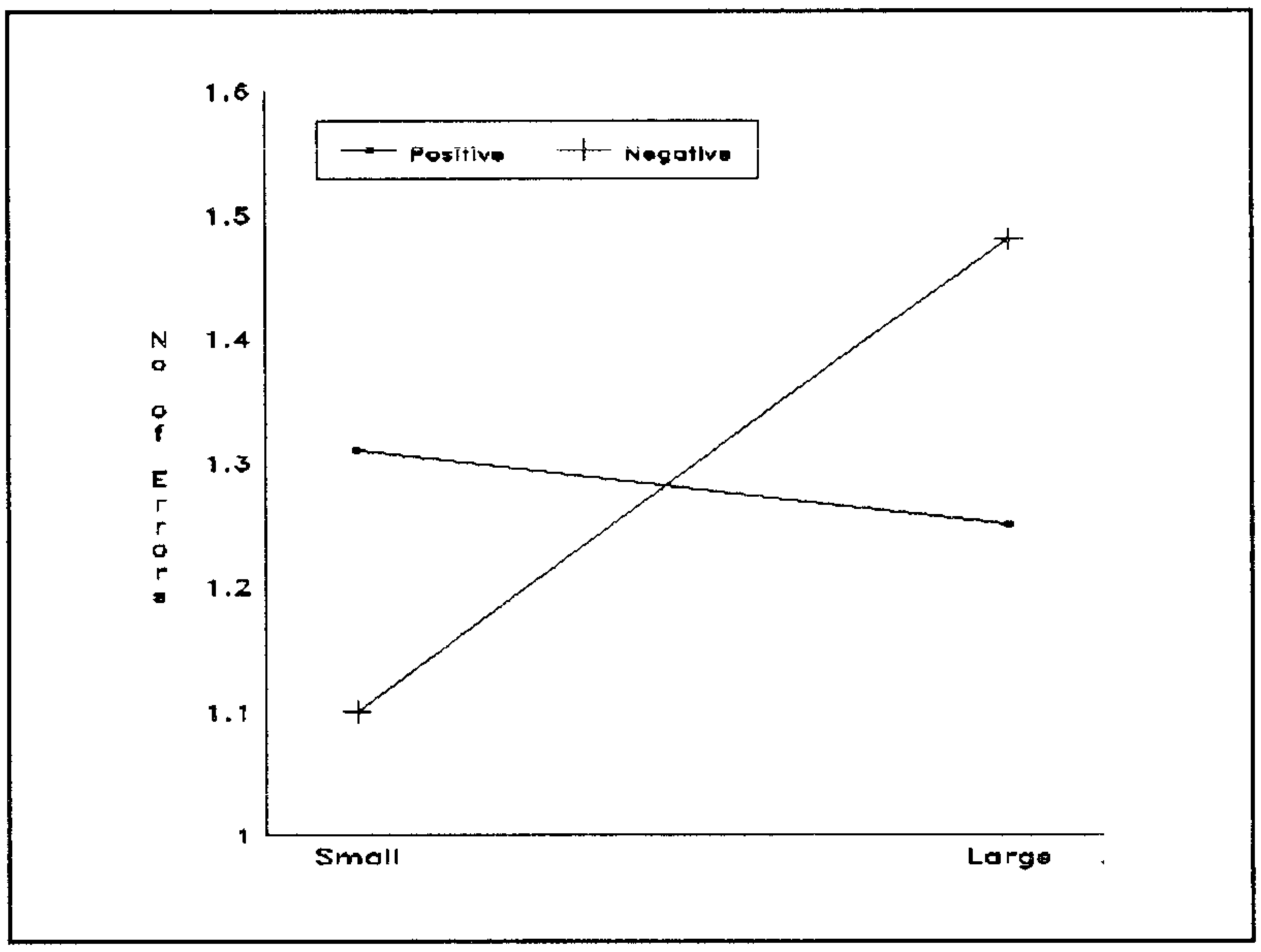
[1] For three-way interactions limiting the familywise error rate for the set of comparisons to $< .05$ can result in a criterion value for statistical significance which is so stringent that none of the comparisons reach significance. Consequently, in this case the familywise error rate has been set at $< .10$.

large) and type of trial (positive vs. negative) as factors, was applied to the data. A significant main effect was found for the imagery and perceptual conditions, (F(1,39) = 84.25, p<.001), with subjects making significantly more errors in the imagery condition (mean no. of errors 1.68) than in the perceptual condition (mean no. of errors 0.89).

A significant interaction was also obtained for positive and negative trials as a function of eccentricity (F(1,39) = 4.97, p<.05). (See Figure 3.3.2 for graphical illustration). The mean number of errors for positive responses in the small and large eccentricity conditions were 1.31 and 1.25 respectively, whereas those for negative responses in the small and large eccentricity conditions were 1.10 and 1.48 respectively. Simple effects analysis, with the criterion value for statistical significance set at .0125 in order to control the familywise error rate, revealed that only the errors for negative trials in the small and large eccentricity conditions differed significantly, F(1,39) = 10.64, p<.01.

Figure 3.3.2. Graphical illustration of the significant interaction between eccentricity and type of trial.



No other main effects or interactions reached significance.

3.4 Discussion

Initial analyses of the data revealed that mean reaction times and mean number of errors were significantly greater for the imagery condition than the perceptual condition, as would be expected on the basis of task difficulty. The reaction time data also revealed two further marginally significant main effects which indicated that longer reaction times were associated with large (vs small) eccentricity presentations and negative (vs positive) responses. These effects perhaps reflect respectively the additional time it might have taken subjects to locate the more peripheral arrows, and the uncertainty associated with termination of the scan path on negative responses.

As regards higher-order effects, the reaction time data also revealed a significant interaction between the imagery and perceptual condition as a function of eccentricity and type of trial. Further analysis revealed that subjects produced significantly faster reaction times on positive responses in the perceptual condition when the arrow was located towards the centre of the field. It is not entirely clear why this effect prevailed, but given the comments in the above paragraph it seems reasonable to suggest that the pattern of data is attributable to task difficulty since all of the task components associated with increased reaction times are absent on this particular subset of trials. Similar considerations also perhaps account for the significant interaction found for the error data, which revealed that subjects made significantly more errors in the large eccentricity condition on negative trials than positive trials.

The primary aim of the current study, however, was to establish whether laterality effects relating to eccentricity could have been responsible for the LH advantage found on the imagery task in the French and Brightwell (1989) study. The most noteworthy aspect of the results, therefore, is the complete absence of any visual field effect as a function of eccentricity, which suggests that the extent to which the lateralized stimulus was offset from the central fixation point was not responsible for the pattern of results obtained by French and Brightwell. Nevertheless, it must also be acknowledged that the absence of any visual field effect as a function of imaginal vs perceptual processing would also appear to cast doubt on the claim that the LH superiority was due to the image scanning component of the task. Indeed the present findings would appear to suggest that the two cerebral hemispheres are equally adept at image scanning.

Of course, discrepant findings such as these are not, as noted previously, uncommon in the area of laterality research since failures to replicate appear in the divided visual field literature relatively frequently. The results of the two studies, therefore, may simply reflect the pervasiveness of this instability. Nevertheless, it would be inappropriate to simply attribute the discrepant findings to this instability without considering other possible alternative explanations for the contradictory results. In this respect, therefore, it would appear necessary to consider differences in design and procedure between the present and earlier study in order to assess whether these could account for the divergent findings.

One aspect which warrants consideration in this respect relates to the positioning of the arrow. In the French and Brightwell study the location of the arrow was totally unpredictable, whereas in the present study position on the horizontal axis was restricted to two specific points. Furthermore, when displacement of the lateralized stimulus from the central fixation point was small the arrow always pointed on the positive trials to one of the two dots in the opposite visual field. Similarly, when displacement was large the arrow always pointed on the positive trials to one of the two dots in the same visual field. It is possible, therefore, that these factors may have provided subjects with sufficient advance information to use a vector-matching strategy as opposed to an image scanning strategy. That is, when the dot pattern was presented subjects may have used their knowledge about possible reference locations to predetermine the correct directions to the dots. They could then simply compare the direction of the arrow directly to these anticipated directions.

However, it must be acknowledged that the above explanation seems unlikely for two reasons. First, all of the subjects reported using an image scanning strategy. Second, although the location of the arrow was restricted within a certain range on the horizontal axis, there were no constraints on location on the vertical axis. Thus, in order to employ a vector-matching strategy it would be necessary for subjects to predetermine the correct directions for all possible locations on the vertical axis with respect to each point within the restricted range on the horizontal axis. Whilst such a strategy is presumably possible, it does seem somewhat implausible. Unfortunately, however, it is not possible to conclude unequivocally that an image scanning strategy was employed in the current study, since the distance between the dot and the arrow was constant. It is not possible, therefore, to demonstrate that reaction times increased linearly with distance.

To summarize, the current findings would appear to suggest that laterality effects relating to eccentricity were not responsible for the LH advantage found in the French and Brightwell (1989) study. However, the findings also cast doubt on the claim that the effect was attributable to the image scanning component of the task. Unfortunately doubts relating to the type of strategy employed by the subjects in the two studies mean that further investigation is required before any firm conclusions can be drawn.

CHAPTER FOUR

4. EXPERIMENT THREE

4.1 Introduction

The inconclusive nature of the findings from the previous study clearly make it necessary to attempt to establish the robustness of the visual field effect reported by French and Brightwell (1989). It was decided, therefore, to replicate this experiment, the general procedure for which was described in the previous chapter. It was hypothesized that reaction times would be linearly related to the distances separating the dot and arrow locations, and that there would be a LH advantage on the task in terms of reaction times and/or errors.

4.2 Method

4.2.1 Subjects

Sixteen subjects participated in the experiment, thirteen females and three males. They were all undergraduates who were right-handed by self-report with normal or corrected to normal vision, and they were aged between 19 and 40 years of age (mean age 26.1 years, SD 7.16). Data from an additional fifteen subjects were excluded from the analysis as described below.

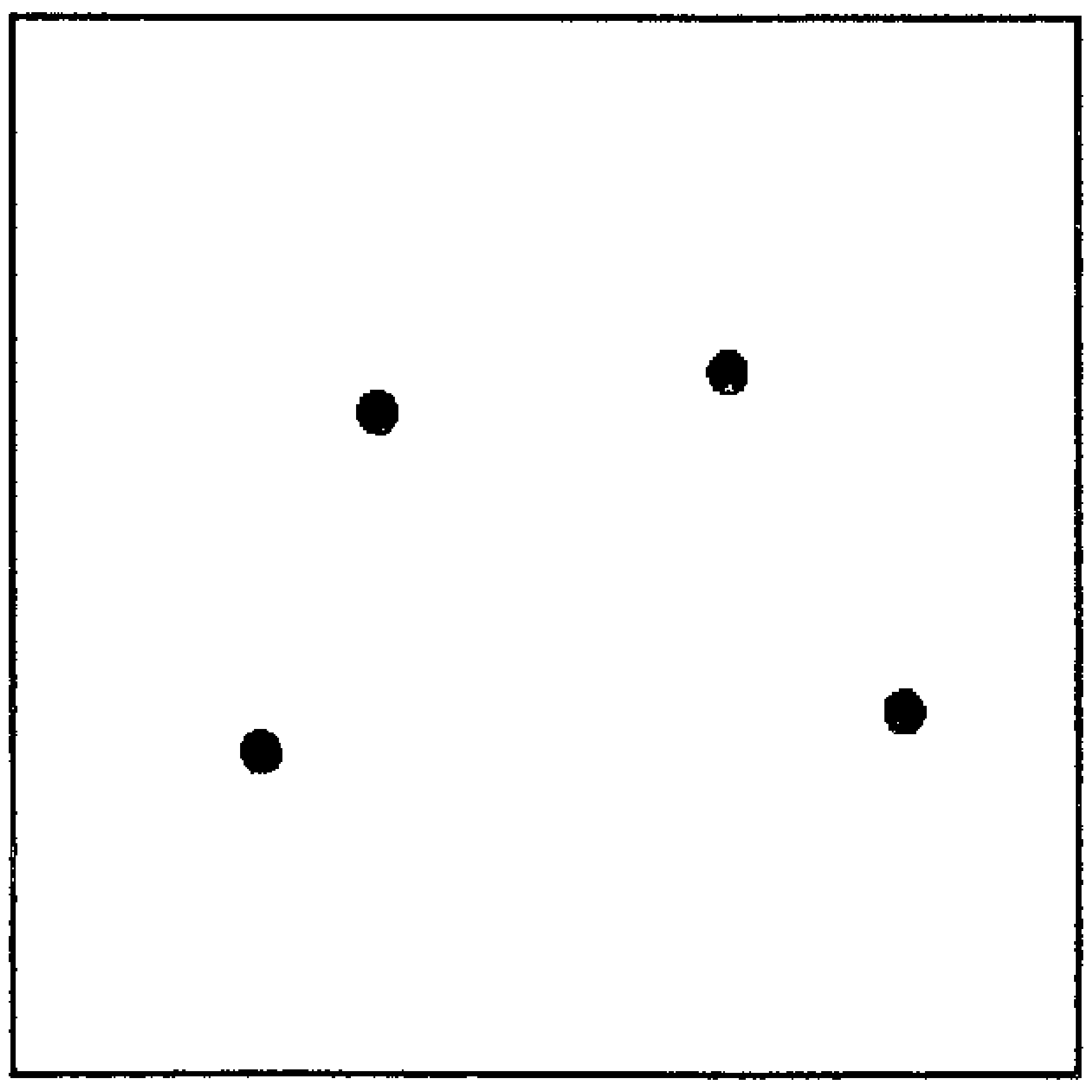
4.2.2 Apparatus

Details for this section are identical to those reported in Chapter Three apart from the following exception. The viewing distance in the French and Brightwell experiment was 50 cm, which corresponds to a visual angle subtended at the eye by the viewing area of 16° horizontally (14.3 cm) and 10° vertically (8.9 cm). In order to ensure, as far as possible, consistency in viewing conditions the subjects in this study therefore viewed the visual display screen from the maximum possible distance of 75 cm. The visual angle subtended at the eye by the viewing area at this distance was 18.7° horizontally (24.5 cm) and 13.4° vertically (17.5 cm).

4.2.3 Stimuli

The following stimuli replicate those described in French and Brightwell (1989). The actual size of the stimuli and the distance of the dots from the central fixation point, however, were adjusted in order to ensure that the visual angle subtended at the eye was the same for both studies.

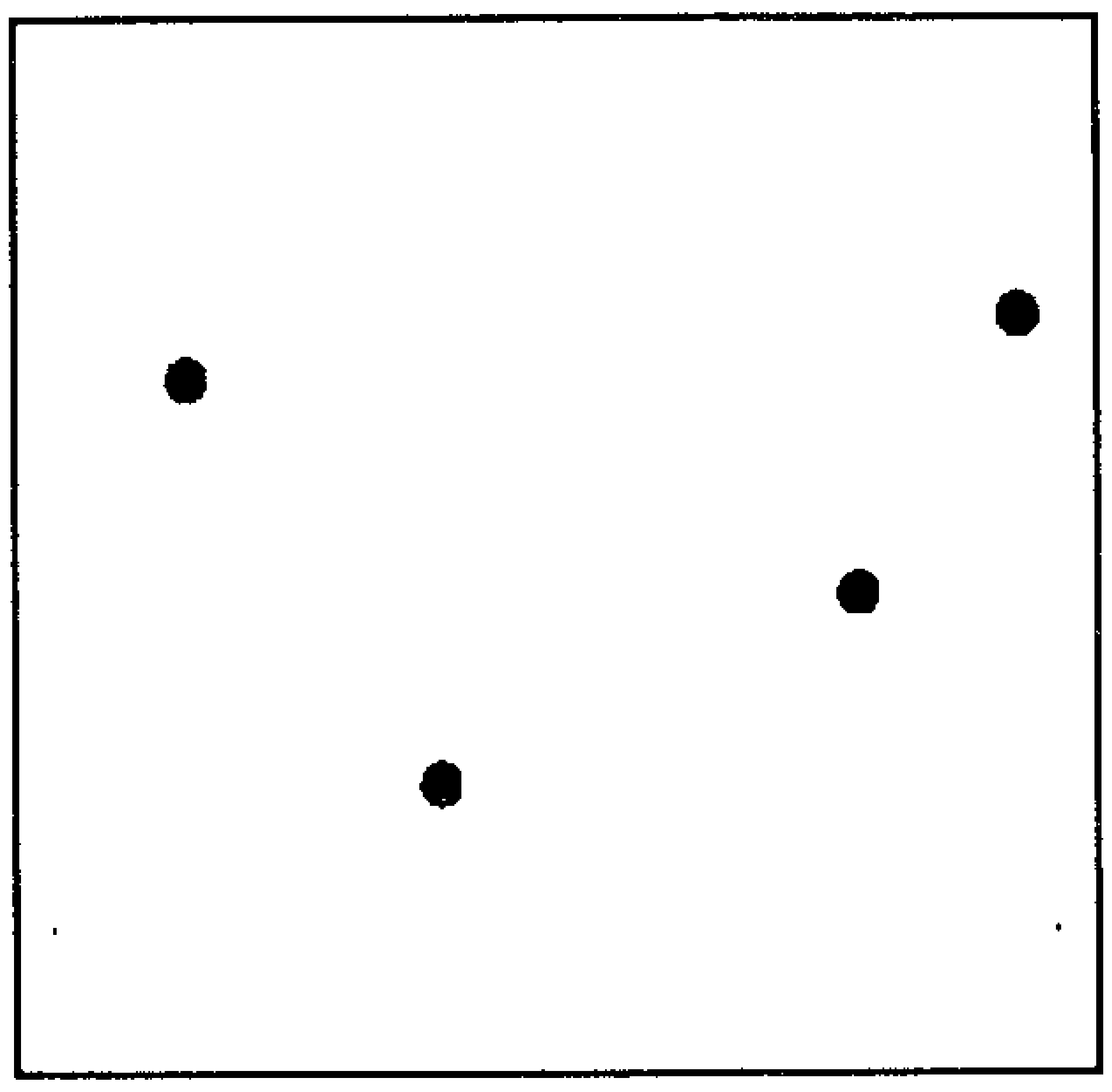
Figure 4.2.3.1. Pattern A. (N.B. Not drawn to scale).



Two dot patterns and their mirror images were used for the experimental trials. Each pattern consisted of four black dots 9 mm in diameter on a white background. At a viewing distance of 75 cm each dot therefore subtended a visual angle of approximately 0.7°. The centres of the dots in Pattern A had the following polar coordinates with reference to the centre of the visual field (distance expressed in terms of visual angle in parenthesis):

i) 44 mm, 44° (3.4°); ii) 43 mm, 151° (3.3°); iii) 72 mm, 222° (5.5°); 75 mm, 325° (5.7°). (A graphical illustration of Pattern A is presented in Figure 4.2.3.1). For Pattern B the centres of the dots were located as follows: i) 81 mm, 23° (6.2°); ii) 73 mm, 160° (5.7°); iii) 59 mm, 247° (4.5°); iv) 58 mm, 346° (4.4°). (A graphical illustration of Pattern B is presented in Figure 4.2.3.2). The fixation field consisted of a black cross located in the centre of the visual field on a white background.

Figure 4.2.3.2. Pattern B. (N.B. not drawn to scale).



The lateralized stimulus was a black arrow 21 mm in length, subtending a visual angle of 1.6°. In order to ensure consistency of stimulus presentation between the two studies arrow location was restricted to an area 21 cm x 13.5 cm, which is equivalent in terms of visual degrees (16° x 10°) to the viewing area used in the French and Brightwell study. Within this area no two arrows were ever presented at the same location, and the arrows were also distributed as evenly as possible within each hemifield. This ensured that, from the subjects' perspective, both the location and the angular direction of the arrow were unpredictable. Finally, in order to avoid confusion, no arrow was ever presented at a location at which a dot had just been presented or within 2 cm of the vertical midline. Within these constraints the arrow was either clearly not pointing at any of the dot locations in the pattern, or else pointing from a distance of 6 cm, 9 cm or 12 cm to one of the locations previously occupied by a dot. These distances correspond to visual angles of 4.6°, 6.9° and 9.2° respectively. (In the French and Brightwell study the distances of 4 cm, 6 cm and 8 cm corresponded to visual angles of 4.5°, 6.7° and 8.9° respectively).

The experimental trials were constructed in the following manner. Each dot pattern was presented on 24 trials in its original orientation. On twelve of these trials every dot location was pointed at from every distance (i.e. 6 cm, 9 cm and 12 cm). On the remaining twelve trials the arrow clearly missed all dot locations. The exact mirror image of each trial was also presented ensuring that any hemifield differences obtained could not simply be due to unintentional biases in favour of one or other visual field.

4.2.4 Procedure

Procedural details are identical to those reported in Chapter Three, apart from the following exceptions. First, no perceptual analogue was used in this study. Second, the arrow either pointed to a location previously occupied by a dot from a distance of 6 cm, 9 cm or 12 cm, or else clearly did not. Finally, sixteen practice trials were given prior to the commencement of the ninety-six experimental trials. The dot pattern employed in the practice trials was not used in the experimental trials. Within the sixteen practice trials, each dot location was pointed at twice. On the remaining eight trials the arrow clearly missed all dot locations. The order of both the practice and the experimental trials was randomized. (See Appendix III for verbatim instructions to subjects).

At the end of the experiment subjects were thanked and fully debriefed. Fifteen subjects who responded correctly to less than 70% of the trials were excluded from the analysis. All of these excluded subjects, however, were replaced in order to ensure that the final subject pool was completely counterbalanced with respect to response hand and fingers used for positive and negative responses.

4.3 Results

Mean reaction times for correct responses and number of correct trials for each subject comprised the data upon which the statistical analyses reported below were performed. Trials in which reaction times exceeded three seconds were treated as errors. These data averaged across subjects are presented in Table 4.3.1 with standard deviations.

Table 4.3.1. Mean RTs (ms) and number correct with standard deviations as a function of distance for each visual field. (NP = not pointing at dot location).

RVF				
	NP	**6 cm**	**9 cm**	**12 cm**
Mean RTs	1098	1125	1137	1316
SD	222	232	221	309
No. Correct	17.94	6.81	5.87	6.69
SD	0.71	0.91	1.02	1.25

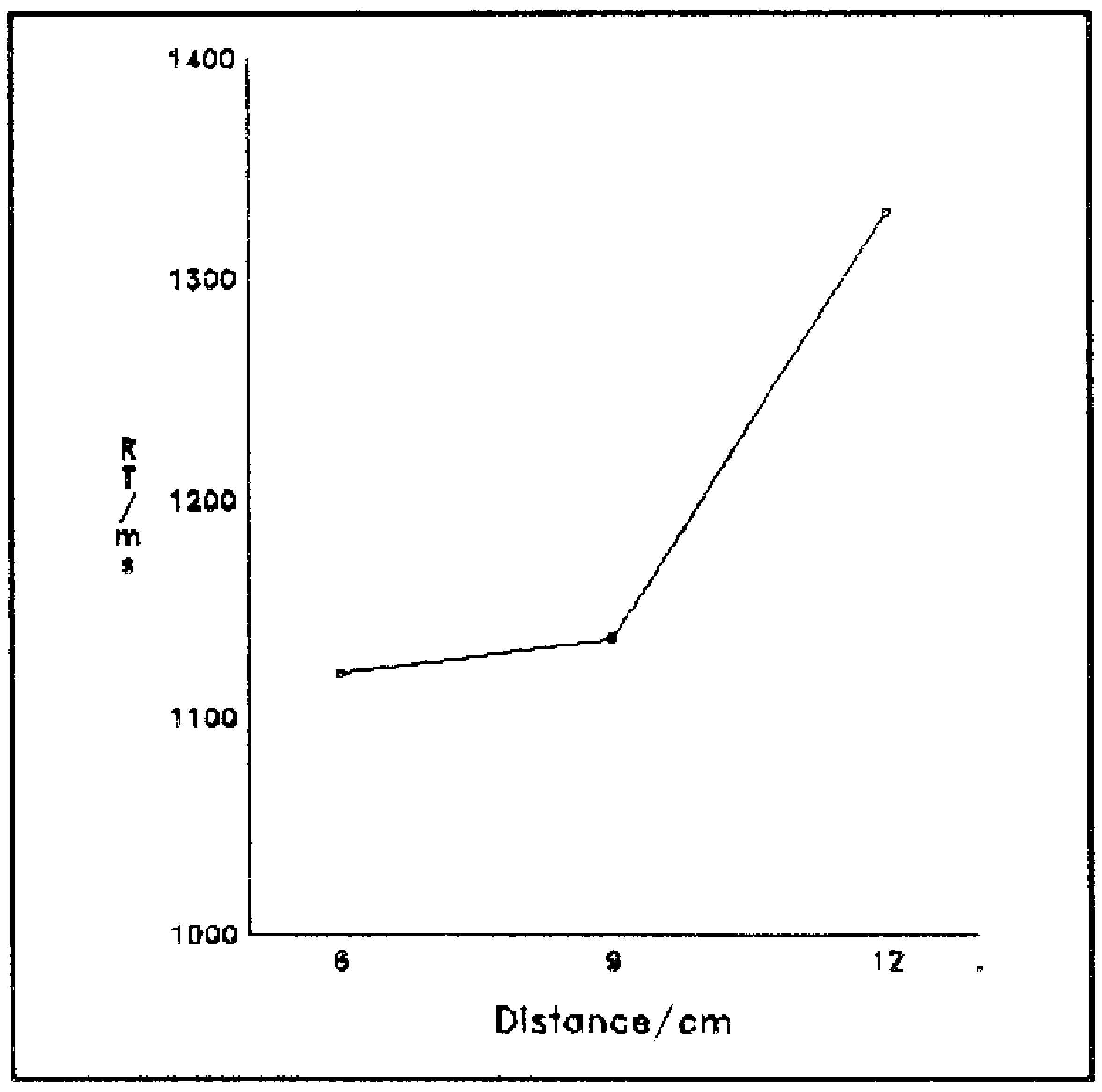
LVF				
	NP	**6 cm**	**9 cm**	**12 cm**
Mean RTs	1091	1114	1135	1344
SD	215	199	234	347
No. Correct	18.42	6.44	6.12	6.25
SD	0.64	1.41	1.20	0.93

Reaction Times

Initially data for correct positive responses were analyzed using a two-way ANOVA with distance (6 cm, 9 cm, 12 cm) and visual field (RVF and LVF) as repeated factors. A significant main effect was found for distance $F(2,30) = 14.12$, $p < .001$. Moreover, the empirical F value still reached significance following adjustment of the degrees of freedom by the average of the Greenhouse-Geisser Epsilon (.87) and the Huynh-Feldt Epsilon (.97) in order to control for possible violations of sphericity ($F(2,28) = 14.12$, $p < .01$).[1] The mean RTs at 6 cm, 9 cm and 12 cm were 1119 ms, 1136 ms and 1330 ms respectively.

A trend analysis was performed on this main effect, revealing a significant linear trend ($F_{linear}(1,15) = 17.38$, $p < .01$). This effect was modified, however, by a significant quadratic trend ($F_{quadratic}(1,15) = 7.90$, $p < .025$). (See Figure 4.3.1 for graphical illustration). No significant main effect was found for visual field and the interaction between distance and visual field did not reach significance.

Figure 4.3.1. Graphical illustration of mean reaction times (ms) for correct positive responses at 6 cm, 9 cm and 12 cm.



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[1] A number of tests for violations of the sphericity assumption exist but problems, primarily involving the tests' oversensitivity, reduce their practical value (e.g. Kesselman, Rogan, Mendoza and Breen, 1980). Consequently, a number of statisticians have recently begun to recommend routine use of a correction factor applied to the degrees of freedom (e.g. Howell, 1992). This permits selection of a larger critical F value, thereby avoiding the positive bias which can result from violations of this assumption. Of the two correction factors available the Greenhouse-Geisser Epsilon tends to be rather conservative and the Huynh-Feldt Epsilon somewhat optimistic. Stevens (1992), therefore, recommends using the average of the two, and this is the procedure used above and in all subsequent analyses.

Mean RTs for correct negative responses were analyzed using a one-way ANOVA with visual field as a within-subjects factor. No significant effect was found.

Accuracy

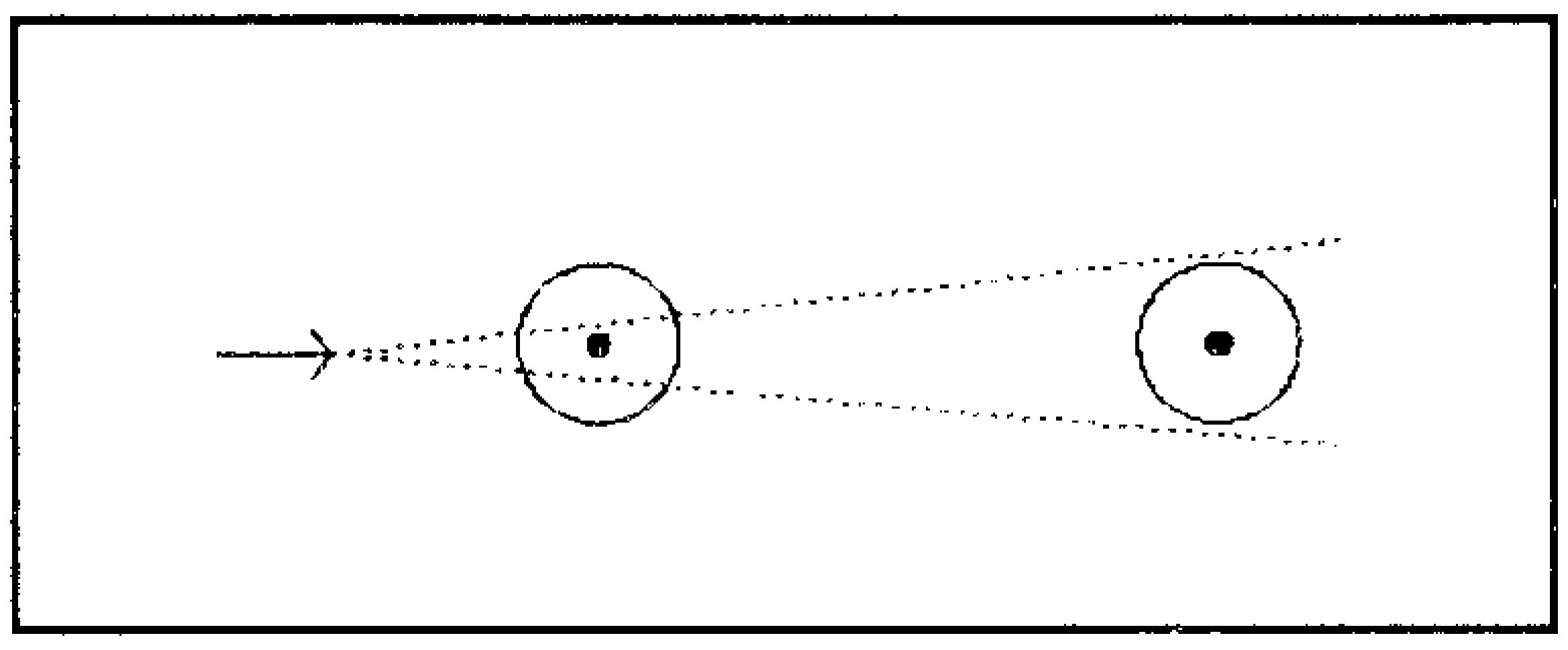
It was necessary to analyze the reaction time data from the positive and negative trials separately in order to facilitate investigation of the possible linear trend relating RT to distance. No such constraints, however, applied to the analysis of the accuracy data, and the data were therefore analyzed using a two-way ANOVA with condition (not pointing and pointing from 6 cm, 9 cm and 12 cm) and visual field as repeated measures. (It was necessary to scale down the number correct in the not pointing condition by a factor of three, as this condition involved a possible maximum score of twenty-four as opposed to eight in each of the pointing conditions).

No main effects or higher-order interactions reached significance.

4.4 Discussion

The analyses revealed that, as predicted, mean reaction times increased significantly with increasing distance. There was, however, no evidence from either the reaction time or error data of any visual field asymmetry. Moreover, while the results clearly demonstrate that reaction times increase with increasing dot-arrow separation, the findings would appear initially to conflict somewhat with previous research in that the significant quadratic trend indicates that the increase in reaction time is not directly proportional to the distance between the dot and the arrow.

Figure 4.4.1. Illustration of Finke and Pinker's (1983) proposal regarding the effects of uncertainty in arrow orientation and dot location.



It is perhaps worthy of note in this respect, however, that departures from linearity have been reported previously. For example, Finke and Pinker (1983), in an extension of their original study, found that subjects made far more errors for the shortest arrow-dot distance than for the other distances. They explained this apparent anomaly by arguing that dot positions were unlikely to be recorded in memory with perfect accuracy. Therefore, each imagined dot will fall into a circular region of uncertainty. Given a constant angular range within which the scanning process is directed, it is more likely that the imagined dot will fall outside of this critical sector the closer it is to the arrow. (See Figure 4.4.1 for graphical illustration of this argument). Evidence in support of this explanation was subsequently provided by Pinker, Choate and Finke (1984).

Of course in the present study the quadratic trend could have resulted from deviations of any of the three data points. Nevertheless, given the above, it is possible that the departure from linearity might have been due to elevated reaction times at the shortest dot-arrow separation, since at short distances even a small displacement in the remembered location of a dot can place it towards the periphery of the acceptable angular range.

The results of the present experiment, however, fail to support the view of a hemisphere asymmetry in image scanning. As this conflicts with previous evidence it would appear necessary, once again, to attempt to examine what factors may have accounted for these divergent findings. One obvious difficulty with the current experiment was the excessively high error rate which resulted in the elimination of nearly half the subjects who were run. In fact, initially it was planned to run forty subjects, but as the experiment progressed it became clear that the task was far too difficult. The decision was, therefore, taken to terminate the experiment when usable data had been obtained from sixteen subjects.

Unfortunately it is not clear what factors could have been responsible for the difference in subjects' performance between the current experiment and the French and Brightwell study. For example, in the current study 48% of the total subject pool responded correctly to less than 70% of trials, whereas in the French and Brightwell study only 17% of the subjects failed to reach this threshold. Consideration of potential sources of divergence between the experiments, however, appears initially to reveal few differences. The subject population was the same in both studies, as was the basic stimulus configuration. Furthermore, in as much as the task requirements were the same in both experiments, there appears to be no compelling reason to believe that this was the source of divergence.

However, a number of potential differences are suggested by the fact that subjects responded much faster in the current study than in the French and Brightwell study. For example, the mean reaction times in the present study for scanning distances corresponding to visual angles of 4.6°, 6.9° and 9.2° were 1119 ms, 1136 ms and 1330 ms respectively. Conversely, in the French and Brightwell study mean reaction times for scanning distances corresponding to visual angles of 4.5°, 6.7° and 8.9° were 1610 ms, 1749 ms and 1922 ms respectively.

One possible explanation for the discrepancy between the two sets of results concerns factors related to viewing conditions. For example, while the task demands and the basic stimulus configuration were identical in both experiments, the stimuli were presented tachistoscopically in the French and Brightwell study and by a microcomputer in the present study. This may have resulted in differences in stimulus-presentation parameters, and there is evidence that such differences can affect response speed (Sergent, 1983). However, while such an explanation could perhaps explain the difference in response latencies between the two experiments, it is not clear whether such factors could account for the extremely high error rate found in the current study.

An alternative explanation for the discrepancy concerns response mode. In the French and Brightwell study subjects responded with the index fingers of both hands, whereas in the current study subjects responded with the index and middle finger of one hand. This perhaps could have contributed to the longer response latencies found in the previous study. However, again it is not clear whether such a factor could explain the divergence in error rates. One final explanation which could perhaps account for the divergence in both response latencies and errors concerns the feedback given to subjects. In the present study subjects were provided with feedback on their response speed after each correct trial. It is possible, therefore, that this may have encouraged them to attempt to respond more rapidly, and therefore perhaps less accurately.

In conclusion, the results of the current study appear to provide no support for the claim that the scanning component of imagery is lateralized to the LH. However, the difficulties experienced by subjects in carrying out the task must cast doubt on the validity of these results, and it is probably inappropriate therefore to draw any firm conclusions regarding the lateralization of the image scanning component.

CHAPTER FIVE

5. EXPERIMENT FOUR

5.1 Introduction

Clearly the difficulties experienced by subjects in the preceding study indicate the need for a simpler experimental task. It was decided, therefore, to modify the task as described below in order to facilitate firm conclusions finally being drawn regarding whether or not the effect found by French and Brightwell (1989) was due to the scanning component of the task. However, it is important to remember that it is also necessary to establish whether the putative effect is specific to the imagery task, since, as noted previously, it could perhaps be due to processes involved in scanning generally. Consequently, it was decided to initially investigate whether performance asymmetries were to be found on a perceptual version of the modified task.

Patterns containing four simple geometric shapes were presented in free vision and continued to be presented throughout each trial. A fixation cross was presented two seconds after pattern onset, and two seconds after the presentation of the cross a geometric shape was briefly presented in the RVF or LVF. The lateralized stimulus was either identical to one of the shapes contained in the pattern or else did not match any of them. On those trials where the briefly presented stimulus was not identical to any of the shapes contained in the pattern the subjects were instructed to indicate this with a negative response. When the lateralized stimulus did match one of the shapes it was located at a distance of 6 cm, 9 cm or 12 cm from the corresponding shape, and subjects were instructed to mentally scan from the centre of the lateralized stimulus to the centre of the corresponding shape before responding.

Obviously it would be expected that reaction times would be related to the distance between the lateralized stimulus and the target stimulus. However, performance on the scanning task would only be expected to vary as a function of visual field if there were asymmetries in the processes involved in scanning generally. Consequently, it was simply hypothesized that there would be a significant linear relationship between reaction times and the distances separating the lateralized and target stimuli.

5.2 Method

5.2.1 Subjects

Forty subjects participated in the experiment, 31 females and 9 males. They were all undergraduates who were right-handed by self-report with normal or corrected to normal vision, and they were aged between nineteen and fifty years of age (mean age 26.85 years, SD 8.09).

5.2.2 Apparatus

Stimuli in this study were generated using the Micro Experimental Laboratory software package. All other details for this section are identical to those reported in Chapter Two.

5.2.3 Stimuli

Two patterns and their mirror images were used in the experimental trials. Each pattern consisted of a configuration of four black geometric shapes on a white background. The maximum visual angle subtended at the eye by any one of the shapes contained in the patterns was 0.91° horizontally (12 mm) and 0.76° vertically (10 mm).

Figure 5.2.3.1. Pattern A. (N.B. not drawn to scale).

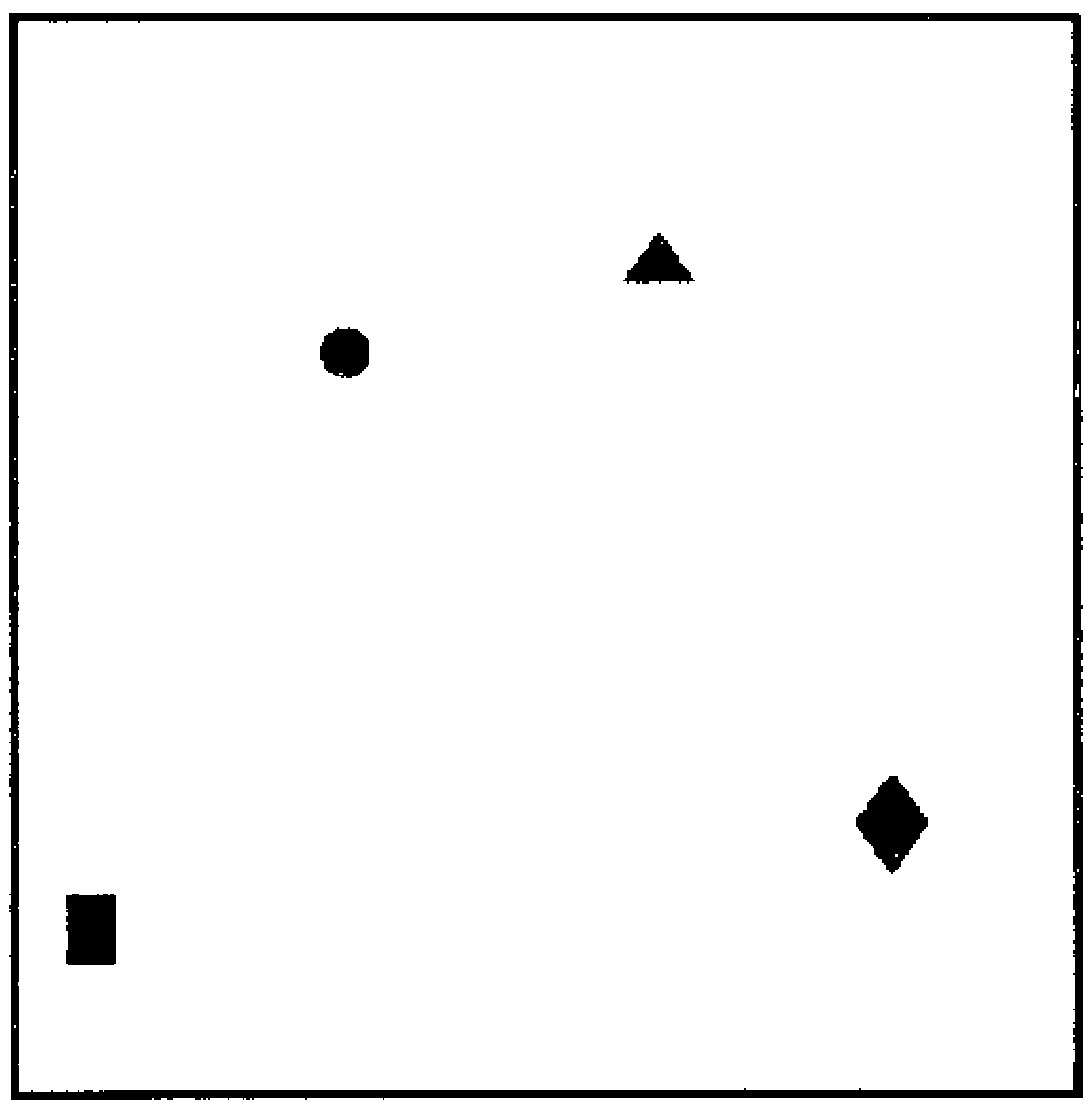
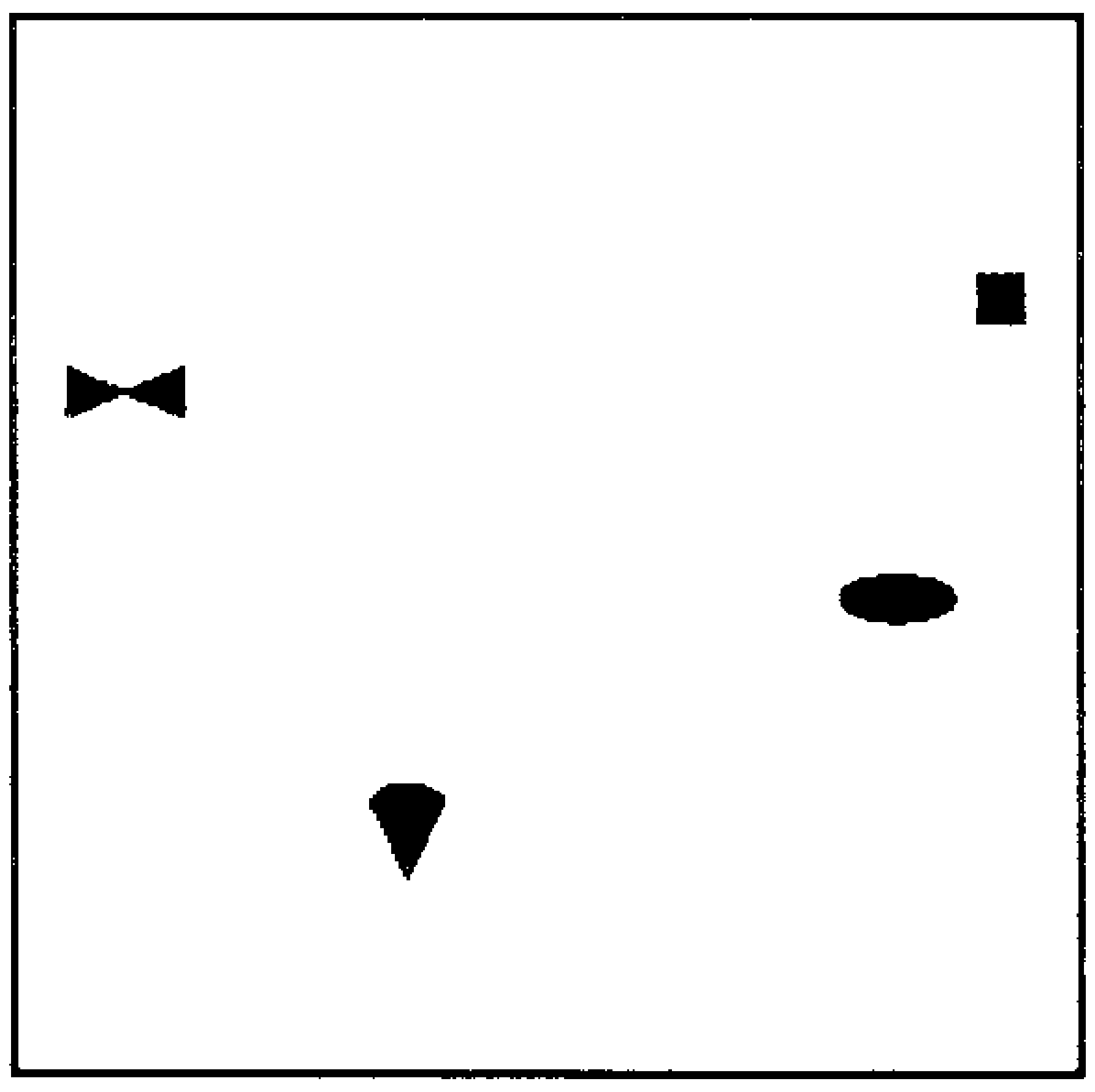


Figure 5.2.3.2. Pattern B. (N.B. not drawn to scale).



Pattern A contained a triangle, a circle, a rectangle and a "diamond" shape at the following polar coordinates with reference to the centre of the visual field (distance expressed in terms of visual angle in parenthesis): i) 63 mm, 72° (4.7°); ii) 50 mm, 127° (3.8°); iii) 94 mm, 216° (6.8°); iv) 70 mm, 325° (4.9°). (See Figure 5.2.3.1 for illustration of Pattern A). Pattern B contained a square, a "bow-tie" shape, an arc and an ellipse at the following locations: i) 81 mm, 23° (6.2°); ii) 73 mm, 160° (5.7°); iii) 59 mm, 247° (4.5°); iv) 58 mm, 346° (4.4°).

(See Figure 5.2.3.2 for illustration of Pattern B). The fixation field consisted of a black cross located in the centre of the visual field.

Each of the geometric shapes depicted in Figures 5.2.3.1 and 5.2.3.2 were also presented on twelve trials as the lateralized stimulus. On six of these trials the lateralized stimulus did not match any of the shapes contained in the pattern. On the remaining six trials the lateralized stimulus was identical to one of the shapes in the pattern. Restrictions on the location of the lateralized stimulus were identical to those reported in Chapter Four, with the exception that on positive trials the lateralized stimulus was located at a distance of either 6 cm (4.6°), 9 cm (6.9°) or 12 cm (9.2°) from the corresponding shape in the pattern.

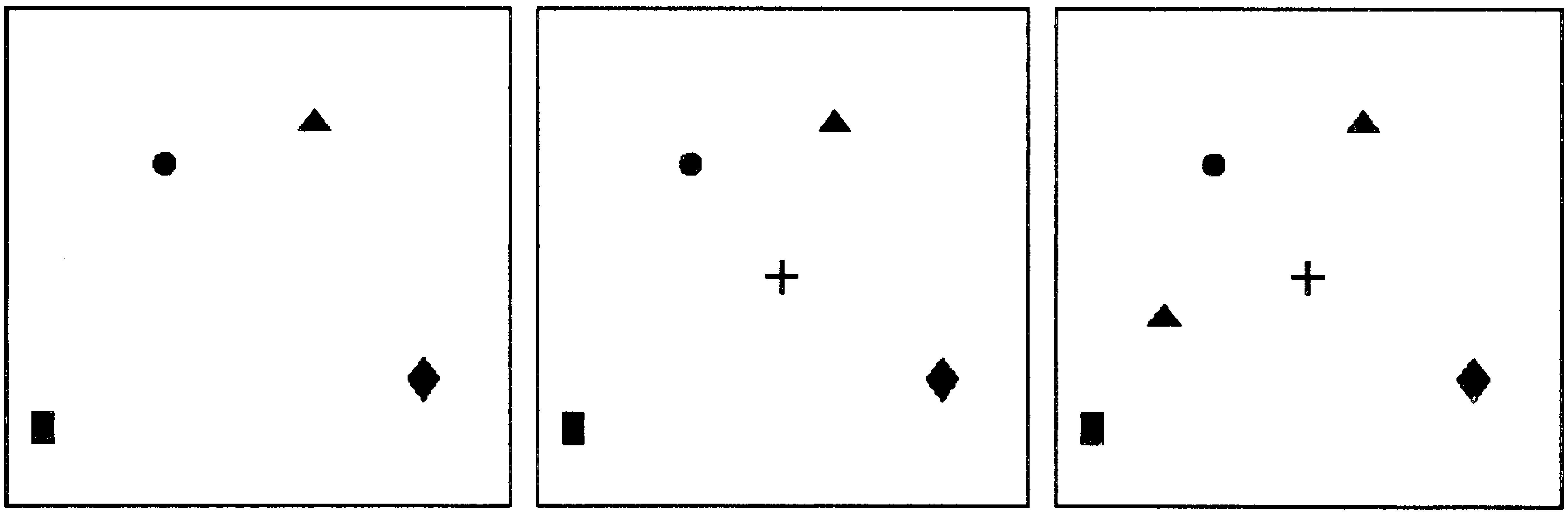
The experimental trials were constructed in the following manner. Each pattern was presented on 24 trials in its original orientation. On twelve of these trials the lateralized stimulus matched one of the shapes contained in the pattern, and was located at a distance of either 6 cm, 9 cm or 12 cm from the corresponding shape. On the remaining twelve trials the lateralized stimulus did not match any of the shapes contained in the pattern. The exact mirror image of each trial was also presented, thus avoiding unintentional hemifield biases.

5.2.4 Procedure

Viewing conditions, presentation of instructions, mode of response and counterbalancing of response hand and fingers were identical in all respects to the details reported in the first paragraph of the procedure section in Chapter Two.

Each pattern remained on the screen throughout each trial. At the beginning of each trial the pattern was presented in free vision for two seconds prior to the presentation of the fixation cross. The cross, which served as the cue for subjects to fixate centrally, was presented for two seconds. At the end of this period the lateralized stimulus was presented for 183 ms in either the RVF or LVF. This sequence is graphically illustrated in Figure 5.2.4.1.

Figure 5.2.4.1. Illustration of the sequence of stimulus presentation. (N.B. not drawn to scale).



Subjects were instructed to respond in the following manner. If the lateralized stimulus did not match any of the shapes contained in the pattern they were to press the NO button. If the lateralized stimulus did match one of the shapes in the pattern subjects were instructed to scan from the centre of the briefly presented shape to the centre of the corresponding shape in the pattern. On reaching the target stimulus they were to press the YES button. (See Appendix IV for verbatim instructions to subjects). Sixteen practice trials, eight positive and eight negative, were given using a pattern (and its mirror image) not employed on the experimental trials. The order of both the practice and experimental trials was randomized.

Subjects were instructed to respond as quickly and as accurately as possible, and the importance of maintaining central fixation whenever the fixation cross was on the screen was stressed both in the initial instructions and throughout the trials themselves. If an incorrect response was made a warning tone was emitted and the words "wrong response" were visually displayed. No feedback was given on correct responses. Response latencies exceeding three seconds were treated as errors.

At the end of the experiment subjects were thanked for their participation and fully debriefed. As in the preceding studies, it was decided to exclude any subjects who responded correctly to less than 70% of the trials. However, none of the subjects' performances fell below this threshold.

5.3 Results

Mean reaction times for correct responses and number of correct trials for each subject comprised the data upon which the statistical analyses reported below were performed. Trials in which reaction times exceeded three seconds were treated as errors. These data averaged across subjects are presented in Table 5.3.1 with standard deviations.

Table 5.3.1. Mean RTs (ms) and number correct with standard deviations as a function of distance for each visual field. (NM = no matching shape in pattern).

RVF				
	NM	**6 cm**	**9 cm**	**12 cm**
Mean RTs	1239	1189	1229	1246
SD	277	272	282	302
No. Correct	22.47	7.25	7.32	7.40
SD	0.50	0.87	0.73	0.90
LVF				
	NM	**6 cm**	**9 cm**	**12 cm**
Mean RTs	1228	1191	1197	1244
SD	297	289	285	282
No. Correct	22.82	7.42	7.47	7.52
SD	0.34	0.84	0.71	0.71

Reaction Times

Initially data for correct positive responses were analyzed using a two-way ANOVA with distance (6 cm, 9 cm, 12 cm) and visual field (RVF and LVF) as repeated factors. A significant main effect was found for distance ($F(2,78) = 5.48$, $p < .01$). Moreover, the empirical F value still reached significance following adjustment of the degrees of freedom by the average of the Greenhouse-Geisser Epsilon (.88) and the Huynh-Feldt Epsilon (.92) in order to control for possible violations of sphericity ($F(2,70) = 5.48$, $p < .01$). The mean RTs at 6 cm, 9 cm and 12 cm were 1190 ms, 1213 ms and 1245 ms respectively.

A trend analysis was performed on this main effect, revealing a significant linear trend ($F_{linear}(1,39) = 7.99, p < .01$), but no significant quadratic trend. No significant main effect was found for visual field and the interaction between distance and visual field did not reach significance.

Mean RTs for correct negative responses were analyzed using a one-way ANOVA with visual field as a within-subjects factor. No significant effect was found.

Accuracy

The accuracy data were analyzed using a two-way ANOVA with condition (not matching and matching from 6 cm, 9 cm and 12 cm) and visual field as repeated measures. (Once again it was necessary to scale down the number correct in the not matching condition by a factor of three, as this condition involved a possible maximum score of twenty-four as opposed to eight in each of the matching conditions).

No main effects or interactions reached significance.

5.4 Discussion

The analyses revealed that, as predicted, mean reaction times increased linearly with increasing distance. Moreover, no significant quadratic trend was found, as perhaps would be expected given that performance on this task would not be affected by the accuracy of remembered locations of the shapes contained in the pattern.

There was, however, no evidence from either the reaction time or error data of any visual field asymmetry. Thus, it would appear that the putative effect found by French and Brightwell is not due to processes involved in scanning generally. It simply remains, therefore, to establish whether performance asymmetries are evident on the imaginal version of the task.

CHAPTER SIX

6. EXPERIMENT FIVE

6.1 Introduction

The task used in this study was precisely the same as that described in the previous chapter, with the exception of the timing of the presentation of the stimuli. Specifically, for the imaginal version of the task the patterns were presented in free vision for five seconds, followed by a three second fixation field. The lateralized stimulus was then presented briefly in the RVF or LVF.

It was hypothesized that reaction times would be linearly related to the distance separating the lateralized stimulus and the target stimulus, and that reaction times and/or errors would vary as a function of visual field.

6.2 Method

6.2.1 Subjects

Forty subjects participated in the experiment, 29 females and 11 males. They were all undergraduates who were right-handed by self-report with normal or corrected to normal vision, and they were aged between eighteen and fifty-one years of age (mean age 27.7 years, SD 8.64).

6.2.2 Apparatus

The stimuli in this study were generated using the Micro Experimental Laboratory software package. All other details for this section are identical to those reported in Chapter Two.

6.2.3 Stimuli

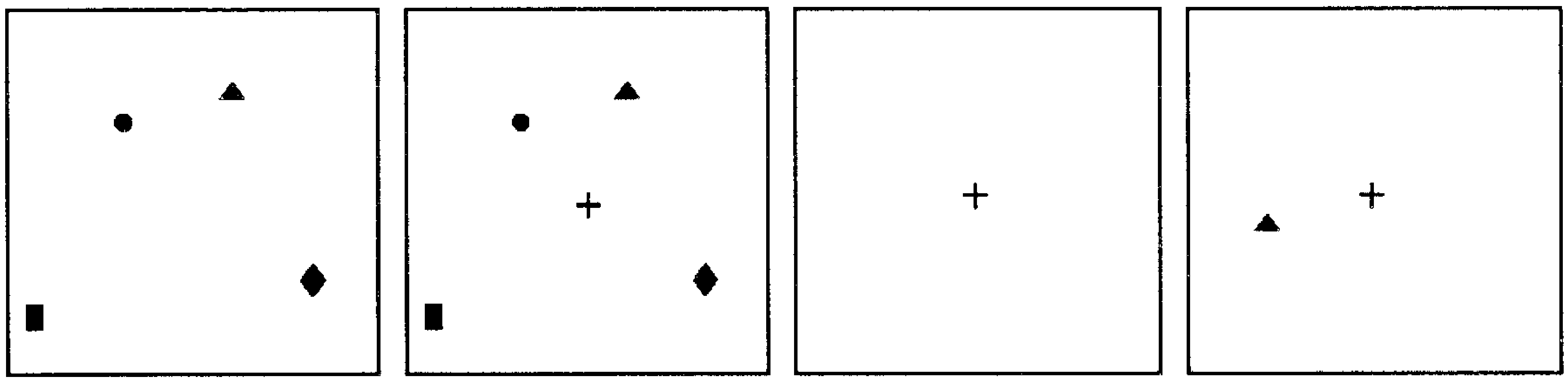
Details for this section are identical to those reported in Chapter Five.

6.2.4 Procedure

On each trial the pattern was presented in free vision for five seconds, and subjects were instructed that they were to try to remember the position of each shape by forming an image of the pattern exactly as it appeared on the screen. After four seconds of the presentation period had elapsed a black cross was presented at the centre of the field, and this was the cue for subjects to fixate centrally by staring directly at the centre of the black cross. The pattern then disappeared from the screen, and the fixation cross was presented for an additional three seconds. At the end of this period a geometric shape was presented for 183 ms in either the RVF or LVF. (This sequence of events is graphically illustrated overleaf in Figure 6.2.4.1).

Subjects were instructed to respond in the following manner. If the lateralized stimulus did not match any of the shapes contained in the pattern they were to press the NO button. If the lateralized stimulus did match one of the shapes in the pattern subjects were instructed to mentally scan across the image from the centre of the briefly presented shape to the corresponding shape in the pattern. On reaching the target stimulus they were to press the YES button. (See Appendix V for verbatim instructions to subjects).

Figure 6.2.4.1. Illustration of the sequence of stimulus presentation. (N.B. not drawn to scale).



Three subjects who responded correctly to less than 70% of the trials were excluded from the analysis. Once again, however, the excluded subjects were replaced in order to ensure complete counterbalancing. All other details for this section are identical to those reported in Chapter Five.

6.3 Results

Mean reaction times for correct responses and number of correct trials for each subject comprised the data upon which the statistical analyses reported below were performed. Trials in which reaction times exceeded three seconds were treated as errors. These data averaged across subjects are presented in Table 6.3.1 with standard deviations.

Table 6.3.1. Mean RTs (ms) and number correct with standard deviations as a function of distance for each visual field. (NM = no matching shape in pattern).

RVF				
	NM	**6 cm**	**9 cm**	**12 cm**
Mean RTs	1388	1558	1525	1580
SD	267	352	348	385
No. Correct	21.66	7.05	6.87	6.67
SD	0.74	1.13	1.26	1.07
LVF				
	NM	**6 cm**	**9 cm**	**12 cm**
Mean RTs	1352	1486	1551	1573
SD	247	384	375	336
No. Correct	21.75	7.32	6.97	6.92
SD	0.79	0.76	1.14	1.11

Reaction Times

Initially data for correct positive responses were analyzed using a two-way ANOVA with distance (6 cm, 9 cm, 12 cm) and visual field (RVF and LVF) as repeated factors. A marginally significant main effect was found for distance ($F(2,78) = 2.93$, $p < .06$). (Following adjustment of the degrees of freedom by the average of the Greenhouse-Geisser Epsilon (.89) and the Huynh-Feldt Epsilon (.93) the relevant values were $F(2,71) = 2.93$, $p < .07$). The mean RTs at 6 cm, 9 cm and 12 cm were 1521 ms, 1538 ms and 1576 ms respectively.

A trend analysis was performed on this marginally significant main effect, revealing a significant linear trend ($F_{linear}(1,39) = 4.15$, $p < .05$) but no significant quadratic trend. No significant main effect was found for visual field and there was no significant interaction between distance and visual field.

Mean RTs for correct negative responses were analyzed using a one-way ANOVA with visual field as a within-subjects factor. A significant difference was found (F(1,39) = 4.65, $p < .05$), with subjects responding significantly faster when the lateralized stimulus was presented in the LVF (mean RT 1352 ms) than in the RVF (mean RT 1388 ms).

Accuracy

The accuracy data were analyzed using a two-way ANOVA with condition (not matching and matching from 6 cm, 9 cm and 12 cm) and visual field as repeated measures. (Once again it was necessary to scale down the number correct in the not matching condition by a factor of three, as this condition involved a possible maximum score of twenty-four as opposed to eight in each of the matching conditions).

A significant main effect was found for condition (F(3,117) = 3.07, $p < .05$). Moreover, the empirical F value still reached significance following adjustment of the degrees of freedom by the average of the Greenhouse-Geisser Epsilon (.91) and the Huynh-Feldt Epsilon (.98), (F(3,110) = 3.07, $p < .05$). A modified version of the Tukey test appropriate for use with repeated measure factors revealed that only the difference between the Not Matching condition and the 12 cm condition was significant.[1] The results of this analysis are summarized in Table 6.3.2.

Table 6.3.2. Mean no. correct and pairwise differences between means for the Not Matching, 6 cm, 9 cm and 12 cm conditions. (The observed F_{Tukey} value for each pairwise comparison is given in parentheses).

	NM	**6 cm**	**9 cm**	**12 cm**
Mean	7.23	7.18	6.92	6.80
6 cm	0.05 (0.10)			
9 cm	0.31 (2.43)	0.26 (2.82)		
12 cm	0.43 (6.81)*	0.38 (6.10)	0.12 (0.56)	

*$p < .05$, $[F_{Tukey}(4,117) = 6.77]$

A marginally significant main effect was also found for visual field ($F(1,39) = 3.54$, $p < .07$), with subjects responding more accurately following LVF presentation (mean no. correct 7.11) than RVF presentation (mean no. correct 6.95).

The interaction between visual field and condition did not reach significance.

6.4 Discussion

The analyses revealed that, as predicted, mean reaction times increased linearly with increasing distance. Moreover, the absence of a significant quadratic trend replicates the findings of the previous study, and provides further support for the

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[1] The majority of multiple comparison tests use the MS_{error} from the overall analysis as the error term. Numerous researchers, however, have observed that this procedure is inappropriate with repeated measures factors (e.g. Keppel, 1982), since in this instance the error term should be based on only those conditions involved in a particular comparison. The above procedure, recommended by Lehman (1991, pp.385-388), limits the error rate according to the rules for the Tukey procedure, but the error estimate for each contrast is based only on the conditions involved in the comparison.

view that the quadratic trend reported in Chapter Four was determined by the uncertainty associated with the angular orientation of the arrow stimulus. A significant main effect for distance was also found for the error data, with subjects responding significantly less accurately in the 12 cm condition than in the Not Matching condition. This would perhaps be expected on the basis of task difficulty.

Of most interest, however, were the findings relating to visual field. For the reaction time data, for example, a significant difference was found for visual field on the negative responses, with subjects responding significantly faster when the lateralized stimulus was presented in the LVF than when it was presented in the RVF. Furthermore, the error data also revealed a marginally significant main effect for visual field, with subjects responding more accurately on LVF presentations than on RVF presentations. Thus, in contrast to the French and Brightwell (1989) experiment, the results of the current study appear to indicate a RH superiority for task performance.

More detailed consideration of the visual field effects, however, would appear to cast doubt on the possibility that the scanning component of the task was responsible for this superiority. The LVF advantage on the reaction time data, for example, was specific to negative responses, and given that on this type of trial there was no requirement to scan across the image this appears to indicate that the effect is related to some other aspect of the task. Similarly, on the error data the absence of a significant interaction indicates that the visual field advantage did not vary as a function of whether the trial was positive or negative, again suggesting that the scanning component was not responsible for the RH superiority.

Unfortunately this study does not by itself allow inferences to be drawn regarding which aspect of the task the asymmetry is related to. Nevertheless, in this respect it is relevant to note that the previous experiment reported in Chapter Five revealed no asymmetries on the perceptual version of the task. This suggests, therefore, that the effect is associated with task components specific to the imagery system. For example, the RH may simply be better at maintaining a more accurate imaginal representation of the relative positions of the different shapes in the pattern, thereby facilitating faster and more accurate performance of the matching procedure. Alternatively, the RH may simply be more adept at maintaining an accurate imaginal representation of each of the component shapes comprising the pattern.

Irrespective of the possible components responsible for the RH advantage, however, it is apparent that these results provide no support whatsoever for French and Brightwell's (1989) claims regarding the lateralization of the scanning component. Nevertheless, it should perhaps be noted that one possible argument that could be advanced against this conclusion relates to the absence of a visual field advantage on the reaction time data for positive trials. Given that the computational approach regards the performance of any one hemisphere as reflecting the product of the component asymmetries, it could perhaps be argued that the putative LH advantage on the scanning component in effect cancelled out the RH advantage on other aspects of the task. Consequently there was no observable asymmetry on the trials involving scanning, but a RH superiority prevailed on the negative trials when scanning was not required. This argument, however, is clearly somewhat speculative, and it fails to provide an explanation of why a LH advantage was found in the French and Brightwell (1989) study but was not evident on the image scanning tasks reported in Chapter Three, Chapter Four and the current study. Indeed given the consistency of the findings overall, it would seem that the most parsimonious conclusion to draw is that image scanning is bilaterally represented.

On a theoretical note, however, it is important to stress that these findings do not in any way detract from the validity of the computational approach to cerebral asymmetry. As noted in Section 1.1.5, for instance, it is possible that within any one cognitive system some processing subsystems may be lateralized to the LH, some to the RH and some bilaterally represented. Thus the findings perhaps best serve to illustrate the danger of attempting to derive general principles that purportedly apply to all subprocessors from studies confined to a single processing component. Indeed in this respect it should perhaps be noted that whilst these results can be accommodated within a computational perspective, they do appear to cast doubt on certain aspects of Kosslyn's theoretical speculations regarding the neural distribution of the imagery system (Kosslyn, 1987; Kosslyn, Flynn, Amsterdam and Wang, 1990).

As noted previously, for example, Kosslyn has argued that subsystems that make use of categorical representations will be stronger and more effective in the LH, whereas subsystems that make use of coordinate representations will be stronger and more effective in the RH. Furthermore, Kosslyn, also states that "scanning should not require use of categorical representations" (Kosslyn, 1987, p. 167). Thus according to this view the image scanning component should be lateralized to the RH. The absence of any evidence to support this claim, therefore, would appear to indicate that contrary to Kosslyn's proposals it is not possible to predict the laterality of a particular processing component from knowledge of the type of representation that is supposedly being utilized. Moreover, this inconsistency necessarily raises a question mark over the validity of other aspects of Kosslyn's model.

CHAPTER SEVEN

7. EXPERIMENT SIX

7.1 Introduction

As noted in Section 1.6.2, Kosslyn's theoretical model of hemispheric specialization has stimulated a great deal of ongoing research. The vast majority of this work, however, has addressed the issue of whether or not there are asymmetries in spatial relations at the perceptual level. Less attention has been paid to the claim that comparable laterality effects will prevail at the imaginal level. There are, of course, some single case studies of patients with unilateral brain damage which appear to provide evidence in support of this claim (Deleval, De Mol and Noterman, 1983; Grossi, Orsini, Modafferi and Liotti, 1986), but relatively few studies have addressed this issue using normal subjects and those that have are not without problems.

For example, as noted previously, Kosslyn (1988) and Findlay, Ashton and MacFarland (1994) reported evidence consistent with the view that the LH is specialized for generating images from categorically stored information, whereas both hemispheres are equally adept at generating images from information which has been globally stored. However, Kosslyn's findings were presented without detailed report of the procedures and analyses necessary for evaluation. Conversely, the study carried out by Findlay and his colleagues involved information input via the haptic modality, and it is a moot point whether representations derived tactually can be regarded as being identical to those stored in long-term visual memory (e.g. Farah, 1988). Overall, therefore, despite the fact that the proposed asymmetry in spatial relations forms the crux of Kosslyn's theory regarding imaginal processes, the evidence in support of this view is less than robust.

Given the above considerations and the doubts raised in the preceding chapter it was, therefore, decided to attempt to assess whether the proposed lateralization of categorical and coordinate spatial relations was evident at the image generational level. Prior to describing the current study, however, it might perhaps be helpful at this stage to reiterate the major points of Kosslyn's theoretical formulations. According to this model both hemispheres have access to stored descriptions in the brain detailing the component parts of objects, and both hemispheres can generate multipart images from these component parts. They differ, however, in terms of the type of spatial relations which are used to depict the relationships between the component parts. Specifically, the LH is thought to be specialized for categorical spatial relations which capture what is stable across instances that may differ in terms of metric units, thereby facilitating recognition of mutable objects. Conversely, the RH is thought to be specialized for coordinate spatial relations which specify the precise locations of the component parts in terms of metric units, and are thought to be important when recognition is contingent on precise spatial relations.

Kosslyn (e.g. 1987, 1988) has argued strongly that letters of the alphabet, which obviously can come in many different fonts, will normally be represented categorically, thereby facilitating recognition of novel variants. Thus it follows that image generation letter classification tasks which require no evaluation of the precise spatial relations between the component parts of letters should be carried out most effectively by the LH. For letter classification tasks which do require such an evaluation, however, a RH superiority would be expected since in this instance coordinate images should be most effective.

In order to test this hypothesis two imagery tasks were used. In the categorical task a lowercase letter was presented briefly in either the RVF or LVF and subjects were required to respond as to whether the uppercase version of this letter contained any curved segments or only had straight lines. In the coordinate task the procedure was exactly the same but the subjects were required to respond as to whether the uppercase version of the letter was symmetrical or asymmetrical along the vertical midline axis. In order to enable assessment of whether any observed asymmetries were specific to the image generation component, perceptual analogues of the two tasks, in which the subjects were presented directly with the uppercase versions of the letters, were also incorporated into the design.

In line with Kosslyn's theoretical formulations it was hypothesized that performance on the two imagery tasks would vary as a function of visual field.

7.2 Method

7.2.1 Subjects

Forty-eight subjects, 16 males and 32 females, took part in the experiment. They were all right-handed by self-report with normal or corrected to normal vision, and they were aged between 17 and 48 years of age (mean age 25.5 years, SD 8.98). Data from a further four subjects were not analyzed as detailed below.

7.2.2 Apparatus

The stimuli in this study were generated using the Micro Experimental Laboratory software package. Viewing distance was 55 cm from a chin-rest positioned in front of the screen. The visual angle subtended at the eye by the screen at this distance was 25.3° (24.5 cm) horizontally and 18.1° (17.5 cm) vertically. All other details for this section are identical to those reported in Chapter Two.

7.2.3 Stimuli

Twelve letters were selected for use in the categorical task. Six had uppercase versions containing only straight lines (E, F, H, N, T, A) and six had uppercase versions containing some curved lines (G, R, Q, B, J, U). For the coordinate task twelve letters were selected the uppercase versions of which were either symmetrical along the vertical midline axis (A, H, M, T, W, X) or asymmetrical (J, E, R, D, F, G).

Each letter was presented in black on a white background at a distance of 3° from the central fixation point along the horizontal meridian. The height of each letter was approximately 1 cm, and at a viewing distance of 55 cm each letter therefore subtended a visual angle of 1°. The fixation field consisted of a black cross located in the centre of the visual field on a white background.

7.2.4 Procedure

Viewing conditions, presentation of instructions, mode of response and counterbalancing of response hand and fingers were identical in all respects to the details reported in the first paragraph of the procedure section in Chapter Two.

The trials were constructed as follows. Each subject carried out two blocks of trials corresponding to the imagery and perceptual conditions. The order of presentation of the two conditions was counterbalanced. Furthermore, within each block the order of two sub-blocks of trials corresponding to the categorical task and the coordinate task were also counterbalanced. At the beginning of each sub-block of trials the experimental instructions for the task were presented on the display screen for the subjects to read, and they were encouraged to ask the experimenter if they required any clarification. Within each sub-block eight practice trials were given prior to the commencement of forty-eight experimental trials. Each letter was presented on eight experimental trials, four in the imagery condition and four in the perceptual condition. Within these four trials there were two LVF presentations and two RVF presentations. The order of both the practice and experimental trials was randomized.

The procedure in the imagery-coordinate sub-block was as follows. At the beginning of each trial the fixation cross was presented, and this served as the cue for subjects to fixate centrally. 1500 ms after the onset of the fixation cross a lowercase letter was presented for 150 ms in either the RVF or LVF. Subjects were instructed to press the YES button if the uppercase version of this letter was symmetrical along the vertical midline axis, and the NO button if it was not. The procedure in the imagery-categorical sub-block was exactly the same as in the imagery-coordinate sub-block apart from the fact that subjects were instructed to press the YES button if the uppercase version of the letter contained any curved lines, and the NO button if it did not. In the perceptual condition the procedure differed only in so far as the uppercase versions of the letters were presented in place of the lowercase versions. (See Appendix VI for verbatim instructions to subjects).

Subjects were instructed to respond as quickly and as accurately as possible. If an incorrect response was made a warning tone was emitted and the words "Wrong Response" were visually displayed. As in previous studies, the importance of maintaining central fixation whenever the fixation cross was on the screen was stressed both in the initial instructions and throughout the trials themselves. At the end of the experiment the subjects were thanked and fully debriefed. Four subjects who responded correctly to less than 80% of the trials were excluded from the analysis. Once again, however, these excluded subjects were replaced in order to ensure complete counterbalancing.

7.3 Results

Mean reaction times for correct responses and mean number correct for each subject comprised the data upon which the statistical analyses reported below were performed. Trials on which reaction times exceeded three seconds were treated as errors. These data, averaged across subjects, are presented in Tables 7.3.1 and 7.3.2 with standard deviations.

Table 7.3.1. Mean RTs (ms) and number correct with standard deviations in the Imagery condition, as a function of type of response for each visual field for the categorical task and the coordinate task.

IMAGERY - CATEGORICAL	RVF		LVF	
	YES	NO	YES	NO
Mean RTs	794	815	817	810
SD	280	246	281	254
No. Correct	11.04	10.31	11.21	10.77
SD	1.25	1.96	1.03	1.70
IMAGERY - COORDINATE	**RVF**		**LVF**	
	YES	NO	YES	NO
Mean RTs	714	770	685	748
SD	169	172	159	151
No. Correct	10.90	10.87	11.17	10.87
SD	1.64	1.42	1.43	1.79

Table 7.3.2. Mean RTs (ms) and number correct with standard deviations in the Perceptual condition, as a function of type of response for each visual field for the categorical task and the coordinate task.

PERCEPTUAL - CATEGORICAL	RVF		LVF	
	YES	NO	YES	NO
Mean RTs	505	515	507	528
SD	149	158	175	158
No. Correct	11.31	11.40	11.08	11.27
SD	0.90	0.84	1.05	1.09
PERCEPTUAL - COORDINATE	**RVF**		**LVF**	
	YES	**NO**	**YES**	**NO**
Mean RTs	521	567	536	586
SD	133	137	126	158
No. Correct	11.27	10.98	11.33	11.02
SD	0.96	1.06	1.02	1.21

Reaction Times

Initially data were analyzed using a four-way repeated measures ANOVA, with condition (imagery vs. perceptual), visual field (RVF vs. LVF), type of task (categorical vs. coordinate) and type of response (positive vs. negative) as factors. A significant main effect was found for condition ($F(1,47) = 186.35, p < .001$), with subjects producing significantly longer RTs in the imagery condition (mean RT 769 ms) than in the perceptual condition (mean RT 533 ms). In addition a significant main effect was found for type of response ($F(1,47) = 18.10, p < .001$), with subjects producing significantly faster responses on positive trials (mean RT 634 ms) than on negative trials (mean RT 667 ms).

A significant interaction was obtained between condition and type of task, F(1,47)

= 15.01, p < .001. (See Figure 7.3.1 for graphical illustration). The mean RTs in the imagery condition for the categorical task and the coordinate task were 809 ms and 729 ms respectively, whereas in the perceptual condition the mean RTs for the categorical task and the coordinate task were 513 ms and 552 ms respectively. Simple effects analysis, with the criterion value for statistical significance set at .0125, revealed that the RTs for the categorical task and the coordinate task in the imagery condition differed significantly (F(1,47) = 9.69, p < .005), whereas those in the Perceptual condition did not.

Figure 7.3.1. Graphical illustration of the significant interaction between condition and type of task.

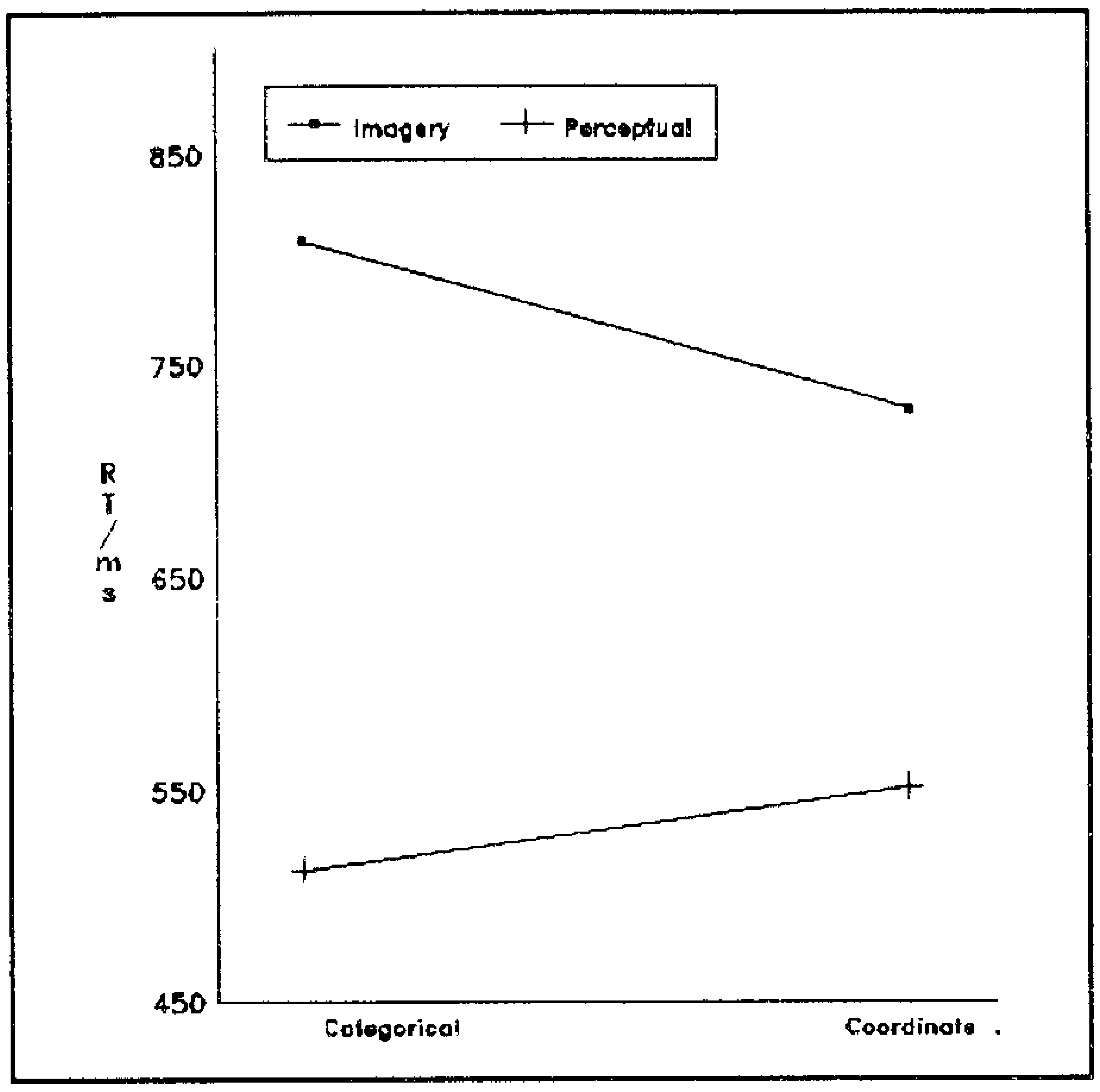
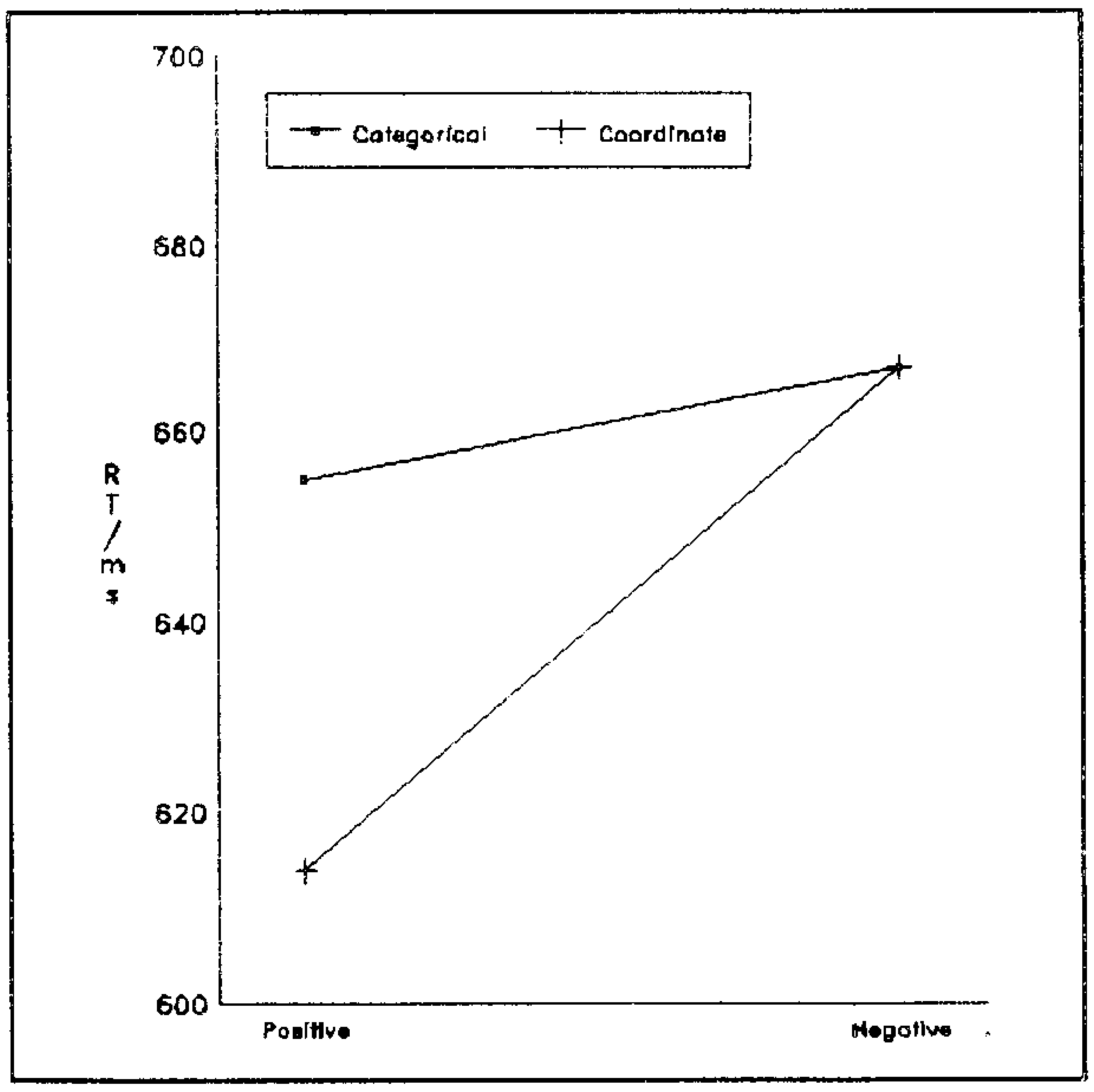


Figure 7.3.2. Graphical illustration of the significant interaction between type of task and type of response.



A significant interaction was also obtained between type of task and type of response, F(1,47) = 10.16, p < .005. (See Figure 7.3.2 for graphical illustration). The mean RTs on the coordinate task for positive and negative response were 614 ms and 667 ms respectively, whereas on the categorical task the mean RTs for positive and negative responses were 655 ms and 667 ms respectively. Simple effects analysis, with the criterion value for statistical significance set at .0125, revealed that only the RTs for positive and negative responses on the coordinate task differed significantly (F(1,47) = 29.29, p < .001).

No other main effects or interactions reached significance.

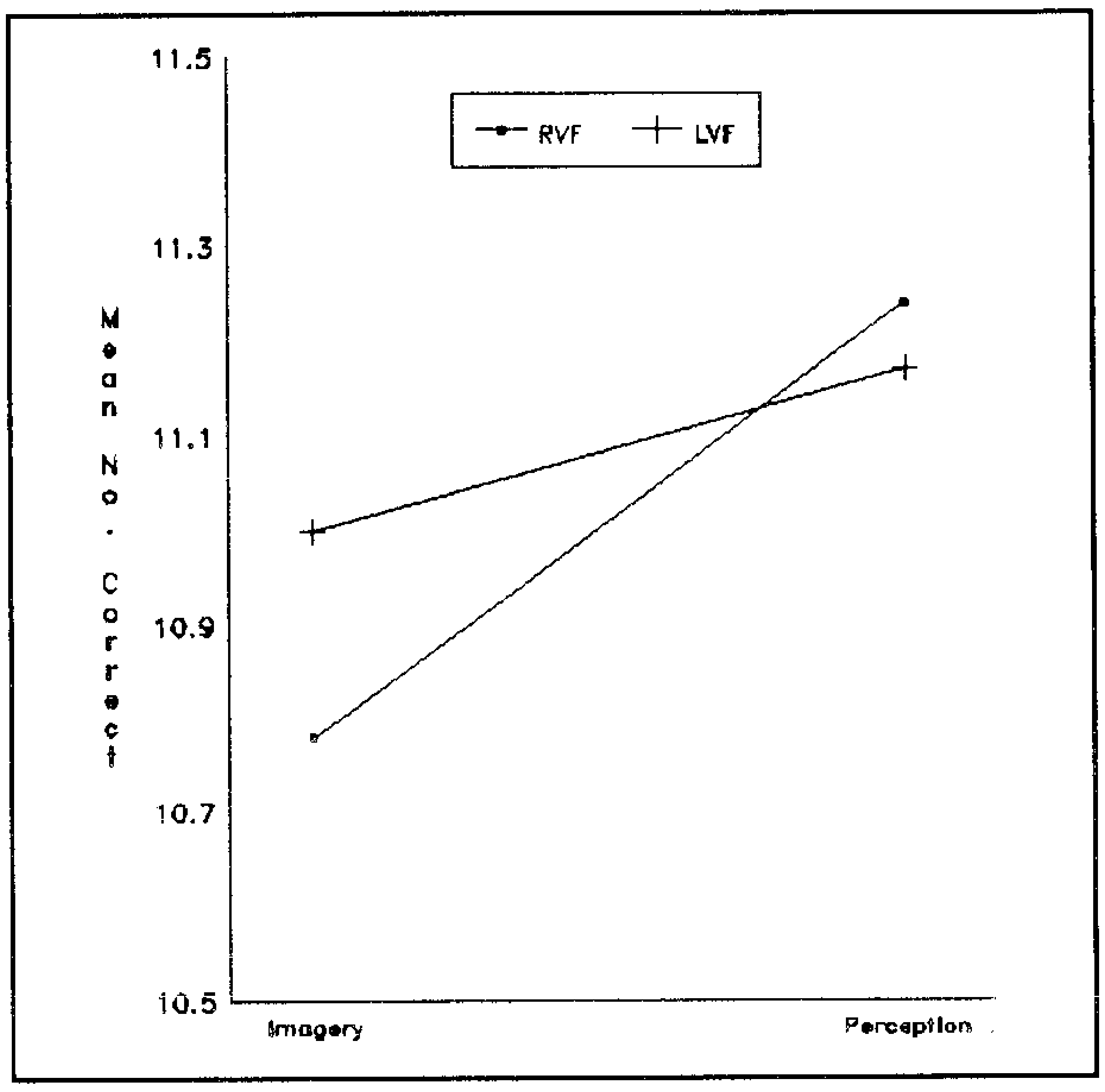
Accuracy

Initially data were analyzed using a four-way repeated measures ANOVA, with condition (imagery vs. perceptual), visual field (RVF vs. LVF), type of task (categorical vs. coordinate) and type of response (positive vs. negative) as factors.

A significant main effect was found for condition, F(1,47) = 5.91, p < .025, with subjects responding significantly more accurately in the perceptual condition (mean no. correct 11.20) than in the imagery condition (mean no. correct 10.89). In addition a significant main effect was found for type of response, F(1,47) = 4.90, p < .05, with subjects responding significantly more accurately on positive responses (mean no. correct 11.16) than on negative responses (mean no. correct 10.93).

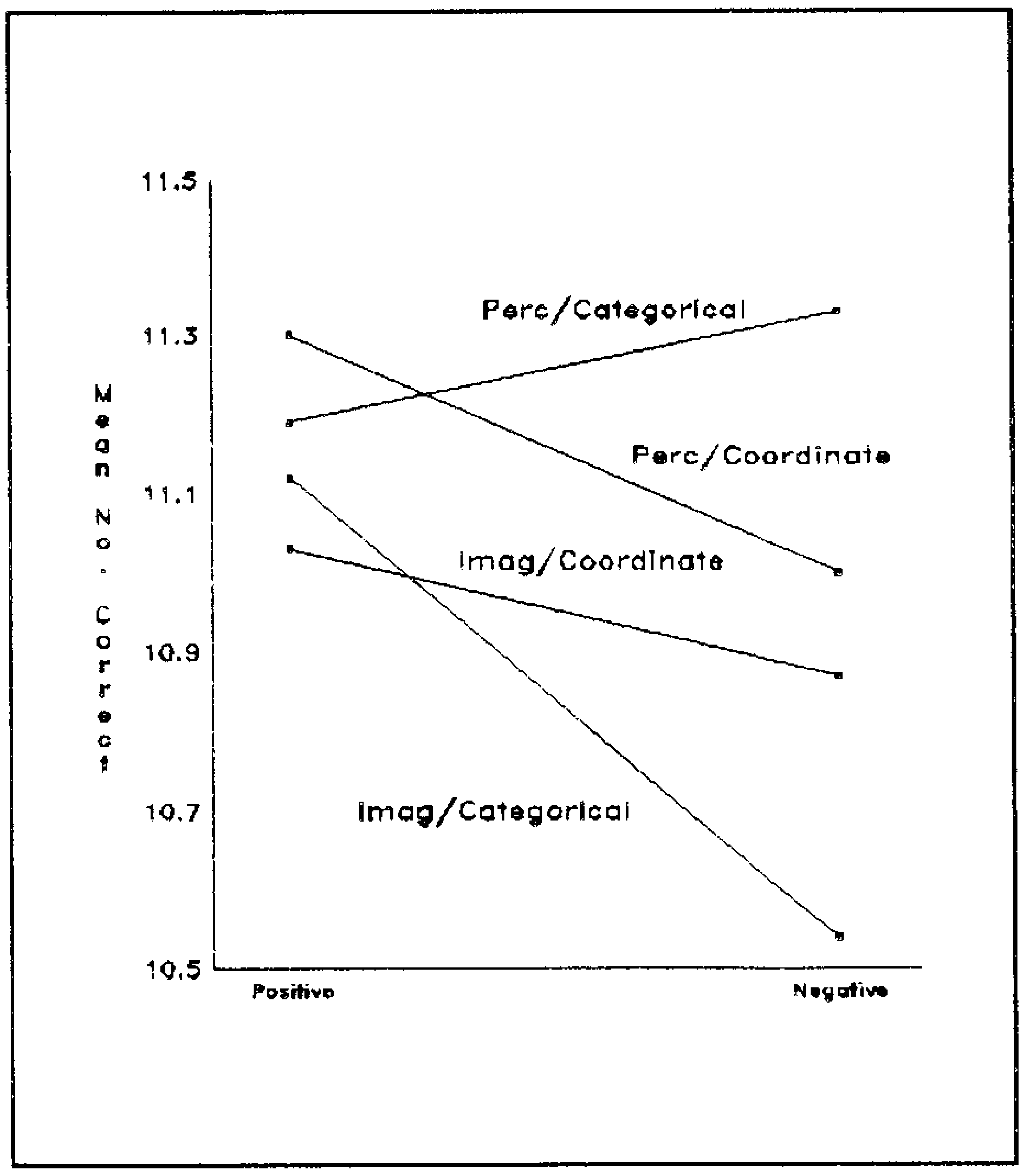
A significant interaction was obtained between condition and visual field, F(1,47) = 4.84, p < .05. (See Figure 7.3.3 for graphical illustration). The mean no. correct on RVF presentations in the imagery and perceptual condition were 10.78 and 11.24 respectively, whereas for LVF presentations in the imagery and perceptual conditions the mean no. correct were 11.00 and 11.17 respectively. Simple effect analysis, with the criterion value for statistical significance set at .0125, revealed that only the mean no. correct for the imagery and perceptual conditions on RVF presentations differed significantly (F(1,47) = 11.11, p<.01.

Figure 7.3.3. Graphical illustration of the significant interaction between condition and visual field.



Finally, a significant interaction was also obtained between condition, type of task and type of response, (F(1,47) = 9.27, p<.01. (See Figure 7.3.4 for graphical illustration). The mean no. correct in the imagery condition for the categorical task were 11.12 for positive responses and 10.54 for negative responses, whereas for the coordinate task the mean no. correct were 11.03 for positive responses and 10.87 for negative responses. In the perceptual condition the mean no. correct for the categorical task were 11.19 for positive responses and 11.33 for negative responses, whereas for the coordinate task the mean no. correct were 11.30 for positive responses and 11.00 for negative responses. Simple effects analysis, with

Figure 7.3.4. Graphical illustration of the significant interaction between condition, type of task and type of response.



the criterion value for statistical significance set at .0125, revealed that only the mean no. correct for positive and negative responses on the categorical task in the imagery condition differed significantly, F(1,47) = 6.55, $p < .0125$.

No other main effects or interactions reached significance.

7.4 Discussion

Initial analyses of the data revealed that mean reaction times and number of errors were significantly greater for the imagery condition than for the perceptual condition, as would be expected on the basis of task difficulty. Furthermore, the reaction time and accuracy data also revealed a significant main effect for type of trial, with subjects responding faster and more accurately on positive trials than on negative. As regards interactions, the reaction time data revealed that the coordinate task and the categorical task differed significantly as a function of both condition and type of trial. Moreover, with respect to the accuracy data, a significant interaction was revealed between condition, type of task and type of trial. Of most interest, however, was the significant interaction obtained on the accuracy data which indicated that responses in the imagery condition and the perceptual condition differed as a function of visual field.

Further analysis of this latter interaction revealed that whilst there was no difference in accuracy on LVF presentations between the imagery and perceptual conditions, subjects responded significantly more accurately on RVF presentations in the perceptual condition than in the imagery condition. The tasks in the perceptual condition required all of the cognitive processing components required by the tasks in the imagery condition, apart from image generation. Thus, given that the observed effect cannot be attributed to differences in cognitive processing components which are involved in both conditions, it would appear that the decrement in LH performance in the imagery condition is associated with the introduction of the image generation processing component.

It is important to stress, however, that demonstrating that the LH is less adept at performing the imagery tasks than the perceptual tasks is not evidence of a RH specialization for image generational processes. In order to demonstrate RH superiority it would be necessary to show that the RH performed better than the LH in the imagery condition, and no such evidence was obtained. Nevertheless, it is still noteworthy that the introduction of the image generation processing component had a deleterious effect on LH performance but not on RH performance. Moreover, what is perhaps of more interest, is that this visual field effect prevailed irrespective of the type of task being performed. Thus, contrary to Kosslyn's claims there would appear to be no evidence in support of the view that the two cerebral hemispheres are specialized for the generation of different types of visual images.

However, whilst type of task did not interact significantly with visual field it was found to vary as a function of other factors in the analysis. With respect to the reaction time data, for instance, it was found that type of task interacted significantly with condition. Although no difference was found between the two tasks in the perceptual condition, subjects responded significantly faster on the coordinate task than on the categorical task in the imagery condition. It is not clear why this effect prevailed. It may, for instance, simply be more difficult to generate the type of representations utilized in categorical judgements than in coordinate judgements. Alternatively it may reflect the fact that the type of information required in order to perform a coordinate evaluation is more readily accessed from an imaginal representation than the type of information required to perform a categorical evaluation. Irrespective of which, if either, of these two accounts is correct, however, the important point to stress is that there was no evidence to suggest that the two hemispheres were differentially influenced by these factors.

Similar considerations apply to the remaining two significant interactions revealed by the analysis. It was found, for instance, that type of task interacted significantly with type of trial. Although no difference was found between positive and negative responses for the categorical task, subjects responded significantly faster on positive trials than on negative trials on the coordinate task. Similarly, the accuracy data revealed that subjects were significantly less accurate on negative trials than on positive trials on the categorical task. In this instance, however, the effect was confined to the imagery condition since no difference was found between the positive and negative responses for perceptual-categorical, perceptual-coordinate or imagery-coordinate trials. Unfortunately it is not clear why these effects prevailed. No simple interpretation suggests itself and it is questionable whether lengthy speculations regarding possible explanations for this pattern of results would contribute anything meaningful to the discussion. Suffice to say, therefore, that once again there was no evidence to suggest that the two hemispheres were differentially influenced by these factors.

To summarize, it would appear that there is no evidence to support the view that the two cerebral hemispheres are differentially specialized for the generation of different types of visual images. Indeed the findings appear to indicate that, irrespective of the type of task being performed, LH performance was adversely affected by the introduction of the image generation processing component whereas RH performance was not. Nevertheless, as noted earlier, this finding cannot be regarded as evidence in support of the view of a RH specialization for image generation. Moreover, given the labile nature of the results of divided visual field studies, it is perhaps inappropriate to attempt to draw definitive conclusions from the results of one experiment.

CHAPTER EIGHT

8. EXPERIMENT SEVEN

8.1 Introduction

The previous study failed to provide any evidence consistent with Kosslyn's claims regarding asymmetries in spatial relations at the image generational level. Nevertheless, it should perhaps be noted in this respect that the studies which have focused on asymmetries in spatial relations at the perceptual level have only really provided support for the claim that the RH is specialized for coordinate representations (see Section 1.6.2). The situation with regard to a LH specialization for categorical representations, however, is somewhat more equivocal, and Kosslyn and his colleagues have argued that this is because the LH effect is sufficiently small to only be detectable over a number of experiments (Kosslyn, Chabris, Marsolek and Koenig, 1992).

Moreover, the studies which have demonstrated a RH effect have used experimental paradigms in which subjects are required to make metric judgements. For example, in one of the studies reported by Kosslyn, Koenig, Barrett, Cave, Tang and Gabrieli (1989) subjects were required to make a categorical judgement by deciding whether a dot was above or below a line, and a metric distance judgement in which they had to decide whether the dot was less than or more than 3 mm from the line. The results revealed a RH advantage on the coordinate task, and, as detailed previously, this effect has been replicated in a number of other studies.

The above suggests, therefore, that perhaps evidence which is consistent with Kosslyn's claims will be more readily available from image generational tasks which require metric judgements. In this respect, a study carried out by Grossi and his colleagues with a patient (AP) who had a left occipital lesion would appear to be of relevance (Grossi, Modafferi, Pelosi and Trojano, 1989). AP was required to imagine what two times presented verbally would look like on a pair of clock faces, and then judge which of the times had the larger angle between the hands. In addition, AP carried out a perceptual control task in which he was presented directly with pairs of clock faces and again had to judge in which of these stimuli the hands formed the larger angle. The results revealed that although he performed well on the control task, on the imagery task his performance was below chance level, and this was interpreted as evidence in support of a LH specialization for image generation. However, given that simply being asked to indicate which of two angles is the larger can be construed as a categorical judgement, it could be argued that the findings support Kosslyn's claims that the LH is specialized for the generation of categorical images. Furthermore, if this argument is valid then it also follows that if the task was modified so that it required a metric rather than a categorical judgement then a RH advantage would be predicted.

In order to test this hypothesis a modified version of the clock test was employed.

In the imagery condition subjects were presented briefly with a time in digital form in either the RVF or LVF, and were required to judge whether the angle formed by the hands of a clock at this time was greater than or less than 90°. The perceptual condition differed only in so far as that a schematic clock face was presented in place of the digital time.

There were two initial hypotheses. First, as a metric judgement is required on both the imaginal and the perceptual task, it was hypothesized that a RH advantage would prevail overall. Second, performance on the imagery and perceptual tasks would be expected to vary as a function of visual field, since if the RH is specialized for the generation of coordinate images then the LH should be more adversely affected by the introduction of the image generation processing component than the RH.

8.2 Method

8.2.1 Subjects

Forty subjects, 21 males and 19 females, took part in the experiment. They were all right-handed by self-report with normal or corrected to normal vision, and they were aged between 18 and 42 years of age (mean age 25.2 years, SD 5.86). Data from a further five subjects were not analyzed as detailed below.

8.2.2 Apparatus

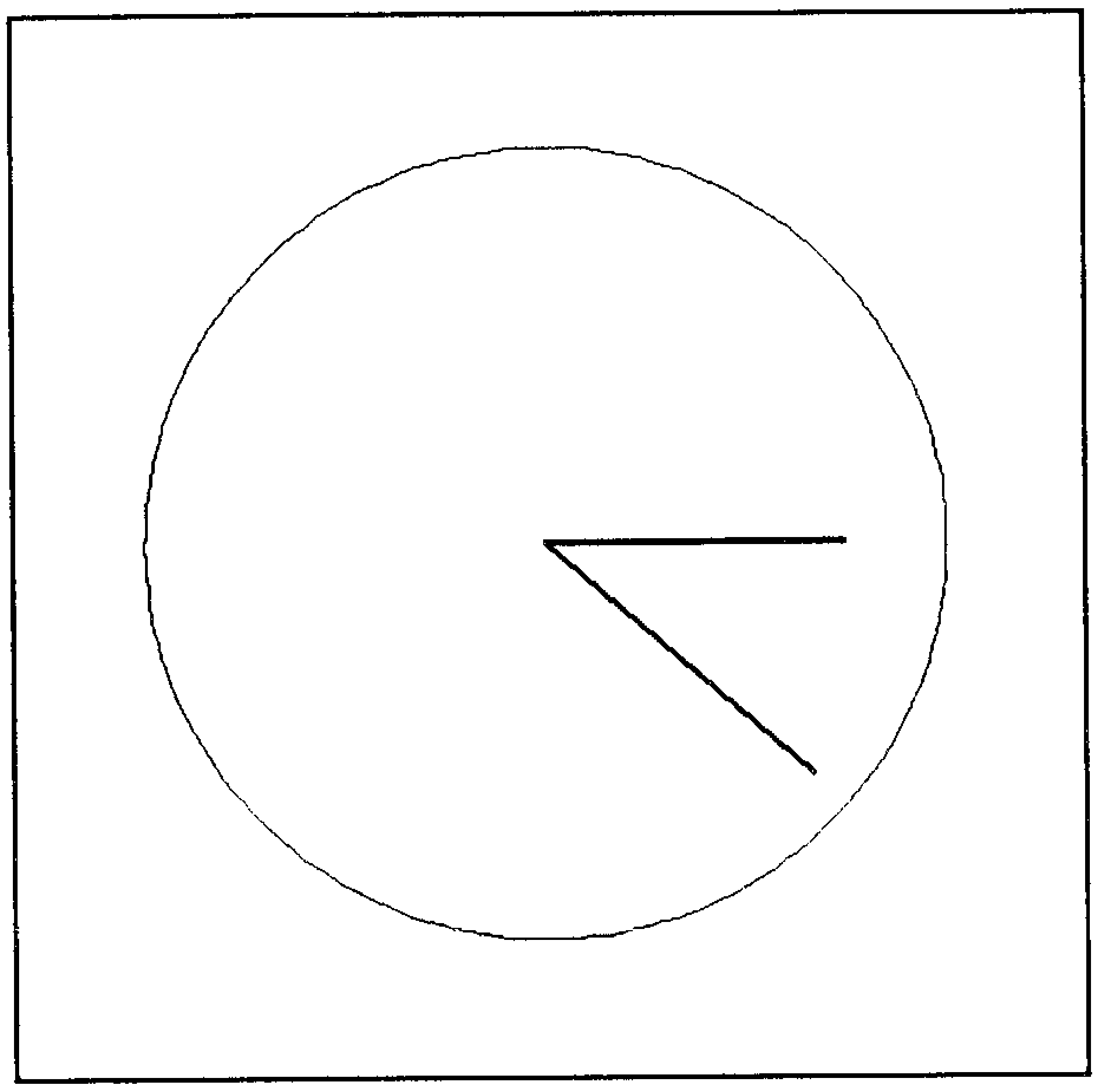
Details for this section are identical to those reported in Chapter Seven, with the exception that in the current study reaction times which exceeded four seconds were treated as errors.

8.2.3 Stimuli

In the imagery condition subjects were presented at the beginning of each trial with a fixation field which consisted of a black cross in the centre of the screen on a white background. Subsequently a time was presented briefly in digital form in either the RVF or LVF. All of the numbers comprising the time were presented in black and were positioned approximately 3 cm to the right or left of the fixation cross. This corresponds at a viewing distance of 55 cm to a visual angle of 3°. The height of each number was approximately 1 cm (1°).

The digital times involved only three positions of the hour hand, namely 3, 6 and 9. The minutes were always multiples of 5 and on trials in which the angle formed by the hands was less than 90° were located either 5 or 10 minutes clockwise or counter-clockwise from the location of the hour hand. On trials in which the angle formed by the hands was greater than 90° the minutes were located either 20 or 25 minutes clockwise or counter-clockwise from the location of the hour hand. All of the times, therefore, involved only three digits, with the hour digit separated from the minute digits by a full stop. Each time was approximately 2.5 cm in width, subtending a visual angle of 2.5°.

Figure 8.2.3.1. Graphical illustration of the schematic clock face used in the perceptual condition. (Not drawn to scale).



In the perceptual condition subjects were again presented at the beginning of each trial with the fixation field, but subsequently a schematic clock face was presented briefly in either the RVF or LVF. This was positioned approximately 3 cm (3°) to the right or left of the fixation cross and was 3 cm (3°) in diameter. The hour hand was 10 mm in length whereas the minute hand was 14 mm in length. These distances correspond to visual angles of 1° and 1.5° respectively. (See Figure 8.2.3.1 for graphical illustration of the clock face). The times presented in analogue form were precisely the same as those presented in digital form.

8.2.4 Procedure

Viewing conditions, presentation of instructions, mode of response and counterbalancing of response hand and fingers were identical in all respects to the details reported in the first paragraph of the procedure section in Chapter Two.

Each subject carried out both the perceptual and imagery conditions, the order of which were counterbalanced. At the beginning of each condition the experimental instructions for the task were presented on the display screen for the subjects to read, and they were encouraged to ask the experimenter if they required any clarification. Within each condition 12 practice trials were given prior to the commencement of 48 experimental trials. The order of both the practice and experimental trials was randomized.

The procedure in the imagery condition was as follows. At the beginning of each trial the fixation cross was presented, and this served as the cue for subjects to fixate centrally. 2000 ms after the onset of the fixation cross a time was presented in digital form for 167 ms in either the RVF or LVF. Subjects were instructed to press the YES button if the angle formed by the hands of a clock at this time was greater than 90°, and the NO button if it was less than 90°. In the perceptual condition the procedure differed only in so far as the schematic clock face was presented in place of the digital time. (See Appendix VII for verbatim instructions to subjects).

Subjects were instructed to respond as quickly and as accurately as possible. If an incorrect response was made a warning tone was emitted and the words "Wrong Response" were visually displayed. As in previous studies, the importance of maintaining central fixation was stressed both in the initial instructions and throughout the trials themselves. At the end of the experiment the subjects were debriefed and questioned concerning the strategies that they had employed in the imagery condition. Five subjects who responded correctly to less than 70% of the trials were excluded from the analysis. Once again, however, these excluded subjects were replaced in order to ensure complete counterbalancing.

8.3 Results

Mean reaction times for correct responses and number correct for each subject comprised the data upon which the statistical analyses reported below were performed. Trials on which reaction times exceeded four seconds were treated as errors. These data, averaged across subjects, are presented in Table 8.3.1 with standard deviations.

Table 8.3.1. Mean RTs (ms) and number correct with standard deviations as a function of type of response for each visual field for the imagery and perceptual conditions. (GT = Greater Than and LT = Less Than).

IMAGERY CONDITION	**RVF**		**LVF**	
	GT	**LT**	**GT**	**LT**
Mean RTs	3657	3636	3638	3569
SD	312	343	359	303
No. Correct	8.07	8.40	8.17	8.07
SD	2.54	2.35	2.80	2.37
PERCEPTUAL CONDITION	**RVF**		**LVF**	
	GT	**LT**	**GT**	**LT**
Mean RTs	2892	2862	2900	2846
SD	208	177	281	146
No. Correct	11.37	11.45	11.30	11.55
SD	1.03	0.74	0.99	0.71

Reaction Times

Data were analyzed using a three-way repeated measures ANOVA, with condition (imagery vs. perceptual), visual field (RVF vs. LVF) and type of response (greater than vs. less than) as factors. A significant main effect was found for condition, $F(1,39) = 232.66$, $p < .001$, with subjects responding significantly faster in the perceptual condition (mean RT 2875 ms) than in the imagery condition (mean RT 3625 ms). A significant main effect was also found for visual field, F(1,39) = 5.28, $p < .05$, with subjects responding significantly faster in the LVF (mean RT 3238 ms) than in the RVF (mean RT 3261 ms). Finally, a significant main effect was found for type of response, F(1,39) = 6.48, $p < .025$, with subjects producing significantly longer latencies on "greater than" responses (mean RT 3271 ms) than on "less than" responses (mean RT 3250 ms).

No interactions reached significance.

Accuracy

Data were analyzed using a three-way repeated measures ANOVA, with condition (imagery vs. perceptual), visual field (RVF vs. LVF) and type of response (greater than vs. less than) as factors. A significant main effect was found for condition, F(1,39) = 96.26, $p < .001$, with subjects responding significantly more accurately in the perceptual condition (mean no. correct 11.41) than in the imagery condition (mean no. correct 8.17).

No other main effects or interactions reached significance.

8.4 Discussion

Analyses of the data revealed that mean reaction times and number of errors were significantly greater for the imagery condition than for the perceptual condition, as would be expected on the basis of task difficulty. Furthermore, the reaction time data also revealed a significant main effect for type of response, with subjects producing significantly longer latencies on "greater than" responses than on "less than" responses. Of most interest, however, was the significant main effect for visual field which revealed that, as predicted, subjects responded significantly faster on LVF presentations than on RVF presentations. This result, therefore, replicates the findings of previous studies, and provides further support for the view that the RH is specialized for tasks involving metric judgements. Nevertheless, the absence of a significant interaction between condition and visual field appears to demonstrate that the RH is not specialized for the generation of coordinate images.

Before drawing any firm conclusions, however, it is important to consider possible alternative explanations for these results. One potential problem, for example, is the possibility that the subjects did not use images on which to make the required judgement in the imagery condition, but some alternative strategy. This seems unlikely, however, given that all but one of the subjects reported that they had used images. Moreover, the subject who did use an alternative strategy was one of those whose data had to be excluded from the analysis because of unacceptably high error rates. Another possible problem is that the imagery task involves several additional steps prior to the image generational stage, and it could be argued that asymmetries on these additional aspects may have obscured the asymmetry associated with the image generation component. Such an argument is difficult to refute unequivocally, but it is perhaps relevant to note in this respect that the preceding study also failed to provide evidence in support of the claim that asymmetries in spatial relations exist at the image generational level.

Thus, given the consistency of the findings overall, it would seem that the most parsimonious conclusion to draw is that the RH is not specialized for the generation of coordinate images. There does, however, appear to be support for the view that the RH is specialized for tasks involving metric judgements. Nevertheless, it is important to note that there would appear to be at least two alternative explanations as to why this effect prevailed. First, in accordance with Kosslyn's model, it could be argued that while there is no support for the view that the two hemispheres are differentially specialized for the generation of coordinate images, the RH advantage indicates that coordinate representations containing the requisite information were used at both the perceptual and imaginal level. Alternatively, it could be argued that there is in fact no difference between the hemispheres at the representational level, rather the pattern of results simply reflects a RH specialization for the extraction of metric information from both imaginal and perceptual representations. It would appear, therefore, that it is perhaps appropriate to carry out one final study in order to attempt to discriminate between these two alternative accounts.

CHAPTER NINE

9. EXPERIMENT EIGHT

9.1 Introduction

The studies reported in the preceding two chapters failed to provide any evidence consistent with Kosslyn's claims regarding asymmetries in spatial relations at the image generational level. Nevertheless, the LVF advantage reported in Chapter Eight indicates that the RH is specialized for tasks involving metric judgements, and this could perhaps also be regarded as evidence in support of the view that the RH is specialized for the representation of coordinate information. Conversely, the finding may simply reflect a RH specialization for the extraction of metric information from any form of representation.

In this respect, a way of evaluating whether or not the asymmetry exists at the representational level is suggested by an experimental paradigm which has been utilized by Farah in a series of studies (Farah, 1985, 1986; Farah, Peronnet, Gonon and Giard, 1988). It has been demonstrated on a number of occasions that a visual image can facilitate visual discrimination of a perceptual stimulus (e.g. Peterson and Graham, 1974). Furthermore, and perhaps more interestingly, the facilitation is content-specific, in that a matching image leads to better discrimination of the perceptual stimulus than a non-matching image (Farah, 1985). According to Farah, this interaction between imagery and perception suggests a common locus of activity, and the content-specific nature of the interaction implies that the common locus consists of representational structures. Evidence in support of this view was provided by a study carried out by Farah, Peronnet, Gonon and Giard (1988). They used precisely the same task as Farah (1985) while recording ERP's to stimuli, and the results indicated that imagery had a content-specific effect on the visual evoked potential which was maximal at the occipital recording sites. The authors concluded, therefore, that the findings supported the claim that image-mediated facilitation occurs because visual imagery activates the same representational structures as visual perception.

Farah (1986) also employed this basic paradigm in an experiment designed to test the laterality of image generation. In this study subjects performed a lateralized tachistoscopic discrimination task, in which they had to decide whether the presented stimulus was or was not a pre-designated target, under two conditions. In the imagery condition they were presented centrally with one of the target stimuli at the beginning of each trial and instructed to retain the stimulus in the form of an image in a precued visual field. A lateralized stimulus was then presented briefly in the designated visual field and subjects had to decide whether it was a target stimulus or not. The baseline condition was identical to the imagery condition apart from the fact that no target was presented at the beginning of each trial.

The results revealed a RVF advantage in the imagery condition when the image and the stimulus were similar, and Farah interpreted this as evidence of LH specialization for image generation. However, as noted previously, this inference was challenged by Sergent (1989) who observed that the design of this study was inappropriate to test image generation as the representation of the mental image was dependent on sensory stimulation rather than on activation of stored information in long-term memory. Nevertheless, notwithstanding the validity of the inferences drawn by Farah, the basic experimental paradigm does suggest a way of evaluating Kosslyn's claims.

The above evidence appears to demonstrate that the greater the visual similarity between the image and the percept, the greater the effect of image-mediated facilitation. According to Kosslyn's formulations, however, the LH is specialized for categorical representations which capture what is stable across instances that may differ in terms of metric units. Therefore, as noted in Chapter Seven, such representations will facilitate recognition of letters of the alphabet depicted in various fonts. Consequently, it follows that if the image and percept represent different forms of the same stimulus the facilitating effect on RVF presentations should be as great as when the image and the percept represent the same form, since the same representational structure should be activated in both instances. On the other hand, the RH is specialized for coordinate representations which specify the precise locations of the component parts of an object. The facilitating effect on LVF presentations, therefore, should be greater when there is a perfect match between the image and the percept.

In order to test this hypothesis a modified version of the task employed by Farah

(1986) was utilized. Two target letters and four non-target letters were used in the study. Non-target letters were selected on the basis of their visual similarity to one of the two target letters in order to reduce the confounding effect of visual dissimilarity between different letters on non-target trials. In the imagery condition one of the target letters was presented centrally at the beginning of each trial and subjects were required to retain the letter in the form of an image in a precued visual field. Subsequently a letter was presented briefly in either the RVF or LVF and subjects had to decide whether it was a target letter or a non-target letter. Visual similarity was manipulated by presenting the lateralized letter in different fonts. On half of the trials the lateralized letter was depicted in precisely the same font as the target letter, whereas on the remaining trials it was drawn in italic. The baseline condition was identical to the imagery condition, apart from the fact that no target letter was presented at the beginning of each trial.

The initial hypotheses of the experiment were: i) that the presence of an image would facilitate visual discrimination between targets and non-targets and ii) that in the imagery condition RH performance would be more adversely affected by image-percept font disparity than the LH.

9.2 Method

9.2.1 Subjects

Forty subjects, 18 males and 22 females, took part in the experiment. They were all right-handed by self-report with normal or corrected to normal vision, and they were aged between 19 and 51 years of age (mean age 27.5 years, SD 8.08). Data from a further two subjects were not analyzed as detailed below.

9.2.2 Apparatus

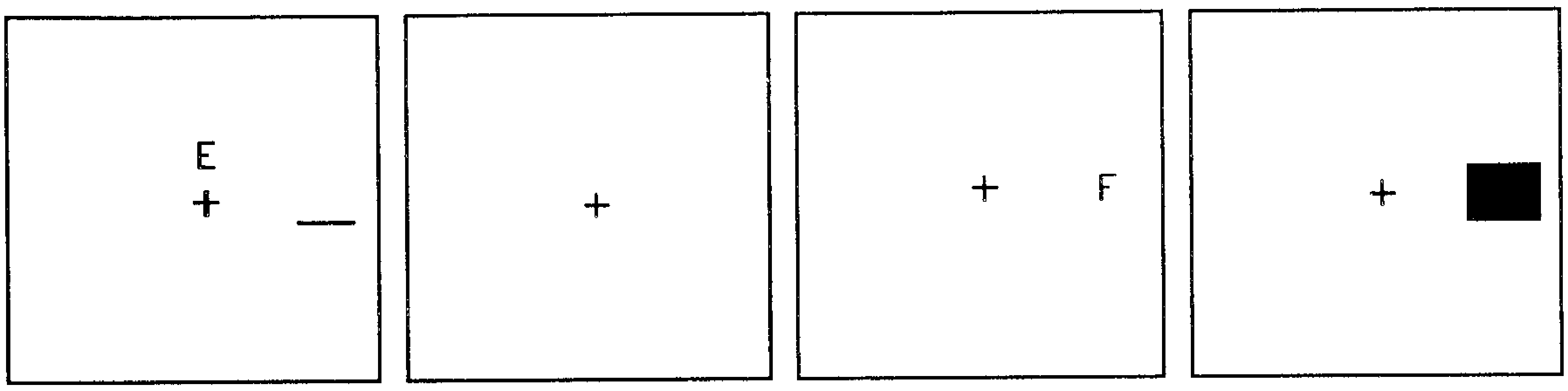
Details for this section are identical to those reported in Chapter Seven.

9.2.3 Stimuli

The letters B and E were selected as the two target stimuli. The non-target stimuli were P, R, F and L. All of the letters were presented in black on a white background and in uppercase. The height of each letter was approximately 1 cm, and at a viewing distance of 55 cm each letter therefore subtended a visual angle of 1°.

In the imagery condition subjects were presented at the beginning of each trial with one of the target letters positioned 1 cm (1°) above a black fixation cross in the centre of the screen. A thin black line, which served as the cue for the position of the upcoming stimulus, was also presented. This was positioned 3 cm (3°) to the right or left of the fixation cross. This display was presented until the subjects pressed the space bar, at which point the target letter and the position cue disappeared. Subsequently a lateralized letter stimulus was presented briefly in the designated visual field followed by a solid black mask 2 cm x 2 cm (2° x 2°). This sequence of events is graphically illustrated in Figure 9.2.3.1.

Figure 9.2.3.1. Illustration of the sequence of stimulus presentation on each trial in the imagery condition. (N.B. not drawn to scale).



The trials in the imagery condition were constructed as follows. Each target letter was presented centrally on 64 trials. On half of these trials the lateralized stimulus was presented in the RVF and half in the LVF. Furthermore, within each visual field the lateralized letter stimulus was presented in the same font as the target letter on half of the trials, whereas on the remaining trials the lateralized letter stimulus was presented in italic. Finally, within each visual field and type of font the lateralized stimulus was the same letter as the target stimulus on half of the trials, whereas on the remaining trials it was a non-target. On non-target trials the centrally presented target stimulus B was always paired with the non-target lateralized stimuli P and R, and the target stimulus E was always paired with the non-target lateralized stimuli F and L.

The sequence of events and the construction of the trials in the baseline condition were identical to those described for the imagery condition, apart from the fact that a target letter was not displayed centrally at the beginning of each trial.

9.2.4 Procedure

Viewing conditions, presentation of instructions, mode of response and counterbalancing of response hand and fingers were identical in all respects to the details reported in the first paragraph of the procedure section in Chapter Two.

Each subject carried out both the baseline and imagery conditions. In order to control for possible carry-over effects, however, the order of the two conditions was not counterbalanced. Rather every subject ran the baseline condition first and the imagery condition second. At the beginning of each condition the experimental instructions from the task were presented on the display screen for the subjects to read, and they were encouraged to ask the experimenter if they required any clarification. Within each condition, 24 practice trials were given prior to the commencement of 128 experimental trials. The order of both the practice and experimental trials were randomized.

The procedure in the baseline condition was as follows. At the beginning of each trial the fixation cross and position cue were presented, and subjects were instructed to stare directly at the cross while directing their attention to the side indicated by the position cue. Once they had achieved central fixation and prepared to see a stimulus in the designated visual field they were instructed to press the space bar. At this point the position cue disappeared and the fixation cross was displayed for an additional 1250 ms. A lateralized letter stimulus was then displayed for 50 ms in either the RVF or LVF, followed by a solid black mask which was presented for 500 ms. Subjects were instructed to press the YES button if the letter was a target stimulus and the NO button if it was not. In the imagery condition the procedure differed only in so far as that at the beginning of each trial one of the target letters was also presented centrally, and subjects were instructed to retain an image of the letter exactly as it appeared on the screen at the position of the upcoming stimulus. (See Appendix VIII for verbatim instructions to subjects).

Subjects were instructed to respond as quickly and as accurately as possible. If an incorrect response was made a warning tone was emitted and the words "Wrong Response" were visually displayed. As in previous studies, the importance of maintaining central fixation was stressed both in the initial instructions and throughout the trials themselves. At the end of the experiment the subjects were thanked and fully debriefed. Two subjects who responded correctly to less than 80% of the trials were excluded from the analysis. Once again, however, these excluded subjects were replaced in order to ensure complete counterbalancing.

9.3 Results

Mean reaction times for correct responses and number correct for each subject comprised the data upon which the statistical analyses reported below were performed. Trials on which reaction times exceeded three seconds were treated as errors. These data, averaged across subjects, are presented in Table 9.3.1 and 9.3.2 with standard deviations. (Please note that the terms "same font" and "different font" refer to the similarity of image to percept in the imagery condition and to the identical partitioning of trials in the baseline condition).

Table 9.3.1. Mean RTs (ms) and number correct with standard deviations in the baseline condition, as a function of type of response for each visual field for same font and different font trials.

BASELINE - SAME FONT	RVF		LVF	
	YES	NO	YES	NO
Mean RTs	1878	1899	1891	1897
SD	142	117	147	118
No. Correct	14.76	15.05	14.23	15.05
SD	1.32	1.13	1.55	1.24

BASELINE - DIFFERENT FONT	RVF		LVF	
	YES	NO	YES	NO
Mean RTs	1898	1917	1896	1906
SD	140	137	158	128
No. Correct	14.05	15.10	15.02	14.80
SD	2.11	1.15	1.25	1.60

Table 9.3.2. Mean RTs (ms) and number correct with standard deviations in the imagery condition, as a function of type of response for each visual field for same font and different font trials.

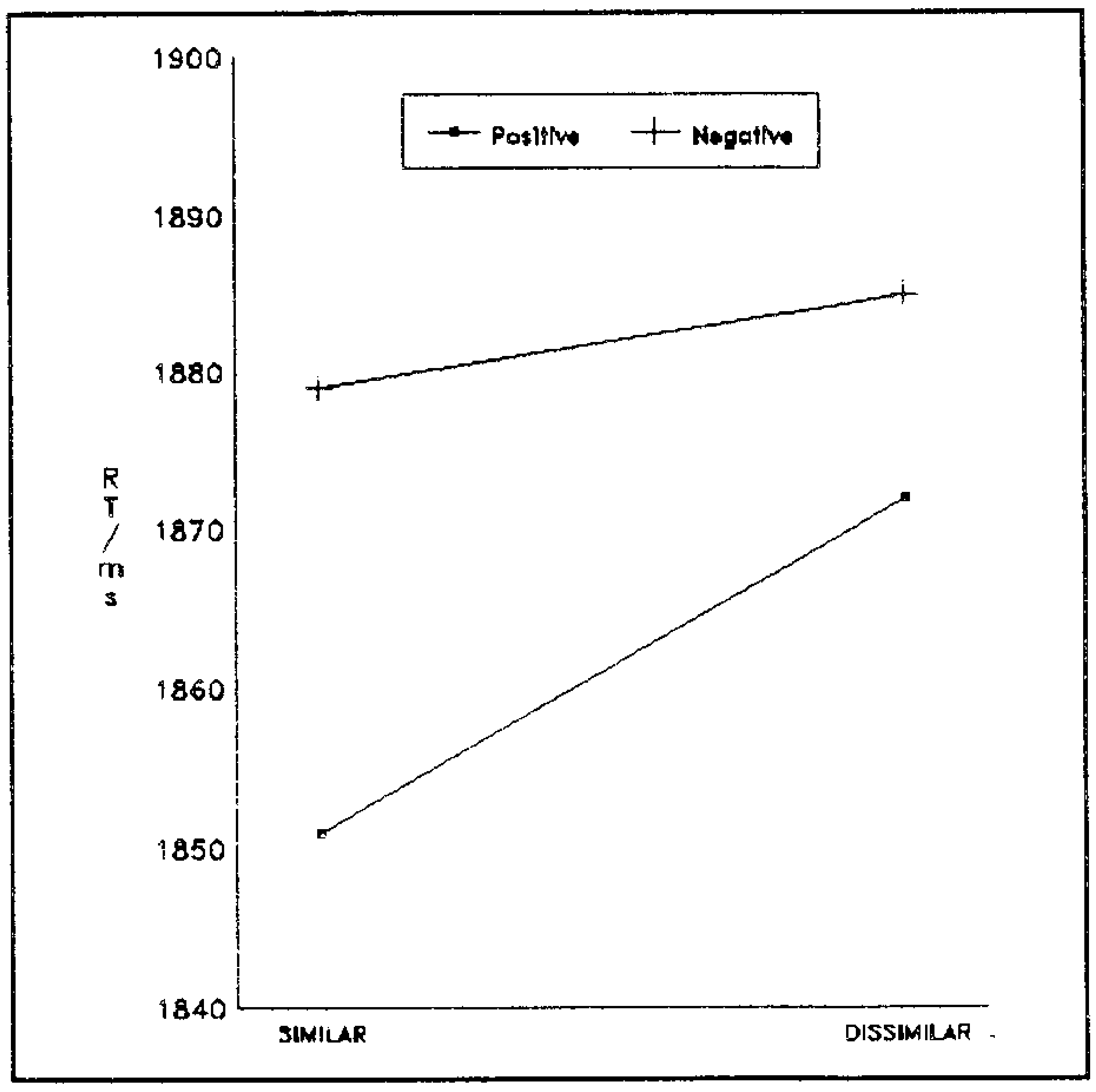
IMAGERY - SAME FONT	RVF		LVF	
	YES	NO	YES	NO
Mean RTs	1812	1863	1825	1858
SD	176	144	176	152
No. Correct	15.10	15.35	14.46	15.40
SD	0.98	0.73	1.68	0.81

IMAGERY - DIFFERENT FONT	RVF		LVF	
	YES	NO	YES	NO
Mean RTs	1850	1855	1845	1863
SD	175	148	168	153
No. Correct	14.10	15.37	14.80	15.22
SD	2.03	0.77	1.09	1.02

Reaction Times

Initially data were analyzed using a four-way repeated measures ANOVA, with condition (baseline vs. imagery), visual field (RVF vs. LVF), similarity (same font vs. different font) and type of response (positive vs. negative) as factors. A significant main effect was found for condition (F(1,39) = 10.22, p<.01), with subjects responding significantly faster in the imagery condition (mean RT 1846 ms) than in the baseline condition (mean RT 1897 ms). A significant main effect was also obtained for similarity (F(1,39) = 8.20, p<.01), with subjects producing significantly longer RTs in the different font condition (mean RT 1878 ms) than in the same font condition (mean RT 1865 ms). Finally a significant main effect was found for type of response (F(1,39) = 6.88, p<.025), with subjects responding significantly faster on positive responses (mean RT 1861 ms) than on negative responses (mean RT 1882 ms).

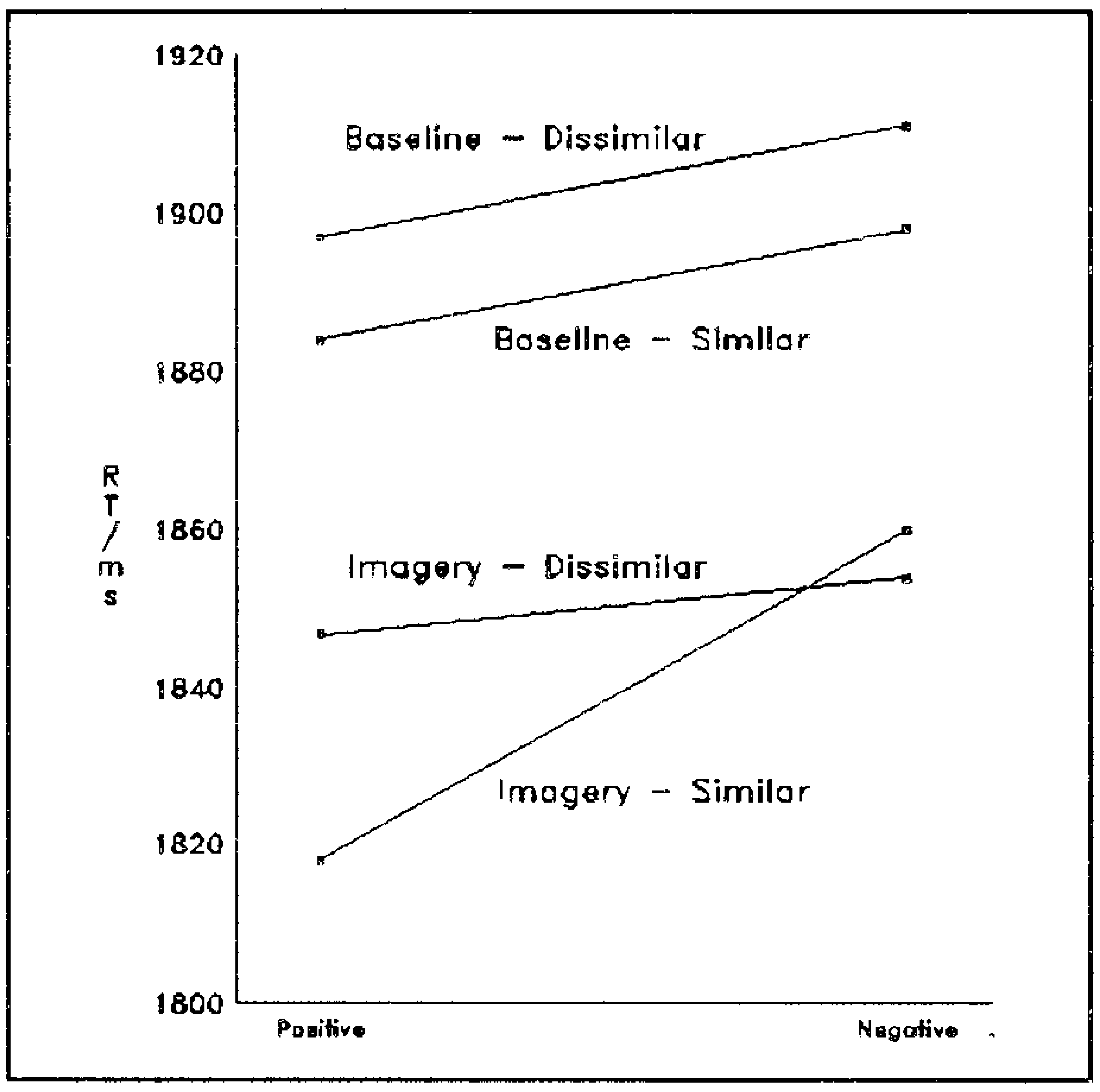
Figure 9.3.1. Graphical illustration of the interaction between similarity and type of response.



A significant interaction was also obtained between similarity and type of response (F(1,39) = 5.39, p<.05). (See Figure 9.3.1 for graphical illustration). The mean RTs for positive responses in the same font condition and different font condition were 1851 ms and 1872 ms respectively, whereas for negative responses the mean RTs in the same font condition and the different font condition were 1879 ms and 1885 ms respectively. Simple effects analysis, with the criterion value for statistical significance set at .0125, revealed that the RTs for positive responses in the same font and different font conditions differed significantly ($F(1,39) = 11.81$, $p < .01$), whereas those for negative responses did not.

Finally, a significant interaction was obtained between condition, similarity and type of response, $F(1,39) = 4.49$, $p < .05$. (See Figure 9.3.2 for graphical illustration). The mean RTs in the baseline condition for same font trials were 1884 ms for positive responses and 1898 ms for negative responses, whereas for different font trials the mean RTs were 1897 ms for positive responses and 1911 ms for negative responses. In the imagery condition the mean RTs for same font trials were 1818 ms for positive responses and 1860 ms for negative responses, whereas for different font trials the mean RTs were 1847 ms for positive responses and 1854 ms for negative responses. Simple effects analysis, with the criterion value for statistical significance set at .0125, revealed that only the positive and negative responses on same font trials in the imagery condition differed significantly, $F(1,39) = 14.82$, $p < .001$.

Figure 9.3.2. Graphical illustration of the interaction between condition, similarity and type of response.



No other main effects or interactions reached significance.

Accuracy

Initially data were analyzed using a four-way repeated measures ANOVA, with condition (baseline vs. imagery), visual field (RVF vs. LVF), similarity (same font vs. different font) and type of response (positive vs. negative) as factors. A significant main effect was found for type of response (F(1,39) = 21.50, p < .001), with subjects responding significantly more accurately on positive responses (mean no. correct 15.16) than on negative responses (mean no. correct 14.56). A marginally significant main effect was also obtained for condition (F(1,30) = 3.86, p < .06), with subjects responding less accurately in the baseline condition (mean no. correct 14.75) than in the imagery condition (mean no. correct 14.97).

A significant interaction was also obtained between visual field and similarity, F(1,39) = 13.60, p < .01, (See Figure 9.3.3 for graphical illustration). The mean no. correct on RVF presentations for same font and different font trials were 15.06 and 14.65 respectively, whereas for LVF presentations the mean no. correct for same font and different font trials were 14.78 and 14.96 respectively. Simple effects analysis, with the criterion value for statistical significance set at .0125, revealed that the same font and different font trials differed significantly on RVF presentations (F(1,39) = 9.16, p < .01), whereas

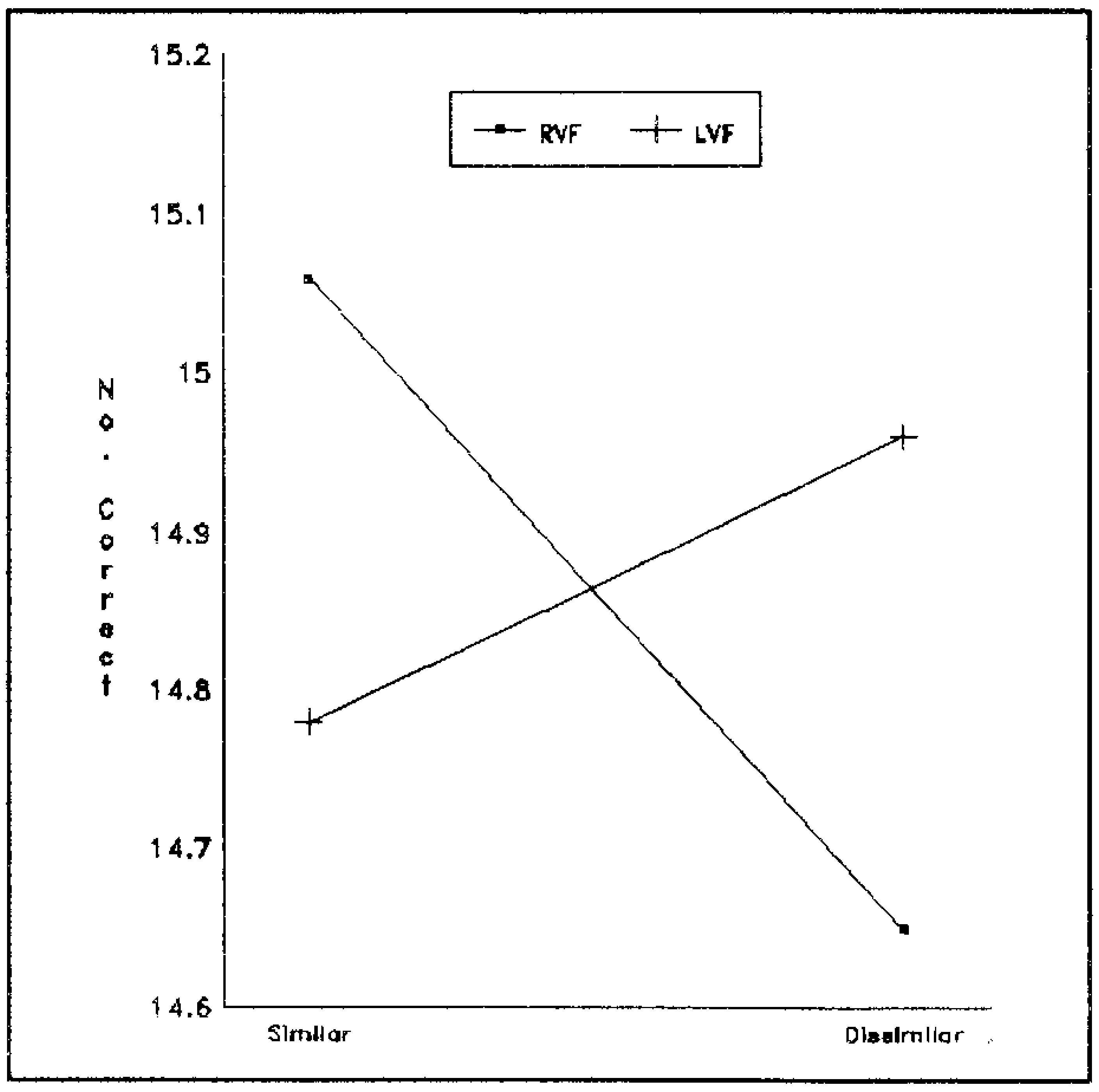
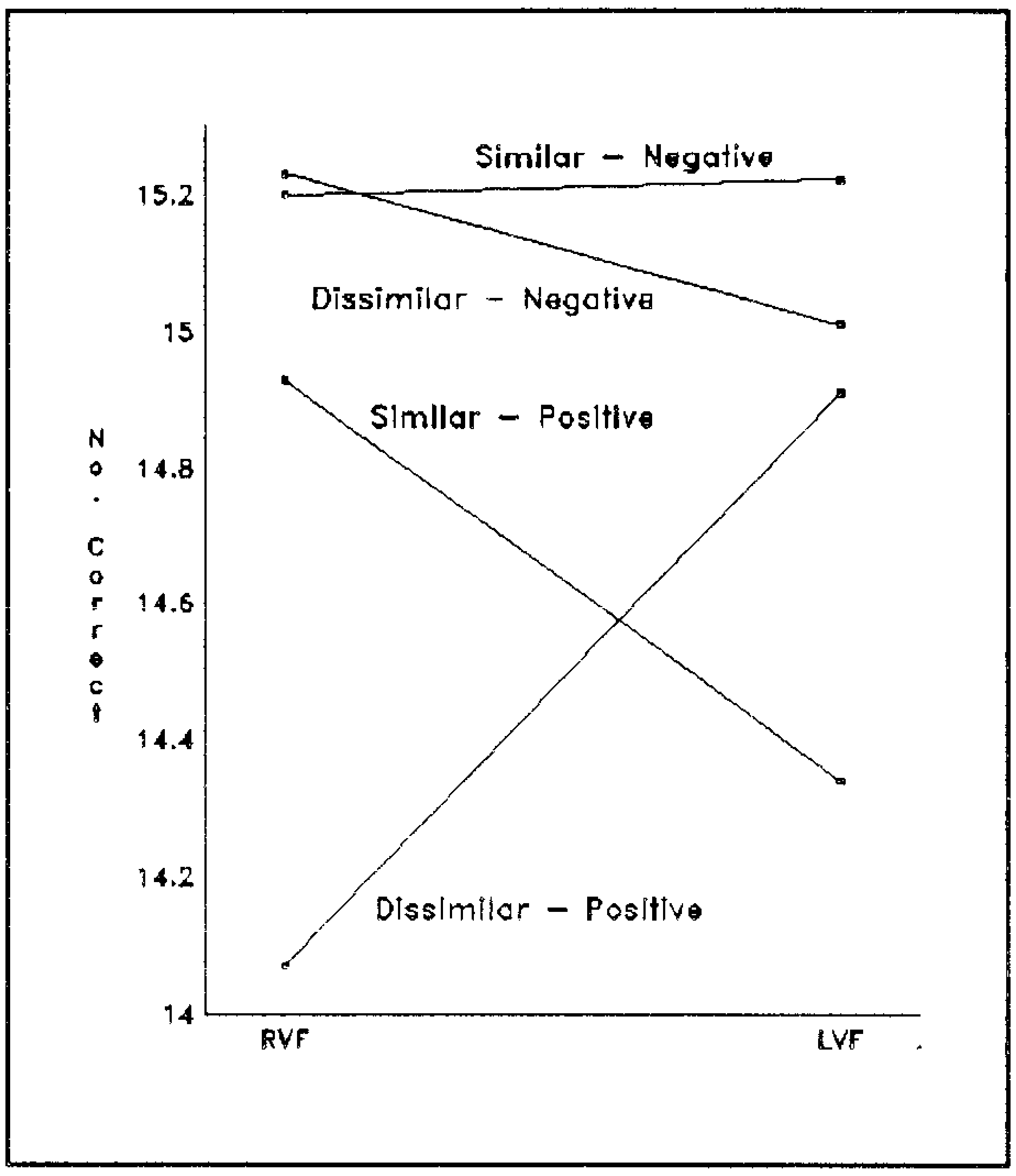


Figure 9.3.3. Graphical illustration of the interaction between similarity and visual field.

there was no difference on LVF presentations.

Figure 9.3.4. Graphical illustration of the interaction between visual field, similarity and type of response.



Finally, a significant interaction was obtained between visual field, similarity and type of response, $F(1,39) = 22.09$, $p < .001$. (See Figure 9.3.4 for graphical illustration). The mean no. correct in the same font condition for positive responses were 14.34 in the LVF and 14.93 in the RVF, whereas for negative responses the mean no. correct were 15.22 in the LVF and 15.20 in the RVF. In the different font condition the mean no. correct for positive responses were 14.91 in the LVF and 14.07 in the RVF, whereas for negative responses the mean no. correct were 15.01 in the LVF and 15.23 in the RVF. Simple effects analysis, with the criterion value for statistical significance set at .0125, revealed that the visual fields differed significantly on positive trials in both the same font condition ($F(1,39) = 11.67$, $p < .01$) and the different font condition ($F(1,39) = 10.81$, $p < .01$). There was, however, no difference on negative responses.

No other main effects or interactions reached significance.

9.4 Discussion

Initial analyses of the data revealed that mean reaction times were significantly greater for the baseline condition than for the imagery condition. Similarly, a marginally significant main effect on the accuracy data revealed that subjects also responded more accurately in the imagery condition than in the baseline condition. Thus it would appear that, as predicted, the presence of an image facilitated discrimination between targets and non-targets. Furthermore, a significant main effect on the reaction time data indicated that responses to same font trials were significantly faster than responses to different font trials. Moreover, both mean reaction times and mean number of errors were found to be significantly greater for negative responses than positive responses. These main effects, however, were modified by a number of significant interactions, the results of which appear to demonstrate content-specific image-mediated facilitation.

As regards the reaction time data, for instance, a significant interaction was obtained between similarity and type of response, with subjects responding significantly faster on positive responses in the same font condition than in the different font condition. The negative responses, however, did not differ. Moreover, this effect was further modified by a significant three-way interaction between condition, similarity and type of response, which revealed that the faster responding of subjects on positive responses on same font trials was confined to the imagery condition. Given that image-percept overlap was greatest on this particular subset of trials, this would appear to indicate that image-mediated facilitation is most effective when there is a perfect, template-style, match between the image and the percept.

The above results are obviously consistent with previous research and presumably, therefore, provide further support for the view that the facilitation effect occurs because the image and percept activate common representational structures. It is noteworthy, therefore, that the reaction time data provides no evidence whatsoever in support of the prediction that visual field performance in the imagery condition would vary as a function of the fonts in which the image and the percept were depicted. According to Kosslyn's theoretical formulations the RH should have been more adversely affected by a disparity between the fonts than the LH, since on RVF presentations it would be expected for the same representational structures to be activated irrespective of the font in which the letter was displayed. Thus it would appear, at least with respect to the reaction time data, that there is no evidence to support Kosslyn's claims regarding asymmetries in spatial relations at the representational level.

Furthermore, the results arising from the accuracy data also conflict with Kosslyn's claims, although there were some visual field effects. A significant interaction, for example, was obtained between visual field and similarity, with subjects responding significantly more accurately on RVF presentations in the same font condition than in the different font condition. There was no difference between the two conditions, however, on LVF presentations. Moreover, once again this effect was modified by a significant three-way interaction between visual field, similarity and type of response, which revealed that there was a LH advantage on positive responses in the same font condition whereas there was a RH advantage on positive responses in the different font condition.

Since the above effect was not specific to the imagery condition it obviously cannot be due to image-mediated facilitation. Presumably, therefore, it is simply related to visual discrimination performance, and generally if stimuli such as single letters are presented for identification or matching a LH advantage is normally found (Beaumont, 1982b). It is not entirely clear, therefore, why a RH advantage prevailed on the positive italic-trials, but one could perhaps speculate that the use of the less common format placed greater demands on aspects of visual processing. In fact there would appear to be some evidence in support of this proposal as previous research suggests that the LH superiority for verbal materials is reduced for stimuli printed in less "natural" type (e.g. Bryden and Allard, 1976; Bruyer and Van Laethem, 1986). Notwithstanding possible explanations for the pattern of results, however, it is clear that the findings again provide no support for Kosslyn's claims.

To summarize, the results of the present study replicate previous findings by demonstrating that the presence of an image facilitates visual discrimination. Moreover, image-mediated facilitation is most effective when the image and the stimulus are visually identical. There was no evidence, however, to support the prediction that RH performance in the imagery condition would be more adversely affected by image-percept font disparity than the LH. Thus, the findings would appear to cast doubt on the claim that asymmetries in spatial relations exist at the representational level.

CHAPTER TEN

10. GENERAL DISCUSSION

The preceding series of studies was motivated by the recent development of computational models of cerebral lateralization. In particular, given the evidence indicating that the LH has a direct role of some kind in the generation of images, the aim was to explore whether or not other components of the imagery system were lateralized to the LH or whether both hemispheres were involved in different aspects of imagery performance. In this respect, therefore, the findings arising from the first five experiments are noteworthy, since they appear to support the claim that it is unreasonable to expect cognitive systems to be lateralized en masse to one hemisphere or the other. Rather the cerebral locus appears to vary as a function of which particular processing component is under consideration.

For instance, the first experiment reported in Chapter Two replicated and extended the work of French and Painter (1991) by providing evidence in support of the view that the RH is specialized for the representation or processing of a specific form of spatial information in images. Conversely, the subsequent studies reported in Chapters Three, Four, Five and Six which were designed to explore the laterality of the image scanning component appeared to indicate bilateral representation. Thus, in accordance with Allen's (1983) proposals, this evidence would appear to support the claim that the processing modules comprising a particular cognitive system may be differentially lateralized to one or other hemisphere.

However, whilst these findings were consistent with the computational approach to cerebral lateralization, they did appear to cast doubt on certain aspects of Kosslyn's theoretical speculations regarding the neural distribution of the imagery system (Kosslyn, 1987; Kosslyn, Flynn, Amsterdam and Wang, 1990). As noted previously, for example, according to Kosslyn's model the image scanning component should be lateralized to the RH, but no evidence which was consistent with this claim was found. Furthermore, the studies reported in Chapter Seven and Chapter Eight also failed to support the view that the LH and RH were specialized for the generation of categorical images and coordinate images respectively.

Nevertheless, the experiment reported in Chapter Eight did reveal an overall RH advantage for tasks involving metric judgements, and it was apparent that this could perhaps be construed as providing evidence in support of the view that the RH is specialized for the representation of coordinate information. However, an alternative view was that the finding simply reflected a RH specialization for the processing of metric information. The final study reported in Chapter Nine, therefore, attempted to assess whether the asymmetry proposed by Kosslyn's model was evident at the representational level. Once again, however, there was no evidence to support the prediction derived from the model. Thus, while Kosslyn's claims regarding a RH advantage for the processing of metric information appear to be valid, there would appear to be little support for the view that this effect ultimately depends on asymmetries in spatial relations at the representational level.

Obviously the above brief summary raises a number of theoretical issues which warrant further consideration. Initially, however, it is perhaps appropriate to give more detailed consideration to any general methodological problems which could perhaps have acted as potential confounds in the current series of experiments, and in this respect the excessively high error rate reported in Chapter Four which resulted in the elimination of nearly half the subjects who were run would appear to warrant further consideration. As noted in this chapter, it was not clear what factors could have been responsible for the difficulties experienced by subjects in carrying out the task. Nevertheless, it is perhaps worth noting that Yuille (1986) has observed that generally individuals often find scanning mental images an onerous task, and consequently such studies frequently involve elimination of relatively large numbers of subjects. Indeed Yuille noted that in one of Kosslyn's image scanning studies 25% of the subjects tested were rejected, and he observed that this obviously raises concerns regarding the selective nature of inclusion of data in the final analysis.

Of course, the elimination of subjects in the study reported in Chapter Four was so extreme that the results of this experiment were completely disregarded. Nevertheless, the above comments do suggest that it is important to consider whether selective inclusion of data was a problem in any of the other experiments involving image scanning. In this respect, there are two studies of relevance; the experiment reported in Chapter Three in which five subjects were eliminated and the study reported in Chapter Six in which three subjects were eliminated. These figures correspond to an elimination rate of 11% and 7% of the total number of subjects run in each experiment respectively, and as such, although a little higher than would perhaps be hoped for ideally, do not appear to be so extreme as to cause serious concern.

Nevertheless, it must be acknowledged that concerns regarding selective inclusion of data are not specific to image scanning experiments, and it should be noted in this respect that of the remaining studies there was one in which the elimination of subjects was relatively high. In the first experiment reported in Chapter Two, for instance, eight subjects were excluded and this corresponds to an elimination rate of 17% of the total number of subjects run. Clearly this is unfortunate as it introduces an element of doubt regarding the generalizability of the left visual advantage reported in this study. Nevertheless, it is perhaps worth noting that this study replicated the effect found in the French and Painter (1991) experiment in which the elimination of subjects was lower (11%). The consistency in the pattern of results reported in the two studies, therefore, could perhaps be regarded as suggesting that the relatively high exclusion rate in the current study did not bias the results in any significant way.

A further methodological issue related to task difficulty concerns the use of perceptual analogues. Experimental designs formulated within the computational perspective are based upon the premise that it is only possible to infer that a visual field advantage on a particular task reflects a specialization for a specific processing component if the influence of this component has been isolated from all other components in the task. In the preceding studies this was achieved by incorporating into the designs a perceptual analogue of the imagery task which required all of the same cognitive components as the imagery task apart from the imaginal component under consideration. Thus if the hemispheres performed equivalently on the perceptual analogue but demonstrated a visual field asymmetry on the imagery task the failure could not be attributed to cognitive processing components involved in both tasks, and was assumed therefore to be specific to the imaginal processing component under consideration.

In fact, the pattern of results reported in the preceding studies only permitted such an inference to be drawn on two occasions. First, in the image scanning experiment reported in Chapter Six a LVF advantage was found for both reaction time and error data. Since no asymmetries had been found in the experiment reported in Chapter Five on a perceptual version of this task, it was inferred that the effect was associated with task components specific to the imagery system. Second, in the image generation classification task reported in Chapter Seven it was found that whilst there was no difference in accuracy on LVF presentations between the imagery and perceptual conditions, subjects responded significantly more accurately on RVF presentations in the perceptual condition than in the imagery condition. It was inferred, therefore, that the decrement in LH performance in the imagery condition was associated with the introduction of the image generation processing component.

One potential problem with the above inferences, however, is that if two tasks are identical as possible apart from the fact that one is imagery based and the other is perceptually based, the latter is likely to be easier. This then raises the possibility that the difference in the pattern of lateralization between the two versions of the task is due to task difficulty rather than a shift to the use of imagery. There are, however, reasons to doubt this alternative account.

For example, if the effect on the image scanning task documented in Chapter Six was simply due to task difficulty then it is somewhat difficult to account for the fact that a LVF advantage specific to the imagery task was not found in the image scanning experiment reported in Chapter Three even though the analyses reported in this chapter revealed that the imagery condition was significantly more difficult than the perceptual condition. Similar considerations apply to the inference drawn in Chapter Seven, since the image generation experiment reported in Chapter Eight also revealed a significant difference between the imagery condition and the perceptual condition, but there were no visual field effects specific to the imagery task. Thus, since the asymmetries that were documented do not appear to have varied systematically in relation to task difficulty, it seems reasonable to conclude that this methodological issue does not impinge upon the major conclusions of this investigation.

However, notwithstanding the validity of the inferences drawn from the reported results, it is perhaps appropriate to give some consideration to the general application of computational models within the area of laterality research, since a number of investigators have expressed reservations in this respect. Some, for example, have questioned whether formal computational models are an appropriate way of conceptualizing the processes involved in imagery. Conversely, others have focused on the issue of whether or not computational models are based on principles that are compatible with the properties of the brain. It would seem appropriate, therefore, to consider the validity of these concerns in a little more detail.

The issue of whether formal models based on computer analogies of cognitive processes represent accurate accounts of cognitive functioning has, of course, long been a matter for debate. Finke (1989), however, has questioned their use specifically in relation to imaginal processes. He argues, for example, that whilst models such as Kosslyn's (1980, 1981, 1987) have much explanatory power, this is gained at the expense of predictive power since any new predictions which are generated tend to be ones which yield refinements to the theory rather than basic understanding. Indeed, as such, Finke believes that these models may be conceptually inhibiting and argues instead for a research strategy based on the premise of searching for general, unifying principles. According to Finke such an approach is facilitated by allowing intuitions to spread without artificially restricting them in any way. By so doing, he believes that it should then become possible to discover broad principles that unify knowledge within a relatively large research domain.

Finke's criticisms, although specifically directed toward computational models of imagery, can perhaps be regarded as being representative of the objections raised by others against the general use of formal models of cognitive processes. However, notwithstanding this consensus amongst critics, it should be noted that many psychologists would argue strongly against such views. Johnson-Laird (1987), for example, believes that psychologists have no right to feel alienated by demands for rigorous explanations in place of intuition-bound predictions. Predictions based on intuitions, for instance, rarely yield solutions to problems other than those which they were designed to solve. Moreover, they seldom can be shown to lead to absurd consequences since hypotheses are derived inductively rather than deductively. Indeed the post-hoc inductive reasoning which inevitably follows from Finke's research strategy seems more likely to lead to inappropriate generalizations than the identification of broad, unifying principles. This is not to say, of course, that computational models are entirely problem-free, but it does suggest that the fact that the perspective demands that theories be precise, explicit and interpretable without recourse to intuition should not perhaps be regarded as a deficiency.

Nevertheless, the second concern relating to computational models which was raised earlier, regarding whether the principles on which the models are based are compatible with the properties of the brain, is clearly more problematic. Sergent (1989, 1990), for example, observes that formal models of cognitive functioning are usually conceived independently of the structural and dynamic properties of the system implementing the computations. It is necessary to consider therefore the possibility that the formalisms of cognitive psychology do not represent an accurate account of how the component operations of a given function are instantiated in cerebral structures. As Sergent (1990, p. 124) observes, "the brain is not organized as a serial computer and may not divide its operations according to our psychological concepts".

Nevertheless, it must also be acknowledged that if we are to explain how the brain organizes behaviour, we need not only a model which is valid in terms of the physiological operation of the brain, but a model of behaviour at the purely psychological level to which to relate brain events. Indeed Beaumont (1983b) has observed that it is difficult to think that there might be a valid neuropsychological description of some ability without it being related to a sound psychological understanding of that ability. Thus, whilst accepting that there may be some incompatibility between such models and the systems they purport to describe and explain, it is perhaps appropriate to focus on how these theories of cognition can, by providing powerful techniques for the decomposition of complex cognitive functions, inform neuropsychological description. Such an approach would perhaps be more fruitful than concentrating exclusively on potential areas of conflict.

Indeed the computational perspective does appear to have provided a much needed analytic focus to research in hemispheric specialization. It is, for example, apparent that it is unreasonable to expect neurological correlates of "language" or "spatial processing". Rather the approach suggests that it will prove more fruitful to look for the neurological correlates of the processing subsystems suggested by contemporary computational approaches to human cognition.

Of course, it must be acknowledged that the instantiation of the computational perspective in Kosslyn's model of cerebral lateralization appears, at least with respect to imaginal processes, to have been somewhat unsuccessful. Nevertheless, it is important to note that while this theory views imagery as a multicomponent process, hemispheric specialization is still conceptualized in terms of a global processing dichotomy. Thus, whilst the computational perspective prevails at the cognitive level, it would appear that in terms of cerebral lateralization the theory simply represents yet another attempt to reduce the multiple specializations of each hemisphere to a single more encompassing function.

The successful application of the computational perspective, however, requires that theoretical formulations regarding cerebral organization eschew the temptation to regard the hemisphere as the basic unit of analysis. Functional considerations need to operate at the level of the subprocessors in order to avoid the identification of opposing conglomerates of only partly related components. Of course any theory developed along these lines would undoubtedly be extremely complex. This complexity, however, would appear to be necessary in order to reflect the true multifactorial nature of the underlying processes.

APPENDIX I

INSTRUCTIONS: EXPERIMENT ONE

In the first (second) part of the study we are going to present you with patterns of four dots to study for five seconds. During this period you should inspect the dot pattern and try to remember the position of each dot by forming an image of the pattern exactly as it appears on the screen. Towards the end of this period a cross will appear at the centre of the screen. When this occurs, you must look directly at the cross and keep looking at it until you have made your response. The cross will be displayed for six seconds (one second) and at the end of this period a circle will be very briefly presented somewhere on the screen. Your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether or not the circle is surrounding a location that was previously occupied by a dot. If it is, press the YES button. If it is not, press the NO button.

Please note that on those trials when the circle is not surrounding a location that was previously occupied by a dot, this will be quite clear. That is to say, on such trials the circle will appear well away from a location occupied by a dot in the pattern. The task does not include trials designed to catch you out.

Please use your Right (Left) hand to press the YES and NO buttons on the mouse throughout the experiment. Press the YES button with your Index (Middle) finger

and the NO button with your Middle (Index) finger. If you make an error you will hear a warning tone from the computer. Use your Left (Right) hand to press the SPACE BAR to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the SPACE BAR when you are ready to begin the practice trials.

APPENDIX II

INSTRUCTIONS: EXPERIMENT TWO

Imagery Condition

In the first (second) part of the study dot patterns will be presented to you to study for five seconds. During this period you should inspect the dot pattern and try to remember the position of each dot by forming an image of the pattern exactly as it appears on the screen. Towards the end of this period a cross will appear at the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response. An arrow will be presented very briefly somewhere on the screen. Your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether or not the arrow is pointing at a location that was previously occupied by a dot.

Please note that on those trials when the arrow is not pointing at a location that was previously occupied by a dot, this will be quite clear. That is to say, on such trials the arrow will point well away from a location occupied by a dot in the pattern. The task does not include trials designed to catch you out.

Please use your Right (Left) hand to press the YES and NO buttons on the mouse throughout the experiment. Press the YES button with your Index (Middle) finger

and the NO button with your Middle (Index) finger. If you make an error you will hear a warning tone from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

Perceptual Condition

In the second (first) part of the study we are going to present you with patterns of four dots to study for three seconds. Towards the end of this period a small cross will appear at the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response. An arrow will be presented very briefly somewhere on the screen. Your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether or not the arrow is pointing at a dot.

Please use your Right (Left) hand to press the YES and NO buttons on the mouse throughout the experiment. Press the YES button with your Index (Middle) finger and the NO button with your Middle (Index) finger. If you make an error you will hear a warning tone from the computer and the words "Wrong Response" will be

displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

APPENDIX III

INSTRUCTIONS: EXPERIMENT THREE

Thank you for agreeing to participate in this experiment. On each trial in the study a pattern of four dots will be presented to you to study for five seconds. During this period you should inspect the dot pattern and try to remember the position of each dot by forming an image of the pattern exactly as it appears on the screen. Towards the end of this period a cross will appear at the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response. An arrow will be presented very briefly somewhere on the screen. Your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether or not the arrow is pointing at a location that was previously occupied by a dot.

Please note that on those trials when the arrow is not pointing at a location that was previously occupied by a dot, this will be quite clear. That is to say, on such trials the arrow will point well away from a location occupied by a dot in the pattern. The task does not include trials designed to catch you out.

Please use your Right (Left) hand to press the YES and NO buttons on the mouse throughout the experiment. Press the YES button with your Index (Middle) finger and the NO button with your Middle (Index) finger. If you make an error you will

hear a warning tone from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

APPENDIX IV

INSTRUCTIONS: EXPERIMENT FOUR

Thank you for agreeing to participate in this experiment. On each trial in the study a pattern containing four geometric shapes will be presented to you for four seconds. Towards the end of this period a small cross will appear at the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response.

At the end of the above sequence a shape will be presented very briefly somewhere on the screen. Your task is to respond AS QUICKLY AND AS ACCURATELY AS POSSIBLE in the following manner. If the shape is not present in the pattern you should press the NO button on the mouse with the Index (Middle) finger of your Right (Left) hand. If the shape is present in the pattern you should mentally scan from the centre of the briefly presented shape across the pattern to the centre of the matching shape. As soon as you arrive at the centre of the matching shape you should press the YES button with the Middle (Index) finger of your Right (Left) hand. If you make an error you will hear a warning tone from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial.

Feel free to ask the experimenter if you need any clarification. Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

APPENDIX V

INSTRUCTIONS: EXPERIMENT FIVE

Thank you for agreeing to participate in this experiment. On each trial in the study a pattern containing four geometric shapes will be presented to you for five seconds. During this period you should inspect the pattern and try to remember the position of each shape by forming an image of the pattern exactly as it appears on the screen. Towards the end of this period a small cross will appear at the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response.

At the end of the above sequence a shape will be presented very briefly somewhere on the screen. Your task is to respond AS QUICKLY AND AS ACCURATELY AS POSSIBLE in the following manner. If the shape is not present in the pattern you should press the NO button on the mouse with the Index (Middle) finger of your Right (Left) hand. If the shape is present in the pattern you should mentally scan from the centre of the briefly presented shape across the image to the centre of the matching shape in the pattern. As soon as you arrive at the centre of the matching shape you should press the YES button with the Middle (Index) finger of your Right (Left) hand. If you make an error you will hear a warning tone from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial.

Feel free to ask the experimenter if you need any clarification. Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

APPENDIX VI

INSTRUCTIONS: EXPERIMENT SIX

Imagery Condition

The experimental procedure for the first (second) block of trials in this condition is as follows. At the beginning of each trial a black cross will appear at the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response. A lowercase letter will then be presented very briefly somewhere on the screen. Your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether the uppercase version of this letter is symmetrical along the vertical axis.

Please use your Right (Left) hand to respond. Press the Left (Right) button of the mouse with your Index (Middle) finger to respond YES, and the Right (Left) button with your Middle (Index) finger to respond NO. If you make an error you will hear a warning tone from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

APPENDIX VI Cont.

In the second block of trials in this condition the experimental procedure is precisely the same as before, apart from the fact that you are required to make a different judgement.

As previously, at the beginning of each trial a black cross will appear at the centre of the screen and when this occurs you must look directly at the cross and keep looking at it until you have made your response. A lowercase letter will then be presented very briefly somewhere on the screen. This time, however, you are required to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether the uppercase version of this letter contains any curved lines.

As before, use your Right (Left) hand to respond. Press the Left (Right) button of the mouse with your Index (Middle) finger to respond YES, and the Right (Left) button with your Middle (Index) finger to respond NO. If you make an error you will hear a warning from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

Perceptual Condition

The experimental procedure for the first(second) block of trials in this condition is as follows. At the beginning of each trial a black cross will appear at the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response. An uppercase letter will then be presented very briefly somewhere on the screen. Your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether this letter is symmetrical along the vertical axis.

Please use your Right (Left) hand to respond. Press the Left (Right) button of the mouse with your Index (Middle) finger to respond YES, and the Right (Left) button with your Middle (Index) finger to respond NO. If you make an error you will hear a warning from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

In the second block of trials in this condition the experimental procedure is precisely the same as before, apart from the fact that you are required to make a different judgement.

APPENDIX VI Cont.

As previously, at the beginning of each trial a black cross will appear at the centre of the screen and when this occurs you must look directly at the cross and keep looking at it until you have made your response. An uppercase letter will then be presented very briefly somewhere on the screen. This time, however, you are required to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether this letter contains any curved lines.

As before, use your Right (Left) hand to respond. Press the Left (Right) button of the mouse with your Index (Middle) finger to respond YES, and the Right (Left) button with your Middle (Index) finger to respond NO. If you make an error you will hear a warning from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

APPENDIX VII

INSTRUCTIONS: EXPERIMENT SEVEN

Imagery Condition

The experimental procedure for the first (second) block of trials is as follows.

At the beginning of each trial a black cross will be presented in the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response. A time in digital form will then be presented very briefly on the screen, e.g. 6.20, and your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether or not the angle which would be formed by the hands of a clock at this time would be greater than or less than ninety degrees.

Please use your Right (Left) hand to respond. Press the Left (Right) button of the mouse with your Index (Middle) finger to respond GREATER THAN and the Right (Left) button with your Middle (Index) finger to respond LESS THAN. If you make an error you will hear a warning tone from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the SPACE BAR to begin each trial. Feel free to ask the experimenter if you need any clarification.

APPENDIX VII Cont.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

Perceptual Condition

The experimental procedure for the first (second) block of trials is as follows. At the beginning of each trial a black cross will be presented in the centre of the screen. When this occurs you must look directly at the cross and keep looking at it until you have made your response. A clock face will then be presented very briefly on the screen, and your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether or not the angle formed by the hands of the clock is greater than or less than ninety degrees.

Please use your Right (Left) hand to respond. Press the Left (Right) button of the mouse with your Index (Middle) finger to respond GREATER THAN and the Right (Left) button with your Middle (Index) finger to respond LESS THAN. If you make an error you will hear a warning tone from the computer and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the SPACE BAR to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

APPENDIX VIII

INSTRUCTIONS: EXPERIMENT EIGHT

Baseline Condition

Thank you for agreeing to participate in this study. Your task in the experiment is to decide whether a letter presented very briefly on the screen is or is not a predesignated target. The two target letters are B and E. The four nontarget letters are P, R, F and L.

At the beginning of each trial a black cross will appear at the centre of the screen. A horizontal line indicating where the upcoming letter will be positioned will also be presented either to the left or right of the cross. You are required to look directly at the cross while directing your attention to the side indicated by the position cue. It is important that you maintain central fixation until you have made your response.

Once you have achieved central fixation and prepared to see a stimulus on the side indicated by the position cue, you should press the space bar. A letter will then be presented very briefly in the cued position, followed by a solid black mask. Your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether or not the letter is a target or a nontarget.

Please use your Right (Left) hand to respond. Press the Left (Right) button of the

mouse with your Index (Middle) to respond TARGET and the Right (Left) button with your Middle (Index) finger to respond NONTARGET. If you make an error you will hear a warning tone from the computer, and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

Imagery Condition

In the second block of trials you are still required to decide whether a letter presented very briefly on the screen is one of the target or nontarget letters.

At the beginning of each trial, however, one of the target letters will be presented just above the fixation cross. You are required to form an image of this letter exactly as it appears on the screen at the position of the upcoming stimulus. Once you have formed the image you should look directly at the fixation cross and keep looking at it until you have made your response.

Once you have formed the image and achieved central fixation you should press the space bar. A letter will then be presented very briefly in the cued position, followed

by a solid black mask. Your task is to indicate AS QUICKLY AND AS ACCURATELY AS POSSIBLE whether or not the letter is a target or a nontarget.

Please use your Right (Left) hand to respond. Press the Left (Right) button of the mouse with your Index (Middle) to respond TARGET and the Right (Left) button with your Middle (Index) finger to respond NONTARGET. If you make an error you will hear a warning tone from the computer, and the words "Wrong Response" will be displayed on the screen. Use your Left (Right) hand to press the space bar to begin each trial. Feel free to ask the experimenter if you need any clarification.

Place your chin on the chin rest and press the F1 key when you are ready to begin the practice trials.

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