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HEMISPHERIC SPECIALIZATION FOR HAPTIC PERCEPTION: THE ROLE
OF TASK DEMAND

City University of New York

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HEMISPHERIC SPECIALIZATION FOR HAPTIC PERCEPTION:

THE ROLE OF TASK DEMAND

by

PEARL WEINSTEIN

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Abstract

HEMISPHERIC SPECIALIZATION FOR HAPTIC PERCEPTION:

THE ROLE OF TASK DEMAND

by

Pearl Weinstein

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The present study investigated the role of level of task demand in lateralized processing of tactuo-spatial stimuli. More specifically, this study examined lateral differences in accuracy and reaction time for matching braille-like tactual patterns under three conditions shown by Posner and Mitchell (1967) to constitute a cognitive hierarchy: Configurational Matching, Semantic Matching and Categorical Matching.

The subjects were 48 right handed college women who were assigned to three equal-size groups. The stimuli were eight different dot patterns with each two patterns given the same name (two patterns each for "Red," "Blue," "Day" and "Night"). The stimuli were paired and were delivered automatically to the left or right index fingers in a quasi-randomized order, and subjects made a judgment of "same" or "different" to each pair. Subjects in the Configurational Group were naive to the pattern names and were instructed

to judge two stimuli the same when they felt identical. Subjects in the other two groups were taught the names of the patterns prior to the matching task. Then, subjects in the Semantic Group were instructed to judge two stimuli the same when they meant the same thing. Subjects in the Categorical Group were instructed to judge two stimuli the same when their meanings fell into the same hierarchical category. Subjects responded by depressing foot pedals for "same" and "different" judgments.

Data were subjected to two 4-way analyses of variance, one for reaction time and one for accuracy. The results of the reaction time analysis showed significant differences among the groups: the Configurational Group showed the fastest reaction time, the Semantic Group responded more slowly and the Categorical Group was slowest. There was a significant interaction between Hand and Group: the response to left hand stimuli was faster than to right hand stimuli in the Configurational Group, and the response to right hand stimuli was faster than to left hand stimuli in the Categorical Group. There was no lateral difference in reaction time in the Semantic Group. There were no significant main effects for hand or for responding foot, but, for subjects in the Semantic Group, the reaction time was faster for the hand which was spatially compatible with the foot designated to respond "same." "Same" judgments were faster than "different" judgments, an effect especially marked in the

Semantic Group. The only significant effect noted on the basis of the analysis of errors was a difference among the groups: subjects in the Configurational Group made significantly fewer errors than subjects in the Semantic and Categorical Groups, which did not differ from each other.

The results are discussed in terms of hemispheric asymmetries for cognitive processing. For right handed women, tactual configurational processing appears to be best performed by the right cerebral hemisphere. Tactual configurational tasks which require verbal categorical processing appear to be best performed by the left cerebral hemisphere.

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CHAPTER 1

INTRODUCTION

A wealth of literature exists on the functional specialization of the cerebral hemispheres for processing information presented through the visual and auditory modalities. Linguistic stimuli are found to be better processed by the left hemisphere of right handed persons, visuo-spatial and musical stimuli by the right hemisphere. Relatively less attention has been paid to the study of lateral asymmetries in processing somatosensory information, with the existing evidence largely derived from the examination of clinical populations. More information on hemispheric specialization for tactile information-processing in normal adults is needed.

Attempts to understand the basis for hemispheric functional asymmetry have focused on the nature of the stimulus material to be processed (e.g., words vs. faces), and more recently, on the type of cognitive processing (e.g., analytic versus holistic) required to perform a task. However, elucidation of the relative roles of the two hemispheres has been hampered by the confounding of sensory, perceptual, cognitive and response factors in experimental designs.

The present study investigated the role of the level of task demand in lateralized processing of tactile stimuli. More specifically, the present investigation examined lateral differences in accuracy and reaction time in a tactuo-spatial matching task under the following conditions: Configuration-al Matching, Semantic Matching and Categorical Matching. Sensory factors were held constant by using the same tactile stimuli for all groups. Response mode was the same for all groups. The groups differed only in their task requirements. Therefore, differences in the direction of lateral superiority among the groups can be ascribed to the cognitive processes involved.

Historical Review: The Concept of Hemispheric Asymmetry of Function

Scientific awareness of and interest in the different functional roles of the right and left cerebral hemispheres dates back to Broca's report in 1865 (cited in Joynt, 1964) of a specific association between aphasia in right handed persons and lesions of the left cerebral hemisphere. This finding that the left half of the brain controlled such a critical human ability as speech marked the beginning of an era in which brain function was conceptualized in terms of the dominance of one cerebral hemisphere over the other. The idea that the left hemisphere was dominant for speech and all higher mental functions, with the right hemisphere

serving as a minor, silent partner -- the "cerebral dominance" theory -- went virtually unchallenged for many years (Giannitrapini, 1969). The theory was given support by the 1900 finding of Liepmann (cited in Benton, 1965) that patients with lesions of the left cerebral hemisphere often suffered from "apraxia", a condition in which intact comprehension and neuromuscular ability are accompanied by an inability to execute a series of movements or skilled acts. The theory was further bolstered by Gerstmann's reports (cited in Benton, 1965) of patients' inability to recognize their own fingers, termed "finger agnosia", in association, again, with left hemisphere lesions. As this deficit was often accompanied by problems in left-right orientation, agraphia and dyscalculia, Gerstmann posited a syndrome, not solely verbal, associated with dominant hemisphere lesions.

Even during these years, however, there were indications that some special functions might be served by the non-dominant hemisphere. As early as 1864, Hughlings Jackson suggested that while intellectual or "propositional" speech was in the domain of the left hemisphere, the right hemisphere served a unique function in the mediation of automatic and emotional speech. Babinski (cited in Benton, 1965) noted the presence of anosagnosia, and more striking, the denial of left hemiplegia, in patients with lesions of the right cerebral hemisphere. The determination of cerebral dominance in left handed persons was also problematic,

as many left handed aphasics were shown to have sustained left, rather than the expected right, cerebral lesions (Conrad, 1949, cited in Benton, 1965). These observations suggested that the non-dominant hemisphere was, in fact, involved in linguistic and other cognitive functions. It was the work of the British and French neurologists during the 1940's and 1950's (e.g., Paterson & Zangwill, 1944; McFie, Piercy & Zangwill, 1950; Hecaen, Ajuriguerra & Massonet, 1951), demonstrating a greater frequency of impairment of visual perceptual and constructional functions associated with right hemisphere damage, that provided the evidence for positing a unique, and not necessarily subordinate, role for the right hemisphere.

The theory of cerebral dominance was thus necessarily revised, leading to the current conceptualization of complementary hemispheric specialization, with each of the cerebral hemispheres subserving unique functions (Milner, 1962; Bogen, 1969; Dimond & Beaumont, 1974; Harnad, Doty, Goldstein, Jaynes & Krauthamer, 1977). Numerous investigations have been conducted which explore the nature of the stimuli associated with predominantly right or left hemisphere processing. Generally, these studies support the concept of the left hemisphere (in right handed persons) as the verbal processor, and the right hemisphere (also in right handed individuals) as the processor of non-verbal, visuo-spatial information. Others raise questions about the

the "material specificity" of hemispheric specialization, and instead, evaluate asymmetries in terms of modes of cognitive processing across types of stimulus materials.

Historical Review: Hemispheric Asymmetry in Modalities

Other than Somatosensory

Clinical populations. A major source of information on hemispheric processing asymmetries are patients who have sustained unilateral brain lesions. Right handed persons who have sustained left hemisphere lesions show deficits in language skills and this provides the best documented evidence for hemispheric specialization. This finding has been repeatedly and extensively confirmed for persons with unilateral stroke and trauma (Lhermitte & Gautier, 1969), and hemispherectomy (Smith, 1966). The role of the left hemisphere in language function is also evident under intracarotid sodium amytal testing (Branch, Milner & Rasmussen, 1964). On the other hand, patients with right hemisphere damage show impairments in spatial relational abilities (Benton, 1969), spatial articulation (Warrington, James & Kinsbourne, 1966), and line orientation (Warrington & Rabin, 1970). They have difficulty recognizing and remembering faces, nonsense figures, and complex patterns, all stimuli which are not easily verbally coded (De Renzi, 1968; Kimura, 1968). Patients with right hemisphere damage have more trouble synthesizing a concept of a total stimulus from

partial or fragmentary sensory information (Lansdell, 1968) and show greater impairment in depth perception (Benton & Hecaen, 1970; Carmon & Bechtoldt, 1969) than patients with damage to the left hemisphere.

Even finer behavioral distinctions may be made when the lesions are clearly localized. Memory defects restricted to particular types of stimulus materials have been found to characterize patients following right versus left anterior lobectomy. Left temporal lobectomy selectively impairs the learning and retention of verbal material (Meyer & Yates, 1955; Milner, 1958) while memory for perceptual material such as places, faces, melodies or nonsense patterns remains intact. Conversely, removal of the right temporal lobe leaves verbal memory intact, but impairs recognition and recall of visual and auditory patterns which do not lend themselves easily to verbal coding (Kimura, 1963; Milner, 1962, 1967; Shankweiler, 1966). Right temporal lobectomy retards the learning of visually guided stylus mazes (Milner, 1965), whereas left temporal lobectomy does not.

Another source of evidence for hemispheric specialization of function derives from studies of people who have had the cerebral hemispheres disconnected by commissurotomy for the relief of intractible epilepsy. The left hemisphere in these patients is proficient in all language skills (Gazzaniga & Sperry, 1967; Sperry & Gazzaniga, 1967).

When verbal identification is required for words or objects presented to the separate visual half-fields, the left hemisphere (RVF) superiority is evident (Sperry, Gazzaniga & Bogen, 1969). When chimeras of stimuli which are difficult to code verbally (e.g., faces, antlers) are presented to these patients such that the midline of the joined stimuli is at visual fixation, the mode of response determines the chimera identified. Chimera in the left visual field are identified when using a non-verbal pointing response and chimera in the right visual field are identified when verbal report is required (Levy, Trevarthen & Sperry, 1972). When presented with simultaneous and conflicting information on orientation of lines or direction of movement of dots to the two visual half-fields, commissurotomy patients match their response to the left visual field stimulus, suggesting right hemisphere predominance for these percepts (cited in Nebes, 1974). Nebes (1974) noted that these patients are also more accurate in perception of the spacing of dot arrays presented in the left than the right visual field, again indicating right hemisphere superiority for visuo-spatial processing.

Normal populations. During the 1950's and 1960's special techniques were developed for demonstrating visual and auditory laterality effects for different types of stimulus material in normal subjects. For the visual system, information reaching each of the peripheral visual fields is

relayed to the contralateral occipital cortex. Thus, by presenting stimuli tachistoscopically in peripheral vision restricted to only one visual half-field at a time, Mishkin and Forgays (1952) were able to show that words are better recognized when presented in the RVF/left hemisphere than in the LVF/right hemisphere. This RVF advantage was confirmed for perception of letters (Heron, 1957; Bryden, 1965), and for simultaneous bilaterally presented words (McKeever & Huling, 1971). In contrast, a right hemisphere superiority has been demonstrated for a variety of visuo-spatial tasks. Dot localization is performed better with LVF stimulation than with RVF stimulation (Kimura, 1969), as is depth perception and line slant orientation (Kimura & Durnford, 1974). Non-verbal stimuli such as faces are processed faster when presented for matching to the LVF (Geffen, Bradshaw & Wallace, 1971). Kimura (1966) demonstrated a dual asymmetry of the brain for visual perception with normal subjects showing superior RVF/left hemisphere perception for letter recognition and superior LVF/right hemisphere perception for the enumeration of dots and forms. She suggested that the left posterior part of the brain is the main processor of verbal-conceptual forms and that the corresponding part of the right hemisphere is predominant for perception of non-verbal stimuli. A dual asymmetry for recognition of alphabetical material (left hemisphere superiority) and recognition of faces (right hemisphere superiority) has also been

obtained using choice (go/no-go) reaction time as the response measure (Rizzolatti, Umiltà & Berlucchi, 1971).

Abandoning the concept that words, because they are verbal, must be best processed by the left hemisphere, Gibson, Diamond and Gazzaniga (1972) presented words in central vision and then required subjects to match words presented tachistoscopically in the left and right visual fields to the previously exposed standard. In this case, a LVF superiority for word-matching accuracy was demonstrated. This finding supports the view that words may be treated either as verbal or visuo-spatial stimuli and that the LVF superiority which characterizes many visuo-spatial tasks can be obtained with words when the cognitive strategy is one of perceptual matching.

A reversal of the expected asymmetry based upon concepts of material specific hemispheric specialization was obtained by Klatsky and Atkinson (1971) in a memory scanning paradigm. Subjects memorized a set of letters, and then matched them to a test stimulus tachistoscopically flashed to the left or right visual field. The test stimulus was a letter or a picture of a common object. Subjects registered a manual response to signify whether the letter, or the first letter in the name of the pictured object, matched or mismatched a letter in the memory set. Reaction times to the letter matches were shorter in the LVF and reaction times to the pictures were shorter in the RVF. This finding

is compatible with a concept of left hemisphere function as verbal (translation of a picture to its name and matching then to the first letter of the name), and right hemisphere function as spatial (configurational matching of letter forms without linguistic encoding).

The other main source of evidence for laterality effects in normal subjects has been the dichotic listening task. Using a technique developed by Broadbent (1954), Kimura (1961) presented competing strings of digits simultaneously to the right and left ears and found that right handed subjects reported more of the digits correctly that were presented to the right ear than to the left ear. Kimura postulated a privileged access (due to ipsilateral suppression) through the contralateral pathway from the right ear to the left (speaking) hemisphere to account for this asymmetry. A dual asymmetry was demonstrated when dichotic melodies were found to produce a left ear superiority in the same normal subjects who showed a right ear superiority for digits (Kimura, 1964). This complementary hemispheric specialization for verbal and non-verbal sound stimuli has been very extensively investigated and confirmed (see Segalowitz & Gruber, 1977).

Historical Review: Hemispheric Asymmetry in Somesthesia

Research on hemispheric specialization in the somatosensory modality has addressed itself largely to the question

of which types of stimuli are better processed by the right or left hemisphere. This has largely been accomplished by comparing responses to various tactile or haptic stimuli presented to the right and left hands, although stimulation has not been restricted to the hands. Patients with unilateral cerebral lesions or commissurotomies have been studied, and there is a growing literature on normal adults and children.

Traditionally, it has been believed that the somesthetic afferents for discriminative sensibility (kinesthesia, two-point discrimination, stereognosis, etc.) are all crossed systems, with fibers from the periphery synapsing at ipsilateral medullary nuclei, and crossing in the medial lemniscus to the contralateral ventrobasal thalamic nuclei, which then project to cortex (contralateral to side of input) (Rose & Mountcastle, 1959). Diffuse sensibility, such as pain, temperature and deep pressure, and light touch were believed to be carried contralaterally by the spinothalamic tracts and then diffusely projected to both cerebral hemispheres. Therefore, lateralized presentation of discriminative stimuli, either to determine tactual thresholds (such as pressure sensitivity, two-point discrimination, or point localization), or to test higher somesthetic functions (such as tactual pattern discrimination or tactual route-finding), would yield evidence of hemispheric specialization. More recently, evidence has been provided that, rather than

being divided along lines of discriminative versus non-discriminative sensation, information obtained through "active" touch (palpation of forms) is carried by the contralateral somatosensory system, whereas somatosensory information obtained through "passive" touch (e.g., pressure, point localization, two-point discrimination) is carried bilaterally to the brain (Gazzaniga & Le Doux, 1978; Wall, 1970; Corkin, 1978). In this case, hemispheric specialization for somatosensory stimulation could be demonstrated only on those somatosensory tasks requiring some active movement or exploration by the subject (e.g., haptic identification of forms, tactile mazes) and not for passive tasks (e.g., vibratory or pressure sensitivity thresholds). The literature will be reviewed for patient populations as well as normal populations of adults and children, with attention to evidence of hemispheric specialization for elementary as well as higher order somesthetic functions.

Clinical populations. Those studies which have investigated sensory thresholds and measures of elementary sensibility in patients with unilateral lesions of the left or right hemisphere have generally not demonstrated differences based upon side of lesion. This has been true whether the measure was double simultaneous stimulation (Bender, 1952), roughness discrimination (Weinstein, Semmes, Ghent & Teuber, 1958), absolute or differential pressure thresholds, two-point discrimination (Carmon, 1971), or sensory thresholds

and position sense (Corkin, Milner & Rasmussen, 1970). On the other hand, when patients with unilateral cerebral lesions are confronted with tasks requiring complex somesthetic processing (e.g., completion of tactile formboards, tactile orientation tasks), those with damage to the right cerebral hemisphere show far greater impairment than those with left hemisphere damage. On a variety of tasks using the Seguin-Goddard formboard (and modifications thereof), which requires placing geometric forms in their matching recessed spaces, patients with right hemisphere lesions show deficits in speed and accuracy of performance (Teuber & Weinstein, 1954; Milner, 1954; Reitan, 1964; De Renzi, Faglioni & Scotti, 1968). Further, when attempting to perform size discriminations requiring matching a wooden cube by palpation to one of like size in an array, patients with right hemisphere lesions show impairments (Weinstein, 1962a). This deficit extends to the learning of tactile discriminations, with right hemisphere lesioned patients showing inferior learning of tactile pattern discriminations (Ghent, Weinstein, Semmes & Teuber, 1955) and solutions to tactile stylus mazes (Corkin, 1965).

In a series of investigations, De Renzi and colleagues demonstrated some of the tactuo-spatial disorders associated with right hemisphere lesions. Patients with such lesions were impaired in the ability to reproduce the spatial orientation of two rods (De Renzi, Faglioni & Scotti, 1971).

They performed poorly when required, without visual guidance, to place drawing pins in a corkboard in a pattern corresponding to a tactual model, indicating difficulty in the localization of points in extrapersonal space (Faglioni, Scotti & Spinnler, 1971). In another experiment (De Renzi & Scotti, 1969), which required patients to trace the outline of wooden nonsense and geometric forms with their index fingers and identify the shapes from a simultaneously observed visual display, patients with right hemisphere lesions were more impaired than those with lesions of the left hemisphere, suggesting a kinesthetic disability, or interference with the ability to utilize the changing direction of the finger in space for shape recognition.

Using another tactuo-visual, cross-modal task, Carmon and Benton (1969) used metal probes arranged in a 3x3 array to stimulate the palms of the hands of right and left unilaterally brain damaged patients. Stimuli varied in number (1, 2 or 3) as well as direction (vertical, horizontal and the two obliques), with the response consisting of pointing or calling the appropriate number on a visual display. There were no lateral differences for tactile perception of numerosity; the hand contralateral to the lesion was always inferior. Patients with left hemisphere damage showed only contralateral deficits in the perception of direction, but those with lesions of the right hemisphere showed bimanual deficits in judging directionality. Carmon and Benton

ascribed this result to the greater role of the right than the left hemisphere in the "mediation of behavior requiring the appreciation of spatial relations" (p. 531). These findings were replicated by Fontenot and Benton (1971), who included aphasic patients in their group with left hemisphere lesions, assuring that the superiority of that group was not attributable to the fact that their lesions were less severe than those with right hemisphere lesions.

No studies have been published which have demonstrated superior abilities of the right hand/left hemisphere as compared to the left hand/right hemisphere in unilaterally brain damaged persons for processing stimuli presented somesthetically.

Studies of somesthetic perception in commissurotomized patients yield markedly different results depending upon whether verbal responses are required. When such patients are required to name objects presented to the right or left hand, those objects palpated by the right hand are more accurately reported. Similarly, the right hand was superior for the retrieval of objects which were named, described, or defined verbally (Sperry & Gazzaniga, 1967; Gazzaniga & Sperry, 1967). However, when tasks required only tactuo-spatial manipulations or non-verbal matching, a clear left hand/right hemisphere superiority was shown. Bogen and Gazzaniga (1965) reported on two patients who switched from right to left hand superiority for copying geometric designs

after surgery. Post-operatively, one patient could only construct Kohs block designs with his left hand. In another report, post-operative somesthetic matching and demonstration of the use of an object through manipulation was better performed by the left hand, even after a delay (Sperry, Gazzaniga & Bogen, 1969). Somesthetic thresholds for pressure sensitivity, two-point discrimination and joint position sense were comparable to normal subjects and did not differ between the left and right hands of eight commisurotomy patients when report utilized hand signals, but left hand performance deteriorated on the latter two tasks when verbal report was required (Milner & Taylor, 1970).

The disconnected right hemisphere has consistently been found to be superior to the left for tasks requiring spatial visualization. In a task requiring matching of two-dimensional, visually presented layouts to tactually presented, three-dimensional structures, the left hand was more accurate (Levy-Agresti & Sperry, 1968). Similarly, the left hand was more accurate on a visuo-tactile version of the Ravens Coloured Progressive Matrices, in which tactile spatial patterns had to be selected which fitted, by matching and spatial analysis, the missing part of visually presented patterns (Zaidel & Sperry, 1973).

Nebes (1971) required patients to identify the circle to which various arcs belonged in either a cross-modal matching task (visual presentation - tactile identification,

tactile presentation-- visual identification) or an intramodal matching task (tactile presentation and identification). Although simple matching of arcs or circles to their like forms was done equally well by both hands, the relating of the part (arc) to the whole (circle) was better performed by the left hand, which Nebes attributed to a right hemisphere ability for perceiving part-whole relationships -- a spatial analytic ability. Similarly, a left hand superiority for figural unification (the ability to tactually select the fragmented pieces from which a specific geometric form could be constructed) was demonstrated (Nebes, 1972).

Milner and Taylor (1972) tested seven commissurotomy patients on a haptic-spatial task. Wire nonsense forms were felt with one hand and matched to the identical shape in a haptic array of four shapes. Six of the seven patients showed superior matching ability with the left hand. Further, many of these patients showed superior left hand matching after varying periods of delay, indicating a capacity of the right hemisphere for non-verbal memory. Right hand matching improved with familiar objects which could be verbally encoded, but was still inferior to left hand matching.

The perception of geometric relationships is largely dependent upon spatial analysis. Franco and Sperry (1977) describe patients (5 commissurotomy, 2 hemispherectomy and 1 agenesis of the corpus callosum) who were presented with

four types of geometric discriminations -- Euclidean, affine, projective and topological -- which lent themselves to decreasing levels of verbal codability. Subjects blindly selected one of three tactual shapes which best fitted a set of five typologically similar geometric forms presented visually. There was consistent left hand/right hemisphere superiority, with the magnitude of this superiority increasing from the Euclidean problems to the topological problems.

In summary, the findings of studies of commissurotomy patients, as well as of studies of patients with unilateral cerebral lesions, implicate the right hemisphere as superior to the left hemisphere for a variety of tasks requiring perception, manipulation, and memory for tactual spatial relationships.

Normal populations. A number of studies investigating lateral differences in basic tactile sensitivity in normal subjects have yielded mixed results. Examining pressure sensitivity, Semmes, Weinstein, Ghent & Teuber (1960) found thresholds lower on the left as compared to the right thumb of 33 male subjects. To determine whether this differential sensitivity was due to a peripheral factor -- specifically, the development of callus on the preferred hand -- Weinstein and Sersen (1961) compared pressure sensitivity of right and left handed men and women. They compared the palms, which might differ in degree of callus, and also the forearms and soles of the feet, which should not differ in thickening of

the skin between the left and right sides. Dextrals showed a greater frequency of superior left-sided sensitivity on all three body parts. Left palm sensitivity was greater even among left handers. Among the subgroup of familial sinistrals, however, significantly more people showed greater sensitivity on the right as opposed to the left palm. Weinstein and Sersen interpreted their results as discrediting the peripheral callus hypothesis, and as evidence for lateral differences in tactile sensitivity based upon a central, perhaps genetically determined mechanism. Subsequent studies by Weinstein (1962b, 1963) have reported significantly greater sensitivity of the phalanges of each finger of the left hand (1962) and of the left breast in females (1963). Of 20 body parts compared in males and females (Weinstein, 1968), women were found to be generally more sensitive to pressure than men, although on only one body part (the index finger) were lateral differences found. However, other investigators have been unable to demonstrate similar lateral differences in pressure sensitivity. Fennell, Satz and Wise (1967) found no lateral differences in threshold between the palms, or in the frequency of greater left hand sensitivity. However, they did replicate the finding of a lower pressure sensitivity threshold on the right hand of familiar sinistrals. Carmon, Bilstrom and Benton (1969), using an electromechanical stimulator which controlled both pressure and area stimulated, found no

lateral differences in perception of pressure or sharpness on the palms or backs of the hands. Thus, with respect to pressure sensitivity in normal adults, the likelihood of a superior sensitivity of the side opposite the non-dominant hemisphere is uncertain.

Testing children between 5 and 11 years of age, Ghent (1961) found lateral differences in pressure threshold in favor of the left hand for girls by 6 years of age and for boys by 11 years of age. However, at 5 years of age the girls showed greater right hand sensitivity and, furthermore, they no longer maintained the left hand advantage by 11 years of age. Again, evidence for a clear, consistent asymmetry is weak.

With respect to two-point discrimination, Semmes, Weinstein, Ghent and Teuber (1960) found no lateral differences in threshold on the thumbs and palms of their normal control subjects. However, there are reports of greater right sided sensitivity of the shoulder (Weinstein, 1968) and of the female breast (Weinstein, 1963). Lower two-point discrimination threshold of the left side is reported for the thigh, calf, sole, forearm and back (Weinstein, 1968). Weinstein (1968) failed to show significant lateral asymmetries for 14 other body parts. No lateral differences in point localization were found by either Semmes et al. (1960) or Weinstein (1968).

Tactile discriminative ability has also been studied by comparing the temporal resolution of numerosity of mechanical pulses delivered to the middle fingers of the right and left hands. Lechelt and Tanne (1975) found greater and generally more accurate report of pulse number with non-preferred hand stimulation, indicating possible minor hemispheric superiority either for perceptual tactile resolution, or tactile sequencing. This is in contrast to the findings of right hand superiority for discrimination of sequential tactile stimuli (Rutschmann, 1969, cited in Nachshon & Carmon, 1975) and for temporal discrimination of tactile signals (Efron, 1963a, 1963b).

When using auditory and visual stimuli, the left hemisphere superiority for a variety of tasks in dextral subjects has been demonstrated with less difficulty and more consistency than instances of right hemisphere superiority. For the tactile modality, it is the superiority of the right hemisphere that has been most consistently demonstrated. Tactual asymmetries are evident in the performance of higher order tasks based upon tactile processing, for as we have seen, hemispheric asymmetry for elementary tactile sensitivity is equivocal at best. Further, in only a few studies has a dual asymmetry been shown for tactual information processing.

Perception of tactuo-spatial directionality is one higher order somesthetic task in which normal right handed

subjects show superior performance with the left than with the right hand. When a linear array of three rods was applied in a vertical, horizontal or oblique direction to the palm of the hand (Benton, Levin & Varney, 1973), subjects made more correct visual identifications of left hand stimuli than of right hand stimuli. This left hand superiority was evidenced not only in group averaged data, but in a significant number of individual subjects. In another study (Varney & Benton, 1975), performance on this tactile-visual matching task was analyzed for eight right handers and eight left handers, some with sinistral and some with dextral familial background. Whereas familial dextrals showed the left hand superiority for directional matching, familial sinistrals showed the reverse lateral superiority, matching more accurately the stimuli to their right hands. No clear asymmetry was shown by dextrals with sinistral parents or by sinistrals with only dextral parents.

To determine whether the asymmetry in tactile directional perception manifested on this task was related specifically to its cross-modal tactile-visual nature, Benton, Varney and Hamsher (1978) developed a similar tactile-tactile matching task for rod orientation. Subjects felt the orientation of metal rods presented as stimuli and selected the matching orientation from a tactile stimulus array. Again, left hand performance was superior, supporting the previous conclusions of this group of investigators that the "right

hemisphere plays the same crucial role in subserving spatial thinking in the tactile modality that it does in the visual modality" (p. 109).

A more complex spatial orientation task used by Dodds (1978) required the subject to tactually explore a random form and then select that form, in a position rotated from the standard in one of eight orientations (0 - 315°, in 45° steps) from a 3-item tactual array. Using right handed subjects in such a tactuo-spatial task, Dodds found the performance of the left hand to be significantly superior to that of the right, a superiority which was evident in 9 of his 10 subjects.

Asymmetry in the performance of tactual shape identification has been explored developmentally by Flanery and Balling (1979). First-, third-, and fifth-grade children and adults made non-verbal "same" or "different" judgments to pairs of random forms presented successively to each hand. In one condition the stimuli were presented singly to each hand. In another, the standards were presented to both hands simultaneously, followed by presentation of the comparison for identification by only one hand. For both conditions, overall left hand accuracy was greater than right hand accuracy. Using a laterality index for both conditions, lateral differences emerged only for fifth-graders and adults, and in both conditions the left hand was more accurate than the right. Further, significantly more older

subjects showed the left hand superiority than younger subjects.

Braille reading is a particularly interesting tactile task as it combines functions postulated to be subserved by both the right hemisphere (tactuo-spatial processing of the dot configurations) and the left hemisphere (linguistic decoding of the symbols). It is therefore especially significant that in studies employing a variety of braille tasks, and testing both children and adults, the performance of the left hand has been found to be superior to the right. While experienced braille readers often use both hands or prefer the right hand for reading, a left hand superiority is exhibited upon experimental test. Hermelin and O'Connor (1971b) reported that blind children read braille more quickly and more accurately with the left hand. Blind adults read with equal speed with the two hands, but are more accurate with the left hand (Hermelin & O'Connor, 1971a).

The process of learning to read braille by tactile-verbal paired association also manifests lateral asymmetry. Rudel, Denckla and Spalten (1974) taught sighted children 7 - 14 years of age to name braille symbols. While a right hand superiority prevailed for 7 - 8 year old girls, and there were no significant hand differences for 7 - 8 year old boys, a superiority of the left hand was evident in boys by 11 years and in girls by 13 years. Rudel et al. (1974)

also found a hand order effect such that the left hand performance was improved by previous right hand braille learning experience, whereas right hand performance was unaffected by previous trials with the left hand. Both the left hand superiority for learning braille symbols and the hand order effect found by Rudel et al. (1974) were replicated by Wagner (Note 1). Further, among a group of 12 left handers, the left hand superiority for braille learning was observed, but the effect on that superiority of prior right hand braille experience was attenuated (Rudel, Note 2). It is of interest to note that in a non-braille tactile-verbal paired associate learning paradigm, adult subjects similarly exhibit more correct responses with the left hand and a steeper learning curve for the left hand (Hatta, 1978).

In part to explore the possibility that the developmentally delayed superiority of the left hand (right hemisphere) seen in girls was due to the greater reliance of females upon verbal strategies, Rudel, Denckla and Hirsch (1977) designed a braille configurational matching task in which no verbal naming was required. Rather, a report of "same" or "different" was required to the tactile matching of braille stimuli in subjects (7 - 14 years of age and some adults) who were naive to the braille code. Again, a left hand superiority for accurate matching was observed after age 10. Rudel et al. (1977) concluded that tactile stimuli, especially those that are unfamiliar, are primarily

processed by the right hemisphere. They suggest that lateralized hemispheric function in the visual and tactual modalities may differ, such that initial tactile exploration, regardless of task, is subserved predominantly by the right hemisphere.

Left hand superiority for braille matching was again reported by Smith, Chu and Edmonston (1977). Normal adults were better able to match a standard braille form to a comparison stimulus from among an array of 10 braille stimuli when feeling with the left hand than when feeling with the right hand. The simultaneous presentation of music to the left ear reduced this left hand superiority, leading the authors to posit an interference effect of music due to an overloading of the right hemisphere.

Although Carmon and Benton (1971) reported no lateral differences for tactile dot enumeration in a population of unilaterally brain damaged patients, Kimura (1966) demonstrated a superiority of the left visual field (right hemisphere) for enumeration of dots presented tachistoscopically to normal subjects. To determine whether the left hand superiority for processing braille stimuli was due to right hemisphere superior ability for dot enumeration, Myers (1976) systematically investigated right and left handed counting of braille dots in adults unfamiliar with braille. No differences between the hands were found, indicating that the left hand superiority for matching braille configurations

and for learning braille symbols is due to hemispheric specialization for functions other than dot enumeration.

Tasks requiring perception of tactile directionality, form recognition, and orientation depend heavily on spatial perception, an ability already demonstrated in other modalities to be largely subserved by the right hemisphere. Tasks which seem to rely upon both spatial and linguistic abilities (tactile-verbal paired associate learning, assorted braille processing tasks) also appear to be better processed by the right hemisphere when presented in the tactile modality. Some investigators have selected tactual tasks which tap functions generally associated with the left hemisphere (e.g., linguistic, temporal) in an effort to evaluate the nature of hemispheric processing in a modality that seems particularly served by the right hemisphere. These studies are relevant to the question of whether the dual asymmetry of function demonstrated in the auditory and visual modalities is also characteristic of the tactile modality.

Since in the auditory modality, asymmetries have been demonstrated under dichotic listening conditions which are less apparent under monaural conditions, Witelson (1974) argued that a tactile task involving interhemispheric competition might make manifest lateral asymmetries in tactile perception not elicited by unimanual stimulation. Using a "dichhaptic" paradigm, Witelson presented pairs of tactuo-spatial nonsense forms to the right and left hands

simultaneously. Subjects were required to identify the forms from a visual display. Cut-out alphabet letter forms were presented dichhaptically for verbal identification. Using 47, 6 - 14 year old right handed boys, Witelson (1974) found superior recognition of nonsense forms felt with the left hand as compared with those felt with the right hand, but only when the response mode was pointing with the left hand. A replication of this experiment (Witelson, 1976a) with an N of 200 (100 males, 100 females) confirmed the left hand superiority for nonsense shape identification for boys as young as six years of age, but failed to show this lateral differentiation for girls by 13 years of age. On the letters task, the results were equivocal. When only 47 boys were tested, no lateral differences in verbal report of tactile letters was evident (Witelson, 1974). However, a report on a sample of 156, 6 - 14 year old boys (Witelson, 1976b) described a significant right hand superiority for the tactile letters task. Another report (Witelson, 1977) described a trend toward better right hand letter perception in 156, 6 - 14 year old normal boys.

Witelson's finding of a dual asymmetry for tactile form versus letter perception was replicated by Cioffi and Kandel (1979), using Witelson's paradigm, in a study of 56 boys and 56 girls between 6½ and 14½ years of age. Nonsense forms, two-letter words, and bigrams (paired consonants) were presented dichhaptically for identification from a visual array.

Both boys and girls showed superior recognition of shapes presented to the left hand and superior recognition of two-letter words presented to the right hand. Bigrams were better processed by the right hemisphere of boys and left hemisphere of girls, suggesting a possible sexual dimorphism for the processing of these more ambiguous stimuli.

Gardner, English, Flannery, Harnett, McCormick and Wilhelmy (1977) adapted Witelson's dichhaptic nonsense shape recognition task for an adult population. Responses included pointing with the right or left hand and vocal identification. Both reaction time and accuracy were measured. Gardner et al. confirmed Witelson's findings of greater accuracy of the left hand for nonsense shape identification for both men and women, regardless of handedness, when responding manually. The vocal response condition did not yield lateral differences in accuracy and produced a marginal right hand superiority in response latency. Gardner et al. also noted an interaction between stimulated and responding hand, such that compatibility between the stimulated and responding hand produced better response (greater accuracy and faster reaction time) than conditions requiring interhemispheric transfer. The best response was to stimuli felt with the left hand and responded to by pointing with the left hand, followed by the "right-right" condition, and then the transfer conditions. Gardner et al. concluded that while the right hemisphere appears to be the superior

tactile-spatial processor, it is not the sole processor and the left hemisphere has some of this ability as well.

The validity of Witelson's task for demonstrating lateral differences in haptic perception has been called into question by two recent investigations. La Breche, Manning, Goble and Markham (1977) administered Witelson's nonsense forms and letter recognition tasks to congenitally deaf and normal control right handed adolescents. Neither the deaf nor the normal subjects showed the left hand superiority for tactile nonsense form recognition from a visual array, nor did they show any lateral advantage for perception of tactile letters, whether responding by finger spelling (with left or right hand) or writing. Rather, a trend toward right hand superiority for nonsense form recognition was demonstrated, with significant right hand superiority when the shape recognition task followed the letter identification task. Cranney and Ashton (1980) administered Witelson's nonsense shape recognition test to 20 right handed hearing children and 19 right handed deaf children falling within the age range of the children studied by Witelson, and also 27 adults. They failed to replicate any of the hand asymmetries reported by Witelson (1974, 1976) or Gardner et al. (1977). Of further interest is a 1942 report by L. P. Gardner who tested the ability of blindfolded right handed college students to read nonsense syllables with the left and right hand. Tactile word stimuli

were created by outlining letters in cord which was secured to cardboard. The left hand was faster and more accurate than the right, although no statistical treatment of the data was reported.

In an attempt to relate lateral asymmetries in tactile perception to different types of stimuli, Oscar-Berman, Rehbein, Porfert and Goodglass (1978) applied competing dichaptic letter, digit, and line orientation stimuli to the palms of the hands of 15 right handed subjects who were required to identify the stimuli in a particular order. Letters were better recognized on the right hand, line orientations on the left hand. No hand superiority was shown for digit recognition. However, these lateral asymmetries were only manifested in the accuracy of the second hand reported. The authors interpret these findings as evidence for the greater sensitivity of tactile short-term memory as an index of hemispheric asymmetry than of measures obtained closer to the perceptual event.

Kleinman and Cloninger (1973) examined intermanual transfer of tactual learning in 32 adults by comparing accuracy of tactual shape recognition for high meaningful (easily verbalizable) geometric forms and low meaningful (difficult to verbally code) random forms. High meaningful shapes were better recognized by the left hand following previous exposure to the right hand, than by the right hand if previous exposure was to the left. The opposite effect

occurred for low meaningful shapes; shapes exposed to the right hand and tested with the left were recognized less frequently than shapes exposed to the left hand and tested with the right. In terms of hemispheric specialization, the authors state that "transfer of tactual information in the corpus callosum from one hemisphere to the other is not bidirectionally equivalent; for meaningful information transfer from the dominant left hemisphere to the right hemisphere is superior to transfer from the right to the left hemisphere, while for low meaningful information, the reverse is true" (p. 879). Thus, a dual asymmetry for hemispheric transfer of tactual information on the basis of ease of verbal encodability or reliance on topographic detail was demonstrated.

Numerous investigators have posited hemispheric differences related to serial versus parallel, or sequential versus simultaneous processing for the left and right hemispheres, respectively (Cohen, 1973; Levy-Agresti & Sperry, 1968). To test this dichotomy as a basis for hemispheric specialization in the tactile modality, Nachshon and Carmon (1975) presented 20 right handed subjects with two tasks, a "spatial" task and a "sequential" task, in which the fingers of each hand were mechanically stimulated in various orders. Subjects had to reproduce the orders by corresponding finger movements. The "sequential" task involved ordered stimulation of three different fingers.

The "spatial" task involved stimulation of fingers such that one finger could be touched more than once, while another might not be stimulated at all on that trial. No lateral differences were exhibited on unimanual stimulation. However, increasing task difficulty by bimanual stimulus presentation (now only two fingers of each hand were stimulated), essentially creating the competition assumed to underlie Witelson's dichhaptic task, resulted in a right hand superiority for "sequential" processing and a left hand superiority for "spatial" processing.

Hemispheric specialization for the processing of sequential tactile stimuli was investigated in a different way by Lechelt and Tanne (1976). Repeated, brief, mechanical stimuli in $1\frac{1}{2}$ second trains of either 5, 6, 7, 9, 11 or 13 pulses were delivered to the right and left middle fingers of three right handed and three left handed male subjects. Subjects reported the number of successive stimuli counted. Nonpreferred hand stimulation yielded significantly higher reports of signal number for all subjects. However, lateral difference in response accuracy shifted from preferred hand superiority for trains of seven or fewer pulses, to non-preferred hand superiority for trains of nine or more pulses. The authors suggest that the functional laterality may depend not only on the stimulus characteristics, but on the strategy employed by the subject, with a counting strategy for individual elements being successfully executed

by the hemisphere controlling the preferred hand for items within the "span of immediate memory" (Miller, 1956), and a more gestalt, poststimulation holistic analysis being used by the other hemisphere for processing the greater number of pulses.

Critique of Studies of Somesthetic Laterality and Rationale for the Present Experiment

Whereas a dual functional asymmetry of hemispheric specialization has been demonstrated for visual and auditory information processing, the nature of lateralized processing of somatosensory information is much less clear. Asymmetry for basic somatosensory sensibility other than pressure sensitivity has not been clearly demonstrated, and the findings of lower pressure thresholds on the left hand have not been confirmed by all investigators. In general, higher order tactile tasks such as perception of directionality, form discrimination and braille symbol processing are better performed with the left hand of normal subjects, and, in unilaterally brain damaged patients, these tasks (with the exception of braille, which has not been fully explored) are more dependent upon an intact right hemisphere than an intact left hemisphere. Similarly, right hemisphere superiority for tasks such as tactile form matching, tactuo-spatial problem solving, and part/whole comparisons, is

seen in commissurotomed patients when a non-verbal response is required.

Attempts to find a complementary specialization of the left hemisphere for somatosensory information processing have met with mixed results. While demonstrating left hand superiority for processing nonsense figures, Witelson (1974) first reported that children showed no lateralized processing of tactile letters, but later reported data on a larger group of subjects that indicated a trend towards right hand superiority (1977), and significant right hand superiority (1976). Although the finding of form and letter specializations of the right and left hemispheres, respectively, was replicated for children by Cioffi and Kandel (1979), it was not replicated on an adolescent population (La Breche et al., 1977) and there are no reports of administration of both tasks to an adult population.

Two investigations have demonstrated dual tactile hemispheric asymmetry for functions akin to tactuo-perceptual memory. Oscar-Berman et al. (1978) found right hemisphere superiority for line orientation and left hemisphere superiority for letter recognition only for stored tactile information. Kleinman and Cloninger (1973) found that transfer of tactile information was not bisymmetrical, but that tactile material which lent itself to verbal coding was better transferred following left hemisphere exposure whereas less verbally codable tactile material was better

transferred following right hemisphere exposure. In addition to the fact that these studies offer very indirect evidence of hemispheric specialization, they also suffer from several methodological difficulties and critical omissions. In the study by Oscar-Berman et al., dichhaptic stimulation was achieved by drawing a pattern on each palm simultaneously by two experimenters. Despite reported efforts to apply stimuli equally and simultaneously, the possibility of systematic lateral bias in stimulation cannot be ruled out. Further, different types of responses, verbal for letters and digits, pointing for lines, were used. These response factors have been shown to be negligible by some investigators (Oscar-Berman, 1974; Gardner et al., 1977), but important by others (Gazzaniga & Sperry, 1967; Witelson, 1974). In the Kleinman and Cloninger study, no information is provided on the sex or handedness of the subjects.

Nachshon and Carmon (1975) reported a dual asymmetry for sequential and spatial (left and right hemisphere, respectively) tasks involving stimulation of the fingers. Although the reproduction of the order in which two or three fingers were stimulated can readily be understood to have a sequential processing component, the basis for their considering the other task as spatial is unclear. In the unimanual task, of the three fingers used, one finger was stimulated twice, one finger stimulated once, and one not at all. The subject had to reproduce this pattern of

stimulation by appropriate finger tapping, "localizing" the fingers for the appropriate number of taps. In the bimanual condition, where only two fingers of each hand were used, one finger or the other received two taps, which had to be reproduced. This task retains a strong sequential component, and its spatial nature is highly questionable.

The study by Lechelt and Tanne (1976) does suggest differential hemispheric modes of processing for estimates of tactile numerosity depending upon whether a detailed counting strategy (subserved by the hemisphere contralateral to the preferred hand) is employed, or a gestalt, holistic estimation strategy (subserved by the hemisphere ipsilateral to the preferred hand) is employed. However, the study used only six subjects, three right handers and three left handers. There was no discussion of how the handedness of these subjects was determined, and considering the uncertain hemispheric specialization for left handers, conclusions regarding hemispheric specialization based upon this study can be considered only suggestive.

Since the superiority of the right hemisphere for processing visuo-spatial material is well documented, as cited above, it is essential that studies purporting to demonstrate tactile laterality effects not be confounded by tasks involving visual perception. Many studies of patients and normal subjects have required cross-modal comparisons, such as the identification of stimuli from a visual array after

they were felt tactually (e.g., Carmon & Benton, 1969; Levy-Agresti & Sperry, 1968; Cioffi & Kandel, 1979). On the basis of these studies, it is uncertain whether the left hand advantage reflects superior right hemisphere ability for higher order tactile perception or for tactual-visual cross-modal integration. Other studies have even further confounded the analysis of lateral differences in tactile perception by employing different response modes for the different tactile stimuli presented; non-verbal response of pointing to a visual array for recognition of tactile shapes, and verbal report as response to tactile letters (e.g., Witelson, 1974, 1976; Oscar-Berman et al., 1978). These different response modes were chosen to facilitate the likelihood of obtaining dual asymmetries. but the simultaneous manipulation of stimulus and response type makes it difficult to determine the contribution of each to the obtained direction of lateral differences.

Five studies of normal subjects have shown left hand tactile processing superiority and have been free of these confounding response factors. Three studies have involved presentation of tactile stimuli with selection of a tactile match as the response, a completely intramodal task (Benton, Varney & Hamsher, 1978; Dodds, 1978; Smith, Chu & Edmonston, 1977). The other two studies required same/different judgments to paired tactile stimuli by manual key press, with responding hands counterbalanced so as not to confound

laterality effects for responding (Flanery & Balling, 1979; Rudel, Denckla & Hirsch, 1977). Of particular interest are a number of studies of braille which have found a right hemisphere/left hand superiority and have used a verbal response mode (which favors the left hemisphere) (e.g., Hermelin & O'Connor, 1971a, 1971b; Rudel, Denckla & Spalten, 1974; Myers, 1976). These have, perhaps, provided the strongest case for the left hand/right hemisphere superiority for tactile processing.

Determining whether there is a dual asymmetry of hemispheric function for processing tactual input is only part of the hemispheric specialization question. The other part concerns the nature of this asymmetry. As mentioned above, some investigators have been concerned primarily with defining the particular stimuli which were best processed by the respective hemispheres (e.g., words versus faces, letters versus forms). Numerous studies have cast doubt on the likelihood that the basis for hemispheric specialization is such a material specificity. Words may be processed best by either the right or left hemisphere depending upon the nature of the processing required (Gibson, Diamond & Gazzaniga, 1972). Faces are sometimes recognized better when presented to the right visual field, sometimes to the left visual field, depending upon whether the cognitive processing mode is analytic for features or holistic for total configurational recognition (Carey & Diamond, 1977).

Efforts to ascribe the basis for hemispheric asymmetries to differing modes of cognitive processing of the cerebral hemispheres have suffered from important confounding factors. Most studies have failed to separate the perceptual aspects of the tasks from the cognitive aspects. Thus, the suggestion of an analytic versus holistic processing dichotomy of the left and right hemispheres was based upon the superiority of the left hemisphere for analyzing detailed linguistic materials whereas the holistic nature of the right hemisphere functioning derived from its superiority for processing entirely different types of stimulus materials such as faces, spatial orientation of lines and figures, etc. One way to confront this problem is to use experimental designs which employ the same stimulus materials, varying only the cognitive task. Only in this way can lateral differences in response be ascribed to differences in the cognitive processing performance of the two hemispheres.

This approach to investigating lateralized cognitive processing was employed during the 1970's to study auditory and visual laterality in behavioral and electroencephalographic paradigms. In a much quoted study, Bever and Chiarello (1974) demonstrated that, with monaural presentation of simple melodies, musically naive subjects showed the expected left ear recognition advantage (Kimura, 1964), but musically experienced subjects showed better recognition

in the right than the left ear. They attributed the differences to a learned analytic information processing mode in the musicians as compared with the more holistic musical information processing of the naive listeners. These findings were confirmed in an EEG study (Davidson & Schwartz, 1977) in which non-musically trained subjects showed greater relative right hemisphere activation while whistling the melody of a song versus reciting its lyrics, while musically trained subjects showed no differences in EEG asymmetry between these tasks.

In other studies using EEG recording during task performance, differences in cognitive processing have been demonstrated by altering the task requirements while presenting the same stimulus materials. For example, McKee, Humphrey and McAdam (1973) found decreasing left/right alpha ratios (indicating increasing left hemisphere activation relative to the right hemisphere) with increasingly difficult linguistic analysis tasks performed on the same auditory material. Robbins and McAdam (1974) reported that when subjects were asked to covertly imagine familiar pictorial material as a mental image of shapes and colors, alpha suppression over the right hemisphere occurred, whereas when covertly imagining those pictures as words which describe the scene, left hemisphere alpha suppression occurred.

Similar separation of cognitive from perceptual laterality effects have been shown in the visual modality.

Neiderbuhl and Springer (1979) tachistoscopically presented single letters to the left or right of fixation, requiring subjects to report whether each letter was a member of a target set. Target sets of two and four letters were used. Of 32 subjects, half were instructed to base their responses on the name of each stimulus. The other subjects were told to use stimulus configuration as the basis for their decision. An interaction between visual field and instructions was obtained, such that the manual reaction time to right visual field (left hemisphere) stimulation was faster than that to left visual field (right hemisphere) stimulation for subjects using the naming mode. The right visual field superiority was not maintained in the configurational match condition, the reverse (left visual field superiority) occurring for the two-target set.

Seamon and Gazzaniga (1973) visually presented pairs of nouns to six subjects in a repeated measures design. Subjects were taught two different coding strategies for relating the nouns: visual imagery and verbal rehearsal. A pictorial probe was then projected tachistoscopically to the right or left of fixation and subjects' manual reaction time to respond to a match or mismatch with either of the previous words was recorded. Right visual field superiority was obtained when subjects were using the verbal rehearsal strategy and the left visual field was superior when subjects used relational imagery for decision making.

In 1967, Posner and Mitchell introduced a reaction time paradigm for investigating cognitive processing which may be utilized to add a new dimension to exploring the nature of hemispheric asymmetries of function. They presented the same stimuli to be processed under three different instructional conditions and used the different reaction times in the three conditions to infer different levels of cognitive processing. In accordance with the subtractive method of Donders (cited in Woodworth & Schlosberg, 1954, p. 32), latency analysis was used as a measure of internal mental processes.¹ The stimuli were visual, simultaneously presented pairs of items (letters, nonsense forms, digits) to which the subject had to manually respond "same" or "different" as quickly as possible. Instructional levels required subjects to classify these stimuli on the basis of physical identity (e.g., AA), name identity (e.g., Aa), and rule identity (e.g., both vowels or both consonants). Physical identity matches were performed most quickly, and increases in reaction time were found for name identity and rule identity, respectively. Posner and Mitchell attributed the reaction time differences in the three cognitive "nodes" to "hierarchical characteristics of information processing" (p. 404).

¹ Donders inferred that subtracting simple reaction time from the time required to respond in a choice situation yields a measure of the duration of the cognitive processing involved in performing the choice.

The hierarchical nature of these cognitive tasks was supported in a study by Beatty and Wagoner (1978) in which pupillary dilation was used as an index of brain activation. Larger dilations, indicative of increased activation, were positively associated with increasing levels of cognitive processing of the types of letter pairs used by Posner and Mitchell (1967).

The Posner and Mitchell paradigm readily lends itself to adaptation for study of hemispheric specialization. First, one may investigate whether the cerebral hemispheres are specialized for processing information in the first two "nodes" of Posner and Mitchell. These nodes, or levels of information processing, are based upon physical identity and name identity. In other words, the matching tasks provide the opportunity to study either hemispheric specialization for configurational/perceptual matching or linguistic/semantic matching. A number of studies (to be discussed below) have been conducted for just this purpose (Geffen, Bradshaw & Nettleton, 1972; Cohen, 1972; Segalowitz & Stewart, 1979). In addition, the Posner and Mitchell paradigm may be used to explore the role of level of information processing itself as a factor in hemispheric asymmetry of function. Might the organization of function of the hemispheres be such that lateral superiority shifts as a function of changing level of cognitive processing? In addressing this question, greater emphasis may be placed on the

processing at Nodes 2 and 3, for these nodes are similar in their requirement for linguistic analysis (speech dominant hemispheric function), but differ in the level of this analysis.

Addressing themselves to the first of these questions, Geffen, Bradshaw and Nettleton (1972) directly applied the Posner and Mitchell paradigm to the study of hemispheric specialization for language and visuospatial processing. Letters in upper and lower cases were tachistoscopically projected in pairs to either the left or right visual field. Twelve subjects (6 men, 6 women) were tested in three conditions: two "pure" conditions, one in which "same" responses could be based on only physical matches and one in which "same" responses could be based on only name matches, and a "mixed" condition in which subjects were required to respond to pairs with the same name, but Aa and AA type pairs were both presented and were both acceptable "same" responses. Manual response time was measured. Stimuli which had the same name were responded to more quickly when presented to the right visual field, whereas stimuli which were physically identical elicited shorter reaction times when presented in the left visual field. This was found in the pure conditions only, and was interpreted as reflecting hemispheric differences in the nature of the tasks best processed by the two hemispheres.

Cohen (1972) applied the same paradigm in a study of 12 subjects, 6 right handers and 6 left handers. Letters were tachistoscopically presented in upper and lower cases to the right and left visual fields. Presentation conformed to Geffen, Bradshaw and Nettleton's "mixed" condition, in which "same" responses could be made on the basis of name or physical identity. Among right handers, there was a smaller mean reaction time difference between name and physical matches in the left hemisphere than in the right. The mean difference between naming and physical matches did not differ between hemispheres for left handers. Name matches were faster in the left hemisphere and physical matches were faster in the right hemisphere, confirming a hemispheric difference in cognitive function for type of processing.

Davis and Schmit (1973) used only pure physical and name match conditions for letters which were presented tachistoscopically to different groups of subjects. For "same" signals, the right hemisphere was more efficient at physical classification than the left, and the left was more efficient at dealing with verbal classification than the right. For "differ" judgments, however, hemispheric superiority was reversed for physical matching (the left hemisphere showed shorter reaction time) and the response to name matches was marginally shorter in the right hemisphere.

Further confirmation of a hemisphere difference based upon cognitive strategy using this same paradigm derives

from a study by Segalowitz and Stewart (1979). Sixty right handed subjects, 30 males and 30 females, made same/different judgments to tachistoscopically presented pairs of letters in the "mixed" condition. There was a significant interaction between visual field and type of match, with a significant left hemisphere advantage for name matches but with a nonsignificant effect for physical matches. Males contributed more to the difference between conditions than females. Since each judgment in the mixed condition could have been based on physical or name characteristics, the authors suggest that women may more readily adopt verbal strategies in such ambiguous situations.

Thus, the first laterality question to which the Posner and Mitchell paradigm may be applied has been addressed in the visual modality, with general confirmation of dual asymmetry of hemispheric function. Application of a similar design to a tactual task is of great interest as it may serve to elucidate the generality of these findings to theories of hemispheric specialization of function. Further, comparisons between the lateral cerebral processing of visual and somatosensory information may be drawn. The second experimental question which may be posed using the Posner and Mitchell paradigm -- that of hemispheric asymmetries related to level of cognitive processing -- is the focus of current studies in auditory (e.g., Belmore, 1980) and visual memory (e.g., Madden & Nebes, 1980), but has not heretofore been

addressed in the area of somesthesia.

The present study was designed to explore lateral differences in type and level of cognitive processing in the tactile modality, using the Posner and Mitchell reaction time paradigm. Comparisons were made between responses to stimulation of the left and right hands when subjects were instructed to make same/different judgments of pairs of tactile patterns on a configurational (physical), semantic (name), or categorical (rule) matching basis. Braille-like patterns were used because they have been shown to reveal asymmetries in tactile information processing, and because they lend themselves to configurational as well as verbal encoding. It was hypothesized that there would be lateral differences in the direction of superiority, first in favor of the left and then in favor of the right hand, with increasing level of cognitive processing from configurational to semantic to categorical. Specifically, it was predicted that, for subjects required to make a configurational match, the performance with the left hand would be better than that of the right hand, and for subjects required to make a categorical match, performance with the right hand would surpass the left. It was further predicted that for subjects required to make a semantic match (intermediate level of processing), the relative performance of the two hands would lie somewhere between the other two conditions, either showing no lateral differences or showing a left or right

hand superiority smaller in magnitude than that shown by subjects in the configurational or categorical groups, respectively.

CHAPTER 2

METHOD

Subjects

Seventy-seven Queens College undergraduate women¹ between the ages of 17 and 25 volunteered to participate in the study. They were told that it was an experiment in tactile perception, but were naive to the purpose of the study.

The criteria for inclusion in the sample were:

1. Right handedness, as determined by:
 - a. Right handed performance on all eight items of a performance inventory. The inventory required subjects to use objects provided to perform manual activities as the experimenter stated them (e.g., "Throw the ball to me") (see Appendix A).
 - b. Subject's report of familial right handedness (i.e., both parents right handed and not more than one left handed sibling).

¹ Only women were used as subjects as there is evidence of gender differences in lateralization of function (e.g., Bryden, 1978; Harris, 1977; McGlone, 1978; Rizzolatti & Buchtel, 1977). Women were selected, as opposed to men, because they may possess greater tactile sensitivity than men (Smith, Chu & Edmonston, 1977; Weinstein, 1968) and because they show consistent lateral differences on braille tasks (Rudel et al., 1977; Smith, Chu & Edmonston, 1977).

2. Demonstrated ability to learn a set of eight tactile-verbal paired associates to criterion within 30 minutes.
3. No current playing of a stringed instrument, as this would increase the chance that the fingers of the two hands may be differentially callused and differentially sensitive to the stimulus patterns.
4. No history of injury to the hands or fingers.

Twenty-nine of the 77 volunteers failed to meet one or more of these criteria¹ and the sample therefore consisted of 48 subjects.

Experimental Design

The 48 subjects were assigned to one of the following three experimental groups (n = 16 in each group): Configurational Group, Semantic Group, or Categorical Group. The first 12 subjects were assigned to each group in succession until there were 4 subjects in each group. The remaining 36 subjects were assigned in random order. All subjects were required to judge whether two successively presented braille-like patterns were the same or different.

Subjects in the Configurational Group were required to match the stimuli solely on the basis of tactile

¹ Five subjects failed to meet the first criterion, 18 failed to meet the second criterion, and 6 failed to meet the third or fourth criterion.

configuration. When the two successive stimuli of a pair felt physically identical, they were to be judged "same". When they did not feel identical, they were to be judged "different".

Subjects in the Semantic Group compared the stimuli on the basis of predetermined arbitrary meaning. When the two successive stimuli of a pair meant the same thing (e.g., "Red #1" and "Red #2" both mean red), they were to be judged "same". When they did not mean the same thing (e.g., "Day #1" and "Blue #1"), they were to be judged "different".

Subjects in the Categorical Group matched the stimuli on the basis of categorical inclusion. When the two successive stimuli of a pair were subsumed under the same supraordinate category (e.g., "Red #1" and "Blue #1" are both "Color"), they were to be judged "same". When they did not belong to the same category (e.g., "Red #1" and "Night #1"), they were to be judged "different".

Stimuli

The stimuli consisted of eight patterns of raised dots, constructed from narrow gauge (1/16") rounded-tip metal rods arranged in a 3 x 3 array (an extension of the standard 2 x 3 braille cell). In close accord with braille specifications, spacing between adjacent points was .1 in. (2.55 mm), and points were raised .035 in. (1 mm) from the

surface. Each of the eight patterns was composed of four dots.

The eight stimuli were selected on the basis of pilot testing of a variety of different patterns. Those which were either too easy to recognize (resulting in errorless configurational matching performance) or too difficult to differentiate (making learning of associated names impossible) were eliminated. Patterns with equal numbers of points were selected to eliminate counting as a cue to judgment. No pattern was the reverse of any other, and each pattern was equally differentiable by active touch from every other pattern.

The patterns were arbitrarily assigned the following four names: "red," "blue," "day," and "night," with two patterns associated with each name. The names were drawn from two semantic categories: "color" and "part of the 24-hour period." The four stimuli associated with "red" and "blue" comprised the "color" category, and the four stimuli associated with "day" and "night" comprised the "part of the 24-hour period" category. The stimulus patterns and their associated names are shown in Figure 1.

For subjects in the Configurational Group, each stimulus was paired with itself to provide a same match, resulting in eight possible same matches. For the Semantic Group, each stimulus was paired with the other which shared its designated name to create a same match. For example, "Red #1"

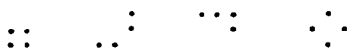
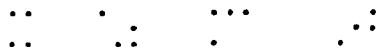


Patterns:				
Name:	Red (#1) Red (#2) Blue (#1) Blue (#2)	Day (#1) Day (#2) Night (#1) Night (#2)		
Category:	 Color		 Part of the 24-Hour Period	

Figure 1. Dot patterns used as tactile stimuli, their assigned names and categorical inclusion.

was paired with "Red #2," "Blue #1" with "Blue #2," etc. In each of the four possible pairs, each member was presented once as the first member of the pair (standard stimulus) and once as the second member of the pair (comparison stimulus), resulting in eight possible same matches. For the Categorical Group, each stimulus was paired with the other member of its category, excluding the pattern which had the same name. Thus, for example, "Red #1" was paired with "Blue #1" and "Blue #2," but never with "Red #2," to provide same matches. There were eight such pairs, which, when presented with each member occupying once the position of a standard stimulus and once the position of a comparison stimulus, provided a total of 16 possible pairs. As a result, there were no Configurational same matches for either the Semantic or Categorical Groups and there were no Semantic same matches for the Categorical Group.

The eight patterns were combined in yet another manner to provide stimulus pairs which served as the different matches for all three groups. Each pair had one member drawn from each category (e.g., "Red #1" from the "Color" category matched with "Day #1" from the "Part of the 24-hour period" category). Thus, the members of these pairs differed on the basis of category inclusion, arbitrary name, and physical identity. There were eight pairs selected, which, with reversal of members between the positions of standard and comparison, provided 16 possible pairs.

In summary, there were eight possible same Configurational Match pairs, eight possible same Semantic Match pairs, 16 possible same Categorical Match pairs, and 16 possible different pairs which were used for all three groups.

Apparatus

Two 3 x 3 arrays of metal probes, each driven by nine Guardian continuous 24V DC solenoids, produced the stimulus patterns. Each solenoid array was mounted on the under-surface of a perforated lucite plate so that the metal probes remained flush with the top surface when unactivated, and extended 1 mm above the surface to create raised dot patterns when energized. The interchangeable lucite plates were placed in the surface of a typewriter table, with the braille cells 26 cm apart, so that the index fingers of the right and left hands could comfortably be placed over the two cells. An opaque lucite panel was mounted above the stimulus cells so as to obscure the stimuli as well as the subject's hands from her view (see Figure 2).

The solenoids were controlled either manually by the experimenter, or automatically by computer. They were energized by a 24 volt power supply with the current limited to approximately .06 amps per solenoid. The solenoids were each connected to the power supply by a switch, and these were correspondingly arranged in two 3 x 3 arrays and mounted with brackets on the experimenter's side of the



Figure 2. Stimulus delivery apparatus showing position of subjects' fingers over stimulus cells, panel to obscure view of hands, and switches for manual control of stimuli.

stimulus table. The solenoid switches for each array went through a single master switch, permitting simultaneous energizing of all solenoids in a given array. They were also connected to a Digital Equipment Corporation PDP 11/34 computer interfaced to a Hazeltine 2000 terminal and Teletype Model 43 (Figure 3). The computer program permitted the experimenter to select one of these sequentially arranged stimulus series (Configurational, Semantic, or Categorical Pairs) and then it activated the solenoids according to a selected sequence.

Simultaneously with presentation of the comparison stimulus in each stimulus pair, a programmable real-time clock on the AR11 board of the computer was activated and reset to zero. Depression of either of the Linemaster Treadlite T-51 foot pedals signalled the computer to stop the real-time clock and measure the elapsed time to the nearest millisecond. The computer recognized whether the "same" or "different" foot pedal was depressed. The print-out listed each stimulus pair, their correspondence (whether they were same or different), the subject's judgment of "same" or "different", and the reaction time.

Procedure

The experiment consisted of a two-part procedure: a learning task and a matching test. In the learning task,

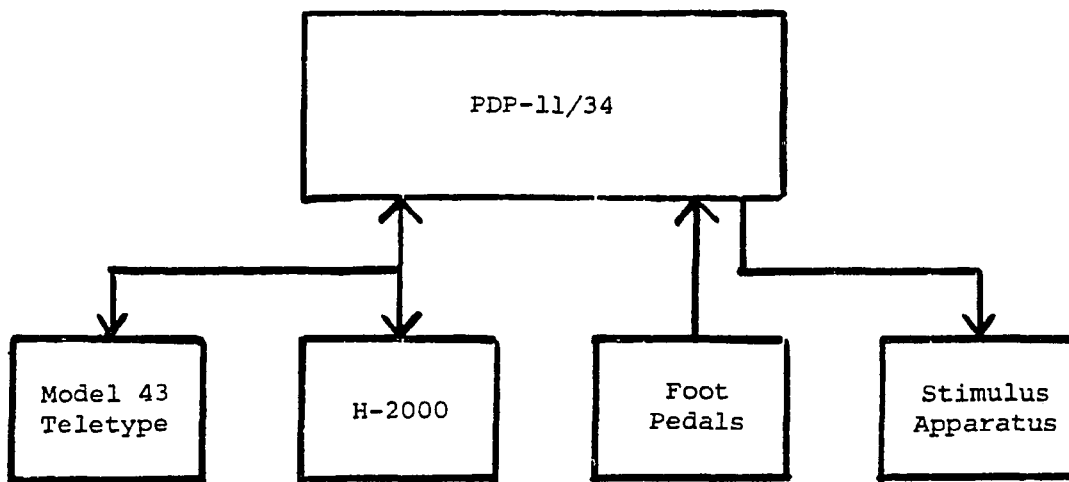


Figure 3. Block diagram for automatic control of test apparatus.

subjects learned to associate the four words ("red," "blue," "day," "night") with the eight tactile patterns. As reference to the verbal meaning of the stimuli was the basis for matching in the Semantic and Categorical Groups, subjects in these groups performed the learning task immediately prior to the matching test. On the other hand, as the basis for matching in the Configurational Group was intended to be non-verbal, subjects in this group performed the learning task only after completing the matching test. This was necessary in order to assure that subjects used in the Configurational Group did not differ from those in the other two groups in their ability to master the learning task.

Subjects were individually tested in a laboratory at Queens College. When she entered the laboratory, the subject immersed her fingers in warm water for five minutes to reduce pretest cutaneous differences between the two hands (differences due to such factors as temperature or recent use of the right hand for writing). The learning task instructions (see below) were read to her during this period. She was then seated before a modified typewriter table containing the stimulus apparatus and told to place her index fingers on the stimulus cells.

The learning task. The names of the eight tactile arrays were taught using a modified paired associate method.

The following instructions were read to the subject:

There are eight different patterns that will be presented to you to feel with your index fingers. These eight patterns are associated with only four different words, so that each word is associated with two patterns. The four different words are red, blue, day, and night. Therefore, you will learn two different patterns that mean red, two different patterns that mean blue, and two patterns each for day and night.

The eight patterns will first be presented in a randomized order to your L/R index finger and I will tell you what each pattern means. You may move your finger on each stimulus array to feel the pattern well. Then, in a new randomized order, the eight patterns will be presented to your R/L index finger and I will again teach you what they mean. This whole teaching procedure will be repeated, randomizing order of pattern presentation, to your L/R and then your R/L fingers again.

Then, I will present these eight stimuli to your L/R finger and you will tell me the names of the patterns after each occurs. I will give you feedback on each trial. I will say "Yes" if you are correct, and I will supply the right answer if you are incorrect. We will continue to alternate series to the right and left hands until the patterns and names are learned.

The eight patterns were randomized ten times, each of the ten orders constituting one paired associate learning trial (see Appendix B). These ten orders were repeated for subjects who required more than ten learning trials to reach criterion. Trials were presented alternately to the right and left hands. Presentation of the first trial to the right or left hand was counterbalanced across subjects

within each group. The first four trials were "teaching trials," during which each pattern was presented for 12 to 15 seconds and was accompanied by the experimenter stating, "This is (name)." On the ensuing trials, subjects reported the verbal associate within the 15 seconds allowed for each pattern, and received feedback in the form of positive acknowledgment ("yes" or "correct"), or correction as required. The stimulus apparatus was operated manually by the experimenter.

The criterion for mastery was 50% overlearning. Subjects had to correctly name all eight items on each of two successive trials (one with the right hand, one with the left hand), followed by continued correct naming on half again as many trials as were required to reach the two successive trial perfect performance. Thus, a subject who responded correctly on trials 7 and 8 received four more trials (two to each hand) on which 100% correct response was required in order to reach criterion. In fact, subjects took an average of 12.29 trials to reach criterion (mean = 12.25, 12.62, and 12.00 trials, $sd = 2.65, 3.12, \text{ and } 3.01$, in the Configurational, Semantic, and Categorical Groups, respectively). There was no evidence of a difference in number of trials to criterion among the groups ($F(2,45) = .37, p < .05$).

The matching test. Comparison pairs were constituted from the eight stimulus patterns depicted in Figure 1.

The following instructions were read to subjects in the Configurational Group:

In this task you will feel pairs of stimuli and you will make judgments as to whether the members of each pair feel the same or different. The stimuli consist of tactile, braille-like patterns which will be presented to your right and left index fingers. Presentations are brief, but you may move your fingers on the stimulus arrays to feel them better.

A stimulus pair consists of a pattern briefly presented to either your right or left index finger (the standard stimulus) followed a few seconds later by another pattern presented to that same finger (the comparison stimulus).

You respond by pressing the foot pedal under your right or left foot. If the two successive patterns feel the same, press the L/R foot pedal. If the two successive patterns feel different, press the R/L foot pedal. You may respond any time after the onset of the comparison stimulus. I am interested in your speed of response as well as your accuracy. Respond as quickly as possible, but try not to be utterly careless.

We will now have eight practice trials to familiarize you with the procedure. Pairs will be presented to your right and left index fingers in random order. Remember: Press the L/R foot pedal when the stimulus patterns feel the same. Press the R/L pedal when the stimulus patterns feel different.

Instructions to subjects in the Semantic and Categorical Groups were the same as above with several modifications. Subjects were told that the stimuli consisted of the "eight braille-like tactile patterns which you have just learned." Subjects in the Semantic Group were instructed to "make judgments as to whether the members of each pair mean the

same or different things. That is, when both members of a pair mean red, blue, day, or night, you will judge 'same'. If one stimulus means blue and the other means day, or if, for example, one means night and the other means red, you will judge 'different.'" Subjects in the Categorical Group were instructed to "make judgments as to whether the members of each pair belong to the same or different categories. That is, if both stimuli are colors, or if both stimuli are parts of the 24-hour period, you will judge 'same'. If one stimulus is a color and the other is a part of the 24-hour period, you will judge 'different'. For example, if one stimulus is blue and the other is red, you will judge 'same' because they are both colors. If one stimulus is night and the other is blue, you will judge 'different' because one is a part of the 24-hour period and the other is a color."

The standard stimulus was presented for one second, followed three seconds later by a .5 second presentation of the comparison stimulus. The intertrial interval was 13 seconds measured from standard stimulus onset on Trial n to standard stimulus onset on Trial n+1. If the subject failed to respond within the 8.5 second response period, that trial was automatically repeated at the end of the stimulus series.

For all subjects, the two patterns comprising a given stimulus pair (the standard stimulus and the comparison

stimulus) were presented to the same hand. Thirty-two same pairs and 32 different pairs were presented to each hand to comprise a total of 128 test trials. (The make-up of the same stimulus pairs for the Configurational and Semantic Groups was achieved by eight presentations of the eight possible pairings of patterns for these conditions. The same stimulus pairs for the Categorical Group as well as the different stimulus pairs for each of the three groups were provided by four presentations of the 16 pairs for those conditions.) The order of stimulus presentation was randomized over 64 trials with the constraints that not more than three consecutive trials be presented to the same hand, and that not more than three consecutive trials be same or different matches. This quasi-randomized stimulus series was repeated, resulting in the total of 128 trials.

The 128 test trials were divided into quarters by three rest breaks, a 2-minute break following the first and third quarters, and a 5-minute break at the halfway point.

Subjects responded by pressing foot pedals to signify the correspondence of the paired stimuli, i.e., whether the standard and comparison stimuli were the "same" or "different." Half the subjects in each group depressed the right foot pedal to signify a response of "same" and the left foot pedal to signify a response of "different." The other subjects had the reverse foot response designation.

Administration of the matching test was preceded by a series of eight practice trials, equally divided between the right and left hands and between same and different pairs.

Detailed information on subjects' handedness and subjects' impressions of the experimental tasks were collected at the end of the session (see Appendices A and C for inventories). Although only those volunteers who regarded themselves as right handed were asked to participate in the experiment, the handedness inventory was administered at the end of the experimental session so as not to call the attention of the subjects to differences between their hands while performing the matching test.

The experiment conformed to a 3 x 2 x 2 x 2 design with two independent factors, Group (3 levels) and Foot Response Designation (2 levels), and two repeated measures, Hand (2 levels) and Stimulus Correspondence (2 levels).

Response Measures

Response measures were reaction time (RT) and accuracy. Reaction time was computed to the nearest millisecond, from the onset of the comparison stimulus to the depression of the foot pedal, for "same" and "different" judgments for the right and left hands. Accuracy was assessed by tabulating the frequency of errors of "same" and "different" judgments for the right and left hands.

Data Analysis

Mean reaction times were calculated for correct responses only. As it is common for reaction time scores to be positively skewed, geometric means, which proportionately reduce the weight of scores at the upper end of the distribution, were taken as the best estimate of reaction time. Geometric means were computed for the reaction times of each subject for (1) left hand-- different matches, (2) left hand-- same matches, (3) right hand-- different matches, and (4) right hand-- same matches. These geometric means were averaged arithmetically across subjects to provide group mean reaction times. The number of errors made by each subject under each of the four above-mentioned hand by type of match combinations was also tabulated and group means obtained.

Two 4-way analyses of variance were performed on the data: one for reaction time and one for number of errors. Differences were considered statistically significant if they reached or exceeded the conventional .05 level of confidence.

CHAPTER 3

RESULTS

Reaction Time

Mean reaction time (RT) increased from configurational matching to semantic matching to categorical matching as follows: Configurational Group--1098.7 msec (SD = 338.7), Semantic Group--1707.1 msec (SD = 487.6), and Categorical Group--2018.8 msec (SD = 343.8). The assumption of homogeneity of variance was accepted on the basis of Hartley's F_{max} test. Analysis of variance revealed these group differences to be highly statistically significant (Table 1).¹ A paired comparison test--Fisher's Least Significant Difference (LSD) procedure (Fisher, 1949, pp. 56-58)--showed that subjects in the Categorical Group reacted significantly more slowly than those in both the Semantic and the Configurational Groups, and that subjects in the Semantic Group

¹ The order in which comparisons are listed in Tables 1 and 7 does not correspond directly to the order of presentation of the results. The table lists group comparisons with respect to the appropriate error term whereas the text presentation treats comparisons with respect to the main experimental hypotheses, treating main effects and interactions for Hand before similar analyses for Foot Response Designation.

Table 1.

Analysis of Variance of Reaction Time Data

Source	Sum of Squares	DF	Mean Square	F	P
Group	28027936.00	2	14013468.00	24.06	.000
Foot	403452.00	1	403952.00	.69	
Group x Foot	58768.00	2	29384.00	.05	
Error	24465632.00	42	582515.00		
Hand	206.25	1	206.25	.02	
Group x Hand	141153.19	2	70576.56	6.84	.003
Foot x Hand	78286.69	1	78286.69	7.59	.009
Group x Foot x Hand	69184.56	2	34592.28	3.35	.045
Error	433380.31	42	10318.58		
Stimulus Correspondence	1100637.00	1	1100637.00	30.23	.000
Group x Stimulus Correspondence	662104.00	2	330152.00	9.09	.001
Foot x Stimulus Correspondence	1349.00	1	1349.00	.04	
Group x Foot x Stimulus Correspondence	63136.00	2	31568.00	.87	
Error	1528977.00	42	36404.21		
Hand x Stimulus Correspondence	6756.88	1	6756.88	.48	
Group x Hand x Stimulus Correspondence	39853.69	2	19926.84	1.42	
Foot x Hand x Stimulus Correspondence	8707.38	1	8707.38	.62	
Group x Foot x Hand x Stimulus Correspondence	4339.62	2	2169.81	.15	
Error	590532.88	42	14060.30		

reacted significantly more slowly than those in the Configurational Group. All differences exceeded the critical LSD value at the .05 level. Therefore, each group differed from each of the other two groups.

As Table 2 shows, overall RT to stimulation of the right hand was virtually identical to that of the left hand when mean RTs were collapsed across the three groups, and there was no evidence of a difference between the two hands when the three groups were combined (Table 1). However, there were clear differences between the two hands which varied as a function of level of task demand (Table 2). In the Configurational Group, a statistically significant left hand advantage was shown. In contrast, the Categorical Group showed a statistically significant right hand advantage. The small difference in favor of the left hand in the Semantic Group was not statistically significant. These differences in the direction of hand advantage among the groups account for the statistically significant Hand x Group interaction (Table 1).

The superiority of the right hand in the Categorical Group represents a significant difference from the left hand advantage in the Configurational Group (total difference = 130.3 msec), and from the hand difference in the Semantic Group (total difference = 87.8 msec); applying Fisher's LSD procedure, both differences exceeded the critical value at the .05 level. However, the magnitude of the left hand

Table 2

Reaction Time (msec) for the Left and Right Hands
as a Function of Task-Demand Group

Group		Left Hand	Right Hand	Left Hand- Right Hand	$t(15)$	p
Configurational	\bar{x}	1071.0	1126.5	-55.5	2.67	<.05
	sd	346.8	333.6			
Semantic	\bar{x}	1700.6	1713.6	-13.0	.35	ns
	sd	504.9	477.8			
Categorical	\bar{x}	2056.2	1981.4	74.8	3.02	<.01
	sd	353.0	335.9			
Total	\bar{x}	1609.2	1607.2	2.0		
	sd	575.1	525.8			

advantage in the Configurational Group did not differ significantly from the non-significant hand difference in the Semantic Group (total difference = 42.5 msec).

To ascertain whether these group differences in lateral advantage were attributable to large hand differences for only a few subjects in the group, or were characteristic of the group as a whole, the number of subjects in each group showing right and left hand superiority in RT was tabulated (Table 3). In the Configurational Group, more subjects showed a left hand advantage than showed a right hand advantage, whereas in the Categorical Group, more subjects showed a right hand advantage than showed a left hand advantage. Subjects in the Semantic Group were equally divided with respect to hand advantage. Application of the binomial test indicated that the right hand advantage for the Categorical Group was statistically significant and the left hand advantage for the Configurational Group approached, but did not reach, the required level of statistical significance. An overall chi-square test indicated a significant difference in the distribution of hand advantage in the three groups ($\chi^2 (2) = 10.17, p < .01$). To examine differences between hand advantage in specific pairs of groups, proportions tests were performed. The proportion of subjects showing left hand superiority was significantly greater in the Configurational Group than in the Categorical Group ($z = 3.18, p < .01$), indicating that the differences

Table 3
Number of Subjects in Each Task-Demand Group
Showing Right or Left Hand Advantage

Group	Left Hand Advantage	Right Hand Advantage	Binomial p
Configurational	12	4	.08
Semantic	8	8	1.00
Categorical	3	13	.02

between the groups in direction of lateral superiority was characteristic of the individual members of the group. There was a trend toward more frequent right hand superiority in the Categorical Group than in the Semantic Group ($z = 1.85, p = .07$). The proportion of subjects showing left hand superiority in the Configurational Group did not differ significantly from that in the Semantic Group ($z = 1.46, p = .15$). Thus, taken together, the various frequency analyses support the findings from grouped data of differences in the direction of hand advantage among the Configurational, Semantic and Categorical Groups.

Mean RT did not differ as a function of the foot designation for "same" or "different" responses (Table 4). When the left foot was designated for "same," the mean RT was 1562.3 msec; when the right foot was designated for "same," the mean RT was 1654.1 msec. This difference was not statistically significant (Table 1). Furthermore, there was no significant interaction between Foot Response Designation and Group. However, there was a relationship between responding foot and stimulated hand. As Table 4 shows, when the left foot was designated for "same" responses, RT to left hand stimulation was faster than to right hand stimulation ($t(23) = 4.86, p < .01$). When the right foot was designated for "same" responses, RT to right hand stimulation was faster than to left hand stimulation ($t(23) = 4.83, p < .01$). These results account for the

Table 4
 Reaction Time (msec) to Stimulation
 of the Left and Right Hands as a Function of
 Foot Response Designation and Task-Demand Group

Group		Left Foot "Same"			Right Foot "Same"		
		Left Hand	Right Hand	Total	Left Hand	Right Hand	Total
Configurational	\bar{x}	990.5	1065.8	1028.1	1151.5	1187.2	1169.3
	sd	381.4	372.9	373.0	298.7	288.2	289.3
Semantic	\bar{x}	1619.8	1726.4	1673.1	1781.4	1700.8	1741.1
	sd	549.6	571.5	554.2	459.1	380.5	416.8
Categorical	\bar{x}	2019.3	1952.3	1985.8	2093.1	2010.6	2051.8
	sd	349.5	349.3	345.4	363.9	330.6	344.6
Total	\bar{x}	1543.2	1581.5	1562.3	1675.3	1632.8	1654.1
	sd	604.1	576.3	587.6	542.8	474.7	507.7

statistically significant interaction between Hand and Foot Response Designation (Table 1).

Interestingly, the Hand x Foot Response Designation interaction was related to Group, as evidenced by the significant Group x Foot Response Designation x Hand interaction (Table 1). This 3-way interaction was primarily due to the fact that in the Semantic Group, the response to stimulation of the left hand was 106.6 msec faster than to stimulation of the right hand when the left foot was designated "same," whereas the response to stimulation of the right hand was 80.6 msec faster than to stimulation of the left hand when the right foot was designated "same" (Table 4). This is graphically portrayed in Figure 4. In neither the Configurational nor Categorical Groups was this hand-foot "compatibility" effect shown for both Foot Response Designations.

As can be seen in Table 5, the mean RT across groups to same matches was faster than to different matches. This difference was statistically significant (Table 1), and was not unexpected in light of a considerable literature reporting faster RT to same than different matches (Hellige, 1975, 1976; Lefton & Haber, 1974; Posner & Mitchell, 1967). Same matches were significantly faster than different matches in the Semantic ($t(15) = 4.43, p < .01$) and Categorical ($t(15) = 2.97, p < .01$) Groups, with the

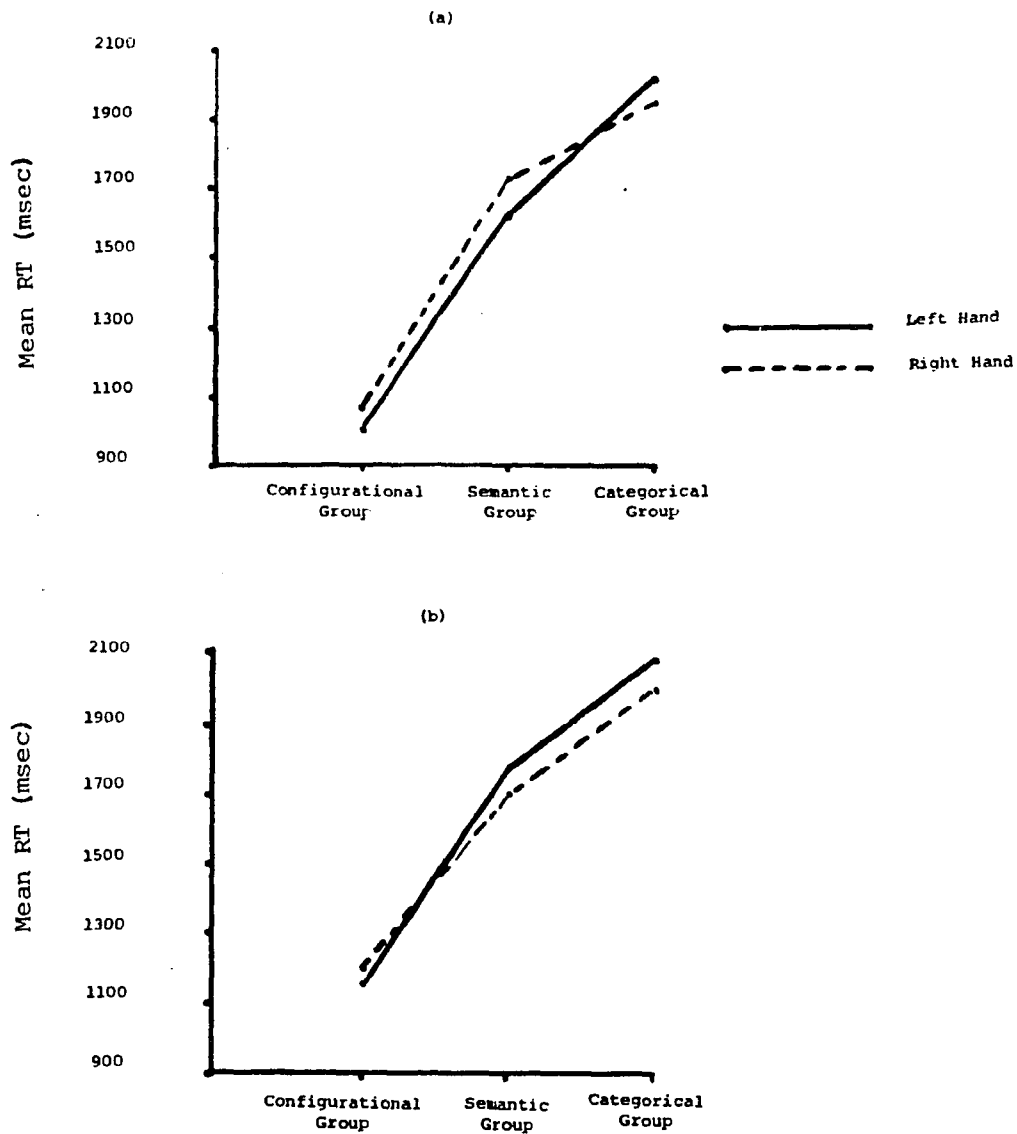


Figure 4. Interaction between Hand, Task-Demand Group and Foot Response Designation:

(a) Left foot designated to respond "same"

(b) Right foot designated to respond "same"

Table 5
 Reaction Time (msec) for Same and Different Matches
 as a Function of Task-Demand Group

Group		Same Matches	Different Matches	Different Matches- Same Matches
Configurational	\bar{x}	1074.1	1123.4	49.3
	sd	357.4	322.7	
Semantic	\bar{x}	1549.1	1865.1	316.0
	sd	420.6	504.8	
Categorical	\bar{x}	1974.3	2063.3	89.0
	sd	371.1	313.8	
Total	\bar{x}	1532.5	1683.9	
	sd	526.9	558.3	

Configurational Group showing a trend in the same direction ($t(15) = 2.0, p = .07$). The significant interaction which was found between Stimulus Correspondence and Group (Table 1) is primarily attributable to the large difference between RT to same and different matches in the Semantic Group (see Table 5). Applying Fisher's LSD test, the magnitude of difference in this group exceeded the critical value at the .01 level of confidence, but did not in either of the other two groups.

Stimulus Correspondence did not interact significantly with either Foot Response Designation or Hand. None of the 3-way interactions involving Stimulus Correspondence were found to be statistically significant, nor was the interaction of all four factors (Table 1).

Accuracy

Subjects in the Configurational Group made the fewest errors and Semantic and Categorical Group subjects made approximately the same number of errors (Table 6). Hartley's F_{\max} test indicated that the data met the requirements for the assumption of homogeneity of variance. There was a statistically significant difference across the three groups in number of errors made (Table 7). The difference between the number of errors in the Configurational Group and the number of errors in each of the other two groups exceeded the LSD critical value at the .05 level; the difference

Table 6

Mean Error Frequencies of the Three Task-Demand Groups as a Function of Hand Stimulated, Foot Response Designation and Stimulus Correspondence

Group	Foot Designation	Left Hand			Right Hand			Grand Total
		Diff.	Same	Total	Diff.	Same	Total	
Configurational	R/L ^a	3.9 (3.27) ^c	2.8 (3.37)	6.9	3.6 (3.20)	3.1 (3.52)	7.0	13.9
	L/R ^b	4.1 (4.70)	3.1 (2.95)	(6.10)	4.0 (3.74)	3.2 (2.38)	(5.25)	(11.04)
Semantic	R/L	6.5 (2.20)	7.2 (4.33)	13.1	7.5 (2.07)	8.2 (4.06)	14.1	27.2
	L/R	6.2 (4.77)	6.2 (4.56)	(6.66)	6.4 (3.29)	6.0 (3.66)	(5.57)	(10.97)
Categorical	R/L	7.8 (3.37)	7.4 (2.20)	13.2	9.1 (4.09)	6.2 (3.24)	14.1	27.3
	L/R	6.4 (3.25)	5.0 (2.20)	(5.30)	6.6 (4.21)	6.1 (3.04)	(6.89)	(11.02)
Total		5.8 (3.77)	5.3 (3.71)	11.1 (6.62)	6.2 (3.84)	5.5 (3.66)	11.7 (6.62)	22.8 (12.50)

^a Right foot designated to press for "same" responses, left foot to press for "different" responses

^b Left foot designated to press for "same" responses, right foot to press for "different" responses

^c sd in parentheses

Table 7
Analysis of Variance of Error Data

Source	Sum of Squares	DF	Mean Square	F	P
Group	472.63	2	236.31	7.63	.001
Foot	32.50	1	32.50	1.05	
Group x Foot	30.79	2	15.40	.50	
Error	1300.40	42	30.96		
Hand	4.38	1	4.38	.74	
Group x Hand	1.79	2	.90	.15	
Foot x Hand	.42	1	.42	.07	
Group x Foot x Hand	5.37	2	2.69	.45	
Error	249.28	42	5.94		
Stimulus Correspondence	18.13	1	18.13	2.16	
Group x Stimulus Correspondence	20.79	2	10.40	1.24	
Foot x Stimulus Correspondence	.13	1	.13	.02	
Group x Foot x Stimulus Correspondence	5.29	2	2.65	.32	
Error	351.90	42	8.38		
Hand x Stimulus Correspondence	.42	1	.42	.12	
Group x Hand x Stimulus Correspondence	3.12	2	1.56	.43	
Foot x Hand x Stimulus Correspondence	2.30	1	2.30	.64	
Group x Foot x Hand x Stimulus Correspondence	9.37	2	4.69	1.30	
Error	151.03	42	3.60		

between the number of errors in the other two groups did not reach this critical value.

No other main effects or interactions were found to be statistically significant.

Relationship between Reaction Time and Accuracy

To determine whether there was a "trade-off" between RT and accuracy, Pearson product-moment correlations were computed for RT and number of errors for the left and right hands of the 16 subjects in each group (a negative correlation coefficient would indicate a trade-off of speed for accuracy). None of these coefficients, which ranged from +.01 to +.30, reached the critical value ($r(14) = .50$) for statistical significance at the .05 level, indicating that there was no trade-off of speed of response for accuracy.

Pearson product-moment correlation coefficients were also computed for RT and errors for the left and right hands for all subjects in the three groups combined. An r of +.38 was obtained for the left hand, and +.45 for the right hand, both of which are statistically significant ($df = 46, p < .01$), indicating that the RT and error measures were reflecting similar aspects of the tasks.

Summary of Results

The results indicate that RT was faster to left hand stimulation than to right hand stimulation for the Configurational Group and faster to right hand stimulation than to left hand stimulation for the Categorical Group. There was no significant difference between the hands for subjects in the Semantic Group. These findings from the group data were also characteristic of the individual members of each group; significantly more subjects in the Configurational Group showed faster RT to left hand than right hand stimulation, and significantly more subjects in the Categorical Group showed faster RT to right hand than to left hand stimulation. In the Semantic Group, subjects were evenly divided with respect to left or right hand advantage in RT. A shift in hand advantage from left to right was associated with the increase in task demand, as RTs in the Configurational Group were significantly faster than in the Semantic Group, which was, in turn, significantly faster than in the Categorical Group.

There was no significant main effect (on RT) of Foot Response Designation. However, in the Semantic Group, the RT to left hand stimulation was significantly faster when the left foot responded "same," and RT to right hand stimulation was significantly faster when the right foot responded "same." This accounted for the statistically significant Hand x Group x Foot Response Designation interaction.

RT to same pairs was significantly faster than to different pairs for both the Semantic and Categorical Groups and approached significance for the Configurational Group. The magnitude of RT advantage for "same" responses was significantly greater in the Semantic Group than in either of the other two groups, and accounted for the statistically significant Group x Stimulus Correspondence interaction.

In terms of accuracy, there were fewer errors made by the Configurational Group than by either of the other two groups. There was no significant difference in frequency of errors between the Semantic and Categorical Groups. There were no lateral differences in accuracy, nor were there any other significant main effects or interactions based upon this measure.

There was no correlation between RT and accuracy for either hand in any of the three groups. When the three groups were combined, there was a statistically significant positive correlation between RT and accuracy for both the right and left hands.

CHAPTER 4

DISCUSSION

The results of this study support the hypothesized difference in direction of hand superiority as a function of difference in level of cognitive processing. The direction of difference in lateral superiority, as measured by reaction time, varied from left hand superiority in the Configurational Group, to no lateral difference in the Semantic Group, to right hand superiority in the Categorical Group. Moreover, these differences in direction of lateral superiority are not due to the asymmetric performance of a few subjects in each of the groups, but, rather, represent the hand superiority of the majority of the members of each group.

The faster RT to left hand stimulation shown by subjects in the Configurational Group supports the findings reported in the literature of left hand superiority for the processing of tactuo-spatial stimuli. The subjects in this group had simply to feel a dot pattern and then judge whether the tactuo-spatial pattern presented immediately thereafter was the same or different. Successful performance on this task may be related to short-term tactual

memory or to facility in processing tactual Gestalts. For both of these capacities, the findings of numerous studies have provided evidence of a left hand superiority, afforded perhaps by the more direct neural connections between the left hand and the right hemisphere of the brain. Tactual matching of non-verbalizable nonsense shapes has been shown to be performed better by the left hand in both children (Witelson, 1976, 1977; Cioffi & Kandel, 1979) and adults (Kleinman & Cloninger, 1973). In addition, memory for tactile line orientation has been found to be better for left hand than for right hand stimulation in adults (Oscar-Berman et al., 1978). Thus, it appears that the processing of tactile configurational information, whether it be in recognition, coding, or short-term memory, is performed better by the right hemisphere of the brain than by the left hemisphere.

Kimura (1966) reported a LVF superiority for enumeration of random dot patterns which she attributed to the relatively greater efficiency of the right hemisphere for processing spatial configurational material. This suggested to Hermelin and O'Connor (1971b) that braille patterns may be treated by the brain as spatial arrays "to be analyzed by the right hemisphere before or while verbal coding of the material takes place in the left" (p. 434). This suggestion is supported by the results of the present experiment as evidenced both by the left hand superiority

and by the faster overall RT of subjects in the Configurational Group in comparison with the subjects in the other two groups who were required to verbally encode the patterns.

An alternative interpretation was offered by Harris (1980) who proposed that the left hand superiority demonstrated on a variety of tactual tasks may be due to special features of the somatosensory system which bias it toward primarily right hemisphere processing. While the visual system has excellent spatial and temporal resolution, permitting almost "simultaneous" processing of information, the skin is much poorer in such discrimination. In order to construct and/or maintain a tactile "picture" of a stimulus, the somatosensory modality requires a far greater development of temporal integration (during active palpation, or during the one second time necessary for registration of tactile sensory information) as well as spatial integration (again, either during palpation or subject to simultaneous masking during passive touch) than in the other modalities, particularly vision. In fact, combined spatiotemporal integration is essential for the formation of Gestalts, or total concepts of tactile stimuli from the piecemeal somatosensory information available to the skin. The slower tempo for tactual as opposed to visual information gathering, as well as the serial nature of tactual exploration, reinforce the spatiotemporal integration needs of this system. It is just this ability for gestalt-like processing which

Harris suggests is the special domain of the right hemisphere of the brain and which establishes a bias toward the right hemisphere for processing of all tactual information. The ability to formulate perceptual Gestalts may be primarily a right hemisphere function and could therefore, as Harris suggests, account for the left hand advantage obtained for the Configurational Group in the present experiment. However, Harris' argument that temporal integration, or the rapid processing of sequential information, is a special ability of the right hemisphere is not supported by the literature and will be discussed below with respect to the results obtained for the Categorical Group.

The task performed by the Categorical Group was far more complex than that performed by the Configurational Group. Patterns had to be recognized by feeling a tactuo-spatial array, then identified on the basis of previous semantic learning, and finally, compared on the basis of semantic classification. Thus, two stages of verbal processing were required (naming and classifying) in addition to the basic tactuo-spatial processing task. Under these conditions, a right hand superiority was evidenced. This is in accord with the finding that children show right hand superiority for haptic recognition of letters (Witelson, 1976, 1977) and bigrams (Cioffi & Kandel, 1979), and adults demonstrate right hand superiority for tactile memory of letters (Oscar-Berman et al., 1978).

The demonstration of a right hand superiority in the Categorical Group suggests that tactuo-spatial tasks which involve, and indeed require, higher order verbal mediation are subject to lateralized cerebral processing which is different from tactuo-spatial tasks which require simple, direct configurational matching with no verbal mediation. Just as visually presented letter pairs are semantically matched more quickly when presented in the right visual field/left hemisphere and physically matched more quickly in the left visual field/right hemisphere (Geffen, Bradshaw & Nettleton, 1972), implying differential hemispheric advantage, so does verbal mediation appear to determine the hemispheric advantage for tactuo-spatial patterns. As noted earlier, Harris (1980) believes that the tactile perceptual system lends itself to right hemisphere processing, and that this bias is not easily overcome. Similarly, Hermelin and O'Connor (1971b) suggest that the verbal processing of braille stimuli under ordinary circumstances of letter naming or fluent braille reading is insufficient to overcome the right hemisphere bias toward configurational processing of these stimuli. Perhaps the present Categorical task, by requiring second order verbal processing--going beyond simple naming to hierarchical verbal-conceptual classification--so heavily engages the left hemisphere that it provides a sufficient condition for overcoming what would

otherwise be a strong right hemisphere bias for tactuo-spatial processing.

The task performed by the Semantic Group required the recognition of tactuo-spatial patterns and the translation of these patterns into verbally coded stimuli. Although the configurational decoding required of subjects in the Semantic Group was the same as that required of subjects in the other two groups, verbal demands were greater than those for subjects in the Configurational Group and less than those for subjects in the Categorical Group. It is possible that the configurational aspects of the Semantic task primarily engaged the right hemisphere, and the verbal naming aspects the left hemisphere, such that neither hemisphere assumed predominance. As a result, behavioral asymmetries were not evident because both hemispheres were more or less equally involved. Viewed in terms of Harris' postulation, the verbal demands of the task were sufficient to engage the left hemisphere, but were not sufficiently great (as was the case in the Categorical Group) to overcome the bias toward right hemisphere processing of tactuo-spatial information.

The difference between the Semantic and Categorical Groups is of particular interest with respect to lateral differences as a function of processing level, as both of these tasks required verbal processing, the former for naming (lower level processing), the latter for both naming and classifying (higher order processing). If lateral

differences in tactile matching were primarily a function of the verbal versus non-verbal nature of the task, the two verbal processing groups (Semantic and Categorical) should show a right hand/left hemisphere advantage and should differ significantly from the Configurational Group which manifests a left hand/right hemisphere advantage. Furthermore, the magnitude of the right hand superiority should not differ between the two verbal groups. In fact, however, the direction of the lateral differences between the hands did differ significantly between these two groups. The Categorical Group showed a significant right hand superiority, whereas the Semantic Group showed no difference between the hands. Also, the magnitude of the hand difference was significantly greater in the Categorical Group than in the Semantic Group. Further, whereas the direction of lateral advantage reversed between the Configurational and Categorical Groups, the hand difference between the Configurational and Semantic Groups was not significant either in direction or magnitude. Taken together, these results suggest that although the linguistic versus non-linguistic nature of the task may be a factor in determining laterality, it is certainly not the major determinant.

These results may be viewed as demonstrating a dual asymmetry of hemispheric processing of tactile stimuli on the basis of cognitive processing mode (non-verbal/configurational processing versus verbal/categorical processing)

while keeping stimulus and response factors constant. In this context, the present findings extend those of Witelson (1976, 1977) and Cioffi and Kandel (1979) of dual asymmetry for shapes (non-verbal) versus letters or bigrams (verbal) in a dichhaptic task using children as subjects. Furthermore, the dual asymmetry for processing of tactile stimuli has now been demonstrated for phenomena closer in time to the perceptual event than was true for the interhemispheric transfer effect based upon degree of verbal encodability of tactile forms (Kleinman & Cloninger, 1973) or for tactile memory for line orientation versus letter stimuli (Oscar-Berman et al., 1978). The results of the present investigation also confirm those of Rudel et al. (1977) in which a left hand superiority for configurational matching of braille patterns was demonstrated. The present results do not support those of Harris (1980) and Rudel et al. (1974) where, on a variety of braille tasks which involved naming, right handed children and adults showed left hand superiority. These latter tasks involved the learning of a series of braille patterns, with number of letters learned in a given number of trials as the measure. As the lateralized aspects of rate of tactile learning (which may involve, among other factors, acquisition strategies, mental imagery, and memory codes) may be quite different from those of performing tactile same/different comparisons, the present results may not be as discrepant from the Harris and Rudel et al.

findings as appears on first sight. Furthermore, if the tasks used by these investigators bear any similarity to those of the present investigation, it is to the Semantic task, in which the level of cognitive processing requires only naming of tactile stimuli. Although my results did not demonstrate a left hand superiority for this task, neither was the magnitude of the lateral difference in the Semantic Group significantly different from the magnitude of the lateral difference in the Configurational Group (in which a left hand superiority was demonstrated). It is interesting to note that the variability in the Semantic Group was slightly higher (although not statistically significant) than in either of the other two groups (see p. 68 and Table 2). Since the failure to find a hand superiority in this group may be due to the relatively greater variability, it would therefore be unwise to rule out the possibility of a left hand superiority for the processing of braille stimuli at the semantic level.

It is interesting to examine what it is about the processing of verbal material which confers an advantage on the left hemisphere. Clearly, the physical matching of letters or words can be performed as well or better by the right hemisphere. Some investigators have suggested that the left hemisphere excels at processing material in the temporal domain, in processing rapid, sequential information (e.g., Efron, 1963a, 1963b, 1963c; Schwartz & Tallal, 1980).

Analytic thinking, an area in which the left hemisphere excels, involves serial proposal and testing of hypotheses. The processing of spoken and written languages also involves rapid sequential changes. The task performed by the Categorical Group required such rapid serial processing. Within a few seconds, two successive dot patterns had to be recognized, translated into a semantic code, and compared to determine whether they fell within the same semantic class. When asked for introspective reports at the end of the experimental session, 11 of the 16 subjects in the Categorical Group explicitly verbalized having employed this sequence of mental processing in performing the task.

Studies of temporal resolution have consistently shown an advantage for the right side of the body. Efron (1963a, 1963b) has reported that, for two bilaterally presented stimuli to be perceived as simultaneous, the left must precede the right by 2-6 msec. As the nerve conduction velocities are not laterally asymmetrical, Efron has suggested that relevant time-linked information is transferred from the non-dominant to the dominant hemisphere before temporal discrimination of simultaneity and order can be performed. Using patients who had suffered right or left hemisphere damage, Efron (1963c) found disturbed processing of both auditory and visual sequencing tasks in aphasic patients who had sustained damage to the left hemisphere. He suggested that the auditory sequencing deficit might underlie

the apparent linguistic disorder in aphasia. Efron's results were confirmed by Swisher and Hirsh (1972). More recently, numerous studies have shown that the lateral asymmetry for speech in favor of the right ear in normal subjects can be manipulated by varying temporal acoustic parameters such as rate of acoustic change (Schwartz & Tallal, 1980), pulse duration (Mills & Rollman, 1979), and number of stimulus transitions within sound sequences (Halperin, Nachshon & Carmon, 1973; Devenyi & Efron, 1979). Deficits in processing the temporal aspects of expressive stimuli (e.g., patterns of oral movements) and auditory stimuli have similarly been demonstrated for patients with unilateral lesions of the left but not the right hemisphere with respect to rate of acoustic change (Tallal & Newcombe, 1978), fusion threshold for clicks (Lackner & Teuber, 1973), and production of complex non-verbal movements (Mateer & Kimura, 1977). This specialization of the left hemisphere for temporal processing has also been reported for the visual modality as evidenced by the report of lower threshold for critical flicker frequency in patients with left, but not with right, temporal lobectomies (Goldman, Lodge, Hammer, Semmes & Mishkin, 1968).

Whereas the rate of acoustic change in normal speech requires processing of changes in a period of less than or equal to 50 msec, the rate of temporal resolution required for translation of the tactile pattern in the present study

into a Categorical same/different judgment was much slower, extending over about 1-2 seconds. This is more akin to the rate of stimulus transitions and span of sequenced stimuli in the experiment of Halperin, Nachshon and Carmon (1973). In that study, a series of three sound frequencies, at 600 msec duration each, with an interstimulus interval of 200 msec, or single-frequency sound durations of 200 and 400 msec with interstimulus intervals of 200 msec, was presented dichotically. Temporal processing was thus performed over 1000-2000 msec. As the number of stimulus transitions (frequency or duration) within the series changed from 0 to 2, ear superiority shifted from left to right, indicating the left hemisphere as the superior temporal processor over this time interval.

In contrast to Harris' proposition that the right hemisphere subserves rapid spatiotemporal integration, a large body of literature lends support to my hypothesis that the superior temporal processing by the left hemisphere underlies its superiority in performing rapid categorical matching.

The findings of this study are in agreement with a growing literature relating changes in lateral functional asymmetries to changes in type and level of information processing. Hemispheric asymmetry for the processing of musical stimuli has been widely investigated since the Bever and Chiarello (1974) study. These investigators showed that

whereas non-musicians recognized notes from a selection better with the left ear, musicians showed better recognition with the right ear. The authors attributed the obtained differences to the different cognitive modes used by musicians and non-musicians--analytic/sequential versus holistic, respectively. Using alpha asymmetry in the EEG as a measure, Davidson and Schwartz (1977) confirmed this direction of hemispheric asymmetry of musicians and non-musicians, and suggested that since the musicians' EEG during whistling was very similar to their EEG during talking, musicians employ a sequential, analytic cognitive mode while performing musical activities. Using reaction time in a dichotic listening task administered to non-musicians, Kallman and Corballis (1975) found a shift in ear advantage for musical sounds from a left ear advantage during the first block of trials, to absence of lateral asymmetry during the following three trial blocks. This may be due to a change in processing strategy as a function of familiarity with the task, akin to the sophistication of musicians, although the authors suggest lateralized changes in attention and fatigue as possible explanations.

As musical tasks become increasingly complex, the left hemisphere becomes more engaged in task performance. Musicians who are required to match tones, identify octave intervals when two tones are presented, and discern octaves among three tones, all under dichotic presentation, show a shift

in accuracy to a right ear superiority for the more complex tasks (Shanon, 1980). Similarly, as linguistic tasks become more complex, EEG alpha ratios (L:R) show a decrease, indicating more left hemisphere engagement (McKee, Humphrey & McAdam, 1974).

Similar results have been obtained for the visual modality. In two studies involving visual memory scanning (Klatsky & Atkinson, 1971; Seamon & Gazzaniga, 1973), tasks involving visuo-spatial matching produced faster RT when presented to the left visual field and tasks requiring matching of verbal symbols with visual images produced faster RT when presented to the right visual field. In the Seamon and Gazzaniga (1973) study, the RT to the verbal/pictorial matches was marginally longer than the RT in the non-verbal condition. Perhaps the longer RT reflects the greater complexity of the verbal/pictorial translation process and it is this increased information processing requirement which underlies the left hemisphere advantage for that task. In the Klatsky and Atkinson (1971) study, RTs to letter stimuli (spatial comparison) were almost 100 msec faster than to picture stimuli (verbal/pictorial translation) and although there was no statistical analysis or discussion of these results, the authors state that "spatial comparisons of letters are undoubtedly faster than a verbal-acoustic comparison process" (p. 338). Thus, the verbal processing may

be best performed by the left hemisphere due to the higher level of cognitive processing (longer RT) required.

Just as shifts in lateral advantage as a function of practice over trial blocks has been demonstrated for an auditory task (Kallman & Corballis, 1975), a similar shift from right to left hemisphere superiority occurs over the course of an experimental session for the naming of new visual symbols representing the digits 1 to 4 (Gordon & Carmon, 1976). Gordon and Carmon interpreted this shift in terms of a shift from emphasis on recognition to emphasis on encoding. Hellige (1976) found a shift from left visual field/right hemisphere to right visual field/left hemisphere advantage in RT and accuracy over trial blocks and sessions for matching "same" letter pairs. He also attributed the shift to the role of the hemisphere handling the most difficult aspects of the task at any given time. Initially, the perceptual aspects were most difficult (right hemisphere), but later the encoding was the most difficult (left hemisphere). When the letters were perceptually degraded, no shift occurred, because the right hemisphere remained the most engaged throughout. Paterson and Bradshaw (1975), using non-verbal, visual stimuli, found a right hemisphere superiority for easy, holistic processing, and a left hemisphere superiority for more difficult analytic processing.

Studies of EEG alpha asymmetry during visual tasks involving varying degrees of difficulty in spatial processing

have confirmed the greater engagement of the right hemisphere in a variety of simple perceptual matching tasks, but a shift to increased left hemisphere processing for the more difficult tasks (Willis, Wheatly & Mitchell, 1979; Ornstein, Johnstone, Herron & Swencionis, 1980; Galin, Johnstone & Herron, 1978).

A similar shift from right to left hemisphere processing takes place at a more molecular level of information processing (Hellige & Webster, 1979). A visual masking stimulus, presented within 30 msec of letter presentation in right or left visual field, serves to perceptually degrade the letter and results in a left visual field advantage for letter recognition. As the interval between stimulus and mask increases, the right hemisphere advantage decreases, suggesting that the relevant visual features of the letters have already been extracted and left hemisphere encoding is in progress.

In the present study, the processing of configurational matches could have been performed in a holistic manner, via a strategy of matching to a perceptual template. This would represent the type of information processing best performed by the right hemisphere. On the other hand, categorical matches require a more sophisticated mode, based more on analysis than recognition, characteristic of left hemisphere processing. Thus, both the type of information to be

processed, and the level of complexity of the task, may account for the difference in lateral advantage observed.

In this experiment, there were no lateral differences in accuracy of matching. The only effect on accuracy found--fewer errors in the Configurational Group than in either the Semantic or Categorical Group-- closely corresponds to the pattern reported by Posner and Mitchell (1967) in which the error rates for the physical, name and rule identity groups were 6, 12 and 11%, respectively. Combined with the hierarchy in reaction times, this suggests that the Configurational Matching task is easiest (shortest RT and fewest errors) and that there is a floor effect for errors in the other two groups, with the difference in cognitive processing being reflected in reaction time. This is supported by the lack of inverse relationship between RT and error scores, indicating that there was no trade-off of speed and accuracy. Subjects performed as accurately as possible, with reaction time probably reflecting the series of mental operations required to achieve that level of accuracy.

The reaction times to same and different matches yielded no surprising results. As has been reported in numerous other studies, reaction time to same matches was faster than to different matches. For example, Hellige (1975, 1976) and Lefton and Haber (1974) reported faster reaction times to pairs of same stimuli than to pairs of

different stimuli presented in central vision. Similarly, Geffen, Bradshaw and Nettleton (1972), using letters as stimuli and requiring either physical or name comparisons, reported responses to same matches were 50 msec faster than to different matches.

In the present experiment, the disparity in RT between same and different matches was particularly marked in the Semantic Group, which accounted for the statistically significant interaction between Stimulus Correspondence and Task-Demand Group. This may be due to the particular way in which subjects could prepare themselves for responses to semantic matches. In this group, each stimulus pattern had only one other pattern with the same semantic designation. Thus, following registration of the standard stimulus, the subject could develop a mental representation of the semantically matched stimulus pattern and prepare to respond "same" on its presentation. Should the comparison stimulus match this mental "template," the RT would be very brief. Should the comparison stimulus not match the template (a different pair), there would be a delay in RT, reflecting the time to discard the first option and select the alternative. This strategy could not be used by subjects in the Categorical Group, as there were more than two possible combinations for both same and different pairs. Although stimulus patterns in the Configurational Group (like patterns in the Semantic Group) had only one correct alternative for a

"same" response and subjects could have prepared themselves for response in the same manner as Semantic Group subjects, "same" responses were faster than "different" responses by a significantly smaller margin than in the Semantic Group. This may be because the RT to same and different configurational matches may represent a floor effect and thus not be as sensitive to possible differences in strategy for decision-making. Alternatively, due to the simplicity of the task, subjects in the Configurational Group may not have found such a preparatory set necessary.

The possibility that subjects in the Semantic Group prepared themselves for "same" responses may be related to another interesting effect evidenced only in the Semantic Group. It was in this group that a type of hand-foot "compatibility" effect was shown. Responses to right hand stimulation were faster when the right foot was designated to respond "same," and responses to left hand stimulation were faster when the left foot was designated to respond "same." Perhaps the readiness for the lateralized "same" response served to prime the corresponding hemisphere and thus enhance its efficiency in processing inputs from the hand of the same side. A similar compatibility effect for stimulus and response on the same side of space has been demonstrated for RT and accuracy of response in another tactile recognition task (Gardner et al., 1977). Gardner and Ward (1979) further demonstrated that the spatial

compatibility between the hand which senses and the hand which responds persists independently of which hemisphere controls the feeling and responding hand (achieved by either sensing or responding with the hands in a crossed position). The spatial compatibility effect has further been explored in relation to simple versus choice RT (Anzola et al., 1977; Berlucchi et al., 1977). In the present experiment, the compatibility effect was observed only in the Semantic Group and then only in relation to the foot designated to respond "same." Due to the restricted circumstances under which it appeared, I suggest that it may be more related to the hypothesized preparatory set for "same" responses in that group than to a more generalized structural (anatomical) or cognitive-spatial compatibility phenomenon.

This study provided no evidence of a dual lateral asymmetry for same and different matches in a tactile task. Egeth and Epstein (1972) hypothesized a right hemisphere advantage for "same" comparisons based upon a right hemisphere superiority for holistic processing, and a left hemisphere advantage for "different" judgments based upon the superior analytic properties of the left hemisphere, but their systematic studies of RT to same and different letter pairs yielded exactly the opposite results. Ensuing studies have yielded inconsistent findings, leading to the conclusion that the underlying substrate for "same" and "different"

judgments is not necessarily lateralized (Atkinson & Egeth, 1973).

In summary, the present experiment has demonstrated differences in the direction of lateral superiority from predominance of the right to predominance of the left cerebral hemisphere for the processing of a set of tactuo-spatial patterns as the cognitive demand of the task varied from configurational matching to categorical matching. Thus, lateralized hemispheric processing of tactuo-spatial information is not based solely, or even primarily, on the nature of the stimuli but rather on the nature of the information processing task to be performed. Configurational matching yields right hemisphere superiority, and verbal/categorical matching yields left hemisphere superiority.

This experiment raises numerous questions about the relationship between hemispheric specialization and level of cognitive demand in tactile perception in various populations. To what extent are the present findings in right handed women generalizable to right handed men, to non-right handed men and women, and to younger and older individuals? Is the tactuo-spatial somatosensory system, by virtue of its inherent differences from other perceptual systems, biased toward right hemisphere processing? How might increasing task demand with non-verbal tactile tasks of graded levels of difficulty affect the direction of lateral superiority between the hands? That is, to what extent is the

difference in direction of lateral superiority a function of the nature of the material processed (verbal versus non-verbal) and to what extent is it strictly a function of the level of processing? How is the compatibility between stimulus and response on the same side of space related to "same" and "different" decisions and to level of cognitive processing?

In addition to the theoretical and conceptual questions raised, the results of the present experiment have practical implications for the teaching of braille. Perhaps the left hand might be used for the initial introduction of braille reading, to acquire familiarity with the tactile configurations. A shift toward use of the right hand might be encouraged as proficiency in decoding develops and the teaching goal changes to attainment of fluency in rapid reading of braille for literary content. Only empirical testing can provide the necessary evidence.

Appendix A. Information Sheet for Determination of Handedness

Name of Subject _____

Subject # _____

Group _____

Date _____

Performance Items:	<u>Right Hand</u>	<u>Left Hand</u>
1. Throw a ball	_____	_____
2. Brush teeth	_____	_____
3. Use a hammer	_____	_____
4. Use scissors	_____	_____
5. Knife for cutting	_____	_____
6. Deal cards	_____	_____
7. Write name	_____	_____
8. Hold thread for threading needle	_____	_____

Personal Handedness Questionnaire:

- Are you righthanded Right Left
or lefthanded?
- Do you consider yourself Strong Moderate Weak
to be strongly, moderately,
or weakly righthanded
(lefthanded)?

Family Handedness Questionnaire:

	Right	Left	Mixed	Don't Know
1. Is your father right- handed or lefthanded?	_____	_____	_____	_____
2. Is your mother right- handed or lefthanded?	_____	_____	_____	_____
3. If you have any siblings (brothers or sisters), give the sex, age and handedness of each.				
1. Sex _____ Age _____	_____	_____	_____	_____
2. Sex _____ Age _____	_____	_____	_____	_____
3. Sex _____ Age _____	_____	_____	_____	_____
4. Sex _____ Age _____	_____	_____	_____	_____

Appendix B. Randomized Orders for Presenting Learning Task Trials

Name _____ RED :: red ..
 Subject No. _____ Condition _____ BLUE ::: blue :::
 Date _____ DAY :: day ::
 NIGHT ::: night ..::

<u>Teach L R</u>	<u>Teach L R</u>	<u>Teach L R</u>	<u>Teach L R</u>
red	DAY	NIGHT	blue
night	blue	RED	BLUE
RED	red	day	RED
blue	RED	BLUE	NIGHT
day	night	night	night
NIGHT	NIGHT	DAY	DAY
DAY	BLUE	red	red
BLUE	day	blue	day
<u>L R</u>	<u>L R</u>	<u>L R</u>	<u>L R</u>
day	DAY	BLUE	RED
blue	day	NIGHT	night
night	NIGHT	night	day
NIGHT	BLUE	blue	BLUE
RED	night	day	NIGHT
red	RED	RED	blue
BLUE	blue	DAY	red
DAY	red	red	DAY
<u>L R</u>	<u>L R</u>		
blue	red		
NIGHT	DAY		
BLUE	night		
DAY	blue		
RED	BLUE		
red	RED		
night	day		
day	NIGHT		

Appendix C. Information Sheet for Counterbalancing
Conditions and Introspective Reports of
Subjects

Subject Name _____

Subject Number _____

Group _____

Date _____

	<u>Right</u>	<u>Left</u>
Finger taught first	_____	_____
Foot pressed for "same"	_____	_____
Position of solenoid array #1	_____	_____
Position of foot pedal #1	_____	_____

Remarks:

1. Method for remembering or distinguishing stimuli.
2. Process used to match stimuli.
3. General feelings about performance: easy? hard?
fatiguing?
4. How many different patterns do you think are being
presented?
Quarter #1 _____ #2 _____ #3 _____ #4 _____
5. Do you think that one hand is doing better than the
other? Which?

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