

THE UNIVERSITY OF CALGARY

THE IMPACT OF STIMULUS TYPE AND RESPONSE DELAY
ON HAPTIC PROCESSING ASYMMETRIES

by

Jill L. Harris

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF PSYCHOLOGY

CALGARY, ALBERTA

APRIL, 1990

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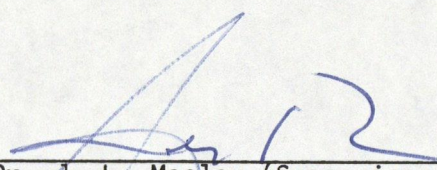
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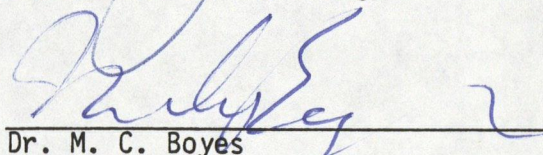
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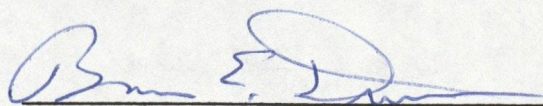
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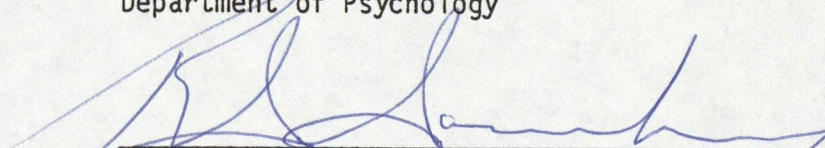
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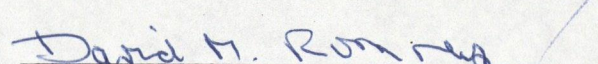
The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "The Impact of Stimulus Type and Response Delay on Haptic Processing Asymmetries" submitted by Jill L. Harris in partial fulfillment of the requirements for the degree of Master of Science.



Dr. J. L. Mosley (Supervisor)
Department of Psychology

Dr. M. C. Boyes
Department of Psychology

Dr. B. E. Dunn
Department of Psychology

Dr. R. S. Sainsbury
Department of Psychology

Dr. D. M. Romney
Department of Educational Psychology

Date April 9/90

ABSTRACT

Four cross-modal matching tasks consisting of the visual recognition of tactually presented single letters, two-letter words, bigrams and Chinese characters were administered to right-lateralized mentally retarded (MR), equal- MA, and equal-CA matched subjects. In addition, two delay conditions (0 and 3 seconds) and two blocks of trials were utilized to assess haptic processing asymmetries as a function of stimulus type, memory and practice. Results indicate that haptic asymmetries are not dependent upon higher-order memorial processing after stimulus offset. This is most likely due to the representational nature of the tactile system. A right-hand advantage for response latencies for words during the second block of 0 delay trials also indicates that introducing a delay is irrelevant. This late-emerging right-hand advantage further suggests that differential processing, in the absence of attentional factors, may require time. An overall left-hand advantage for response latencies for "same" responses and a right-hand advantage for percent correct "different" responses were demonstrated. These findings, in conjunction with trends toward left- and right-hand advantages for percent correct "same" responses and A' , respectively, suggest that differential hemispheric processing is dependent upon the specific information processing requirements rather than upon the stimulus type "per se". A left-hand advantage for response latencies for "same" Chinese characters was demonstrated by the MA group while adults exhibited a trend toward a left-hand advantage. This advantage was due to increased right-hand latencies, rather than decreased left-hand

latencies, further confirmation that different types of analyses are employed by the two cerebral hemispheres. No hand differences were exhibited by the MR group. Practice trial data indicate that MR and, to a lesser degree, MA subjects experience difficulty focusing attention on and encoding relevant stimulus features. The MR group's significantly lower accuracy for "different" responses as well as poorer discriminability (A') during experimental trials indicate that these attentional deficits are further exacerbated in the absence of a visual reference.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Lary Mosley, for his patience and guidance during the preparation of this thesis. I would also like to express my appreciation to the members of my committee, Dr. M. C. Boyes, Dr. B. E. Dunn, Dr. D. M. Romney, and Dr. R. S. Sainsbury for their assistance and time. I especially thank Bruce Dunn for his statistical help, but most particularly for his friendship, advice and counselling expertise.

I would like to thank the children at Don Bosco School for their enthusiastic participation in this study as well as the parents, staff and school administrators for their permission and support. I also extend my appreciation to the staff, parents, guardians, and clients at the VRRRI for their cooperation and help. I would also like to thank the students at the University of Calgary who participated in this research.

Finally, I am indebted to my family and friends for their encouragement and support. In particular, I wish to thank my husband, Bob, and my daughters, Stephanie and Erin. Without their faith, patience and love this thesis would not have been possible.

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INTRODUCTION

Lateralization is the specialization of a function or activity in one side of the organism. There is an extensive body of literature indicating that the left and right cerebral hemispheres are differential information processors. While estimates vary, research indicates that approximately 90% of the population is right-handed (Kolb & Whishaw, 1980). Of these right-handers, approximately 95% have "language" processing in the left hemisphere while only 70% of left handed individuals are left hemisphere dominant for language (Kolb & Whishaw, 1980). Within the right-handed population, the left hemisphere appears to be superior for the processing information such as the recognition of letters and words, performing complex voluntary movements, verbal memory, speech, reading, writing and arithmetic. The right hemisphere is superior for tasks which require the recognition of geometric patterns, faces, environmental sounds, music, visual memory, direction, shape rotation and the tactual recognition of complex patterns, braille and nonsense shapes. Because of this "nonverbal" versus "verbal" distinction between the right and left hemispheres respectively, the left hemisphere has often been described as a "linguistic", sequential and analytic processor while the right hemisphere has been described as a "nonlinguistic", visuospatial, holistic and nonsequential processor. However, it should be remembered that hemispheric specialization is relative rather than absolute. As such, hemispheric specialization is not necessarily specialization for the recognition of and processing of verbal versus nonverbal information. Rather, a hemisphere is specialized for the

recognition of certain information parameters and the control of certain aspects of behaviour. For example, there appears to be a right ear (left hemisphere) advantage for certain parameters or characteristics of the stimulus which are included in speech e.g., phonemic discrimination involves the detection of changes in the signal over time. Conversely, there is a left ear (right hemisphere) advantage for aspects of intonation, timbre and melody which do not require an analysis of the phonetic composition (Ardila & Ostrosky-Solis, 1984). Thus, there is convincing evidence that each of the two hemispheres is specialized for, or has an advantage for, the processing of certain types of information and controlling certain aspects of behaviour. This evidence comes from four major areas of study: neurological, neurophysiological, anatomical and behavioural (functional).

Neurological (Clinical) Studies

Lesion Studies

The oldest method of studying hemispheric asymmetries is the systematic evaluation of patients suffering from circumscribed unilateral lesions due to strokes, surgery or head wounds. While Dax (1836, in Penfield & Roberts, 1959) had suggested that speech processes were lateralized to the left hemisphere a quarter of a century before Broca's reports, there appears to have been little serious consideration given to the notion of subdivisions of functional areas within the brain until Broca presented evidence that a portion of the brain was expressly devoted to speech. It is generally acknowledged that it was Broca's 1861 observation of aphemia

(aphasia) due to a restricted lesion in the third frontal convolution of the left hemisphere in the absence of other serious deficits which was of monumental importance in the history of neurology (Penfield & Roberts, 1959). Carl Wernicke's description of the loss of receptive language skills (as opposed to Broca's expressive aphasia) resulting from damage in the left temporal lobe further validated the notion of asymmetrical brain functioning (Segalowitz, 1983).

Subsequent research has demonstrated that the predominant symptoms of right hemisphere damage include impaired spatial orientation (frontal and parietal), constructional apraxia, spatial alexia and agraphia (parietal), spatial agnosia and altered perception of spatial relations (occipital). Lesions in the left hemisphere generally result in language related deficits such as Broca's aphasia and poor movement programming (frontal), altered phoneme discrimination and altered verbal memory (temporal). The type of deficit observed depends upon the hemisphere affected and the site of the lesion within that hemisphere. For example, Boll (1974) observed deficits in direction discrimination following lesions to the right and left hemispheres. Thus, patients with lesions in the right hemisphere made significantly more errors with their left- than right-hand on tactile-perceptual ability measures while the reverse was found for patients with left hemisphere lesions. However, comparisons of the total number of errors made with both hands revealed that right hemisphere lesions caused deficits in discrimination in both hands, while lesions to the left hemisphere affected sensitivity in the right-hand only.

Commissurotomy Studies

Further neurological evidence for hemispheric specialization comes from studies of individuals who have had the corpus callosum severed to prevent the spreading of intractable epileptic seizures. Because split-brain patients appeared to function normally in the normal routine of daily living, early investigators facetiously concluded that the only indubitable role of the corpus callosum was to transmit epilepsy from one side of the brain to the other (Segalowitz, 1983; Kupferman, 1985). Indeed, a series of elegant experiments conducted by Roger Sperry and Michael Gazzaniga (cited in Kupferman, 1985) confirmed that in order to demonstrate the split-brain patient's often subtle deficits, neurological assessments must utilize the selective presentation of information to each of the hemispheres separately. A number of subsequent studies have demonstrated that while each hemisphere is capable of receiving input from all sensory systems, the two hemispheres are unable to communicate with one another. The disconnection and differential processing of the two hemispheres has consistently been demonstrated utilizing dichotic, tachistoscopic and tactual tasks. These studies have consistently revealed that when the left hemisphere has access to information it is able to initiate speech and communicate regarding that information while the right hemisphere appears to play a special role in tasks which require spatial-perceptual analyses such as facial recognition and pattern identification (Gazzaniga, 1970; Levy, Trevarthen, & Sperry, 1972; Kupfermann, 1985).

Sodium Amytal

The most accurate technique for clinically ascertaining cerebral

dominance for language is the Wada test (Wada & Rasmussen, 1960). Administered prior to surgery for the treatment of neurological disorders such as epilepsy, sodium amytal is injected into the common carotid artery, inducing a temporary deactivation of function in the hemisphere ipsilateral to the side of injection. Injections into the left carotid artery produce a two to three minute period of anaesthesia to the left hemisphere producing a right-sided paralysis and a global or near global aphasia. In contrast, injection into the right artery produces more transient speech disruptions (Filskov, Grimm, & Lewis, 1981; Segalowitz, 1983).

While neurological studies would indicate that the left and right hemispheres are differential processors, caution should be exercised when comparing clinical and normal populations. The Wada test is limited to use with clinical populations and may not be reliably generalizable to neurologically intact individuals. Similarly, commissurotomy patients all have histories of neurological disturbance. The surgical procedure, as well as the potential for postoperative reorganization of brain functioning, make extrapolation to normals questionable (Segalowitz, 1983). Moreover, there appears to be an above normal occurrence of left-handedness among clinical populations exhibiting epilepsy, cerebral palsy, mental retardation, stuttering and dyslexia accompanied by incomplete lateralization or mixed dominance (Geschwind & Galaburda, 1985; Kupfermann, 1985; Rider, Imwold, Griffen & Sander, 1985). Therefore, reliance on the abnormal model of brain-behaviour relationships can only equip researchers with

provisional interpretations of cerebral organization. The study of the brain in its pathological condition can only furnish tentative answers regarding the purpose a structure serves in its undamaged state (Filskov et al., 1981; Segalowitz, 1983).

Neurophysiological Evidence

Two direct and noninvasive techniques for studying hemispheric specialization involve the recording of electrical brain activity (event related potentials) and the amount of blood flowing to particular regions of the brain (rCBF).

The Average Evoked Response

The basic assumption when using event-related potentials (ERPs) is that "as a result of the event an ensemble of neurons functionally related with such an event exhibits a particular spatiotemporal organization" (Harmony, 1984). Differential brain activity is measured by placing electrodes on the scalp over specific areas of the left and right hemispheres. The use of AER's involves averaging the responses evoked during repeated presentations of a single stimulus type. Hence, the AER corresponds to the express effect of the stimulus. However, AER analyses are limited by the length of segments which can be used (less than one second) and by the number of presentations over which the stimulus remains effective (Segalowitz, 1983). As such, one can assess how a single word in a sentence is processed depending upon the context within which it is presented (i.e., fire as a noun or a verb). Alternatively, the comparison of the relative amplitude of the alpha frequency bands (8-12 Hz) is not restricted to short, time-linked activities, allowing the assessment of asymmetrical brain wave

activity during longer tasks (i.e., working on a puzzle). The presence of alpha activity indicates that the brain area is resting but alert. Conversely, during concentrated thinking "fast wave" beta (13-30 Hz) activity is exhibited. Thus, there is greater alpha activity in the right hemisphere during verbal tasks and greater left hemisphere alpha activity during spatial tasks (Galin & Ornstein, 1972).

Regional Cerebral Blood Flow (rCBF)

Because the brain has no significant capability for anaerobic metabolism, it depends upon adequate circulatory transport for the maintenance of cerebral metabolism and local homeostasis. Although mean cerebral blood flow and metabolism are not significantly affected by changes in mental activity, regional cerebral blood flow does increase in areas of the brain specifically involved with a particular activity (Chien, 1985). The principal method of measuring blood flow is by administering a substance containing a short-lived, diffusible tracer such as xenon-133. Tracers accumulate in areas of cerebral blood flow, thereby allowing one to localize regions of functional activity in a noninvasive manner (Chien, 1985). For example, research indicates that during verbal activities there is a corresponding increase in left temporal and frontal temporal lobe blood flow (Segalowitz, 1983; Kolb & Whishaw, 1980) while visual stimulation results in increased blood flow in the occipital lobes (Chien, 1985).

Anatomical Evidence

There is also confirmation of asymmetrical anatomical brain organization. The first consistently found asymmetry in the human brain was that the right sylvian fissure curved upward posteriorly,

ending in a higher position than does the left sylvian fissure. Conversely, the left sylvian fissure is usually longer than the right, resulting in a larger planum temporale on the left. Geschwind and Levitsky (1968) first confirmed that there was an easily discernable asymmetry in the upper surface of the posterior part of the left temporal lobe in the adult brain. Subsequent research has since shown that a larger left planum temporale is evident in the adult, neonate and fetal brain (Kertesz, Black, Polk & Howell, 1986; Geschwind & Galaburda, 1985a, 1985b, 1985c; Witelson and Pallie, 1973; Wada, Clarke, & Hamm, 1975). The larger planum temporale constitutes a significant portion of the left hemisphere speech zone known as Wernicke's area. As such, it has been suggested that the anatomical differences parallel the functional asymmetry of the two hemispheres in mediating language.

Autopsy and "in vivo" measurements of anatomical asymmetries using CAT scans and Magnetic Resonance Imaging (MRI) have indicated strong parallels between anatomical and functional asymmetries. However, while asymmetries have been found in brains assumed to have no pathology (Witelson & Pallie, 1973; Galaburda, Corsiglia, Rosen, & Sherman, 1987) there is often a failure to define the presence or absence of pathology in their subjects (Kertesz et al., 1986) or tests are conducted on clinical populations (as discussed in Geschwind & Galaburda, 1985). Therefore, caution must be exercised when making interpretations of asymmetrical development in clinical populations. As previously noted, clinical populations have histories of neurological disturbance. Moreover, there is an above normal

occurrence of left-handedness among clinical populations accompanied by incomplete lateralization or mixed dominance (Geschwind & Galaburda, 1985; Kupfermann, 1985; Rider et al., 1985). Thus, it should be stressed that not all asymmetries are part of normal development. Rather they may be the result of disorders of hemispheric development (Geschwind & Galaburda, 1985).

Behavioral (Functional) Asymmetries

Dichotic, tachistoscopic and dichhaptic studies with both clinical and normal populations have demonstrated a left hemisphere superiority for "linguistic" and analytical skills and a right hemisphere advantage for visuospatial, "nonlinguistic" information processing (Hahn, 1987; Boll, 1974; Bradshaw, Burden, & Nettelton, 1986). Tests utilized to study behavioural asymmetries typically present stimuli simultaneously to the two ears, eyes (hemifields), or hands. Differential performances are assumed to reflect differential hemispheric processing.

Visual Half-field Studies

The visual system is completely crossed so sensory events experienced in the left visual field (LVF) are projected to the right visual cortex while events experienced in the right visual field (RVF) are projected to the left visual cortex. Tachistoscopic tasks involve the brief presentation of a visual stimulus either unilaterally (to only one visual half-field) or bilaterally, in which case information to the LVF is different from that presented to the RVF. In either testing situation, reception of a stimulus is solely by the contralateral hemisphere. A right visual field (left hemisphere)

superiority has been found for verbal material such as words (Leventhal, 1988; Hahn, 1986). Visual-half field advantages are less consistent for single letters (Broman, 1978). A left visual field (right hemisphere) superiority has been demonstrated for the recognition of familiar and unfamiliar faces (Broman, 1978), emotional perception (Ley & Bryden, 1979; Safer, 1981), shape matching, forms, depth perception and line orientation (Segalowitz, 1983).

Generally, visual half-field studies have yielded inconsistent results. One major problem with the use of tachistoscopic techniques is that a failure to fixate at the point defining the boundary between the LVF and the RVF results in one half-field becoming a full visual field (Young & Ellis, 1976; Hahn, 1986). As well, although a visual half-field X retinal locus of projection interaction has been found (Sergent, 1983, cited in Hahn, 1986), studies have used differing degrees of visual angle from center fixation when presenting stimuli. Similarly, tachistoscopic stimulus presentations must be brief (less than 150 msec) to prevent scanning, often resulting in much lower recognition scores, making comparisons among different lateralization measures difficult (Eling, 1983).

Attentional biases may also modify visual field superiorities. Leventhal (1988) found an RVF advantage for unilaterally presented words when fixation points were at center and to the right while a left fixation point yielded a LVF. However, in a bilateral presentation condition, directional fixation points inhibited the recognition of words presented to the uncued dominant hemisphere and magnified word recognition when the nondominant visual field was cued.

Priming effects may also selectively activate one hemisphere or the other (Hahn, 1986), again suggesting that apparent non-lateralization or discrepant findings may be artifactual (Young & Ellis, 1976).

Dichotic Listening

Unlike the visual system, the auditory system is not completely crossed. However, stimuli appear to be projected primarily to the contralateral hemisphere. Consequently, if the reports of one ear are more accurate than reports from the other ear, the hemisphere contralateral to the more accurate ear is assumed to be the more efficient processor for that particular stimulus type. The dichotic listening technique is the predominant means of evaluating lateralization of function in normal populations, particularly child populations (Hahn, 1986). Studies consistently report a right ear advantage (REA) for verbal material such as consonant-vowel (CV) syllables, words and digits (Shankweiler & Studdert-Kennedy, 1967; Knox & Kimura, 1970; Bakker, Hoefkens, & Van der Vlugt, 1979). While left ear advantages (LEA) are less consistent, a significant LEA or a trend toward a LEA has been reported for nonverbal material (Knox & Kimura, 1970; King & Kimura, 1972; Mahoney & Sainsbury, 1987). Kimura (1961a) interprets these results as suggesting a parallel between functional and structural brain asymmetry based upon a structural account that the ipsilateral input from one ear is suppressed by the contralateral input from the other ear.

There are, however, a number of factors that must be considered when interpreting the results of dichotic listening tasks. For example, it has been demonstrated that the REA is extremely sensitive

to variations in a number of acoustical properties of the stimulus such as voice onset time, place of articulation, frequency bandwidth, intensity of the signal and stimulus duration (Bradshaw et al., 1986; Segalowitz, 1983; Ardila & Ostrosky-Solis, 1984). As well, stimulus dominance may play a role in laterality effects as there is often a consistent proclivity for one stimulus in a dichotic pair to generate more correct responses, regardless of the ear of input (Bradshaw et al., 1986). As such, it appears that properties other than the stimulus "per se" affect the degree and direction of ear advantages.

A possible explanation for the relative instability of the REA for verbal material is due to an incomplete suppression for the ipsilateral input. As a consequence, the contralateral pathway may simply have the advantage under dichotic stimulation (Segalowitz, 1983).

Alternatively, the context within which a subject is presented the stimulus can affect the resultant hemispheric advantage. Although embedding syllables in speech sounds has been found to elicit a REA, embedding those syllables in a series of musical stimuli resulted in a LEA (Spellacy & Blumstein, 1970, cited in Segalowitz, 1983). Similarly, presenting nonsense words in sentences results in a REA while removing sentence aspects leads to a REA loss (Mavlov, 1980 in Segalowitz, 1983) indicating that psychological variables are important when assessing ear advantages.

Subjects may also have a bias toward the right ear for reasons other than right ear - left hemisphere language dominance. Attentional factors are important variables. As such, if allowed to

report material in any order, subjects often report everything from one ear first (usually the right) (Segalowitz, 1983; Bradshaw et al., 1986). Kimura (1961a) found that within left and right hemisphere language dominant groups left-handers favoured the left ear while right-handers in both language dominance groups favoured the right ear. Kinsbourne (1978) has proposed a preferential attention model, suggesting that each hemisphere controls attention to the contralateral perceptual space. He posits that while the cerebral hemispheres are in a dynamic state of equilibrium, when one hemisphere becomes more active, attention is biased toward the contralateral side of perceptual space. Kinsbourne's model does explain changes in asymmetries due to practice and memory.

It is evident that task demands as well as the acoustic properties of the stimulus can interact to produce the perceptual asymmetries observed under dichotic stimulation conditions. Caution should be exercised when interpreting results since a functional asymmetry is not necessarily indicative of a parallel structural asymmetry.

Motor Tasks

Research has indicated that in primates fine motor movements of the distal limbs (most particularly the hands) are controlled by the contralateral hemisphere while gross motor movements are primarily controlled by ipsilateral processes (Kuypers & Brinkman, 1970; Brinkman & Kuypers, 1972). As such, left-right fine motor asymmetries are thought to reflect cerebral lateralization. Studies assessing the existence of motor asymmetries indicate that activation of the left

hemisphere's language system facilitates the activation of other motor systems within the same hemisphere. Kimura (1973) found that while spontaneous movements increase in both hands during speaking, more movements are made by the right-hand than the left. Subsequent research has demonstrated task related shifts in asymmetry of free movements. Thus there is an increase in right-hand free movements during speech regardless of the content (Lavergne, & Kimura, 1987) and during a verbal constructional task (Hampson & Kimura, 1984). Conversely, an increase in left hand movements during nonverbal manipulation tasks has been found (Hampson & Kimura, 1984).

The Dual-Task Interference paradigm has also confirmed asymmetrical hemispheric processing. Kinsbourne and Cook (1971) devised a vocal-manual interference paradigm based upon the observation that simultaneous performance of two unrelated tasks results in poorer performance when tasks are controlled by the same hemisphere than when each task taxes a different hemisphere (Kinsbourne & Hicks, 1978). Thus, it is assumed that the brain operates most efficiently with lateralized input (hence direct contralateral access) of the task to the appropriate hemisphere.

Research has demonstrated a greater rate of left finger tapping during speech (Lomas & Kimura, 1976; Piazza, 1977), dowel balancing during speech (Kinsbourne & Cook, 1971; Hicks, 1975) and humming (Hicks, 1975) and a disruption of left finger tapping during concurrent spatial tasks (Cramer & Ashton, 1981, in Hampson & Kimura, 1984) and humming (Piazza, 1977). A decrease in right and left hand finger tapping during verbal and nonverbal tasks, respectively are

indicative of a left hemisphere superiority for speech processes and a right hemisphere superiority for meaningless or nonspeech processing.

Rose (1985), investigating the effect of concurrent auditory input on tactual processing in young children, also found evidence of competition during discordant tasks. Juxtaposing music and the palpation of nonsense shapes, she found a left-hand advantage in the absence of music and a disruption of left-hand performance during music.

Taken together, results from interference and activation studies appear to provide additional support for asymmetrical brain functioning. However, such results are still controversial since task difficulty as well as motivational and strategy factors may also affect the degree of asymmetrical performance in addition to brain specialization (Ardila & Ostrosky-Solis, 1984).

Somesthetic Processing

Generally speaking, functional asymmetries within the somatosensory system have been less well studied than asymmetries within the auditory and visual systems. Within the somatic sensory modality there are four submodalities. These submodalities are proprioception, pain, temperature and discriminative touch. The proprioceptive system is concerned with the sense of limb and body position, both static and dynamic. The term "haptic" perception is typically used in the literature to refer to the process of actively touching, exploring or discriminating a stimulus with one's hands or fingers.

Evidence for Lateralization of Tactile Processing

As noted, it is estimated that 90% of the population is right-handed. It has been assumed that the dominant hand, that is, the hand contralateral to the "speech" hemisphere is the superior hand for a most tasks (i.e., writing, dexterity). However, it is important to distinguish between preference and performance (Corballis, 1983). Although an individual may prefer to use one hand for a particular task, performance may be superior with the nonpreferred or nondominant hand. Evidence suggests that the nondominant hand, controlled primarily by the right hemisphere, is superior on a variety of spatial processing tasks (Witelson, 1974, 1976; Bradshaw et al., 1986; Hahn, 1987). As well, studies with clinical populations would indicate that the right hemisphere is specialized for processing tactuo-spatial information (Boll, 1974). The differential hand performances by clinical and neurologically intact individuals on tactual tasks are assumed to reflect differences in the efficiency of processing in the contralateral hemisphere.

Lesion Studies

Early investigations using patients suffering from lesions restricted to either the left or right hemispheres suggested the existence of contralateral control of tactile perception. In a series of studies with brain-injured subjects Teuber and Weinstein (in Kinsbourne, 1978) demonstrated a marked effect of right hemisphere damage on spatial perception. They found spatial transfer ability, size discrimination and two-point discrimination to be significantly impaired in patients with unilateral right hemisphere lesions as

compared to controls and patients with lesions to the left hemisphere.

Subsequent research has confirmed differential motor and/or sensitivity losses due to left and right cerebral lesions. A left hemisphere lesion predominantly affects right-sided motor function while a right hemisphere lesion will mainly affect left-sided motor skill. With respect to sensitivity and tactile perceptual abilities, right hemisphere lesions typically result in deficits in both hands, while left hemisphere lesions primarily affect right-hand sensitivity only.

Some researchers (i.e., Luria, 1977; Semmes, 1960 , in Ardila & Ostrosky-Solis, 1984) have presented evidence that left hemisphere lesions tend to affect motor control of both hands whereas right hemisphere lesions result in deficits largely confined to the left-hand. Others, i.e., Corkin (in Kolb & Whishaw, 1980) have found no evidence of asymmetrical somatosensory function. Still others (i.e., Boll, 1974) indicate greater right hemisphere control of both ipsilateral and contralateral tactile perception. Comparing performance on three tactile perceptual ability tests (finger localization, finger tip number writing and tactile form recognition) in patients with naturally occurring lesions, Boll (1974) found that subjects with right hemisphere lesions made significantly more errors with the left- than with the right-hand while left hemisphere lesions resulted in significantly more errors with the right-hand. When the total number of errors made with both hands was analyzed according to the side of the lesion, it was found that significantly more errors on measures of tactile-perceptual ability were made by right hemisphere

lesion subjects. As well, the side contralateral to the right hemisphere lesion was significantly more impaired than was the side contralateral to the left hemisphere lesion. Ipsilateral deficits were also significantly greater with the right as compared to the left hemisphere lesion subjects. It was concluded that the right cerebral hemisphere is pre-eminent in producing tactile-perceptual deficits in patients with a variety of naturally occurring brain lesions. Lewis and Kamptner (1987) offer further evidence for right hemisphere superiority on spatial tasks. Performance on Block Design and the Street Gestalt Completion Test was more impaired in patients with right hemisphere lesions than in patients with left hemisphere lesions. While these results are in conflict with previous research, earlier studies have primarily depended on data derived from patients with penetrating head wounds. Differences in ipsilateral and contralateral tactile-perceptual deficits may be due to the type of lesion.

Commissurotomy Studies

Investigations with split-brain primates have demonstrated that gross movement of the arms are equally efficient in ipsilateral and contralateral conditions. However, ipsilateral hand and finger movements lack the proficiency exhibited by the contralateral distal extremities (Kuypers & Brinkman, 1970; Brinkman & Kuypers, 1973).

Work with split-brain human subjects also suggests that, while some ipsilateral control is evident, contralateral control of distal arm movements is superior (Trope, Fishman, Gur, Sussman, & Gur, 1987; Gazzaniga, 1970). Trope et al. (1987) investigated the extent of

ipsilateral visuo-motor control of fingers in two split-brain patients. Subjects were tachistoscopically presented with line drawings of left and right-hands. A single finger was marked with an arrow in each trial and subjects were required to move the finger indicated by the arrow. Results indicated that while contralateral control was significantly better for both hands, the thumb and index fingers of both hands also exhibited above chance ipsilateral control. Furthermore, there was more ipsilateral control for left-hand fingers, indicating a greater degree of ipsilateral control is exerted by the left than by the right hemisphere.

Gazzaniga (1970) has posited that cross-cuing is responsible for the contradictory results in animal and human split-brain research. He argues that rather than a cross-over of information via central neural channels, there are a variety of secondary cues made available by overt changes executed by the other hemisphere.

With respect to manipulospacial abilities, evidence suggests that the left-hand is more proficient than the right-hand for certain tasks. Split-brain patients exhibit a left-hand advantage for the visual recognition of tactually presented nonsense shapes, tactual geometric figure matching and block design as well as for drawing, despite being right-handed (Corballis, 1983; Ardila & Ostrosky-Solis, 1984).

The evidence derived from human and animal lesion and commissurotomy studies would suggest that while the left hemisphere may be pre-eminent in controlling both the left- and the right-hand for motor skills, the right hemisphere plays a more predominant role

in tactual perceptual control. Clearly, the critical aspect of the right hemisphere's superiority is not due to superior perceptual or motor skill since the right-hand is normally used for manipulating objects and drawing and the left hemisphere recognizes when a word which represents an object is presented. Rather, the left hemisphere (right-hand) appears to have spatial difficulties when it must represent the object using manipulative responses (LeDoux, Wilson & Gazzaniga, 1977). It has been posited that the right hemisphere superiority is due to a mechanism which analyzes the hands' motor and perceptual activities, thus acting as a mediator between spatial and motor representation (Corballis, 1983; Ardila & Ostrosky-Solis, 1984).

Commissurotomy patients consistently demonstrate a left-hand superiority on a variety of manipulation and spatial tasks. The research indicates that the skills necessary for these nonverbal activities are asymmetrically organized and reside within the right hemisphere.

Behavioral Tactile Asymmetries

While it would be imprudent to ignore the possibility that clinical populations may have abnormal cerebral organization, results derived from normal populations also indicate differential tactile processing within the left and right cerebral hemispheres. Semmes, Weinstein, Ghent, and Teuber (1960), the first to investigate laterality differences in tactile perceptual ability in the normal population (Kinsbourne, 1978), found a greater left-hand sensitivity to tactile stimulation for normal adults. Finlayson and Reitan (1976) were among the first to assess asymmetrical motor and tactile-

perceptual performances in children. Although a right-hand advantage on motor tasks (grip strength and finger-tapping speed) was observed, no differences were found for the tactile perceptual tasks (finger-localization and finger-tip symbol recognition). However, Finlayson and Reitan (1976) required subjects to verbally identify which finger had been touched, and verbalize which number had been written upon their finger tips. As research has indicated that digits and single letters yield inconsistent hand advantages, i.e., left, right, or no differences, (Oscar-Berman, Rehbein, Porfert, & Goodglass, 1977; Witelson, 1974; Witelson, 1976; Klein & Rosenfield, 1980) their failure to find a left-hand superiority is not surprising. Since Semmes et al.' (1960) work, research has consistently demonstrated that the left side of the body is more sensitive to tactile stimulation. However, the tasks utilized to assess differential somesthetic processing in the normal population primarily measured tactile acuity asymmetries.

Witelson (1974) pioneered the dichhaptic stimulation technique for testing differential tactile-spatial processing in the neurologically intact individual. Her research was unique in that it was the first to assess whether the observed left-hand superiority for nonlinguistic spatial tactual material in clinical samples was paralleled in the normal population. Furthermore, prior research had not assessed the impact of linguistic versus nonlinguistic stimuli on differential hand performances. Witelson's original study utilized 10 second tactual presentations of pairs of single letters and nonsense shapes. The nonsense shapes were designed to be as unfamiliar and

meaningless as possible while the single letters were chosen to tap verbal processes. Subjects responded by pointing with the left or right-hand to the two shapes he had just felt. In the letters task subjects were presented with two consecutive pairs of simultaneously presented stimuli in each trial and were required to verbally name the four letters just felt.

When a left-hand response was used, the perception of shapes presented to the left-hand was greater than the perception of right-hand shapes with a left-hand response. A right-hand response yielded no significant left-right differences. Results also indicate a possible order effect. While there was a significant difference between the left and right-hands for nonsense shapes when given before the letters task, the left-right difference was not significant when the letters task was given prior to the nonsense task. In 1976 Witelson expanded the nonsense shapes task to include girls as well as boys. While there was no difference in overall accuracy between boys and girls, boys obtained greater left than right-hand scores. In addition, a significant hand X sex interaction indicated that while the left-hand score was significantly better than the right-hand score for boys, there was no differences between hands for girls. These results were interesting considering a dichotic listening test administered as an index of left hemisphere specialization for language resulted in greater right than left ear accuracy for both boys and girls. Witelson concluded that the greater left-hand scores for boys, which was consistent with her previous results, could not be attributed to differential asymmetry in tactile sensitivity for boys,

nor was it likely due to greater use of left hemisphere verbal-analytic strategies on the part of the girls as the use of nonsense shapes was designed to eliminate this possibility. Rather, it was due to greater tactual processing abilities with the left-hand in boys between 6 and 13 years of age.

While subsequent studies have found a relatively consistent left-hand advantage for nonsense shapes and line orientation (Cioffi & Kandel, 1979; Gibson & Bryden, 1983; Dawson, 1981; Etaugh & Levy), there are inconsistent results for single letters and digits (Oscar-Berman et al., 1978; Witelson, 1974, 1976; Klein & Rosenfield, 1980). The inconsistencies reported in the literature appear to be related to factors such as gender, the meaningfulness of the stimulus elements, the use of dichhaptic vs haptic stimulation, and memory.

Gender

As noted, Witelson (1976) found no difference in overall accuracy between boys and girls. Boys, however, obtained greater left than right-hand scores for nonsense shapes, relative to girls. Subsequent studies have also reported that males are more accurate than females with the left-hand for identifying nonsense shapes (Gibson & Bryden, 1983; Dawson, 1981) while others report a left-hand advantage for nonsense shapes for both sexes (Flanery & Balling, 1979; Etaugh & Levy, 1981; Cioffi & Kandel, 1979; Dodds, 1978; Gardner, English, Flannery, Hartnett, McCormick & Wilhelmy, 1977).

Gibson and Bryden (1983) employed single letters and nonsense shapes to assess verbal and nonverbal performances, respectively in 8 to 14 year old children. Overall, the left-hand accuracy exceeded

right-hand performance. In addition, left-hand accuracy was significantly better in the nonsense shape task whereas there were no significant differences between hands on the letters task. Further analyses indicated that only boys showed a significant left-hand advantage for nonsense shapes. However, when data for 10 year old girls was ignored, sex-related differences disappeared. Gibson and Bryden (1983) concluded that the small sex differences provided weak confirmation for gender related asymmetries positing that gender differences are the result of a task-independent bias which favours the left-hand in males.

Dawson (1981) administered the Vocabulary and Block Design tests of the Wechsler intelligence scale prior to a dichhaptic nonsense task to ensure that results were not attributable to group differences in verbal or visuospatial skills. While there were no differences between males and females on either subtest score, males exhibited greater accuracy than females on the nonsense task in grade six and adult subjects. Gender differences were exhibited for the left-hand only; there were no differences between males and females for the right-hand. Results indicate a left-hand advantage for nonsense shapes for males and no hand differences for females at any age. Van Blerkom (1985) found that while both males and females in grades one to 10 exhibited a small but significant left-hand advantage, males were significantly more accurate overall than females.

Assessing asymmetrical performances in children, Etaugh and Levy (1981) found that 4 and 5 year old girls and boys did not differ in overall performance, both showing a significant left-hand advantage

for the visual identification of dichhaptically presented nonsense shapes. Similarly, Klein and Rosenfield (1980) found a significant left-hand advantage for nonsense shapes in both boys and girls. Although no significant hand differences for single letters was observed, mean accuracy scores indicated a slight left-hand advantage. This study did find, however, a trend toward differential performances attributable to gender. Overall, boys performed better on the spatial task while girls did better than boys on the linguistic task.

Flanery and Balling (1979) assessed performances of first-, third-, and fifth-grade children and adults on dichhaptically and haptically palpated nonsense shapes. Males and females demonstrated a left-hand superiority at all age levels although left-hand performance improved with age. Hatta, Yamamoto, Kawabata and Tsutui (1981) found that females exhibited a right-hand superiority for haptically presented concrete shapes while there were no significant differences between hands for males. However, as Hatta et al. (1981) utilized concrete shapes as stimuli, the right-hand superiority is most probably due to the fact that verbal mediation was employed.

Yandell & Elias (1983) dichhaptically presented pairs of circles and squares with distinctive features (V-shaped cutouts or notches) to twenty female subjects and found a right-hand advantage. Unfortunately, no males were included nor has the methodology utilized been replicated. Whether this hand advantage is due to gender differences or due to the use of stimuli which could be easily verbally labelled remains to be tested. Oscar-Berman et al. (1978) found a right-hand advantage for single letters, a left-hand

for line orientation and no differences for digits for both males and females. Others have failed to find a hand advantage for letters (Witelson, 1974, 1976; Klein & Rosenfield, 1980; Hunt, Edwards, & Quest, 1988) or digits for males and females (Finlayson & Reitan, 1976).

Cioffi and Kandel (1979) extended Witelson's (1974, 1976) initial methodology by using dichhaptically presented bigrams and words in addition to nonsense shapes to assess laterality in six to 14 year old males and females. While both sexes exhibited a right-hand advantage for words, boys identified more bigrams with their left-hand while girls displayed a right-hand superiority. There were no hand differences for single letters for either sex. However, in contrast to Witelson (1976) a left-hand advantage was observed for the nonsense task in boys and girls.

While a relatively consistent left-hand advantage for nonsense shapes has been found, there is disagreement as to the existence of gender differences in spatial tasks. Although sex differences are not always found, when they are observed they tend to favour males for better overall performance (Witelson, 1976; Gibson & Bryden, 1983; Van Blerkom, 1985) as well as for greater left-hand performance (Witelson, 1976; Dawson 1981). It has been postulated that the superior performance of boys on spatial tasks is indicative of greater right than left hemisphere specialization for spatial processing in males and more bilateral representation in females (Witelson, 1976; McGlone, 1980; Lewis & Kamptner, 1987). In a review of anatomical, clinical and perceptual studies of adults McGlone (1980) concluded

that cerebral asymmetries are more pronounced in males than in females. However, even when sex differences are exhibited, they are usually weak and/or nonsignificant. In a review of studies involving infants and children Hahn (1986) concluded that neither the male nor the female brain is more asymmetrically organized. The literature indicates that if sex differences do occur, they are related to the onset of puberty due to environmental and/or hormonal factors (Corballis, 1983; Geschwind & Galaburda, 1985a, 1985b, 1985c). There is some evidence that the age of onset of puberty, rather than gender "per se" may explain results. Waber (1977, in Corballis, 1977) found that regardless of sex, early-maturing adolescents did better on tests assessing verbal ability than spatial ability. Conversely, late-maturers performed better on spatial as opposed to verbal tasks.

There is still a great deal of controversy surrounding the issue of gender related differences in degree of hemispheric asymmetry. Some have argued that methodological differences may account for inconsistencies (Cohen & Levy, 1986) while others cite strategy and attentional factors (Witelson, 1976; Bryden, 1980; Hahn, 1986).

Meaningfulness of Stimuli

Most studies use nonsense shapes and single letters as the nonverbal and verbal stimuli respectively. The use of these stimuli suggests that it is the unequivocal nature of the stimulus materials (verbal versus spatial) utilized which will determine the direction of asymmetry.

While the majority of tactile studies using "nonverbal" stimuli, i. e. nonsense shapes, lines, dots confirm a left-hand advantage for

tactuo-spatial processing, it has been argued that it is not the verbal or spatial nature of the stimulus "per se" which elicits differential hemispheric processing (Smith, Cash, Barr, & Putney, 1986; O'Boyle, Van Whye-Lawler, & Miller, 1987; O'Boyle & Murray, 1988). Rather, tactile asymmetries appear to be dependent upon the physical characteristics of the stimulus and the facility with which the stimulus can be verbally or spatially analyzed. Indeed, studies involving the use of braille are used to bolster a process-oriented model of tactile processing (O'Boyle et al., 1987). These studies consistently find a solidly reliable left-hand advantage for learning braille, reading speed and accuracy in blind (Hermelin & O'Connor, 1971) and sighted subjects (Rudel, Denckla, & Spalten, 1974). Braille is ostensibly "verbal" material which should, therefore, predict a right hemisphere advantage. However, the dot patterns are more amenable to spatial analysis by the right hemisphere, resulting in a left-hand advantage.

Because the process-oriented approach (eg., Bryden & Allard, 1976; Sergent, 1982; O'Boyle et al., 1987) regards hemispheric specialization as relative rather than absolute, each hemisphere is viewed as being capable of analyzing either "verbal" or "spatial" information. However, as each hemisphere is most efficient when employing the "preferred" processing mode, tactile asymmetries ensue because of the cognitive processes used to perform the task. The use of single letters in tactile tasks, then, would appear to tap both left hemisphere "verbal" skills and right hemisphere "spatial" skills resulting in a lack of hemispheric differentiation.

O'Boyle et al. (1987) employed a novel paradigm in a series of experiments to investigate the impact of orientation and concurrent tasks on differential hand performances. In the first experiment capital letters were traced on the left and right palms of the hands either in the normal orientation (as they would appear to the subject if reading text) and upside down. The left-palm was significantly more accurate than the right-palm. As well, the left-palm advantage appears to be a function of orientation. When the letters were presented upside down the left-palm was more accurate. However, when the letters were traced in the normal orientation both hands performed equally. It was concluded that spatial considerations "override" the linguistic characteristics of the stimulus. To assess whether the left-hand superiority was, in fact, due to the greater spatial analysis efficiency by the right hemisphere O'Boyle et al. (1987) introduced concurrent spatial and verbal loading during the letter tracing trials. As previously noted, interference tasks are predicated upon the assumption that the increased processing demands of two related tasks will result in a performance decrement. During a spatial memory task there were no reliable differences between the left- and right-palms in recognition performance, again indicating a right hemisphere superiority for processing spatial information. During the verbal loading task a left- palm recognition advantage was again observed. As well, the left-palm advantage was present in the load and no-load condition, further supporting the notion that the processes involved in haptic manipulation and recognition of single letters are primarily spatial.

Hunt et al. (1988), hypothesized that subjects may initially exhibit a left-hand advantage because letters, not normally processed via the tactile modality, are treated as novel stimuli. They posited that with repeated exposure letters would become more familiar and only then would the expected right-hand advantage for linguistic material emerge. While a significant left-hand advantage was found on the first series of trials (three random presentations of each of the 26 letters of the alphabet) there were no differences between hands for Series 2 or 3. These authors hypothesized that the task had not yet become "linguistic" enough to elicit a right-hand advantage.

It would appear that single letters may not be sufficiently linguistic to elicit differential performances. It has been postulated that letters must be presented in a meaningful manner (ie. as words) in order to be unequivocally linguistic (Cioffi & Kandel, 1979). Thus, although single letters are familiar and linguistic they are most probably coded spatially as well as verbally because tactile presentations may emphasize the more salient spatial qualities. The result is the activation of both cerebral hemispheres simultaneously. Indeed, while Cioffi and Kandel (1979) found a significant right-hand advantage for words, the left-hand performance for processing words was above chance, emphasizing that specialization is relative rather than absolute and the need for relatively complex stimuli to tap specialized processing capabilities of a particular hemisphere.

It is also imperative that each stimulus within a series of trials be of equal processing difficulty in order to afford unbiased tests of differential processing accuracy. Indeed, Yandell and Elias

(1983) have reported that some stimuli are more easily identified than others. In order to mitigate potential biases, they utilized circles and squares with distinctive features. The resultant right-hand advantage was interpreted as evidence that the right hemisphere was not necessarily the dominant hemisphere for spatial processing. However, despite efforts to assuage stimulus dominance, within a process-oriented framework the stimuli employed in the Yandell and Elias (1983) study could be construed as eliciting more left hemisphere analyses. Witelson's (1974; 1976) shapes have also been criticized on the grounds that some may be easily verbalized (e. g. Flanery & Balling, 1979) and there is some evidence that geometric shapes are processed more readily by the left hemisphere (Lewis & Kamptner, 1987). As a result, the right-hand advantage may be due to a verbal labelling response elicited by the use of "distinctive" features on geometric figures.

The use of overtly verbal stimuli has resulted in differential hand advantages. Cioffi and Kandel (1979) demonstrated a significant right-hand advantage for dichhaptically presented two-letter words. Vargha-Khadem (1982) utilized three-letter nouns and nonsense shapes for verbal and nonverbal assessment, respectively. A greater right-hand accuracy was found for both tasks although the right-hand advantage was not significant for the nonverbal task.

O'Boyle and Murray (1988) found a left-palm (right hemisphere) advantage for the identification of four-letter names although the observed left-palm superiority was particularly marked when the names were presented in an upside-down orientation. These authors suggested

that the lack of left hemisphere processing (as expected due to the linguistic nature of the stimuli) may be due to a right hemisphere superiority for all forms of tactile stimulation. On the other hand, it is possible that using proper names (Mike, Mark, etc) constituted meaningless stimuli. That is, each letter was processed singly and a unitary precept of the word was ignored thereby eliciting a right hemisphere spatial advantage rather than a left hemisphere advantage expected by the verbal nature of the names.

As noted, nonsense shapes are the most prevalent means used to assess right hemisphere processing of tactually presented spatial information while single letters and digits are most frequently used to tap left hemisphere processes. The evidence suggests that these stimuli may activate processes within both cerebral hemispheres to a greater or lesser extent depending upon the complexity of the stimulus elements.

It would appear that the magnitude and direction of tactile-perceptual asymmetries are a function of the nature of the stimulus used and the type of analysis utilized by each of the hemispheres rather than a verbal-nonverbal distinction. However, only three studies (Cioffi & Kandel, 1979; Vargha-Khadem, 1982; O'Boyle & Murray, 1988) have assessed left hemisphere processing of complex verbal stimuli presented via the tactile modality in neurologically intact individuals. Two (Cioffi & Kandel, 1979; Vargha-Khadem, 1982) suggest that the left hemisphere is superior for more complex linguistic stimuli. Furthermore, only one (Cioffi & Kandel, 1979) has assessed right hemisphere processing utilizing meaningless stimuli containing

stimulus elements comparable to those used for linguistic processing. It is essential that studies employ stimuli which contain similar design elements in order to assess comparable left and right-hand differences (Smith et al., 1986).

Dichhaptic vs Haptic Stimulation

As previously noted, Witelson (1974) pioneered the dichhaptic stimulation technique to assess differential hand performance in the neurologically intact individual. However, several studies have since confirmed that haptic palpation is sufficient to elicit hand advantages.

Flanery and Balling (1979) explicitly investigated the need for dichhaptic stimulation for the elicitation of hemispheric differences. Children and adults were randomly assigned to either a condition in which only one hand was stimulated on a given trial or a condition in which each hand palpated a different form simultaneously on each trial. Although dichhaptic stimulation was more difficult for subjects than the haptic condition, the left-hand was significantly more accurate than the right-hand for both conditions. Furthermore, while accuracy increased with age, the magnitude of the differences between hands did not increase significantly as a function of age or gender. An analysis of variance performed on the laterality coefficients also indicated that dichhaptic stimulation was unnecessary.

Subsequent research has confirmed Flanery and Balling's (1979) conclusions that haptic presentations are sufficient for differential hand performances. Hatta et al., (1981) found a left-hand advantage for haptically presented concrete shapes in 10 to 12 year old males.

As well, while overall accuracy improved with age, the left-hand improved more than the right. This steeper learning curve for the left-hand has also been observed in studies utilizing dichhaptic stimulation (Dodds, 1978).

Fogliani, Fogliani-Messina, Barletta, & Caruso (1982) examined the relationship between differential hand performance and task complexity. Both the low and high complexity tasks involved haptic palpation and visual recognition. During the low-complexity task subjects were required to select the shape just felt from 12 items in the visual display. During the high-complexity tasks the stimuli were rotated either 90, 180 or 270 degrees. Subjects were informed of the direction of the rotation and were required to choose the original (upright) shape from the 12 on the visual display. Fogliani et al. (1982) found a decrement in right-hand performance accompanied by a marginal left-hand superiority on the high-complexity task. Furthermore, males showed no difference between hands on the more complex task while dextral females demonstrated a significant left-hand superiority. Thus, although males showed better overall performance than females, consistent with some previous research (Witelson, 1976; Dawson, 1981; Van Blerkom, 1985), females exhibited greater functional asymmetry on the more complex task.

Rose (1984) developed a modification of Witelson's (1974; 1976) task in order to test very young children. In this adaptation, the child palpated an object without seeing it and then the familiar (previously felt) object was displayed next to a novel stimulus. In preferential looking paradigms it is assumed that the subject will

exhibit differential responsiveness. Thus selective fixation on the novel stimulus indicates familiarization with the palpated stimulus. A higher left-hand novelty score is interpreted as evidence for right cerebral hemisphere specialization while a higher right-hand novelty score is indicative of left hemisphere processing. Rose's (1984) results demonstrated that one, two and three year old children significantly preferred the novel object regardless of hand or gender. As well, novelty scores were higher for the left than the right-hand for the two oldest groups but not the one year old group, indicating a left-hand advantage for meaningless objects for males and females as young as two years of age using a haptic palpation paradigm.

Cohen and Levy (1986) devised a study in which subjects were required to judge the similarity of haptically or dichhaptically presented tactual stimuli varying in texture and shape. During haptic presentations a stimulus pair was presented to either the left or the right-hand only for comparison. During dichhaptic presentations one stimulus of each pair was felt by the left-hand while the other stimulus was felt by the right-hand. Subjects were required to verbally indicate the extent to which the stimuli in each pair were similar or dissimilar. Analyses of variance indicate better discrimination of categories in the Left-Hand condition than in the Right-hand condition for both males and females. However, males were better able to categorize on the basis of texture and shape than were females in the Both Hands condition. Females performed significantly better with haptic presentation to the left-hand than they performed in the dichhaptic condition. Males, on the other hand, performed

equally as well during unimanual stimulation to the left-hand as they did with the left-hand during the dichhaptic presentation trials.

Because studies have consistently demonstrated that the differential performances are relative rather than absolute, as evidenced by the good performances of the left and right-hands during "verbal" and "spatial" tasks respectively under dichhaptic stimulation conditions (e.g. Cioffi & Kandel, 1979; Dodds, 1978; Witelson, 1974; 1976), both hemispheres appear to be involved, although to differing extents (Bryden & Allard, 1976; Sergent, 1982; O'Boyle et al., 1987). This also appears to be the case for unimanual or haptic processing (Hatta et al., 1981; Cohen & Levy, 1986; Flanery & Balling, 1979). While there are few studies investigating tactuo-spatial processing under haptic stimulation conditions, results indicate a left hand advantage for tactuo-spatial processing consistent with the dichhaptic literature. However, the data also suggests equivalent performances by both males and females under haptic stimulation conditions across a variety of age groups (Flanery & Balling, 1979; Cohen & Levy, 1986; Rose, 1984). Gender differences in previous studies may be due to a reduced performance by females under dichhaptic stimulation. Cohen and Levy (1986) have hypothesized that the decrement in performance under dichhaptic conditions may be due to greater interference, competition or cross-over of information when both cerebral hemispheres have access to the same information via the tactile modality. Therefore, the contribution of both hemispheres may reduce the performance of females.

Memory

In the typical cross-modal matching task the tactile target stimulus is projected to one hemisphere while the visual recognition stimulus (target/nontarget) is projected to both hemispheres. Flanery and Balling (1979) argued that the bilateral visual component may mask hemispheric differences existing in the initial processing of tactual information. The cross-modal paradigm has also been criticized on the grounds that the visual and tactile modalities have differential processing capacities. Duda and Adams (1987) argue that tactile tasks require complex co-ordination of both motor and sensory information which may yield between and within subject variability. However, these arguments appear unjustified as the ability to discriminate simple objects within the visual and haptic modalities as well as across the two modalities (visual-tactile; tactile-visual) has been demonstrated in 4 week (Walker-Andrews & Gibson, 1986), 4 month (Streri & Spelke, 1988) and 6 month (Bushnell, 1986) old infants. Moreover, although lateralization of haptic processing via cross-modal matching is not manifest until two years of age in the nonretarded individual (Rose, 1984; 1985) relatively consistent lateralization effects using the cross-modal matching paradigm have been demonstrated for children as young as two years, preschool and elementary school children, adolescents and adults (Rose, 1984; 1985; Witelson, 1974, 1976; Etaugh & Levy, 1981; Cioffi & Kandel, 1979; Hahn, 1986; Hatta et al., 1981; Fogliani et al., 1982).

Cross-modal studies do, however, require subjects to match a tactual stimulus to a visual image, often with 3 to 5 second delays between palpation termination and response (visual) recognition.

Noting that hemispheric differences in handling visual and auditory information may be magnified when storage is required, Oscar-Berman et al. (1978) explicitly investigated the impact of memory on differential tactile processing of verbal and nonverbal material. Letters, digits and lines in differing orientations were simultaneously drawn on the palms of both hands. Subjects were required to identify both stimuli felt in the order designated by the experimenter after stimulus presentation. Results indicated differential hand performance for second reports only; no differences were present with first reports of any stimulus type. A left-hand advantage was found for line stimuli, a right-hand superiority for letters, and no differences between hands for digits. Oscar-Berman et al. (1978) interpreted their results as support for the view that tactile perception may be asymmetrical only at later stages of information processing (e.g., memory).

Adams and Duda (1986) and Duda and Adams (1987) argue that both hemispheres may be comparable in spatial-form perception at initial perceptual levels and that tactuo-spatial lateralization may only emerge when higher order, post-categorical processes are involved. In a series of dichhaptic tasks requiring visual identification of tactually presented 8- and 12-point random shapes, a left-hand advantage was found only in the task which involved a 1.5 second delay

between the end of the palpation interval and the presentation of the recognition display (Adams & Duda, 1986; Duda & Adams, 1987).

These results are in accordance with those reporting a LVF advantage for complex patterns only after a delay between target and recognition display presentations (Dee & Fontenot, in Adams & Duda, 1986) as well as those which report a left-hand advantage for tactually presented nonsense shapes in which a delay has been explicitly introduced (Gardner et al, 1977; Oscar-Berman et al., 1978). As such, it has been suggested that hemispheric superiorities may be confounded with memory, i.e., hemispheric asymmetry for tactual processing may emerge only when higher order memorial processing of the somesthetically presented information occurs (Oscar-Berman et al., 1978; Yandell & Elias, 1983; Adams & Duda, 1986; Duda & Adams, 1987).

Conclusions

A growing body of evidence, gleaned from a diverse research base, suggests that there exists a left hemisphere advantage for processing verbal or meaningful material and a right hemisphere superiority for processing nonverbal or meaningless material in the right-handed population. Although caution must be exercised when extrapolating from clinical populations to normal populations there do appear to be strong parallels between results from neurological, anatomical, neurophysiological and behavioral areas of study.

Noninvasive techniques involving the presentation of stimuli via dichotic, tachistoscopic and, more recently, dichhaptic and haptic presentation appear to provide viable means of assessing asymmetric information processing. However, certain caveats apply.

Inconsistencies are due to a number of factors. Because differential cerebral processing appears to be relative rather than absolute, it is not feasible to simply dichotomize stimuli as verbal and nonverbal. Rather, to infer structural organization from functional asymmetry one must equate elements across the "verbal/nonverbal" distinction. As well, ear, visual half-field and hand advantages are relatively fragile. As such, factors such as memory, attention and motivation may attenuate or accentuate the incidence of observed differential processing capabilities between the two cerebral hemispheres.

Lateralization in the Mentally Retarded

Currently, the American Association on Mental Deficiency (AAMD) defines mental retardation (MR) as "significantly subaverage general intellectual functioning existing concurrently with deficits in adaptive behavior, and manifested during the developmental period" (Grossman, 1983). In practice, the retarded person is characterized as having an IQ score below 70 (two or more standard deviations from the mean) and exhibiting a lack of competency or compliance with respect to the precepts of personal independence and social responsibility expected of his/her age and cultural group. In order to differentiate mental retardation from additional disorders of human behavior, the upper limit of the developmental period is set at 18 years of age. The retarded individual is, then, by definition, below average in intellect and is, therefore, usually weak in most areas of cognitive functioning. While research on hemispheric asymmetries has greatly increased our knowledge of cognitive processing within each of the two cerebral hemispheres in the nonretarded individual, there is a paucity

of research regarding the specialization of hemispheric functioning in retarded individuals. Furthermore, most research has focused on the Down syndrome subject and relatively few studies have included nonretarded subjects of equivalent mental (MA) and chronological (CA) age. These problems exacerbate the ongoing debate as to whether retardation implies "delayed" or "slow" by reference to an implicit norm of development or whether structural (qualitative) differences exist between the retarded and the nonretarded individual.

Visual Half-field Studies

The few tachistoscopic studies which have addressed the question of visual half-field asymmetries in the "non-normal" population have focused on the learning disabled (dyslexic, delayed readers, slow learners) rather than on the retarded individual. These studies would indicate either an anomalous pattern of cerebral dominance (i.e., reversed dominance) (Williams, Keough, Fisher, Seymour, & Tanner, 1980) or no visual half-field superiority (Olson, 1973). With respect to retarded individuals, Smith et al. (1986) assessed visual half-field asymmetries in retarded subjects with severe language deficits. In order to eliminate problems of attentional bias and priming effects common to the majority of visual half-field studies, Smith et al. (1986) employed unilateral presentations of randomly mixed linguistic and nonlinguistic stimuli. As well, to eradicate the possibility that stimuli which require a left to right scan (i.e., alphabetically formed words) bias asymmetry, stimuli consisted of superimposed elements. Meaningful stimuli consisted of circles, squares, triangles, etc., while meaningless stimuli were composed by superimposing two or

more elements taken from the meaningful symbols. A significant dominant visual field superiority was found for meaningful symbols (circles, triangles, etc) and a significant nondominant visual field superiority was found for the meaningless symbols.

While these authors did not include subjects matched for CA and MA, these results are in the direction found for nonretarded adults and children. Perhaps most noteworthy is the fact that Smith et al. (1986) were able to demonstrate disparate left and right visual field advantages using stimuli containing equivalent elements for verbal and spatial processing respectively. As well, the asymmetry appears to exist despite receptive and expressive language deficits. This lends further credence to the position that structural asymmetries underlying observed behavioral asymmetries are the same for normal and retarded populations.

Dichotic Listening Studies

The small number of studies assessing ear asymmetries in the mentally retarded indicate that retarded individuals (not including Down syndrome) exhibit performance patterns comparable to those of equal MA nonretarded subjects. Jones and Spreen (1967) dichotically presented one-syllable nouns to educable retarded children (6 to 12 years). Each dichotic pair consisted of an abstract and a concrete noun matched for the first phoneme or phoneme blend. Subjects were required to repeat as many words from each of the eight sets of three noun pairs. There was a significant difference between ears with higher recall for words presented to the right ear than for words presented to the left ear. Moreover, level of recall for concrete

words was significantly higher than that for abstract words. Although the Jones and Spreen (1967) results indicate that the dichotic listening task is difficult for the retarded individual (as evidenced by the low level of overall recall of 27 %), the direction of ear asymmetry does conform to those found in the nonretarded individual.

Zekulin-Hartley (1982) assessed differential processing of computer-spoken digits in a group of Down syndrome (DS) children, a group of nonDS retarded children matched to the DS group for MA and CA, and a group of nonretarded children of equivalent MA to the retarded groups. While the Down syndrome group displayed a significant LEA, the nonDS and equal MA groups exhibited a significant REA.

Recognizing that problems with the comprehension of, and the following of, instruction may eclipse the contribution of cerebral asymmetry in the performance of retarded subjects with language limitations Pipe and Beale (1983) employed an auditory discrimination procedure prior to dichotic presentations. During a dichotic digits task children indicated which digit they had heard by pressing the button associated with that digit during the discrimination training. During the dichotic word test subjects pointed to a line drawing of the word they heard from a four choice display. Pipe and Beale (1983) found a significant REA for the digits and words for the normal group. The retarded group exhibited a significantly smaller REA for words as compared to the normal group as well as a nonsignificant trend toward a REA for the digits task. However, absolute ear asymmetries (AEAs), obtained by ignoring the direction of the asymmetry, indicated that

rather than differences in the magnitude of ear asymmetries, group differences were due to a greater frequency and/or degree of atypical LEAs on the part of the retarded group. These findings are consistent with others who suggest a greater incidence of anomalous lateralization in clinical populations (ie. learning disabled, retarded) (Williams et al., 1980; Geschwind & Galaburda, 1985). However, research suggests that anomalous handedness and/or cerebral dominance may be related to the severity of mental retardation (Soper, Satz, Orsini, Van Gorp, & Green, 1987; Roy, Elliot, Dewey, & Square-Storer, in press). Consequently, inconsistent data derived from the assessment of individuals with severe handicaps may reflect pathological asymmetry rather than a normally developing reversed structural asymmetry.

Mildly retarded individuals do, in fact, appear to perform equivalently to, and exhibit similar ear asymmetries as their equal MA counterparts. Hornstein and Mosley (1986) dichotically presented digit pairs and complex tone pairs to a group of mildly retarded individuals, an equal CA group and an equal MA group of nonretarded individuals. Subjects were presented with a tone/digit pair followed immediately by a tone/digit probe. Subjects were required to respond "yes" if the two presentations (tone/digit-probe) were the same and "no" if the two were different. All groups exhibited a REA for digit stimuli and a LEA for tone stimuli.

Lateralization of Tactile Processing

No study has explicitly investigated differential hand performances in the retarded individual and the data concerning

hemispheric specialization in the slowly developing or learning disabled individual is scant and inconsistent. Witelson (1977) compared dyslexic and normal children of comparable CA on dichhaptic nonsense shape and letters tasks. Normal children demonstrated a significant left-hand advantage for shapes and a slight right-hand advantage for letters. Conversely, dyslexic children exhibited a left-hand advantage for letters and no hand advantage for shapes. Williams et al. (1980) evaluated dichhaptic performances of normal (6-0 to 6-11 years) and slowly developing (5-0 to 9-6 years) children. They found no hand differences for the recognition of dichhaptically presented shapes for normal right-handed children while the slowly developing children exhibited a right-hand superiority.

As with studies on lateralization most research assessing the motor skills of the mentally retarded focus on Down syndrome persons (i.e., Anwar, 1983). Investigations do suggest, however, that while MR subjects appear to have impoverished performance relative to their nonMR peers on upper limb speed and accuracy tasks, MR's do achieve levels of performance similar to equal MA subjects on reciprocal tapping, speeded sequencing and maze tracing (Roy et al., in press) and form board tasks (Harris, 1987).

Cross-modal Matching

While experimental research on laterality indicate the retarded subject is capable of processing information within modalities (Hornstein & Mosley, 1986; Smith et al., 1986; Jones & Spreen, 1967), few have evaluated the individual's ability to transfer information across modalities and, as noted previously, none has evaluated haptic

processing asymmetries. Cross-modal matching tasks involve the integration and analysis of input to different sensory systems and is evident in early infancy in the nonretarded individual (Rose, 1984; Bushnell, 1986; Walker-Andrews & Gibson, 1986; Streri & Spelke, 1988).

With respect to intramodal matching, O'Connor and Hermelin (1961) assessed visual and stereognostic shape recognition in DS and nonDS retarded individuals, children and adults. Subjects were presented with five shapes either visually or haptically. Each shape was presented twice successively to the retarded and child groups and once to the adult subjects. The same shapes, in addition to five novel stimulus shapes, were presented in succession one minute after stimuli presentations. Subjects were required to indicate which shapes were new and which were familiar. Results indicated that adults were superior in tactile rather than visual discrimination. Normal children's tactile and visual performances did not differ. DS subjects were superior in the visual recognition of new and familiar shapes whereas nonDS retardates performed significantly better when required to discriminate haptically. While adults were superior to the other groups in their ability to discriminate visually, there were no differences between the nonDS retarded, nonretarded children and adults in their ability to tactually discriminate shapes.

Subsequent research also indicates that normal, DS and nonDS retardates do not differ in their ability to match and recognize visually presented line drawings (Hermelin & O'Connor, 1961). These results also support the position that retarded individuals perform equivalently to nonretarded children on within modality tasks.

While clinical and anecdotal literature argue that learning disabled and mentally retarded individuals are frequently deficient in integrative and transfer capabilities and have difficulty assimilating information presented via different sensory channels (Keefe, 1985; Salmon, Pear, & Kuhn, 1986; Tzuriel & Klein, 1985), the experimental, albeit limited, evidence would suggest that the retarded individual's performance is comparable to that of the nonretarded individual.

Pipe and Beale (1983) used a visual response display (line drawings of the words) in a dichotic listening task. They found similar ear advantages for normal, DS and nonDS retarded subjects. Despite directional differences for the DS subjects (LEA) as compared to the normal and nonDS retarded subjects (REA), mentally retarded subjects do appear to be capable of performing a cross-modal task. Similarly, Sommers and Starkey (1977) required the visual recognition of dichotically presented words by low and high functioning DS children and nonretarded children. Although neither DS group exhibited cerebral dominance patterns, they were able to perform the cross-modal task (as exhibited by screening). Hermelin and O'Connor (1961) also demonstrated that MR subjects are capable of performing a cross-modal task requiring the visual identification of tactually presented shapes which shared or did not share the same name with the response display. Davidson, Pine, Wiles-Kettenmann, and Apelle (cited in Davidson, 1985) compared moderately mentally retarded and nonretarded children on haptic shape matching tasks using intra- and cross-modal haptic-visual conditions. They also evaluated scanning style usage of both groups. These authors found identical patterns of errors for mentally retarded

and nonmentally retarded children of equivalent MA. As well, both groups followed the same pattern of search style for the identification of haptically presented stimuli. These results again indicate that MR and nonMR equal MA subjects perform comparably on haptic tasks.

Conclusions

Notwithstanding the dearth of studies assessing laterality in the right-handed retarded individual, results suggest ear and visual half-field asymmetries comparable to those demonstrated by nonretarded right-handed subjects. Furthermore, a comprehensive review of the dichotic stimulation literature with mentally retarded subjects suggests that differences between retarded and equal MA nonretarded subjects in the magnitude of the observed asymmetries may be a reflection of strategy and attentional differences (Mosley & Vrbancic, in press). These authors concluded that retarded individuals (with the exception of Down syndrome) demonstrate a pattern of asymmetrical processing similar to that of nonretarded individuals when matched for mental age. In addition, it was concluded that the greater magnitude in performance exhibited by equal MA subjects can be eradicated by the use of dichotic monitoring techniques. This technique reduces the influence of subject initiated strategies resulting in equivalent performances by retarded and nonretarded equal MA subjects (Nugent & Mosley, 1987). While discretion is advised when generalizing results derived from a population of retarded individuals with known organic brain dysfunction (i.e., Down syndrome) to groups for whom etiology is not known, it would appear that when studies equate tasks demands

(attentional, strategy, motivational and/or procedural factors are held constant), mildly retarded individuals perform equivalently to, and exhibit the same pattern of differential cerebral processing as, nonretarded individuals equated for mental age.

Furthermore, the limited number of experiments evaluating MR individual's abilities to perform cross-modal tasks indicate that the cross-modal matching paradigm is a viable means of assessing laterality within this population.

The Present Study

Although each of the two cerebral hemispheres is capable of analyzing both "verbal" or "spatial" information, data derived from diverse sources suggest that the left and right hemispheres are differentially efficient information processors. As such, the left hemisphere is superior when processing information such as words, letters, and digits, while the right hemisphere is superior for tasks requiring the recognition of patterns or shapes, faces, nonspeech sounds, and direction or orientation. Moreover, while the information regarding lateralization in the retarded individual is sparse, it does suggest that mentally retarded individuals exhibit comparable patterns of cerebral asymmetry to those of normal and clinical groups. However, the direction and magnitude of the asymmetrical information processing appears to depend not only upon the type of stimuli to be processed (i.e. "verbal/nonverbal") but also upon the stimulus characteristics, as well as on factors such as motivation, memory, attentional biases and strategy differences.

Witelson (1974; 1976) was the first to utilize dichhaptic stimulation to assess lateralization of tactile processing in the neurologically intact individual. Subsequent research has demonstrated that dichhaptic and/or haptic stimulation techniques elicit a fairly consistent left-hand advantage for processing spatial information such as nonsense shapes, line orientation and braille. Studies which have utilized concrete shapes, words, or stimuli which can be easily labelled tend to elicit a right-hand advantage. These results, demonstrated in both normal and clinical populations, parallel those obtained using dichotic and tachistoscopic techniques and appear to be a viable means of increasing our knowledge of lateralization in the mentally retarded. Research has also confirmed that haptic stimulation is sufficient to elicit differential hand performance (Flanery & Balling, 1979; Hatta et al., 1981; Fogliani et al., 1982; Rose, 1984; Cohen & Levy, 1986). In addition, the use of haptic stimulation, as opposed to dichhaptic stimulation, eliminates attention and strategy differences common among groups of differing mental abilities.

The proposed research will examine left and right index finger performances of mentally retarded individuals, adults and children as a function of stimulus type as well as response delay utilizing a cross-modal matching paradigm (tactile presentation - visual recognition).

There is a paucity of data regarding haptic asymmetries for "verbal" information. Studies utilizing single letters have largely resulted in no hand differences suggesting that letters are neither sufficiently "verbal" nor "spatial" to elicit differential

performances. In light of the significant right-hand advantage for two- and three-letter words (Cioffi & Kandel, 1979; Vargha-Khadem, 1982) the present study should reveal the following:

1) Recognition response times will be faster for words presented to the right-index finger for all groups. In addition, it is predicted that the right-index finger will be more accurate than the left-index finger for words.

The data consistently reveals a left-hand advantage for nonsense shapes and complex designs. Cioffi and Kandel's (1979) demonstration of a left-hand advantage for two-letter bigrams, coupled with O'Boyle and Murray's (1988) research demonstrating an enhanced left-hand advantage when names were presented in an upside-down orientation suggest that the meaningfulness of the stimulus is an important factor in differential performance. It is, therefore, predicted that:

2) Recognition response times will be faster and identification will be more accurate when two-letter bigrams and Chinese characters are presented to the left-index finger in the no delay condition.

It has been suggested that laterality may be dependent on or enhanced by higher order memory processes. If these arguments that memory is an important factor in the degree and/or direction of asymmetrical processing are correct, the present study should reveal that:

3) More words will be correctly identified with the right-index finger in the delay condition than in the no delay condition.

If, on the other hand, the delay between stimulus offset and recognition display onset merely gives the subject the opportunity to use rehearsal strategies, stimuli which are amenable to verbal labelling should also elicit a right-hand advantage. In this case, it is predicted that:

4) While more bigrams will be identified with the left-index finger in the no delay condition, in the delay condition a right-index finger advantage will emerge. A right-index finger advantage will be elicited by single letters in the delay condition as compared to no differential finger performances in the no delay condition.

There is considerable evidence that experience and practice effects affect performance. Some studies assessing differential performance over series of trials have demonstrated a larger percentage of errors on the first series of trials (O'Boyle & Murray, 1988) while others find a shift from a left-hand advantage to equivalent left- and right-hand performances in later trials (Hunt et al., 1988). It is predicted that:

5) Performance accuracy and recognition response times will improve during the second block of trials.

The research indicates that MR's perform equivalently to equal MA nonretarded subjects while adults tend to outperform both groups on a variety of lateralization, motor and sensory tasks (Hornstein & Mosley, 1986; Mosley & Vrbancic, in press; Roy et al., in press; Hermelin & O'Connor, 1961; O'Connor and Hermelin, 1961; Davidson, 1985). It is therefore hypothesized that:

6) The adult group will respond faster and have more correct recognition responses than the child and mentally retarded groups while the child and mentally retarded groups will have similar performances.

METHOD

Subjects

Equal numbers of right lateralized males and females in each of three groups were individually tested. The first group consisted of 24 mildly retarded (MR) individuals accessed through the Vocational and Rehabilitation Research, Calgary. Twelve females (CA = 28.08, SD = 8.99; MA = 7.74, SD = 2.59) and 12 males (CA = 31.67, SD = 6.71; MA = 8.24, SD = 2.35) participated in both sessions. Only individuals who could read simple words were recruited for the study. Potential subjects were told the nature and purpose of the study either individually or in small groups and their consent was obtained prior to requesting parental/guardian consent. While participation was purely voluntary and the issue of monetary reward was not mentioned at the time of gaining consent, subjects who completed both sessions were paid \$4 at the completion of the second session.

The second group consisted of elementary school children matched for mental age (MA) with the (MR) subjects and were drawn from grades 1, 2, and 3 at Don Bosco Elementary and Junior High School of the Calgary Separate School System. Only children assessed by his/her school as having normal intelligence and no learning disabilities were included in this group. MA was assessed using the Peabody Picture Vocabulary Test at the beginning of the first session. Twelve females (CA = 8.13, SD = .88; MA = 8.07, SD = .95) and 12 males (CA = 8.10, SD = 1.05; MA = 7.94, SD = 1.07) were tested during regular school hours. While parental consent was obtained prior to speaking with any child, the nature and purpose of the task was explained to each child and

he/she was told that they did not have to help unless he/she really wanted to. Four dollars for each child who completed both sessions was donated to the school for the purchase of library books acknowledging the participation of the children.

The third group of subjects consisted of individuals matched to the MR subjects for chronological age (CA) drawn from the Department of Psychology, University of Calgary subject pool. A total of eighteen females (CA = 24.44, SD = 3.01) and 18 males (CA = 24.67, SD = 3.33) were tested. Subjects were told prior to giving consent that they would receive \$4.00 if they completed both sessions.

Only subjects who did not speak Chinese and had no working knowledge of Chinese characters were included in the study.

Apparatus

Assessment of Laterality: A pencil, a toothbrush, a spoon, a comb and a ball were used to demonstrate handedness. A ball was used to determine the dominant foot. Eye dominance was assessed by a paper hole test (Porac & Coren, 1977).

Coin Recognition Task: Quarters, nickels, dimes, and pennies were used to determine tactile discriminability.

Haptic Task: During each task the subject was seated in front of a testing box approximately 45 cm³ (after Witelson, 1974). The solid front of the box prevented subjects from seeing the test stimuli. The box was constructed with arm holes 10 cm apart through which the subject placed both arms up to mid-arm length with the hands placed palms down with the heels of the hands resting on the bottom of the

testing box. This position was reasonably comfortable for the subjects. Subjects were also allowed to remove their hands from the box between practice and experimental trials. When the subject's index fingers were positioned one finger was aligned and in contact with the test stimulus and the other with a "blank". Soft wrist bands prevented the subject from moving his/her arms while palpating the stimuli.

The recognition slides were projected via a Kodak Ektagraph slide projector (Model AF-2) fitted with a Gerbrands tachistoscopic shutter (Model 66) onto a 20 cm X 20 cm rear projection screen located in the center of the front of the test box at eye level.

A Calrad Electret Condenser Microphone voice key (Model 10-91) connected to a Lafayette timer (Model 1431A) and a Lafayette Clock/Counter (Model 54417-A) recorded the recognition time for each trial. The onset of the response slide activated the timer and the subject's verbal response stopped the timer. The verbal response and the response time were then recorded by the researcher.

Stimuli

All letter stimuli were smooth plastic Monaco Font block script upper case letters. The Chinese characters were constructed of acrylic. Each stimulus was approximately 1.5 cm X 1.5 cm in size. The "blank" was a 5 cm X 5 cm square of smooth plastic. For presentation the stimuli and blanks were mounted 10 cm apart on the central portion of an 8 cm X 30 cm piece of particle board (the base) which slid into slots in the bottom of the test box.

Practice Stimuli

Stimuli for the four practice tasks consisted of the two-letter words TÓ, IF, SO, OR and AM, the single letters J, M, L, F, and H, the bigrams (SP, PN, DQ, GS and NG) and five Chinese characters (nonsense stimuli). Refer to Appendix A for samples of practice and experimental Chinese characters. Practice stimuli were randomly selected from all possible choices remaining after experimental stimuli were chosen. None of the practice stimuli was used as experimental stimuli.

Experimental Stimuli

Words: Word stimuli consisted of five two-letter words (IS, IT, AN, UP, and GO) randomly chosen from all possible two letter words, excluding the five practice two-letter words, in which the consonant was the same as that of the single letter stimuli.

Single Letters: Letter stimuli consisted of the five upper case consonants S, T, P, N, and G.

Bigrams: Bigrams consisted of two upper case consonants randomly selected from those generated to have no associated meaning for subjects. Consonant pairs (bigrams) for the experimental trials were BV, RF, LK, ZJ, and CH.

Nonsense Stimuli: The nonsense stimuli consisted of Chinese characters. The criteria for choosing the Chinese characters were as follows: 1) the major portion of the character could not look like an Arabic letter (eg. no T, J, S configurations); 2) no enclosed boxes; 3) as few angles as possible; and 4) as few separate lines as possible.

During experimental trials, for each stimulus type a stimulus was randomly presented a total of four times to the right and four times to the left index fingers with the restriction that no stimulus immediately preceded or followed itself to either hand.

Recognition Display

Practice Trials: There was a separate recognition display for each trial in each task. Each display consisted of four numbered stimulus choices (one just palpated and three distracters) in black on a white 20 cm X 10 cm card. In the case of words and bigrams, distracters were chosen so that the first letter of one of the three distracters matched the first letter of the practice stimulus while the second letter of one of the distracters was the same as the second letter of the palpated practice stimulus. For example, for the practice stimulus "IF", one distracter was IN while a second distracter was OF. The third distracter was randomly chosen from all possible distracters.

Experimental Trials: There was a separate recognition display for each trial in each task. Each recognition slide consisted of a single stimulus (Chinese character, single letter, bigram or two-letter word) in black on a white background. All recognition stimuli were projected to approximate the same physical dimensions as the palpated test stimulus.

The recognition slide could contain any one of the following: a) the stimulus just palpated (30 trials in each task); b) a different stimulus from that just palpated but one of the five test stimuli (5 trials in each task); c) a different stimulus (5 trials in each task).

The recognition stimuli were presented either immediately following each haptic palpation (no delay) or after a 3 second delay. One half of the trials in each task had no delay, and one half had the 3 second delay. Delay and no delay trials were randomized within blocks of 20 trials for each task.

Procedure

All children were given the PPVT-R prior to testing. MR, equal MA, and equal CA subjects were all given the Coin Recognition Task which required the tactile identification of pennies, nickels, and dimes with the index-fingers. Handedness was established by having subjects throw a ball, simulate brushing one's teeth, draw a simple picture, comb one's hair, use a spoon, and print or write one's name. Footedness was established by requiring subjects to kick a ball. To establish eye dominance the subject held, at arms length, a card at eye level and viewed, with both eyes open, a target through a hole in the card. The subject was then required to move the card toward his/her face while keeping the target in view. The eye employed to view the target at the close-up position was considered to be the dominant eye. In order to participate in the study subjects had to be right-handed, rightfooted and right-eyed and be able to tactually identify the coins. Since each eye has a right/left visual half-field, a single eye cannot address the laterality question. Therefore, the right eye dominance requirement was for consistency only.

During all palpation trials subjects rested the heels of their hands on the floor of the test box with their index fingers raised. A

stimulus pair (test stimulus and blank) was positioned under the subjects index fingers. The experimenter told the subject when to lower his/her index fingers. The interval began when the fingers were lowered and ended when the experimenter instructed the subject to raise their fingers. At no time were the stimuli visible to the subject. Palpation intervals were pre-determined for each stimulus type for each subject.

Palpation Intervals: Prior to each of the four experimental tasks, defined by the type of stimulus presented, individual palpation times were established. The subject palpated a practice stimulus while viewing a response card with four numbered stimuli (one palpated and three not palpated distracters) and he/she verbally identified the number associated with that stimulus on the response card. If the incorrect stimulus was identified the subject was told to feel the stimulus again. The recognition times for the first three trials were discarded and the mean for the remaining seven recognition times was calculated. That mean recognition time was then used as the palpation time for the experimental trials on that task for that subject.

Prior to each task, all subjects were told whether single letters, bigrams or Chinese characters were going to be presented. Instructions prior to receiving two-letter words varied for adult subjects only. MA and MR subjects were told they would be feeling two-letter words.

Influence of Instruction (Adult Subjects): In the case of words, three conditions were utilized for three adult groups to determine if instruction impacted response times. There were six males and six

females for each of the three instruction conditions. Subjects in Condition I were told that they would be feeling two-letter words. All stimuli and response choices were two-letter words. In Condition II, subjects were simply told they would be feeling two letters. Again, all palpated stimuli and visual response choices were two-letter words. Subjects in Condition III were told they would be feeling two letters. However, one half of the palpated practice stimuli were two-letter bigrams and one half were two-letter words. All stimulus response cards in Condition III contained two bigram and two word choices. Analyses of variance for response times (RT) for correct "yes" responses, RT for correct "no" responses, percent correct "yes" and percent correct "no" responses yielded no significant effects at $p < .01$. In addition, ANOVAs for RT for correct "yes" responses, correct "no" responses, percent correct "yes" and percent correct "no" responses yielded no significant effects when Conditions I and II were compared with subjects in Condition III. As such, the data for the twelve subjects in Condition III were not included in the final analyses. Subjects in the MA and MR groups were told they would be receiving two-letter words, palpated two-letter words, and were presented with two-letter words in the response displays.

Experimental Trials: During experimental trials the experimenter told the subject when to lower his/her fingers. At the end of the predetermined palpation interval the experimenter told the subject to "lift" his/her fingers and look at the screen directly in front of him/her. A recognition slide was presented to the subject either immediately or after a 3 second delay. The subject responded verbally

either "yes" (felt that shape) or "no" (did not feel that shape). The experimenter recorded the subject's response ("yes"/"no") and response time and a new trial began. While subjects were informed that there were trials during which the slide would be presented immediately after the "lift" command and trials during which there would be a slight delay between the end of the palpation interval and the onset of the slide, no warning was given to the subject prior to a trial as to whether that trial was a delay or no delay trial. No feedback was given to the subject regarding response accuracy or actual speed. However, if a subject asked how he/she was doing, the experimenter told the subject he/she was doing well.

Subjects were tested in two separate sessions (each approximately 45 minutes in length). Pretests and two tasks were given in the first session and the remaining two tasks were given approximately one week later. All possible orders for stimulus type presentations (24) were utilized. Combinations were randomly assigned to subjects in each group.

RESULTS

The Biomedical Computer Programs-P series (BMDP) software was utilized for all statistical analyses of variance (ANOVA). All between group results derived from repeated measures ANOVAs were examined and supported by nonparametric Kruskal-Wallis analyses (Appendix B), due to the failed assumption of homogeneity of variance. The Greenhouse-Geisser adjustment to degrees of freedom was used to report all within subject effects and the alpha level of $p < .01$ was utilized for all tests of statistical significance. Tukey B tests of ordered means were used where appropriate.

Practice Trials

The amount of time, in seconds, required to correctly identify which of four stimuli in a visual display was the same as the stimulus being palpated (palpation durations) was subjected to a Group (CA, MA, MR) X Sex (male, female) X Index Finger (left, right) X Stimulus Type (two-letter words, bigrams, single letters, Chinese characters) X Index-Finger (left, right) ANOVA with Stimulus Type and Index-Finger as a repeated measures. The source table for the main ANOVA can be found in Appendix C.

Results indicated a significant main effect for Group, $F(2, 65) = 35.98$, $p < .01$. Adults ($M = 4.56$ seconds, $SD = .828$) were significantly faster than the child ($M = 9.30$, $SD = 2.500$) and retarded ($M = 10.86$, $SD = 4.054$) groups which did not differ.

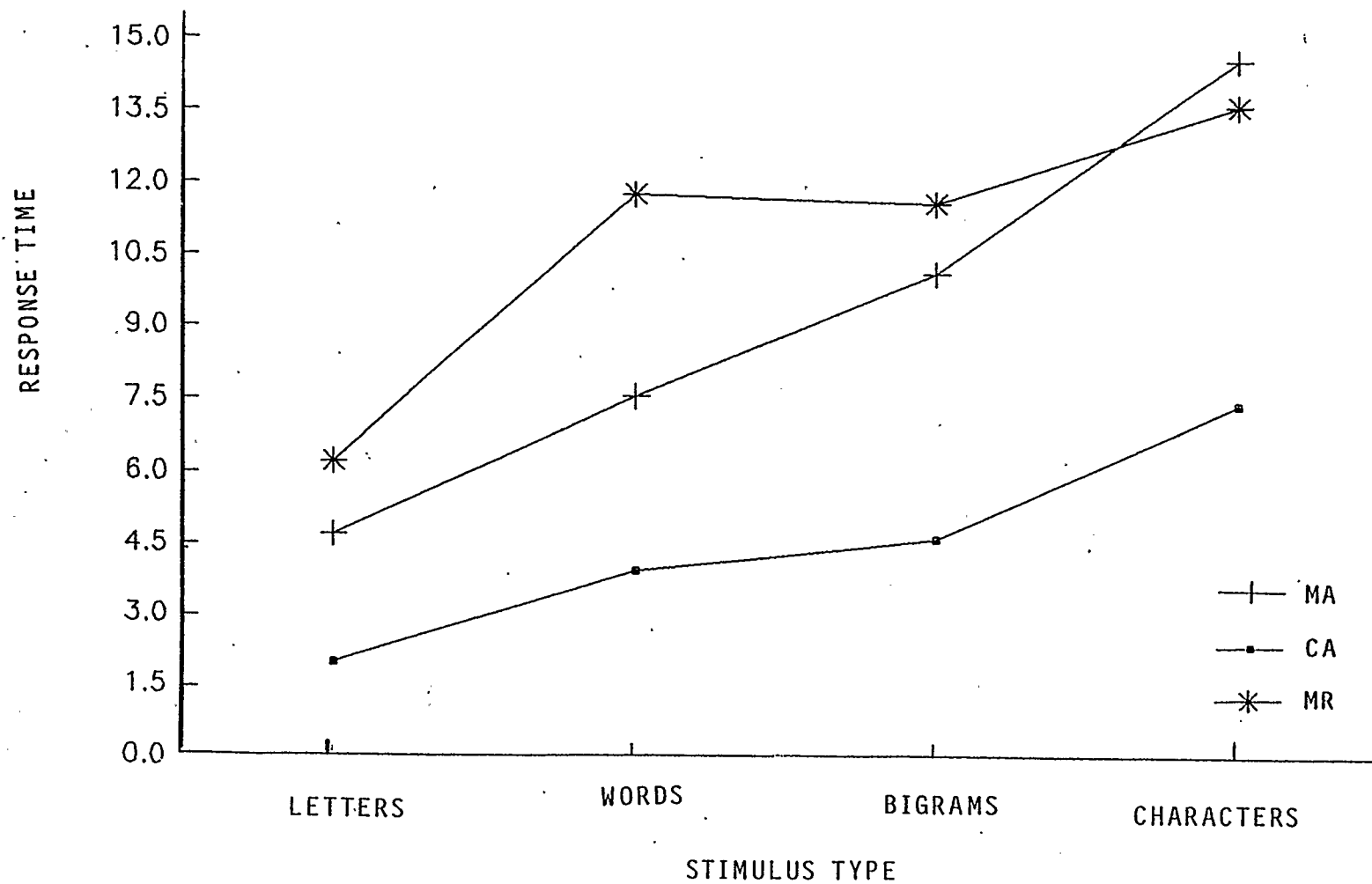
A significant main effect for Stimulus Type, $F(3, 195) = 119.86$, $p < .01$, was also obtained. There were significant differences in

response times between all Stimulus Types. The mean response time was fastest for single letters ($M = 4.33$, $SD = 2.897$) followed by two-letter words ($M = 7.79$, $SD = 4.665$), bigrams ($M = 8.83$, $SD = 4.886$) then Chinese characters ($M = 11.96$, $SD = 5.215$).

A significant Group X Stimulus Type interaction was also found, $F(6, 195) = 7.32$, $p < .01$ (Figure 1). Cell means and standard deviations are presented in Table 2 (Appendix C). Tests of simple main effects (Table 3, Appendix C) indicated significant differences between stimulus types within groups as well as significant differences across stimulus types as a function of group. Tukey B tests indicated that the CA group was significantly faster than the MA and MR groups for all Stimulus Types. While the MA group was significantly faster than the MR group for single letters, two-letter words and bigrams, both groups had similar response latencies for Chinese characters. Inspection of the data also indicated that the CA group was significantly faster when identifying single letters as compared to words and bigrams. Response latencies were significantly longer for Chinese characters. A similar pattern was exhibited by the MR group. The MA group was significantly faster when matching single letters, followed by words, bigrams and Chinese characters. No other main or interaction effects were found.

In order to examine the relationship between palpation duration (Practice trials) and recognition time for the Experimental trials, palpation duration was regressed on recognition time for Experimental Trials. Separate analyses were conducted for recognition times for correct "yes" responses (palpated stimulus and response slide were the

Figure 1
Practice Trial Palpation Interval
Group X Stimulus Type Interaction



same) and recognition times for correct "no" responses (palpated stimulus and response slide were different). Both analyses revealed a significant positive relationship between palpation duration and recognition time; i. e., subjects who took longer to correctly match the palpated stimulus to the visual display during practice also took longer to correctly identify "same" and "different" targets during the experimental trials.

Experimental Trials

Percent Correct "Same" Responses

The percentage of correct "same" responses (subject said "yes" when palpated stimulus and response slide were the same) was subjected to a Group (CA, MA, MR) X Sex (male, female) X Index Finger (left, right) X Stimulus Type (two-letter words, bigrams, single letters, Chinese characters) X Delay Condition (delay, no delay) X Block (Block I, Block II) ANOVA with Index Finger, Stimulus Type, Delay Condition and Block as repeated measures. The main source table can be found in Appendix D.

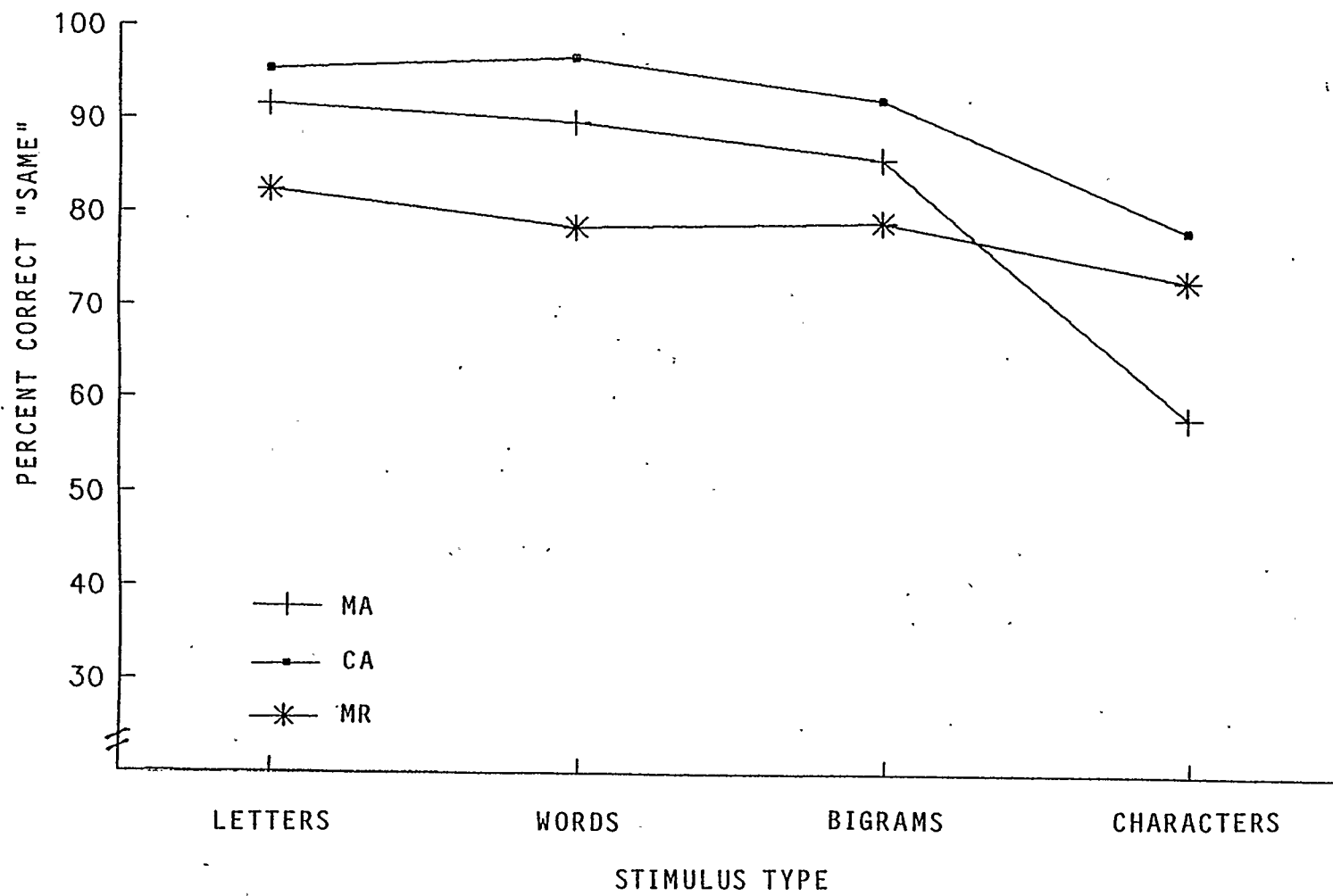
The analysis indicated a significant main effect for Group, $F(2, 66) = 8.83$, $p < .01$. The CA group ($M = 90.21\%$, $SD = 5.41$) was significantly more accurate than the MA ($M = 80.87\%$, $SD = 9.05$) and MR ($M = 77.79\%$, $SD = 14.86$) groups which did not differ significantly.

A Tukey B test on the ordered means for the Stimulus Type main effect, $F(3, 198) = 51.48$, $p < .01$, revealed that accuracy was significantly better for single letter ($M = 89.59\%$, $SD = 12.79$), two-

letter words (\underline{M} = 87.83%, \underline{SD} = 14.59) and bigrams (\underline{M} = 85.09%, \underline{SD} = 14.33) than was accuracy for Chinese characters (\underline{M} = 69.22%, \underline{SD} = 19.11).

There was also a significant Group X Stimulus Type interaction (Figure 2), $F(6, 198) = 7.37$, $p < .01$. The cell means and standard deviations for the Group X Stimulus Type interaction are presented in Table 2, Appendix D. Tests of simple main effects (Table 3, Appendix D) indicated significant differences in accuracy across Stimulus Type for the MA and CA groups. The MR group exhibited no significant differences in response accuracy for any stimulus type while both the MA and CA groups were significantly less accurate when responding to Chinese characters as compared to any other Stimulus Type. Tests of simple main effects also indicated significant differences between groups as a function of Stimulus Type. A Tukey B analysis revealed that while CA and MA groups demonstrated similar accuracy rates for single letters, bigrams and words, the CA group was significantly more accurate than the MA group when identifying "same" Chinese characters. The data also indicated a similar accuracy pattern when comparing the MA and MR groups. While both groups performed equivalently for single letters, words and bigrams the MR group was significantly more accurate than the MA group for Chinese characters. The CA group was significantly more accurate than the MR group for words only. As Figure 2 indicates the interaction effect was due to the decrements in accuracy for "same" Chinese characters trials on the part of the CA and MA groups. No other main or interaction effects were found.

Figure 2
Percent Correct "Same" Group X Stimulus Type Interaction



Percent Correct "Different" Responses

The percentage of correctly identified "different" responses (subject said "no" when palpated stimulus and target were "different") was subjected to a Group (CA, MA, MR) X Sex (female, male) X Stimulus Type (two-letter words, bigrams, single letters, Chinese characters) X Index Finger (left, right) ANOVA with Stimulus Type and Index Finger as repeated measures (Table 1, Appendix E). Given the basic percentage differences (25% vs 75% for correct "different" and "same" responses, respectively) for each subject for some levels of some of the variables, there were too few data points, necessitating collapsing across Block and Delay condition.

The analysis indicated a significant main effect for Group, $F(2, 66) = 51.76$, $p < .01$. The CA group ($M = 86.60\%$, $SD = 6.19$) and the MA group ($M = 75.66\%$, $SD = 11.87$) did not differ significantly. Both groups were significantly more accurate than the MR group ($M = 44.56\%$, $SD = 21.45$).

There was also a significant main effect for Stimulus Type, $F(3, 198) = 37.34$, $p < .01$. Identification of "different" single letters ($M = 77.78\%$, $SD = 26.12$), words ($M = 74.53\%$, $SD = 24.98$), and bigrams ($M = 71.55\%$, $SD = 31.89$) was significantly better than for Chinese characters ($M = 51.90\%$, $SD = 25.40$). Single letters ($M = 77.78\%$) were more accurately identified than were bigrams ($M = 71.55\%$). A significant main effect for Index-Finger, $F(1, 66) = 7.22$, $p < .01$, was found. The right Index-Finger (71.03%) was significantly more accurate as compared to the left Index-Finger (66.84%) when identifying "different" stimuli.

The analysis also indicated a significant Group X Stimulus Type (Figure 3), $F(6, 198) = 4.58$, $p < .01$, interaction effect. Cell means and standard deviations are reported in Table 2, Appendix E. Tests of simple main effects (Table 3, Appendix E) indicated significant Group differences across Stimulus Types as well as significant Stimulus Type differences across Groups.

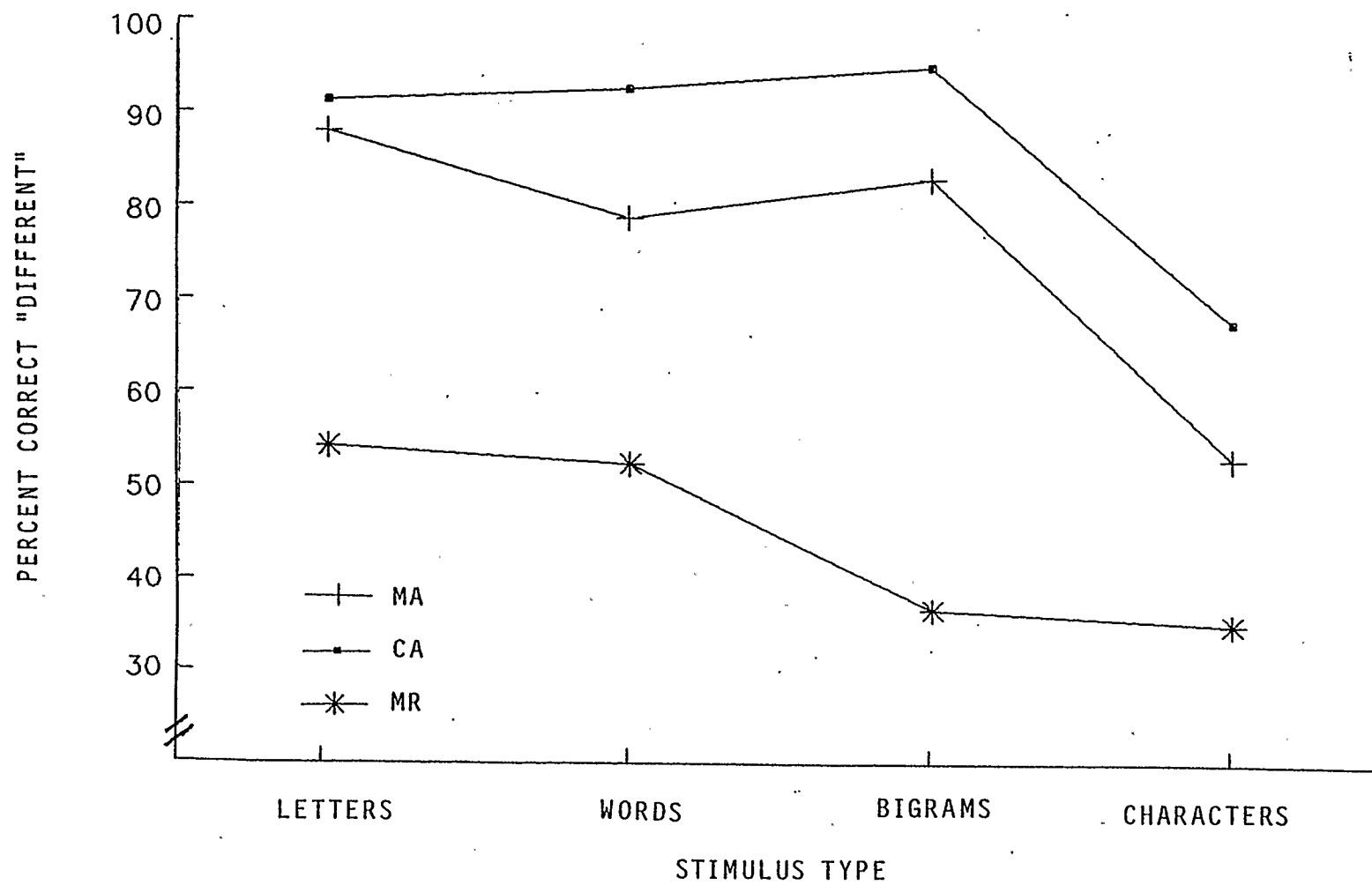
Tests comparing groups indicated that while adults and children had similar accuracy percentages when the target and stimulus were "different" for single letters, adults were significantly more accurate than the MA group for all other Stimulus Types. Children, in turn, were significantly more accurate than the MR group for all Stimulus Types.

A Tukey B test of the ordered means also indicated that the CA group was equally accurate when recognizing "different" single letters, two-letter words and bigrams. However, accuracy for Chinese characters was significantly poorer. A similar pattern was exhibited by the MA group. The MR group, demonstrating chance performance for both single letters and two-letter words, were significantly less accurate for both bigrams and Chinese characters, exhibiting below chance accuracy rates. No other main or interaction effects were significant.

Recognition Times For Correct "Same" Responses

A mean recognition response time, in seconds, was constructed from a possible total of five (occasionally three or four) values per subject per cell. That mean became the value for that subject in that

Figure 3
Percent Correct "Different" Group X Stimulus Type Interaction



cell. In situations where there were no values for a subject in a particular cell (e.g. bigram, right-finger, 0 delay, block I) either because all responses for that condition were incorrect or because correct responses did not yield a response time (i.e., subject spoke or coughed at response slide onset which stopped the timer) a missing value estimation procedure was employed (Appendix F).

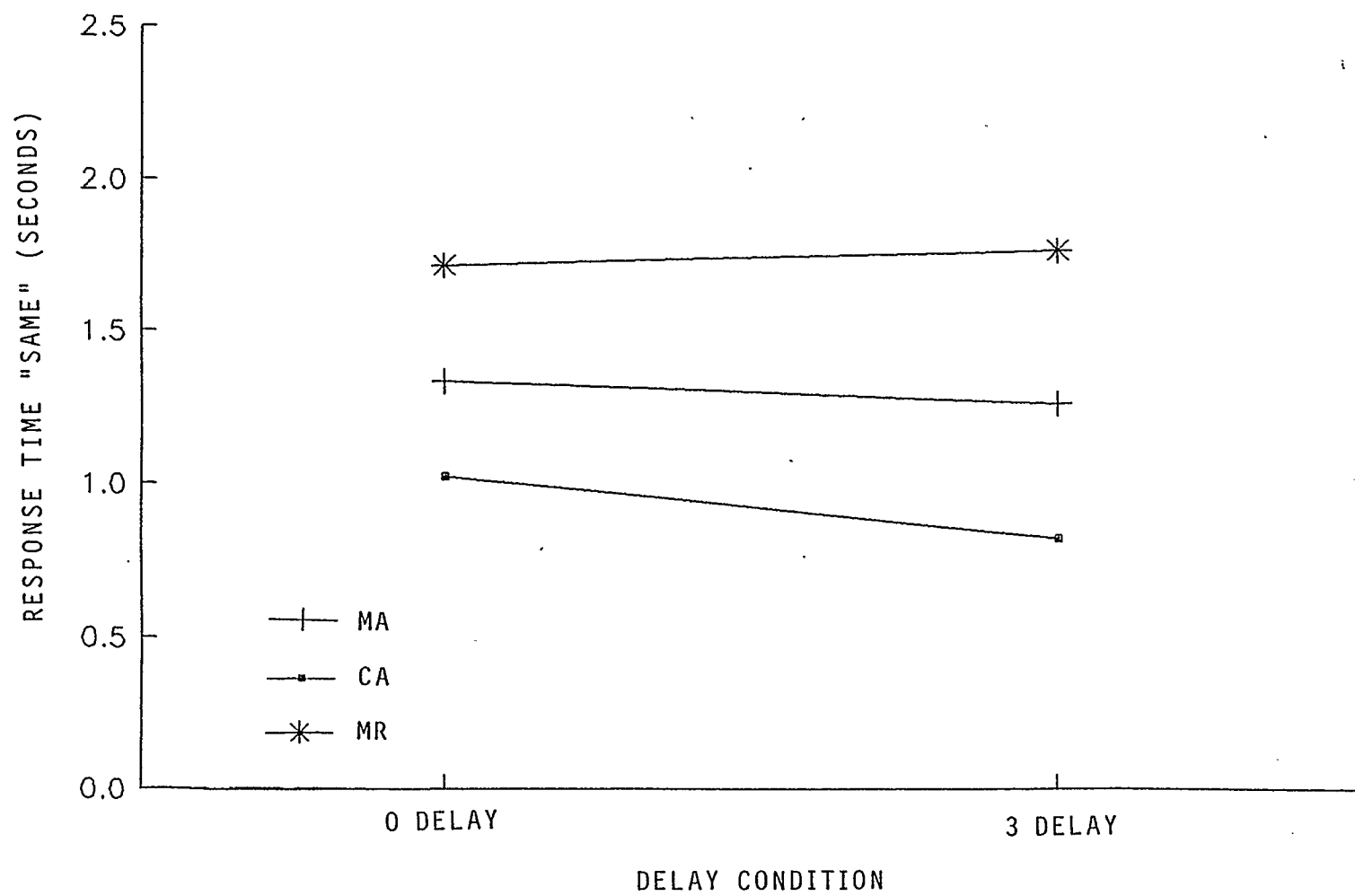
The amount of time, in seconds, required to correctly recognize "same" stimuli and response slides was subjected to a Group (CA, MA, MR) X Sex (male, female) X Stimulus Type (two-letter words, bigrams, single letters, Chinese characters) X Index Finger (left, right) X Delay (0, 3) X Block (I, II) ANOVA with Stimulus Type, Index Finger, Delay and Block as repeated measures (Table 1, Appendix G).

Main effects of Group, $F(2, 66) = 11.33$, $p < .01$, and Delay condition, $F(1, 66) = 8.18$, $p < .01$ were found. Adults ($M = 0.922$, $SD = 0.118$) were significantly faster than the MR group ($M = 1.739$, $SD = 0.973$) while the MA group ($M = 1.297$, $SD = 0.262$) did not differ significantly in the amount of time required to correctly recognize "same" trials from either the CA or the MR groups.

Recognition times were significantly faster when there was a three second delay between palpation offset and target onset ($M = 1.282$, $SD = 0.674$) than when the target was presented immediately following stimulus presentation ($M = 1.357$, $SD = 0.683$).

In addition, a Group X Delay interaction, $F(2, 66) = 7.52$, $p < .01$ was found (Figure 4). Cell means and standard deviations are presented in Table 2 (Appendix G). Tests of simple main effects (Table 3, Appendix G) indicated no within group differences in recognition

Figure 4
Recognition Time for "Same" Group X Delay Condition
Interaction



response times as a function of delay condition. The interaction was due to Group differences within each Delay Condition. Tukey B tests indicated that while the CA group was significantly faster in recognizing "same" stimuli relative to the MR subjects during both Delay conditions, CA subjects were significantly faster than the MA group only for the three second Delay condition. While differences between the MR group and the MA group were not significant during no Delay trials, the slightly faster recognition times during the three second Delay condition on the part of the MA group resulted in significant differences.

The analysis also indicated a main effect for Stimulus Type, $F(3, 198) = 25.14$, $p < .01$. The effect was due to the significantly longer time required to correctly recognize Chinese characters ($M = 1.584$, $SD = 0.799$) as compared to single letters ($M = 1.167$, $SD = 0.807$), two-letter words ($M = 1.209$, $SD = 0.605$) and bigrams ($M = 1.319$, $SD = 0.650$) which did not differ.

Main effects were also found for Block, $F(1, 66) = 17.57$, $p < .01$ and Index-Finger, $F(1, 66) = 10.02$, $p < .01$. Inspection of the data indicated that recognition times were significantly longer for trials within Block I ($M = 1.373$, $SD = 0.691$) as compared to trials within Block II ($M = 1.266$, $SD = 0.660$). The Left Index-Finger ($M = 1.281$, $SD = 0.623$) was significantly faster than the Right Index-Finger ($M = 1.358$, $SD = 0.724$).

Results also indicated a Group X Index-finger X Stimulus Type interaction, $F(6, 198) = 3.89$, $p < .01$. Cell means and standard deviations can be found in Table 4 (Appendix G). Tests of simple main

effects (Table 5, Appendix G) revealed that only the MA group exhibited significant differences across Stimulus Type as a function of Index-finger. Tukey B tests indicated that the MA group took significantly longer to identify Chinese characters when presented to the Right Index-finger as compared to the Left Index-finger (Figure 5).

A significant Stimulus Type X Index-Finger X Delay Condition X Block interaction was also found, $F(3, 198) = 3.9692$, $p < .01$, (Figure 6). Cell means and standard deviations are presented in Table 6, Appendix G. Tests of simple main effects (Table 7, Appendix G) revealed that the interaction was due to changes in response times for the right index-finger during 0 delay trials across Blocks I and II. Tukey B analyses indicated that no significant differences between Stimulus Types for the right index-finger during Block I. Nor did response times decrease significantly from Block I to Block II for letters, bigrams or Chinese characters. However, recognition response times decreased significantly from Block I to Block II for words. As well, the nonsignificant improvements response times for bigrams, and letters as well as the significant improvement across Blocks for words resulted in significantly longer response times for Chinese characters than for any other stimulus type during Block II trials. No other main or interaction effects were significant.

Recognition Times For Correct "Different" Responses

An ANOVA was performed on recognition times for correct "different" responses with Group (CA, MA, MR) and Sex (male, female)

Figure 5
Recognition Time for "Same" Group X Index-Finger X
Stimulus Type Interaction

RESPONSE TIME "SAME" (SECONDS)

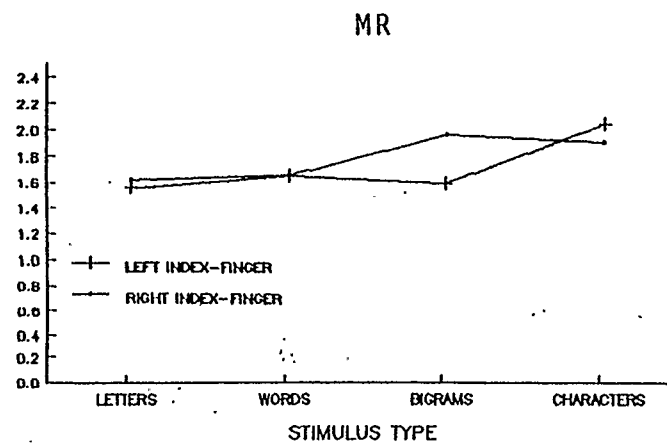
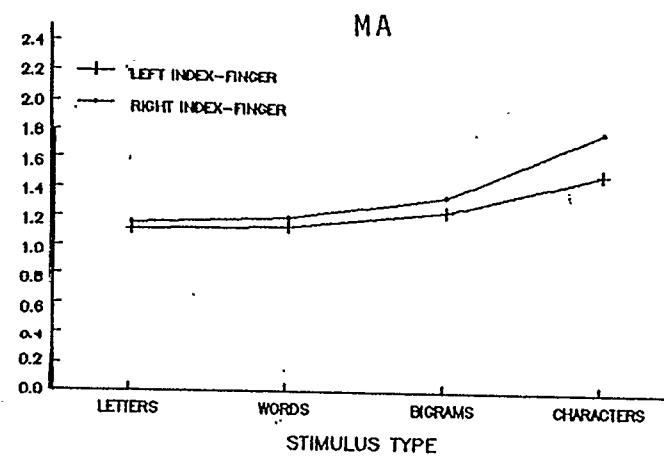
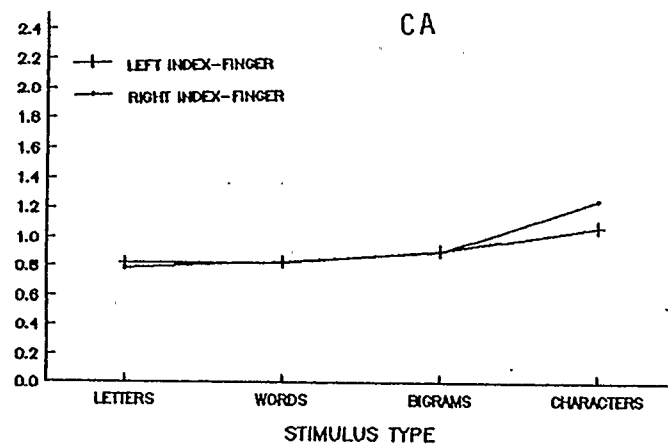
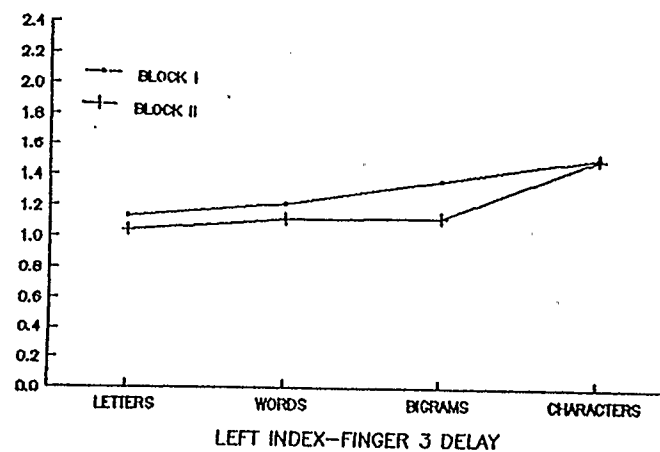
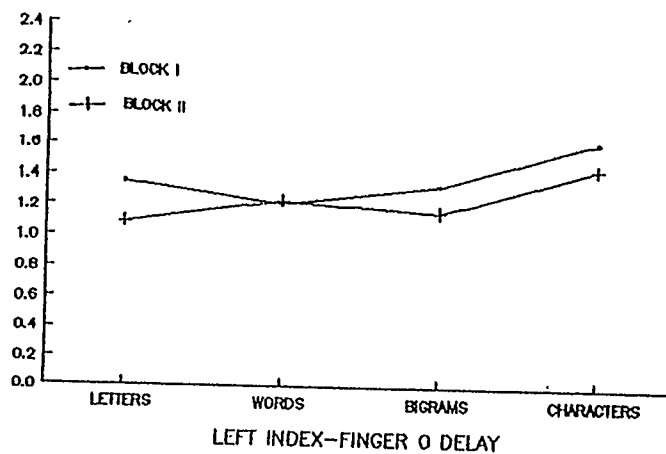
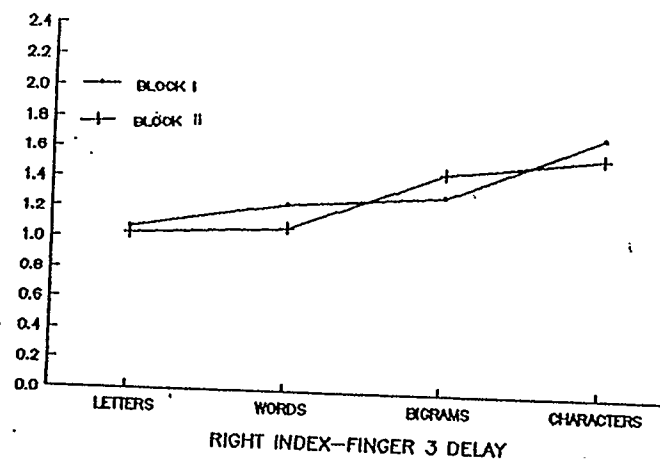
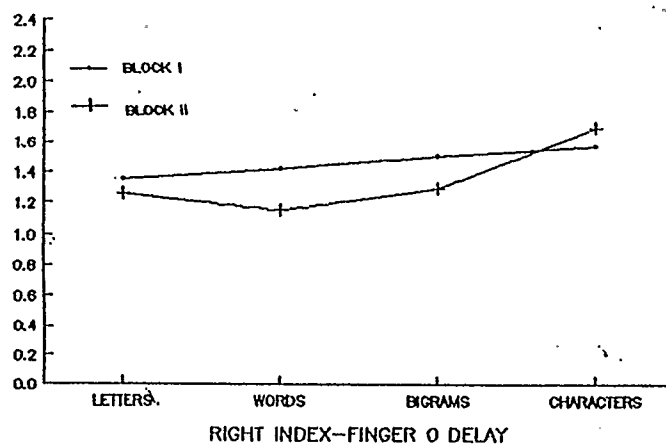


Figure 6
Recognition Time for "Same" Stimulus Type X Block X
Delay Condition X Index-Finger Interaction

RESPONSE TIME "SAME". (SECONDS)



as the between measures and Index Finger (left, right) and Stimulus Type (two-letter words, bigrams, single letters, Chinese characters) as repeated measures (Table 1, Appendix H).

Response times were collapsed across Block and Delay condition due to the basic percentage differences (25% vs 75% for correct "different" and "same" responses, respectively) for each subject for some levels of some of the variables. Therefore, mean recognition response times were constructed from a total possible of five values per subject per cell. That mean became the value for that subject in that cell. Again the missing value estimation procedure (Appendix F) was utilized.

The analysis indicated a significant main effect for Group, $F(2, 66) = 34.02$, $p < .01$. Adults and children did not significantly differ in the amount of time required for the correct recognition of "different" stimuli. Mean recognition times were 1.076 ($SD = 0.119$) seconds and 1.464 ($SD = 0.354$) seconds for adults and children respectively. Both groups were significantly faster than the MR group ($M = 2.741$ seconds, $SD = 1.188$). No other main or interaction effects reached statistical significance.

Signal Detection Analyses

Signal detection analyses were also conducted to assess sensitivity. The utilization of d' and Beta in signal detection theory rests upon the specific assumption that the distributions of signal and noise are both normal (McNichol, 1972). However, A' and Beta'' (B'') are nonparametric measures which make no assumptions regarding

underlying distribution (Pollack & Norman, 1964; Hodos, 1970; Grier, 1971). A' was used to obtain the estimates of subjects' ability to make sensory judgments with the left and right index fingers. B'' was employed to estimate a subjects' response criteria.

A'

A' (Grier, 1971) was used to measure the sensitivity or discriminability of "same" stimulus and response slide from "different" stimulus and response slide. The formula for A' is:

$$A' = .5 + [(y - x)(1 + y - x) / 4y(1 - x)]$$

where x = the probability of a false alarm

y = the probability of a hit

Values for A' range from 0 to 1. A completely insensitive observer produces a value of .5 (chance performance) while a perfect performance produces an index of 1.

A' values were computed for all subjects and those values were subjected to a Group (CA, MR, MA) X Sex (male, female) X Index Finger (left, right) X Stimulus Type (words, bigrams, letters, Chinese characters) ANOVA with Index Finger and Stimulus Type as repeated measures (Table 1, Appendix I).

The analysis indicated a significant main effect for Group, $F(2, 66) = 54.06$, $p < .01$. Examination of the data indicated that adults ($M = .922$, $SD = .041$) were significantly more sensitive than the MA ($M = .815$, $SD = .092$) group which was significantly more sensitive than the MR group ($M = .590$, $SD = .169$).

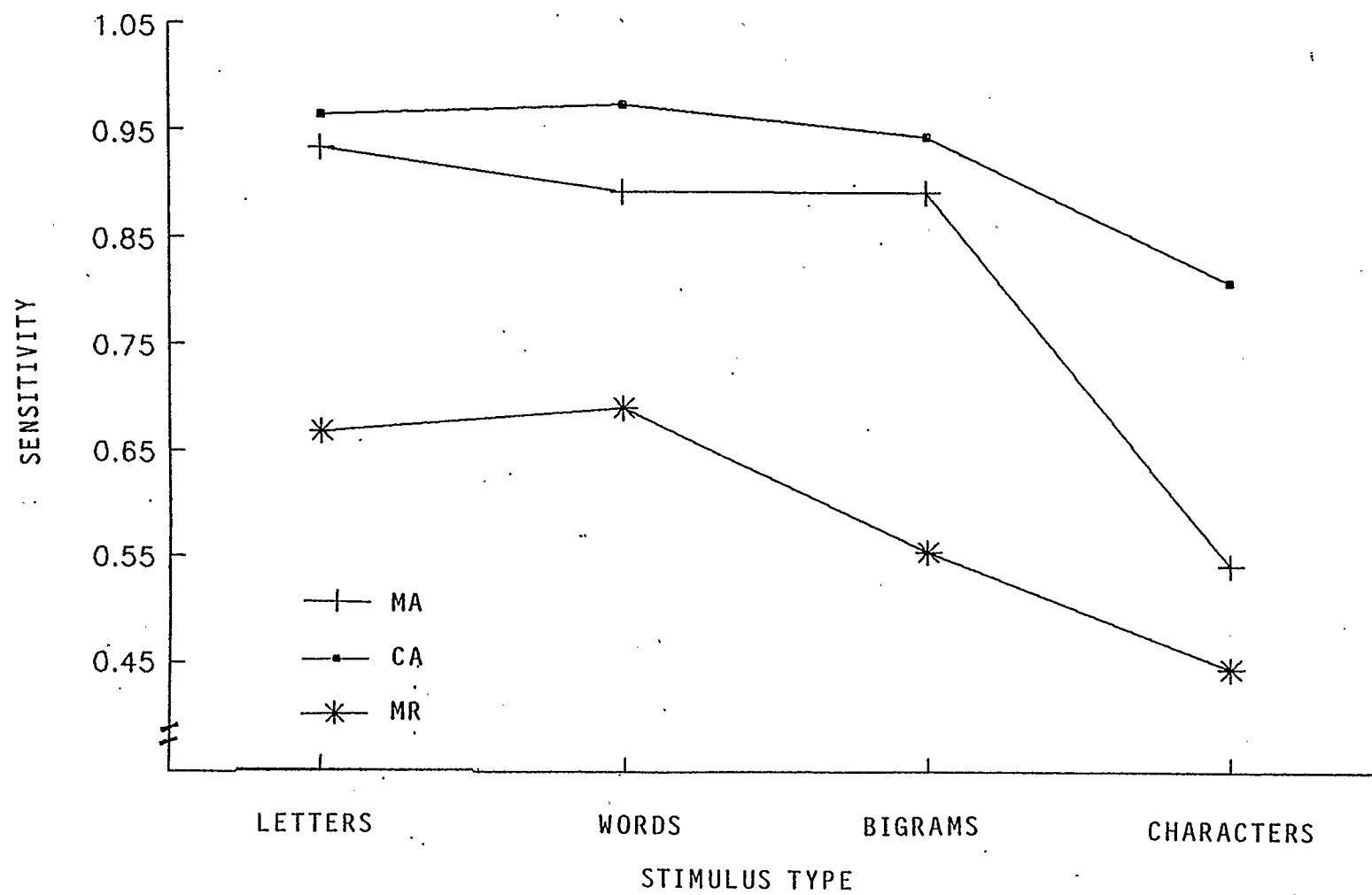
A significant main effect for Stimulus Type was also indicated, $F(3, 198) = 43.92$, $p < .01$. Subject's sensitivity was greatest for letters ($M = .856$, $SD = .213$) and two-letter words ($M = .852$, $SD = .181$), both of which were more discernable than bigrams ($M = .796$, $SD = .251$). Sensitivity was significantly lower for Chinese characters ($M = .599$, $SD = .253$).

A significant Group X Stimulus Type interaction (Figure 7) was also found, $F(6, 198) = 4.14$, $p < .01$. Cell means and standard deviations can be found in Table 2, Appendix I). Tests of simple main effects (Table 3, Appendix I) indicated significant differences in sensitivity between Groups as well as between Stimulus Type. Tukey B tests revealed that the CA group demonstrated equivalent performance for all Stimulus Types. While the MA group did not differ from the CA group for single letters, two-letter words and bigrams, the MA group exhibited significantly less sensitivity for Chinese characters. Both MA and CA subjects were significantly more sensitive than the MR group for all Stimulus Types. The MR group demonstrated equivalent ability to differentiate "same" from "different" single letters and two-letter words which was significantly better than for bigrams. Performance for Chinese characters, significantly lower than for any other Stimulus Type, was below chance. No other main or interaction effects were significant.

B''

B'' (Grier, 1971) is a nonparametric index which measures response bias. This index ranges from +1 to -1. Negative scores

Figure 7
A' Group X Stimulus Type Interaction



indicate a lax criterion (there is a bias for saying "yes") while positive scores indicate stringent criterion (a bias toward saying "no").

The formula for computing B'' is:

$$B'' = [y(1 - y) - x(1 - x)] / [y(1 - y) + x(1 - x)]$$

where x = the probability of a false alarm

y = the probability of a hit

B'' values were computed for all subjects and those values were subjected to a Group (CA, MR, MA) X Sex (male, female) X Index-Finger (left, right) X Stimulus Type (words, bigrams, letters, Chinese characters) ANOVA with Index-Finger and Stimulus Type as repeated measures (Table 1, Appendix J).

The analysis indicated no significant main or interaction effects. However, inspection of the data indicated that the variability within groups was so great that it masked any between group effects. Means and standard deviations can be found in Table 2, Appendix J.

The use of B or B'' rests upon the explicit manipulation of payoffs or consequences for hits (subject says "same" when target and visual display are the same) and false-alarms (subject says "same" when target and visual display are different). Because hit and false-alarm rates are related, if one is increased, so is the other (McNichol, 1972). Therefore, the experimenter can influence the likelihood of hits and false alarms with the use of payoffs.

In the present study no feedback as to performance was given. As such, concluding that the failure to find group differences is indicative of similar decision making rules is erroneous.

DISCUSSION

Establishing Palpation Intervals

In the haptic processing domain a number of fixed palpation intervals have been employed. Two to ten second palpation intervals have been used for single letters and digits and three to 10 second palpation intervals for nonsense shapes for both adults and children (Van Blerkom, 1985; Witelson, 1974; Witelson, 1976; Cioffi & Kandel, 1979; Dawson, 1981; Etaugh & Levy, 1981; Flanery & Balling, 1979; Klein & Rosenfield, 1980). A ten second contact with the stimulus has been employed in studies using bigrams (Cioffi & Kandel, 1979) and intervals of 10 (Cioffi & Kandel, 1979) and 15 (Vargha-Khadem, 1982) seconds have been utilized for tasks involving the active palpation of words.

Very few studies have utilized subject determined palpation intervals. Yandel and Elias (1983) found that adults demonstrated high levels of accuracy for geometric shapes with mean response latencies of five seconds while children usually required 15 seconds to dichhaptically explore lower case consonants and letter-like shapes (Walch & Blanc-Garin, 1987). Lederman, Jones and Segalowitz (1984) indicated that adults generally took 2 to 3 seconds to haptically discriminate roughness and between five and 15 seconds to discriminate between dichhaptically presented stimuli. Hunt et al. (1988) examined response latencies for the verbal identification of haptically palpated single letters and found that males and females took 4.17 and 4.42 seconds, respectively. Hatta et al. (1981) found that children in

the sixth grade (6.11 seconds) were significantly faster than children in the fourth grade (6.54 seconds) when matching line drawings to haptically explored concrete shapes. Fourth grade children, in turn, were significantly faster than those in the second grade (7.52 seconds) for the same stimuli.

The intervals traditionally reported are usually based upon those initially established by Witelson (1974) for assessing the lateralization of tactile processing in children. However, response latencies appear to vary considerably both as a function of age as well as stimulus complexity. Unfortunately, those studies which have utilized self-regulated palpation intervals ignore this data and concentrate on differential accuracy rates. Only Walch and Blanc-Garin (1987) utilized latency information to establish fixed palpation intervals in their second experiment.

In the present study, the use of ten practice trials prior to each block of experimental trials for each stimulus type allowed the subject not only the opportunity to practice feeling the stimuli, they also ensured that all subjects had sufficient sensory input upon which to base their responses. The practice trial data confirmed that the adults were significantly faster than the other groups for all stimulus types and were in agreement with research indicating that individuals of lower mental age require more time for tactuo-spatial processing (Hatta et al., 1981). While the child and retarded groups did not differ overall, the Group X Stimulus Type interaction revealed that the children were significantly faster than the retarded group for all stimulus types except for the Chinese characters. However, all

groups demonstrated response latencies well within the range of palpation intervals typically employed during both haptic and dichhaptic stimulation tasks.

While all subjects in the present study performed within the range of traditionally utilized intervals the significant differences as well as the considerable variability demonstrated by both the MR and MA groups underscores the possibility that inconsistent results in previous research may be due to too little or too much time during the initial sensory processing phase. While previous research has utilized pre-set fixed palpation intervals with a visual display presented after palpation, the present study utilized simultaneous tactile and visual input. If subjects of comparable chronological and/or mental age require differing amounts of time to make an accurate match when visual information is present, it is highly probable these same subjects would require different palpation intervals when no visual cues are present during the palpation period. The demonstration of significant differences between groups and between stimulus types as well as the Group X Stimulus Type interaction stresses the importance of establishing individual palpation intervals for individual subjects for each stimulus type prior to assessing information processing via the tactile modality.

Gender Related Differences

The present study failed to demonstrate gender differences for response latencies or accuracy. Nor was gender related asymmetrical hand performance observed. There is a controversy regarding the

existence of gender differences in tasks assessing asymmetric functioning in the tactile modality. Furthermore, when differences are found they usually favour males for overall greater accuracy and for better left-hand performance relative to females (Witelson, 1976; Dawson, 1981; Klein & Rosenfield, 1980; Gibson & Bryden, 1983; McGlone, 1980; Duda & Adams, 1987). However, differentiation on the basis of gender is frequently not significant (Cranney & Ashton, 1982; Cohen & Levy, 1986; Hatta et al., 1981).

Waber (1979) has argued that spatial ability is systematically related to the rate of physical maturation and the extent of androgenization in both males and females. However, Hassler and Birbaumer (1986) found that prior to puberty boys were more accurate on a spatial task relative to girls while no gender differences were exhibited after the onset of puberty (menses onset for girls, voice change for boys). Others (i.e., Bryden, 1979) argue that evidence suggesting that lateralization may be present at or shortly after birth would suggest that there is no causal relationship between rate of maturation and degree of lateralization.

Furthermore, studies utilizing haptic as opposed to dichhaptic stimulation suggest equivalent performances by both males and females across a variety of age groups (Flanery & Balling, 1979; Dodds, 1978; Lederman, et al., 1984; Cohen & Levy, 1986; Hunt, et al., 1988). Results of the present study are consistent with earlier research indicating comparable performance during haptic tactuo-spatial tasks, both for accuracy, response latency and asymmetrical processing.

Right-Hand Advantages

Very few studies have assessed tactile asymmetries for "meaningful" stimuli. Because research in the auditory and visual modalities demonstrate right ear and visual field superiorities for verbal material (Shankweiler & Studdert-Kennedy, 1967; Knox & Kimura, 1970; Hahn, 1986; Leventhal, 1988), researchers have attempted to assess tactuo-spatial processing asymmetries utilizing similar verbal stimuli (ie. single letters, digits). Witelson's (1974) original study utilized single letters in an attempt to assess the left hemisphere processing of tactually presented verbal material. While she found no evidence for asymmetrical performance with three second palpation intervals, subsequent studies utilizing single letters have demonstrated inconsistent results. Oscar-Berman et al. (1978) found a right-hand advantage for letters for males and females using a passive stimulation technique. However, Hunt et al. (1988) found a left-hand advantage for both males and females for verbal identification of haptically presented capital letters. The differential hand performance was manifested during the first series of trials only (each series consisted of 3 presentations of the 26 letters). Walch and Blanc-Garin (1987) found a significant left-hand advantage for dichhaptically presented single letters for girls and no hand advantages for boys.

Gibson & Bryden (1983) assessed the differential processing of dichhaptically presented sandpaper letters and found no hand differences for girls or boys across a variety of ages (8 to 14 years). O'Boyle et al. (1987) and Hunt et al. (1989) found no hand

differences in response latencies in tasks requiring the verbal identification of capital letters. However, as both studies utilized different orientations of the verbal stimuli, it is unclear whether the lack of asymmetrical processing reflects "verbal" (letter) or "spatial" (rotation) processing.

Because hemispheric asymmetries are relative rather than absolute, as evidenced by performance deficits rather than an absence of processing ability in both clinical and normal populations, it appears that single letters may not be sufficiently "verbal" to elicit differential performance in the tactile modality. There is, however, a dearth of studies assessing tactile performance with more complex verbal stimuli although the two which have utilized overtly "verbal" material (Cioffi & Kandel, 1979; Vargha-Khadem, 1982) strongly suggest that right-hand advantages may emerge when the left-hand is sufficiently disadvantaged (i.e., "nonverbal" right hemisphere processes cannot attach sufficient meaning so the left-hemisphere is more efficient).

The present study utilized single letters and two-letter words in order to assess whether increasing the meaningfulness of tactually presented material would differentially affect performance. The present study failed to find asymmetrical performance for single letters for any dependent measure while a right-hand advantage was found for words during 0 Delay trials within Block II only. Given the inconsistency in previous literature differential performance was not expected for single letters. More surprising was the failure to obtain

a right-hand advantage for two-letter words (Hand X Stimulus Type) regardless of Delay condition or Block.

The present study utilized haptic presentations in conjunction with a forced-choice response mode. Two earlier studies required subjects to report both of the dichhaptically presented stimuli from a visual display containing 6 (Vargha-Khadem, 1982) and 8 (Cioffi & Kandel, 1979) response choices. It has been suggested that asymmetries may emerge as function of the distribution of attention across space (Kinsbourne, 1978). The left hemisphere has control mechanisms to direct attention to the right side of the body as well as primary control over verbal processing. Therefore, when the left hemisphere verbal processor is activated by any linguistic stimulus (i.e., speech, anticipation of speech, hearing speech) that activation biases all attention to the right. This theory is compatible with and may explain earlier results. It is likely that reading the words in the response display (a left hemisphere process) "primed" the left hemisphere, immediately directing attention to the right hemispace. Therefore, any processes which are controlled by the left hemisphere (i.e., motor and tactile processes on the contralateral side) would show an advantage.

The present study presented only one stimulus to one hand (index-finger) and one bilateral visual stimulus on any given trial, minimizing attention to "overtly" verbal processes. Consequently the failure to find a robust Hand X Stimulus Type interaction may be because both hemispheres are able to process the words while the single bilateral visual stimulus minimized the potential attentional

bias toward a particular hemisphere which may have accentuated asymmetrical processing in the earlier research.

An overall right-hand advantage for judging "different" stimuli was also obtained in the present study. Due to the fairly consistent "nonverbal" versus "verbal" distinction between the right and left hemispheres respectively, on a variety of lateralized auditory and visual tasks, the left hemisphere is often described as an analytic, sequential processor while the right is usually associated with visuo-spatial, holistic analyses. De Renzi (1979) has hypothesized that the left hemisphere's contribution to the processing of spatial information increases when that processing progresses beyond the level of purely "spatial" information and encompasses specific types of analyses (i.e., deduction of spatial relationships). Others (Bradshaw, 1978; Cranney & Ashton, 1982) have also suggested that the right hemisphere is specialized for making rapid matches while the left hemisphere is specialized for discerning nonmatching features. However, few studies assessing the laterality of haptic processes have utilized a forced-choice (same/different) response paradigm.

For example, Flanery and Balling (1979) assessed asymmetrical accuracy for nonsense shapes in a "same/different" paradigm under dichhaptic and haptic stimulation conditions. After a 10 second palpation interval a comparison form, either the same as the target, or a foil (randomly chosen from a pool of "nontarget" stimuli), was tactually presented. A significant left-hand superiority was demonstrated. However, while subjects made similar errors with their left-hands for "same" and "different" responses, the right-hand was

significantly more accurate when judging "different" as compared to "same" stimuli.

Lederman et al. (1984) conducted a series of experiments to assess the existence of lateralized perception of roughness. No evidence of differential hand performance was found when subjects chose the one of three tactually manipulated response stimuli which matched the palpated target. However, a third experiment required subjects to explore two stimuli with one hand (e.g. left index-finger felt stimulus A and left middle finger felt stimulus B). In one task subjects decided if A and B were "same" or "different". In the second task A and B were always different and subjects were required to report which surface was rougher. They found that the global accuracy was equivalent for both hands. However, comparisons of proportion correct for "same" as compared to "different" trials indicated that, while both hands were significantly more accurate on "same" as compared to "different" trials, the effect was greater for the left- than the right-hand.

Yandel and Elias (1983) demonstrated a right-hand advantage for accuracy and latency when subjects were required to indicate when a palpated geometric shape was the same as the simultaneously presented visual stimulus. Although it was argued that the stimuli utilized were assessing spatial capabilities, the distinctive features and the facility with which geometric shapes may be verbally coded would suggest that left as opposed to right hemispheric processing was being tested. Unfortunately, Yandel and Elias reported correct "same" matches only, prohibiting analysis of "same" vs "different"

asymmetries to determine whether the right-hand advantage was due to the simultaneous visual and tactile presentations, stimulus specific analyses ("verbal" coding), or to task demands (type of analysis required).

Generally speaking, tactile tasks which involve the comparison of nonsense shapes, textures and roughness (Flanery & Balling, 1979; Cohen & Levy, 1986; Lederman et al., 1984) have found a greater left-hand advantage for "same" as compared to "different" trials. It has been argued that factors such as stimulus complexity, subjective familiarity and strategy can affect the amount of processing in each hemisphere (Bradshaw, 1978; Walch & Blanc-Garin, 1987; Hunt et al., 1988; Hunt et al., 1989). However, visual half-field and dichotic listening studies suggest that the left hemisphere is superior for slower, analytic processes while the right predominates when a more rapid Gestalt analysis is necessary (Bradshaw, 1978).

Therefore, the right-hand advantage for "different" stimuli in the present study may be indicative of differential analysis, i.e., the right-hand (left hemisphere) may have an advantage when required to analyze "different" features. A trend toward a right-hand advantage for discriminability of "same" from "different" (A') also suggests differential information processing.

Left-Hand Advantages

Tasks which assess "spatial" processing in the tactile domain typically utilize solid nonsense shapes patterned after Witelson's (1974) stimuli. Although a left-hand advantage (Witelson, 1974; 1976;

Dodds, 1978; Cioffi & Kandel, 1979; Gardner et al., 1977) or, at least a trend toward a left-hand superiority (Walch & Blanc-Garin, 1987; Lederman et al., 1984) has been demonstrated using similar stimuli, no hand differences (Hatta, 1978; Hannay & Smith, 1979; Hunt et al., 1989; Adams and Duda, 1986) or right-hand superiorities have been demonstrated for ostensibly spatial material (Vargha-Khadem, 1982; Yandel & Elias, 1983; Hannay & Smith, 1979).

One of the major shortcomings of these stimuli is that each hemisphere is not "challenged" to equivalent degrees. In order to accurately assess laterality of function it has been argued that stimuli must consist of similar design elements and be of comparable complexity (Smith et al, 1986). The present study employed two-letter bigrams patterned after Cioffi and Kandel's (1979) stimuli and Chinese characters in order to provide meaningless stimuli of comparable complexity. It was predicted that bigrams and Chinese characters would elicit more accurate and faster responses when presented to the left-hand.

The data indicated a left-hand advantage for response latencies to "same" Chinese characters for the MA group only. However, a trend toward a left-hand advantage for response latency for Chinese characters was exhibited by the CA group. The MR group's lack of differential performance is most likely due to their greater variability. The left-hand advantage was due to a significant increase in response latency for the right-hand and corresponds with Oscar-Berman et al.'s (1978) finding that a significant left-hand advantage for lines was due to a right-hand decrement rather than a left-hand

improvement. It has been suggested that slower, analytic processes may predominate in the left hemisphere (Bradshaw, 1978). As such, the longer right-hand latencies for Chinese characters as compared to any other stimulus type in the present study suggest that the left hemisphere (right-hand) employed a different and/or less efficient type of analysis than did the right hemisphere (left-hand).

While the accuracy data did not yield a Stimulus Type X Hand interaction, the Group X Stimulus Type interaction for percent correct "same" responses suggests that the Chinese characters were the most difficult to process. The adult and child groups experienced a significant drop in accuracy for Chinese characters although the adults were significantly more accurate than the children. The mentally retarded groups' consistent performance across all stimulus types is indicative of a bias toward saying "same", particularly for Chinese characters. The significant differences between adults and MRs for all but "same" Chinese characters as well as the similar accuracy demonstrated by the MA and MR groups for all stimulus types but Chinese characters would further support this position. In addition, the MR group's low accuracy for "different" responses and poor A' scores suggest poor discriminability. Consequently, the failure to find differential performance for this group may be due to their propensity to say "same", most likely due to task difficulty.

Previous research suggests that task difficulty or complexity may impact differential performance on tactile tasks. Hatta (1978) found no hand differences in accuracy for the haptic recognition of nonsense shapes. Positing that task difficulty may be an important factor in

asymmetric hemispheric processing, a second experiment utilizing a more complex task resulted in a left-hand advantage. Similarly, Duda and Adams (1987) found a left-hand advantage for 12-point but not less complex 8-point shapes. As such, it has been argued that stimuli of low complexity may be labelled more readily than more complex patterns so both hemispheres demonstrate equal processing efficacy.

In the present study the adult group's shorter palpation intervals, higher accuracy for "same" and "different" responses as well as greater discriminability (A') for Chinese characters as compared to the MA group indicates that processing was less difficult for the CA group. As each hemisphere is most efficient when operating within its "preferred" processing mode, which may not be manifested until each hemisphere is sufficiently challenged (Bryden & Allard, 1976; Sergent, 1982; O'Boyle, 1987), the CA group may have been able to apply some labelling strategy to the Chinese characters, despite attempts to control for this possibility (see Method p. 57). Therefore, a left-hand superiority was observed for the Chinese characters only for the group which found the task complex enough to place left hemisphere processing at sufficient disadvantage, resulting in a right hemisphere advantage, i. e., the MA group.

An overall left-hand advantage for "same" response latencies was obtained. In addition, a trend toward a left-hand advantage for accuracy for "same" responses was demonstrated. As noted, it has been hypothesized that the right hemisphere is specialized for making rapid comparisons of the integrated whole whereas detailed analyses which involve discrete features are better performed by the left hemisphere,

at least with respect to the visual and auditory modalities (Bradshaw, 1978; De Renzi, 1979; Cranney & Ashton, 1982). The results of the present study would indicate that each hemisphere processed the tactile information differentially depending upon the specific information processing requirements. That is, the right hemisphere processes had the advantage when global (holistic) information was present and the left hemisphere processes were superior when analyses of nonmatching stimuli were required (analytic).

The Impact of Memory on Lateralization

When a target stimulus is presented simultaneously with, or immediately following, stimulus presentation the precategorical information is available for the duration of the rapidly decaying sensory trace. It has been argued, on the basis of visual half-field research (i. e. Dee & Fontenot, 1973; Moscovitch, Scullion & Christie, 1976), that both cerebral hemispheres are capable of processing the information held in this short-term precategorical trace (i. e. visual icon). Thus, lateralization may emerge only when later stage selective, categorical encoding mechanisms act upon the information available during the earlier stages of processing.

Assessments of lateralization within the tactile domain in the neurologically intact individual are invariably patterned after Witelson's (1974) original technique. In this method the subject's hands are placed out of view within the testing box. Then, after palpation, the subject removes his/her hands and points to a visual display (usually containing 4 to 6 shapes) in order to identify one or

both shapes felt. Although the majority of studies utilize this method little attention is paid to variations in the amount of time between the end of the palpation period and the subject's response.

Adams and Duda (1986) have argued that the very nature of the cross-modal matching paradigm introduces a delay condition either explicitly (Gardner et al., 1977; Oscar-Berman et al., 1978;) or implicitly (Witelson, 1974; Cioffi & Kandel, 1979; etc). Consequently it has been posited that asymmetrical processing may emerge only under conditions in which a memory component is introduced (Oscar-Berman et al., 1978; Yandel and Elias, 1983; Adams & Duda, 1986).

The present study employed two delay conditions (0 and 3 seconds) in order to assess the influence of delay on lateralization of tactile processing. If laterality is dependent upon or enhanced by higher order memorial processes (the information is no longer available via the short-lived stimulus trace) (Moscovitch, et al., 1976; Duda & Adams, 1987) an interaction between Hand and Stimulus Type as a function of Delay condition should have occurred. The present study indicated that introducing a delay had no impact on the accuracy for "same" or "different" responses. While the overall response latencies for "same" responses were significantly faster for the 3 second delay trials, a Delay Condition X Hand X Stimulus Type interaction was not obtained.

In the present study if the delay impacted differential tactile performance, one would expect the interaction to occur during the trials in which the tactile information was no longer available from the tactile trace (3 second delay trials). Yet, the Stimulus Type X

Block X Delay Condition X Hand interaction indicates differential performance for the right-hand as a function of Block in the 0 Delay condition only, suggesting that an explicit delay is not responsible for differential performance.

Differences in processing visual and tactile information may explain the role of memory in eliciting differential performance. In contrast to the visual system, information presented via the tactile modality is not received simultaneously. Rather, subjects rely on the representation of the stimulus features and must retain information regarding the previously explored area of the stimulus while palpating later features (de Renzi, 1979). As such, some information may already have been recoded by later stages of processing while other features are still being analyzed at the precategorical trace level. If memory is implicated in lateralization, the process of holding information in memory during palpation may result in differential performance.

Because a delay will not impact what has already taken place, introducing a short delay after palpation should be non-influential. Indeed, a left-hand advantage has been obtained when attempts have been made to control for memory (i. e. no delay, short palpation & response exposure) (Van Blerkom, 1985).

As noted, it has been postulated that the right hemisphere is superior when rapid comparisons of and/or matches to the integrated whole are required whereas analyses which involve discrete features are better performed by the left hemisphere (Bradshaw, 1978). Although the majority of tactile studies utilize a multistimulus response display, all require the subject to match the palpated stimulus to a

stimulus in the display. As such, the type of analysis required during most haptic tasks, rather than memory "per se", may enhance a relatively fragile laterality effect. In the present study the right-hand advantage for words observed after repeated exposure (Block II) may be due to a change in strategy after familiarization with the Stimulus Type. Consequently, the right hemisphere "matching" strategy may have been replaced with a left hemisphere "verbal" strategy.

The faster response latencies for "same" responses for the 3 second Delay condition in the present study may be explained by the representational nature of the tactile system. If some information was still held as a trace memory, the immediate visual display may have interrupted a consolidation process, resulting in a slower response. The delay may have provided time to select relevant material from long-term store resulting in faster responding. Or, the delay may have merely given the subject time to prepare for the onset of the visual display. Subjects found the tasks difficult and required a great deal of concentration. Therefore, although subjects were told to keep their eyes on the screen in front of them during palpation, subjects may have needed the delay period to focus their attention on the visual display and prepare to respond.

It is unlikely that overt rehearsal was taking place. If subjects had been using a rehearsal strategy, one would expect a Stimulus Type X Delay condition effect, resulting in faster response latencies for letters, words and bigrams and no change, or possibly a decrement in performance, for Chinese characters. This did not occur. Furthermore,

the 0 and 3 Delay trials were randomized giving little opportunity for subjects to mobilize fast enough to rehearse on the 3 Delay trials.

Although the delay factor resulted in an overall improvement for "same" response latencies, introducing a delay did not serve as an enhancer for lateralized tactile processing in the present study. If the two cerebral hemispheres exhibit specialized functions only when a task requires decisions based upon information which is no longer accessible from the tactile trace (i. e. higher order cognitive processes), asymmetrical tactile processing, in the absence of a delay, may be due to the representational nature of the tactile system.

Performance Over Time On Tactile Tasks

Few studies have assessed differential tactuo-spatial performance across blocks of trials. While O'Boyle and Murray (1988) found a higher percentage of errors for identifying letters on the first series of trials, a left-hand advantage was demonstrated for all blocks. Duda and Adams (1987) found a left-hand advantage for shapes only for the first 10 of a series of 40 presentations of nonsense shapes. Nilsson, Glencross and Geffen (1980) found a left-hand advantage for nonsense shapes in the first 20 trials as well a shift toward reporting the left-hand stimulus first in the second 20 trials. With respect to response latency, Hunt, et al. (1988) found a shift from a left-hand advantage for capital letters to equivalent hand performance for response latencies from the first series (three

presentations of each letter) to the second and third series of trials.

While haptic/dichhaptic studies have utilized 8 to 153 trials (Klein & Rosenfield, 1980; Cohen & Levy, 1986) few have assessed changes in asymmetrical performance over time, and there appear to be inconsistencies with respect to those which do. The present study examined accuracy and recognition response latency over two blocks of twenty trials each. While accuracy did not change over trials, response latencies were significantly longer for Block I as compared to Block II trials. The Stimulus Type X Hand X Delay Condition X Block interaction indicated that the right-hand experienced a decrease in response latencies for all but Chinese characters during the second block of 0 delay trials. The data also indicated that response latencies for single letters and bigrams did not improve significantly over block although the decline in latencies for bigrams just failed to reach significance. However, during Block II trials response latencies for words improved significantly. These results may be indicative of a practice effect which resulted in a right-hand (left hemisphere) advantage for stimuli with high verbal associations as compared to stimuli with low verbal association when a response is required immediately after stimulus presentation. Moreover, the trend toward an increase in response latency for Chinese characters for the right-index finger in conjunction with a decrease for the left-hand is suggestive of the emergence of differential performance. Changes in lateral asymmetry over trials have also been demonstrated for dichotically presented piano tones and two-syllable nouns (Sidtis &

Bryden, 1978)-as well as for emotional sounds (Mahoney & Sainsbury, 1987). Results in the present study appear consistent with dichotic listening studies which suggest stimulus specific shifts in processing strategies occur with repeated exposure.

Hunt et al. (1988) suggested that the shift from a left- to equivalent hand performance for letters was due to familiarization with the task. They posited that a left hemisphere processing strategy advantage may have emerged if further trials had been given. But, no hand differences were found in a second experiment (Hunt et al, 1989) utilizing rotated letters over 5 series of trials (each series contained 32 trials). However, as letters appear to be amenable to spatial and verbal analyses, they may not be sufficiently complex to elicit differential processing, even after repeated exposure. As such, a shift in hemispheric processing strategies would not be expected.

The few tactile studies which have assessed differential performance over time indicate that a left-hand advantage for accuracy in "spatial" material emerges either immediately or relatively early. Results of the present study suggest that the elicitation of differential performance may require time. Methodological differences between the present and earlier studies may explain the discrepancy. Attentional factors have been demonstrated to affect the rate of development of asymmetrical performance (Mahoney & Sainsbury, 1987). In the present study the single response slide may have minimized attentional biasing.

As noted, few studies have investigated changes in response patterns. Therefore, it is difficult to assess whether the present right-hand advantage for response latency for "same" words, in the absence of differential accuracy is due to the emergence of a processing strategy for "meaningful" stimuli.

Group Differences

Although accuracy for the recognition of tactually presented stimuli improves with age (i.e., Hatta et al., 1981; Davidson, 1985), nonretarded individuals are capable of cross-modal matching in early infancy (Rose, 1984; Bushnell, 1986; Walker-Andrews & Gibson, 1986; Streri & Spelke, 1988). However, as noted, relatively few studies have assessed the mildly retarded individual's ability to match within or across modalities. While research on cross-modal matching in mildly retarded individuals is rare, the available literature suggests that these individuals can match tactually presented material to a visual display (Hermelin & O'Connor, 1961a; Pipe & Beale, 1983; Davidson, 1985).

Research also indicates that individuals of lower mental age require more trials in the early phase of learning tasks and are inefficient with respect to attention (Zeaman & House, 1963, in Mosley, 1987). Furthermore, pilot data for the present study indicated that children required longer palpation intervals relative to adults when identifying letters, words and bigrams in the absence of a visual display. Consequently, it was predicted that adults would be faster

and more accurate than the MR and MA groups, while these two groups would not differ.

The Group X Stimulus Type interaction for practice trials in the present study indicated that the adult group was significantly faster than the child and retarded groups for all stimulus types. These results appear consistent with research indicating that subjects of higher mental age use more efficient search strategies (Davidson, 1985) as well as faster responding with increasing age (Hatta, et al., 1981).

However, the child group, matched for mental age with the mildly retarded group, was significantly faster than the MR group for all stimulus types but Chinese characters. Although the retarded group's performance was within the range of palpation intervals typically set by researchers for nonretarded subjects, response latencies were significantly slower and more variability was demonstrated. These results are consistent with previous research indicating that retarded individuals require longer amounts of time to process information (Nettlebeck, 1985) and demonstrate significantly more between- and within-subject variability (Baumeister, 1987) than do nonretarded individuals.

It has been posited that retarded subjects and, to a lesser extent, equal MA subjects are less efficient at directing attention to relevant stimulus features (Nugent & Mosley, 1987) and often fail to durably encode stimulus features (Mosley, 1987). As such, group differences may be due to less efficient search strategies interacting with the complexity of and/or familiarity with the stimuli. Research

indicates that haptic movement patterns change as a function of instruction (Klatzky, Lederman & Reed, 1987; Lederman & Klatzky, 1987). As well, the degree of stimulus complexity and familiarity alters speed (Hunt, et al., 1987) and accuracy (Adams & Duda, 1986; Duda & Adams, 1987; Walch & Blanc-Garin, 1987) for tactile tasks. In the present study subjects were told what type of stimulus they would be palpating (e. g. two-letter words) and the response display contained only that stimulus type. Mosley (1987) has argued that low MA individuals may be less likely to utilize verbal encoding strategies. The CA group and, to a lesser extent the MA group, may have utilized verbal cues present in the visual response displays during practice trials, resulting in more efficient and faster tactile search strategies. The MR group, however, may have failed to use adequate verbal strategies to extract the tactile information, resulting in longer response latencies. The difficulty with utilizing a verbal encoding strategy for Chinese characters is reflected in the significantly longer response latencies for all groups.

With respect to experimental trials, the CA group was significantly faster and more accurate than the MR group with the exception of accuracy for "same" responses. The Group X Stimulus Type interaction for percent correct "same" responses indicated equivalent performance for the adult and MR groups for all but words. Both groups were significantly more accurate for Chinese characters than MA subjects. However, the MR group's significantly lower accuracy for "different" responses and their significantly lower A' scores as compared to the CA and MA groups suggest that the MRs performance was

due to a bias toward making a "same" response. During practice trials subjects were corrected when errors were made. While subjects were informed that there would be "same" and "different" trials, the lack of feedback during experimental trials may have been interpreted as meaning a correct response had been made. It is also possible that the MR subjects responded "same" whenever they were uncertain. Indeed, retarded subjects have also exhibited a tendency toward saying "yes" in a visual discrimination task utilizing Chinese characters (Hornstein & Mosley, 1979). Research has indicated that retarded subjects display more wariness and failure expectancy as compared to nonretarded individuals (Zigler & Balla, 1982; Beveridge & Conti-Ramsden, 1987) and tend to exercise a greater degree of caution prior to making a response (Nettlebeck, 1985). It has also been postulated that a curvilinear relationship exists between performance and motivational factors (Belmont & Mitchell, 1987). That is, subjects may give up trying if a task is too easy or too difficult. As such, the propensity toward saying "same" in the present study may have created a response set due to the difficulty of the task, a greater degree of caution, or a combination of both factors. The lack of feedback may have exacerbated this situation.

The lack of significant differences in accuracy for "same" responses between adults, children and retarded subjects in conjunction with significant differences between retarded and nonretarded subjects of equivalent mental age for accuracy for "different" responses and sensitivity (A') underscores the necessity for caution when comparing groups on the basis of the number of

correct responses only. Because the number of correct responses may confound accuracy with response bias, it is imperative that recognition accuracy be assessed by a measure which is independent of response bias.

As noted Group X Stimulus Type interactions for percent correct "different" responses and sensitivity (A') indicated that the retarded subjects were significantly poorer for all Stimulus Types as compared to nonretarded children of equivalent mental age. While adults were significantly more accurate than children for all but "different" single letters, both groups had similar discriminability for all but Chinese characters. While the accuracy data corresponds to previous research indicating an overall increase in performance with age (i. e. Hatta, et al., 1981), the A' scores suggest that sensitivity may be a relatively stable trait, at least for more familiar stimuli (letters, words and bigrams). While previous haptic/dichhaptic studies have not employed sensitivity measures, the MA group's lower sensitivity and greater variability for Chinese characters is most likely due to the unfamiliarity of the stimuli resulting in a less durable encoding process.

The MR group demonstrated significantly less discriminability for all Stimulus Types as compared to the CA and MA groups. While the MR subject's propensity toward saying "same" may have been heightened by nonintellective factors (i. e. uncertainty), results suggest inadequate encoding of the salient features of the stimuli in the absence of a visual cue. Retarded subjects often fail to spontaneously employ strategies which would enhance the efficiency with which they

focus on the salient stimulus features (Mosley, 1987). Consequently, this group may have been less efficient than CA and MA subjects in the use of feature extraction processes. Similarly, mentally handicapped individuals frequently experience difficulty focusing attention on more than one dimension at a time as well as generalizing learned material to new situations (Salmon et al., 1986; Tzuriel & Klein, 1985). While the retarded subjects were able to discriminate between some tactile and visual features, as evidenced by the significant differences between letters and words as compared to bigrams and significantly poorer performance for Chinese characters for sensitivity, their overall performance strongly suggests inefficient allocation of attention to and encoding of the salient stimulus features. The difficulty experienced during experimental trials was most likely exacerbated by the absence of a visual reference.

Group differences as a function of Delay condition were also found. While the adult group was faster than the retarded group for both delay conditions, adults were faster than children for 3 second delay trials only. The MA group, in turn, was significantly faster than the MR group for 3 second delay trials. It would appear that the overall decrease in response latencies, as reflected in the main effect for Delay condition, is due to the faster, albeit nonsignificant, performance on the part of the adult and child groups. The MR group, in contrast, exhibited no decline in response latencies for 3 second as compared to 0 Delay trials. The superior performance by CA and MA subjects does not appear to be due to a memory component "per se", as MRs have demonstrated equivalent performance for Russian

and Greek letters after long delays between tactual presentation and visual recognition (Hermelin & O'Connor, 1961a). However, the Hermelin and O'Connor (1961a) and O'Connor and Hermelin (1961) studies assessed accuracy data while the present study found a group effect for response latencies only. It is possible that the delay only impacts latency for responding but not accuracy. It is also possible that the bias toward "same" masked accuracy differences in the present study.

Results of the present study suggest that retarded individuals experience difficulty focusing attention on the salient stimulus features. Because their performance was well within norms for majority of haptic studies, retarded individuals do appear capable of performing cross-modal matching tasks when a visual reference is supplied (practice trials). The poor performance during experimental trials is most likely due to the removal of this visual reference during palpation. Thus, their disadvantage due to inefficient selection of salient stimulus features appears to be enhanced when subjects have no visual reference to guide their motor movements. Indeed, the Hermelin and O'Connor (1961a) study manually guided the hands around the stimuli and the Davidson (1985) studies did not restrict movements to the digits only. While mentally retarded individuals can be taught a strategy for using movements appropriate for the task (Roy et al, in press) as well as specific strategies to pick out salient stimulus dimensions (Mosley, 1987), the ten practice trials utilized in the present study may not have been sufficient to eradicate group differences due to strategy deficiencies. Furthermore, the change from the visual cue during practice trials to a forced-

choice response during experimental trials may have enhanced their inability to change strategies.

Conclusions

Results of the present study indicate that both cerebral hemispheres are capable of processing tactile information which spans the "verbal"/"nonverbal" continuum as evidenced by above chance performance with both hands as well as by equivalent performances on most of the independent measures. Furthermore, results suggest that the type of analysis, rather than the stimulus type "per se", determines the direction of asymmetrical haptic processing. The significant and near significant left-hand advantage for response latencies for "same" Chinese characters exhibited by children and adults respectively, as well as the overall left-hand superiority for "same" response latency and accuracy measures suggest that the right hemisphere is preeminent for rapid, holistic matches, independent of the stimulus material. Similarly, the right-hand advantage for "different" responses as well as a trend toward a right-hand superiority for A' are indicative of a slower, analytic analysis being performed more efficiently by the left hemisphere.

Consequently, it is concluded that differential performance may occur only when one hemisphere is at a disadvantage and/or different strategy requirements are necessary in order to extract pertinent information. Indeed, the nature of the traditional haptic/dichhaptic tasks also require specific analytic strategies as subjects must match the "same" stimulus from the array to that which has been felt. As

such, the left-hand advantage in earlier studies may be due to the type of analysis required rather than to the "spatial" nature of the stimuli. That is, the left-hand may be superior for "same" judgements (global information) while the right-hand is superior for "different" (nonmatching) judgements. Introducing attentional factors (i.e., multistimulus arrays) may either enhance the effect or speed up the emergence of asymmetries. The late emerging right-hand advantage for words in the present study also supports the conclusion that methodological factors in earlier research capitalize on attentional biases.

Results indicate that the cross-modal matching paradigm is a viable means of assessing functional tactile asymmetries in the nonretarded population. However, group differences suggest that this technique puts retarded individuals at an even greater disadvantage than do dichotic and visual half-field assessments which are known to be more difficult for this group. Even when factors which may result in strategy differences were minimized (individual palpation intervals, haptic rather than dichhaptic stimulation, a single response display rather than multiple choices), the greater variability and poorer performance demonstrated by the mentally retarded subjects are indicative of strategy and attentional deficits.

Noninvasive techniques involving dichotic and tachistoscopic presentations appear to provide viable means of assessing asymmetrical processing along the "verbal/nonverbal" continuum. Results derived from the more recent assessment of differential processing of "verbal"

vs "nonverbal" information presented via the tactile modality are less consistent. Consequently, it is suggested that future research assess haptic processing asymmetries as a function of information processing demands rather than stimulus type.

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APPENDIX A
Samples of Chinese Characters

坐 刃 及

易 公 龙

去 氏 尔

APPENDIX B
Kruskal-Wallis

The Kruskal-Wallis test, a nonparametric one-way analysis of variance by ranks, tests whether k independent samples have been drawn from the same population or if differences between the groups denote legitimate population differences. Each N observation is replaced with a rank from 1 (smallest score) to rank N (largest score) in a single series and the differences among the average ranks assessed. When the Kruskal-Wallis value is significant, at least one of the groups was drawn from a different population.

Formulas for Kruskal-Wallis (Kraft & van Eden, 1968)

$$H = 12 / N(N + 1) \sum (R_i - n_i \bar{R})^2 / n_i$$

$$\text{The } F \text{ approximation} = [(M - k + 1) / (k - 1)][H / (M - H)]$$

degrees of freedom:

$$v_1 = 2(k - 1)[(k - 1)(M - k + 1) - V / MV] \text{ and}$$

$$v_2 = (M - k + 1 / k - 1)(v_1)$$

where:

$$M = (N^3 - \sum n_i^3) / N(N + 1)$$

$$V = 2(k - 1) - \{2[3k^2 - 6k + N(2k^2 - 6k + 1)] / 5N(N + 1)\} - [(6 / 5)(\sum 1 / n_i)]$$

Table 1
H and F approximations

Source	H	F approx
PRACTICE TRIALS		
Letters	43.98	70.23 *
Words	40.26	53.81 *
Bigrams	40.71	55.51 *
Chinese Characters	32.93	33.33 *
PERCENT CORRECT "SAME"		
Letters	10.92	6.40 *
Words	8.41	4.70
Bigrams	20.44	14.63 *
Chinese Characters	12.93	7.87 *
Left Index-Finger	13.96	8.68 *
Right Index-Finger	11.84	7.06 *
Block I	10.45	6.07 *
Block II	16.99	11.26 *
0 Delay	14.50	8.98 *
3 Delay	13.90	8.63 *
PERCENT CORRECT "DIFFERENT"		
Letters	22.94	17.45 *
Words	33.40	34.34 *
Bigrams	43.24	81.07 *
Chinese Characters	20.51	14.71 *
Left Index-Finger	39.50	51.08 *
Right Index-Finger	39.97	52.74 *
RECOGNITION TIMES FOR "SAME" RESPONSES		
Letters	29.63	27.04 *
Words	36.99	43.26 *
Bigrams	33.57	34.72 *
Chinese Characters	24.24	19.06 *
Left Index-Finger	39.26	50.29 *
Right Index-Finger	41.01	56.67 *
Block I	38.54	47.93 *
Block II	37.09	43.55 *
0 Delay	24.53	19.37 *
3 Delay	48.12	98.04 *

Table 1 continued

Source	H	F approx
RECOGNITION TIMES FOR "DIFFERENT" RESPONSES		
Letters	32.35	31.13 *
Words	43.55	67.98 *
Bigrams	34.75	37.43 *
Chinese Characters	15.20	9.69 *
Left Index-Finger	41.57	58.96 *
Right Index-Finger	44.00	70.33 *
A'		
Letters	33.65	34.90 *
Words	41.01	56.69 *
Bigrams	41.77	59.77 *
Chinese Characters	31.08	29.57 *
Left Index-Finger	42.87	64.54 *
Right Index-Finger	43.84	69.49 *
B''		
Letters	.20	.10
Words	4.69	2.45
Bigrams	2.68	1.36
Chinese Characters	3.47	1.78
Left Index-Finger	1.09	.54
Right Index-Finger	.40	.20

* $p < .01$

df = 2, 61

Table 2
Mean Ranks and Standard Deviations

Stimulus Type	GROUP					
	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
PRACTICE TRIALS						
Letters	13.750	9.489	44.250	12.851	51.500	16.102
Words	15.979	10.687	39.583	15.537	53.938	15.160
Bigrams	14.333	8.293	45.875	14.214	49.292	17.492
Chinese	17.042	10.832	50.292	12.814	42.167	21.058
PERCENT CORRECT "SAME"						
Letters	45.688	17.623	37.708	18.844	26.104	21.151
Words	46.292	18.343	33.750	17.343	29.458	23.444
Bigrams	49.020	15.290	38.417	19.534	22.063	18.355
Chinese	45.500	17.337	24.438	17.552	39.563	22.295
Left Finger	49.333	14.468	32.042	16.531	28.125	24.561
Right Finger	48.500	14.892	30.250	17.407	30.750	24.527
Block I	47.771	16.744	31.208	16.967	30.521	24.180
Block II	50.875	12.298	29.438	17.105	29.188	24.174
0 Delay	49.729	15.323	30.896	17.409	28.875	23.194
3 Delay	49.500	13.649	30.188	16.749	29.813	24.907
PERCENT CORRECT "DIFFERENT"						
Letters	46.396	14.347	42.792	17.034	20.313	19.430
Words	53.292	13.799	37.438	17.152	18.771	14.728
Bigrams	53.313	11.317	41.042	16.020	15.125	11.161
Chinese	49.938	14.665	36.938	17.874	22.625	20.593
Left Finger	53.979	12.865	39.208	15.526	16.313	13.895
Right Finger	53.167	12.282	40.646	17.281	15.688	11.855
RESPONSE TIME "SAME"						
Letters	19.417	12.737	37.875	21.931	52.208	12.007
Words	17.042	12.559	38.917	16.884	53.542	14.309
Bigrams	17.438	11.250	40.229	17.519	51.833	16.700
Chinese	19.333	11.348	43.375	16.234	44.792	22.310
Left Finger	15.854	9.821	40.625	16.099	53.021	15.764
Right Finger	14.563	9.097	43.854	16.371	51.083	14.837

Table 2 Continued
Mean Ranks and Standard Deviations

Stimulus Type	GROUP					
	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
Block I	15.479	10.606	42.521	14.747	51.500	16.967
Block II	15.979	10.406	42.021	16.559	51.500	16.213
0 Delay	19.729	13.392	41.313	19.214	48.458	18.336
3 Delay	13.417	8.329	41.771	13.149	54.313	13.901
RESPONSE TIME "DIFFERENT"						
Letters	21.604	12.797	32.646	19.535	55.250	13.871
Words	15.125	11.052	39.854	13.125	54.542	15.091
Bigrams	18.542	10.412	36.813	19.427	54.146	14.294
Chinese	24.542	13.244	36.875	18.140	48.083	23.619
Left Finger	17.625	10.595	35.354	15.608	56.521	14.293
Right Finger	15.750	9.865	38.021	15.632	55.729	13.122
A'						
Letters	49.646	14.441	43.188	17.975	16.667	13.256
Words	54.688	11.994	38.542	17.360	16.271	11.069
Bigrams	53.229	14.239	41.188	16.146	15.083	9.590
Chinese	55.396	11.412	30.938	18.347	23.167	17.125
Left Finger	56.188	12.759	36.646	15.326	16.667	11.752
Right Finger	55.771	10.948	37.854	15.631	15.875	12.331
B''						
Letters	37.625	19.157	35.021	22.849	36.854	21.003
Words	43.792	19.791	31.271	22.390	34.438	18.899
Bigrams	40.125	22.249	38.479	19.078	30.896	20.710
Chinese	30.333	22.223	37.833	19.004	41.333	20.712
Left Finger	39.979	19.974	35.667	23.136	33.854	19.901
Right Finger	38.646	20.970	35.875	21.858	34.979	20.635

APPENDIX C

Source Tables, Means and Standard Deviations:
Practice Trials

Table 1
Source Table for Main ANOVA

Source	SS	df	MS	F
Group (G)	4247.674	2	2123.837	37.00 *
Sex (S)	148.652	1	148.652	2.36
G X S	385.360	2	192.779	3.36
Error	3798.758	66	57.405	
Type (T)	4187.336	3	1395.778	115.88 *
T X G	577.635	6	96.273	7.47 *
T X S	17.064	3	5.688	0.93
T X G X S	64.440	6	11.240	0.93
Error	2384.439	198	12.045	
Index-Finger (I-F)	.948	1	.948	0.08
I-F X G	8.634	2	4.317	1.95
I-F X S	3.800	1	3.880	0.72
I-F X G X S	5.798	2	2.899	0.30
Error	264.805	66	4.012	
T X I-F	37.404	3	12.468	3.84
T X I-F X G	19.658	6	3.276	1.01
T X I-F X S	12.665	3	4.222	1.30
T X I-F X G X S	13.490	6	2.248	0.69
Error	643.034	198	3.248	

* $p < .01$

Table 2
Group X Stimulus Type Means and Standard Deviations

Stimulus Type	GROUP					
	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
SINGLE LETTERS	2.035	0.505	4.742	2.531	6.249	3.025
WORDS	3.993	1.040	7.603	2.991	11.817	4.851
BIGRAMS	4.691	1.051	10.187	3.778	11.661	5.418
CHINESE	7.508	2.012	14.674	3.769	13.699	5.892

Table 3
Simple Main Effects Source Table for
Group X Stimulus Type Interaction

Source	SS	df	MS	F
Group X Stimulus Type	577.6355	6	96.2725	7.47 *
Group, at Single letters	232.1997	2	116.0986	9.64 *
Group, at Words	773.1677	2	386.5839	32.10 *
Group, at Bigrams	666.2551	2	333.1276	27.66 *
Group, at Chinese	712.6778	2	356.3389	29.58 *
Type, at CA	369.6993	3	123.2331	10.23 *
Type, at MA	1279.7585	3	426.5862	35.41 *
Type, at MR	704.4947	3	234.8316	19.50 *
Within Cell Error	2384.9341	198	12.0450	

* $p < .01$

APPENDIX D

Source Tables, Means and Standard Deviations:

Percent Correct "Same" Responses

Table 1
Source Table for Main ANOVA

Source	SS	df	MS	F
Group (G)	64248.358	2	32124.179	8.83 *
Sex (S)	7299.566	1	7299.566	2.01
G X S	16.260	2	8.130	.16
Error	240188.180	66	3639.215	
Type (T)	148618.324	3	49539.441	51.48 *
T X G	42545.427	6	7090.905	7.37 *
T X S	4585.050	3	1528.350	1.59
T X G X S	2739.608	6	456.601	.47
Error	190525.185	198	962.248	
Block (B)	251.355	1	251.355	.53
B X G	2144.024	2	1072.012	2.28
B X S	352.344	1	352.344	.75
B X G X S	258.441	2	129.221	.27
Error	31067.867	66	470.725	
T X B	1948.074	3	649.358	1.56
T X B X G	6339.344	6	1056.557	2.54
T X B X S	773.043	3	257.681	.62
T X B X G X S	2162.427	6	360.405	.87
Error	82234.956	198	415.328	
Index-Finger (I-F)	1772.761	1	1772.761	4.35
I-F X G	2157.962	2	1078.981	2.65
I-F X S	0.473	1	0.473	.00
I-F X G X S	894.385	2	447.193	1.10
Error	26923.326	66	407.929	
T X I-F	2120.522	3	700.507	1.90
T X I-F X G	2814.885	6	469.148	1.27
T X I-F X S	2576.019	3	858.673	2.33
T X I-F X G X S	1416.920	6	236.153	.64
Error	73033.122	198	368.854	
B X I-F	1638.563	1	1638.563	4.97
B X I-F X G	724.441	2	362.221	1.10
B X I-F X S	26.053	1	26.053	.08
B X I-F X G X S	1106.566	2	553.283	1.68
Error	21753.534	66	329.599	

Table.1 continued
Source Table for Main ANOVA

Source	SS	df	MS	F
T X B X I-F	187.602	3	62.534	.20
T X B X I-F X G	1853.962	6	308.994	.99
T X B X I-F X S	543.987	3	181.329	.58
T X B X I-F X G X S	1236.795	6	206.133	.66
Error	61800.872	198	312.126	
Delay (D)	1090.375	1	1090.375	3.12
D X G	36.003	2	18.002	.05
D X S	96.285	1	96.285	.28
D X G X S	1249.135	2	624.568	1.79
Error	23037.607	66	349.055	
T X D	1707.109	3	569.036	1.62
T X D X G	803.830	6	133.972	.38
T X D X S	1091.171	3	363.724	1.04
T X D X G X S	887.517	6	147.920	.42
Error	69486.341	198	350.941	
B X D	320.261	1	320.261	.81
B X D X G	277.691	2	138.846	.35
B X D X S	185.073	1	185.073	.47
B X D X G X S	54.608	2	27.304	.07
Error	25995.523	66	393.872	
T X B X D	1458.342	3	486.114	1.83
T X B X D X G	1739.837	6	289.973	1.09
T X B X D X S	2193.696	3	731.232	2.75
T X B X D X G X S	2620.212	6	436.702	1.64
Error	52631.133	198	265.814	
I-F X D	727.875	1	727.875	2.39
I-F X D X G	2098.128	2	1049.064	3.44
I-F X D X S	209.646	1	209.646	.69
I-F X D X G X S	277.503	2	138.752	.45
Error	20141.878	66	305.180	
T X I-F X D	421.178	3	140.393	.41
T X I-F X D X G	3349.490	6	558.248	1.63
T X I-F X D X S	823.935	3	274.645	.80
T X I-F X D X G X S	1495.920	6	249.320	.73
Error	67850.320	198	342.678	

Table 1 continued
Source Table for Main ANOVA

Source	SS	df	MS	F
B X I-F X D	51.660	1	51.660	.15
B X I-F X D X G	561.260	2	280.630	.84
B X I-F X D X S	67.035	1	67.035	.20
B X I-F X D X G X S	86.760	2	43.380	.13
Error	22040.065	66	333.940	
T X B X I-F X D	1602.540	3	534.180	1.80
T X B X I-F X D X G	877.691	6	146.282	.49
T X B X I-F X D X S	1321.359	3	440.453	1.48
T X B X I-F X D X G X S	2081.663	6	346.944	1.17
Error	58901.841	198	297.484	
* $p < .01$				

Table 2
Group X Stimulus Type Means and Standard Deviations

Stimulus Type	GROUP					
	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
SINGLE LETTERS	95.19	5.78	91.36	10.74	82.23	16.28
WORDS	96.19	4.10	89.20	13.80	78.09	16.67
BIGRAMS	91.57	9.84	85.16	10.97	78.54	18.50
CHINESE	77.58	10.90	57.77	19.03	72.32	20.68

Table 3
Simple Main Effects Source Table for
Group X Stimulus Type Interaction

Source	SS	df	MS	F
Group X Type	42545.427	6	7090.905	7.37 *
Type, CA	5263.157	3	1745.384	1.81
Type, MA	17551.772	3	5850.591	6.08 *
Type, MR	1206.221	3	402.074	.42
Group, at letters	577395.117	1	577395.118	600.05 *
Group, at Words	555025.945	1	555025.945	576.80 *
Group, at Bigrams	516749.641	1	516749.641	537.02 *
Group, at Chinese	344890.041	1	344890.041	358.42 *
Within Cell Error	190525.185	19	962.248	

* $p < .01$

APPENDIX E

Source Tables, and Means and Standard Deviations:

Percent Correct "Different" Responses

Table 1
Source Table for Main ANOVA

Source	SS	df	MS	F
Group (G)	182716.274	2	91358.137	51.76 *
Sex (S)	257.335	1	257.335	.15
G X S	863.816	2	1764.872	.24
Error	116481.573	66	1764.872	
Type (T)	58567.061	3	19522.354	37.34 *
T X G	14370.017	6	2395.003	4.58 *
T X S	106.019	3	35.340	.07
T X G X S	3178.726	6	529.788	1.01
Error	103512.552	198	522.791	
Index-Finger (I-F)	2529.252	1	2529.252	7.22 *
I-F X G	1322.816	2	661.408	1.89
I-F X S	206.641	1	206.641	.59
I-F X G X S	86.469	2	43.234	.12
Error	23130.448	66	350.461	
T X I-F	724.214	3	241.405	.80
T X I-F X G	2930.448	6	488.408	1.63
T X I-F X S	503.658	3	167.886	.56
T X I-F X G X S	1926.712	6	321.119	1.07
Error	59478.844	198	300.398	

* $p < .01$

Table 2
Group X Stimulus Type Means and Standard Deviations

Stimulus Type	GROUP					
	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
SINGLE LETTERS	91.25	8.99	87.92	12.50	54.17	31.47
WORDS	92.50	10.87	78.77	15.93	52.33	26.17
BIGRAMS	95.00	7.22	82.98	17.09	36.67	28.54
CHINESE	67.67	16.98	52.96	20.03	35.06	27.30

Table 3
Simple Main Effects Source Table for
Group X Stimulus Type Interaction

Source	SS	df	MS	F
Group X Stimulus Type	14370.017	6	2395.003	4.58 *
Group, at letters	20202.778	2	10101.389	19.32 *
Group, at Words	20006.343	2	10003.170	19.13 *
Group, at Bigrams	45537.006	2	22768.504	3.55 *
Group, at Chinese	12797.021	2	6398.510	12.24 *
Within Cell Error	14370.017	198	522.791	

* $p < .01$

APPENDIX F

Missing Value Estimation Procedure for
Recognition Times for "Same" and "Different" Responses

Missing Value Estimations Procedure for Recognition Times
for "Same" and "Different" Responses

A missing data point for a particular cell (e. g. bigram, right index-finger, 0 delay, block I for recognition times for "same" responses or, bigram, right index-finger for "different" responses) was possible if: (a) all possible responses for that particular cell were incorrect; (b) correct responses did not yield a response time (i.e. subject spoke or coughed at response slide onset which stopped the timer); or (c) a combination of a and b.

For "same" responses, all subjects in the CA group yielded a mean recognition response time for each cell. In the MA group (N = 24), 12 subjects accounted for 23 missing data points (768 data points in total) while 11 MR subjects (N = 24) accounted for a total of 24 missing values out of a possible 768. Refer to Table 1 for numbers of missing data points for each condition. All subjects in the CA and MA groups yielded a mean recognition response time for each cell for "different" responses. In the MR group (N = 24) 15 subjects yielded a total of 36 missing data points out of a possible 192 (Table 2).

A regression analysis regressing recognition response times for correct "same" responses on response times for incorrect responses (subject said "different" when target and stimulus were "same") indicated a significant proportion of the variance of response times for correct responses could be accounted for by response times for incorrect responses. A separate regression analysis regressing recognition response times for correct "different" responses on

response times for incorrect responses (subject said "same" when target and stimulus were "different") also indicated a significant proportion of the variance of response times for correct responses could be accounted for by response times for incorrect responses.

In order to determine what values would replace missing data points, means and standard deviations for recognition times for incorrect "yes" responses (subject responded "no" when stimulus and response display were the same) were calculated for each group for each repeated measure (i. e. MR group, bigram, right index-finger, 0 delay, block I). The standard deviations were then multiplied by 2.575 (z-score at $p < .01$) and the product added to the mean for that particular condition. The resulting value was then used as the recognition time for a missing data point for that particular condition as well as for any recognition time above that value. The same procedure was utilized to determine estimates for missing "different" recognition response times.

Table 1
 Number of Missing Data Points for "Same" Responses
 for MA and MR Groups

		BLOCK							
		I				II			
DELAY		0		3		0		3	
GROUP		MA	MR	MA	MR	MA	MR	MA	MR
<hr/>									
TYPE									
LETTERS									
Left		0	0	0	0	0	0	0	0
Right		0	1	0	0	1	1	0	0
WORDS									
Left		0	0	0	0	0	1	0	0
Right		2	1	0	1	0	1	0	0
BIGRAMS									
Left		0	0	0	0	0	0	0	0
Right		0	0	0	1	0	0	0	3
CHINESE									
Left		0	2	6	5	1	1	3	3
Right		1	1	2	1	5	0	2	1

Table 2
Number of Missing Data Points for "Different" Responses
for MR group

STIMULUS TYPE	INDEX-FINGER	
	LEFT	RIGHT
LETTERS	5	3
WORDS	2	3
BIGRAMS	8	4
CHARACTERS	5	6

APPENDIX G.

Source Tables and Means and Standard Deviations:
Recognition Response Times for Correct "Same" Responses

Table 1
Source Table for Main ANOVA

Source	SS	df	MS	F
Group (G)	257.178	2	128.589	11.33 *
Sex (S)	0.930	1	0.930	.08
G X S	5.173	2	2.587	.23
Error	749.332	66	11.353	
Type (T)	60.571	3	20.190	25.14 *
T X G	2.209	6	0.368	.46
T X S	3.022	3	1.008	1.25
T X G X S	2.513	6	0.419	.52
Error	159.026	198	0.803	
Block (B)	6.526	1	6.526	17.57 *
B X G	0.091	2	0.046	.12
B X S	0.007	1	0.006	.02
B X G X S	0.847	2	0.423	1.14
Error	24.508	66	0.371	
T X B	0.574	3	0.191	.53
T X B X G	0.687	6	0.115	.32
T X B X S	0.139	3	0.046	.13
T X B X G X S	1.021	6	0.170	.47
Error	71.195	198	0.360	
Index-Finger (I-F)	3.406	1	3.406	10.02 *
I-F X G	0.710	2	0.355	1.04
I-F X S	0.140	1	0.140	.41
I-F X G X S	0.624	2	0.312	.92
Error	22.431	66	0.340	
T X I-F	1.706	3	0.569	1.94
T X I-F X G	6.842	6	1.140	3.89 *
T X I-F X S	0.469	3	0.157	.53
T X I-F X G X S	1.382	6	0.230	.79
Error	58.012	198	0.293	
B X I-F	0.343	1	0.343	1.12
B X I-F X G	0.306	2	0.153	.50
B X I-F X S	0.036	1	0.036	.12
B X I-F X G X S	1.769	2	0.885	2.88
Error	20.266	66	0.307	

Table 1 continued
Source Table for Main ANOVA

Source	SS	df	MS	F
T X B X I-F	2.625	3	0.875	2.12
T X B X I-F X G	2.004	6	0.334	.81
T X B X I-F X S	0.242	3	0.081	.20
T X B X I-F X G X S	1.258	6	0.210	.51
Error	81.590	198	0.412	
Delay (D)	3.279	1	3.279	8.18 *
D X G	6.030	2	3.015	7.52 *
D X S	0.088	1	0.088	.22
D X G X S	1.181	2	0.091	.23
Error	26.449	66	0.401	
T X D	3.636	3	1.212	3.39
T X D X G	4.199	6	0.699	1.96
T X D X S	1.160	3	0.387	1.08
T X D X G X S	0.248	6	0.041	.12
Error	70.858	198	0.358	
B X D	0.411	1	0.411	.74
B X D X G	0.894	2	0.447	.81
B X D X S	0.453	1	0.453	.82
B X D X G X S	0.688	2	0.344	.62
Error	36.606	66	0.555	
T X B X D	0.975	3	0.325	.85
T X B X D X G	2.705	6	0.451	1.18
T X B X D X S	0.948	3	0.316	.82
T X B X D X G X S	1.301	6	0.217	.57
Error	75.893	198	0.383	
I-F X D	0.135	1	0.135	.44
I-F X D X G	0.304	2	0.152	.49
I-F X D X S	0.106	1	0.106	.34
I-F X D X G X S	0.216	2	0.108	.35
Error	20.445	66	0.310	
T X I-F X D	0.604	3	0.201	.69
T X I-F X D X G	1.858	6	0.310	1.06
T X I-F X D X S	0.519	3	0.173	.60
T X I-F X D X G X S	1.171	6	0.195	.67
Error	57.613	198	0.291	
B X I-F X D	0.019	1	0.019	.06
B X I-F X D X G	0.419	2	0.210	.64

Table 1 continued
Source Table for Main ANOVA

Source	SS	df	MS	F
B X I-F X D X S	0.377	1	0.377	1.14
B X I-F X D X G X S	0.166	2	0.083	.25
Error	21.739	66	0.329	
T X B X I-F X D	3.969	3	1.323	4.62 *
T X B X I-F X D X G	1.507	6	0.251	.88
T X B X I-F X D X S	0.268	3	0.089	.31
T X B X I-F X D X G X S	0.889	6	0.148	.52
Error	56.714	198	0.286	

* $p < .01$

Table 2
Group X Delay Condition Means and Standard Deviations

Delay	GROUP					
	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
0 DELAY	1.022	0.147	1.335	0.300	1.714	1.037
3 DELAY	0.821	0.103	1.260	0.262	1.764	0.926

Table 3
Simple Main Effects Source Table for
Group X Delay Condition Interaction

Source	SS	df	MS	F
Group X Delay	6.0299	2	3.2787	8.18 *
Delay, at equal CA	.4860	1	.4860	1.21
Delay, at equal MA	.0683	1	.0683	.17
Delay, at MR	.0238	1	.0238	.05
Group, at 0 Delay	5.7653	2	2.8827	7.19 *
Group, at 3 Delay	10.6766	2	5.3383	13.32 *
Within Cell Error	26.4493	66	.4008	

* $p < .01$

Table 4
Group X Stimulus Type X Index-Finger Means
and Standard Deviations

	GROUP					
	CA		MA		MR	
Stimulus Type	MEAN	SD	MEAN	SD	MEAN	SD
SINGLE LETTERS						
Left	0.819	0.161	1.113	0.413	1.537	1.117
Right	0.786	0.146	1.152	0.588	1.594	1.312
WORDS						
Left	0.825	0.148	1.123	0.255	1.642	0.842
Right	0.836	0.161	1.185	0.334	1.646	0.829
BIGRAMS						
Left	0.903	0.167	1.226	0.346	1.608	0.764
Right	0.900	0.178	1.330	0.404	1.945	1.121
CHINESE						
Left	1.063	0.151	1.483	0.450	2.034	1.159
Right	1.243	0.160	1.769	0.427	1.912	1.338

Table 5
Simple Main Effects Source Table for
Group X Index-finger X Stimulus Type Interaction

Source	SS	df	MS	F
Group X I-F X Type	6.842	6	1.140	3.89 *
Group X I-F, letters	.0545	2	.027	.09
Group X I-F, words	.729	2	.364	1.24
Group X I-F, bigrams	.024	2	.012	.04
Group X I-F, Chinese	1.079	2	.539	1.84
Type X Index-finger, CA	.322	3	.111	.38
Type X Index-finger, MA	.455	3	.152	.52
Type X Index-finger, MR	1.355	3	.452	1.54
Group X Type, Left I-F	.599	6	.099	.34
Group X Type, Right I-F	1.673	6	.279	.95
Type at left I-F, CA	.925	3	.308	1.05
Type at right I-F, CA	3.062	3	1.021	3.48
Type at left I-F, MA	2.129	3	.710	2.42
Type at right I-F, MA	5.819	3	1.937	6.61*
Type at left I-F, MR	3.602	3	1.201	4.10
Type at right I-F, MR	2.330	3	.777	3.24
Within Cell Error	58.012	198	.293	

* $p < .01$

Table 6

Stimulus Type X Index-Finger X Delay X Block
Means and Standard Deviations

		DELAY							
		0				3			
BLOCK		I		II		I		II	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
TYPE									
LETTERS									
Left		1.359	0.944	1.091	0.559	1.131	0.841	1.043	0.832
Right		1.355	1.229	1.258	1.261	1.073	0.767	1.027	0.681
WORDS									
Left		1.218	0.576	1.238	0.792	1.212	0.587	1.115	0.776
Right		1.417	1.037	1.149	0.503	1.242	0.686	1.078	0.603
BIGRAMS									
Left		1.340	0.577	1.161	0.467	1.364	1.207	1.119	0.584
Right		1.505	0.705	1.289	0.708	1.310	1.072	1.463	1.457
CHINESE									
Left		1.630	0.868	1.452	0.868	1.516	1.009	1.507	1.518
Right		1.566	0.857	1.688	1.029	1.725	1.088	1.585	0.982

Table 7
Simple Main Effects Source Table for
Stimulus Type X Index-Finger X Delay Condition X
Block Interaction

Source	SS	df	MS	F
T X B X D X I-F	3.9692	3	1.3231	4.62 *
T X D X I-F, Block I	1.91261	3	.6375	2.23
T X D X I-F, Block II	2.6394	3	.8798	3.07
T X I-F X B, Delay 0	3.5739	3	1.1913	4.16 *
T X I-F X B, Delay 3	3.0201	3	1.0067	3.51
T X I-F, Delay 0, B I	1.7632	3	.5877	2.05
T X I-F, Delay 0, B II	2.1181	3	.7060	2.47
I-F X B, D 0, letters	.5250	1	.5250	1.83
I-F X B, D 0, words	1.4819	1	1.4819	5.174
I-F X B, D 0, bigrams	.0239	1	.0239	.08
I-F X B, D 0, Chinese	1.6439	1	1.6439	5.74
T X B, Left I-F, D 0	1.6021	3	.5340	1.86
T X B, Right I-F, D 0	3.2387	3	1.0796	3.77 *
T, Right I-F, D 0, B I	1.8783	3	.6261	2.19
T, Right I-F, D 0, B II	12.0087	3	4.0029	13.98 *

* $p < .01$

Table 8
Group X Stimulus Type Means and Standard Deviations

Stimulus Type	GROUP					
	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
SINGLE LETTERS	0.803	0.147	1.133	0.486	1.568	1.204
WORDS	0.832	0.150	1.155	0.281	1.645	0.821
BIGRAMS	0.902	0.167	1.280	0.354	1.779	0.865
CHINESE	1.153	0.143	1.626	0.405	1.975	1.195

APPENDIX H

Main ANOVA Source Table:

Recognition Times for Correct "Different" Responses

Table 1
Source Table for Main ANOVA

Source	SS	df	MS	F
Group (G)	291.595	2	145.798	34.02 *
Sex (S)	0.000	1	0.000	.00
G X S	2.539	2	1.270	.30
Error	282.830	66	4.285	
Type (T)	9.978	3	3.326	2.65
T X G	7.674	6	1.279	1.02
T X S	1.362	3	0.454	.36
T X G X S	2.790	6	0.465	.37
Error	248.452	198	1.255	
Index-Finger (I-F)	0.230	1	0.230	.33
I-F X G	0.194	2	0.097	.14
I-F X S	2.628	1	2.628	3.76
I-F X G X S	3.722	2	1.861	2.67
Error	46.073	66	0.698	
T X I-F	0.456	3	0.152	.20
T X I-F X G	2.269	6	0.378	.49
T X I-F X S	4.262	3	1.421	1.84
T X I-F X G X S	7.826	6	1.304	1.69
Error	152.860	198	0.722	

* $p < .01$

Table 2
Group X Stimulus Type Means and Standard Deviations

Stimulus Type	GROUP					
	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
SINGLE LETTERS	1.017	0.178	1.292	0.426	2.936	1.914
WORDS	0.991	0.139	1.404	0.307	2.557	1.485
BIGRAMS	1.061	0.148	1.501	0.542	2.433	1.248
CHINESE	1.233	0.176	1.661	0.580	3.043	1.804

APPENDIX I

Source Tables, Means and Standard Deviations:

Signal Detection Analyses (A')

Table 1
Source Table for Main ANOVA

Source	SS	df	MS	F
Group (G)	11.067	2	5.533	54.06 *
Sex (S)	0.221	1	0.221	2.15
G X S	0.081	2	0.041	.40
Error	6.756	66	0.102	
Type (T)	6.332	3	2.111	43.92 *
T X G	1.194	6	0.199	4.14 *
T X S	0.043	3	0.014	.30
T X G X S	0.170	6	0.028	.59
Error	9.516	198	0.048	
Index-Finger (I-F)	0.228	1	0.228	6.86
I-F X G	0.051	2	0.025	.77
I-F X S	0.081	1	0.081	2.43
I-F X G X S	0.022	2	0.011	.33
Error	2.190	66	0.033	
T X I-F	0.185	3	0.062	1.73
T X I-F X G	0.301	6	0.050	1.41
T X I-F X S	0.192	3	0.064	1.79
T X I-F X G X S	0.379	6	0.063	1.77
Error	7.047	198	0.036	

* $p < .01$

Table 2
Group X Stimulus Type Means and Standard Deviations *

	GROUP					
	CA		MA		MR	
Stimulus Type	MEAN	SD	MEAN	SD	MEAN	SD
SINGLE LETTERS	.964	.041	.934	.072	.669	.279
WORDS	.973	.025	.893	.132	.690	.197
BIGRAMS	.943	.101	.927	.098	.554	.285
CHINESE	.809	.093	.542	.219	.445	.259

* range 0 - 1

Table 3 .
Simple Main Effects Source Table
for Group X Stimulus Type Interaction

Source	SS	df	MS	F
Group X Stimulus Type	1.1939	6	.1989	4.14 *
Group, at single letters	1.2678	2	.6339	13.19 *
Group, at words	1.0105	2	.5052	10.51 *
Group, at bigrams	2.1451	2	1.0726	22.32 *
Group, at Chinese	1.7132	2	.8566	17.82 *
Type, CA	.4123	3	.1375	2.86
Type, MA	2.4121	3	.8040	16.73 *
Type, MR	.9290	3	.3097	6.44 *
Within Cell Error	9.5155	198	.0481	

* $p < .01$

APPENDIX J

Source Table, Means and Standard Deviations:

Signal Detection Analyses (B'')

Table 1
Source Table for Main ANOVA

Source	SS	df	MS	F
Group (G)	1.047	2	0.523	.68
Sex (S)	0.210	1	0.210	.27
G X S	0.551	2	0.275	.36
Error	51.039	66	0.773	
Type (T)	2.507	3	0.836	2.15
T X G	4.507	6	0.751	1.93
T X S	0.678	3	0.226	.58
T X G X S	3.024	6	0.504	1.30
Error	77.043	198	0.389	
Index-Finger (I-F)	0.300	1	0.300	.82
I-F X G	0.011	2	0.006	.01
I-F X S	0.387	1	0.387	1.05
I-F X G X S	0.106	2	0.053	.14
Error	24.192	66	0.367	
T X I-F	0.054	3	0.018	.06
T X I-F X G	1.721	6	0.287	.88
T X I-F X S	0.209	3	0.070	.21
T X I-F X G X S	1.303	6	0.217	.67
Error	64.556	198	0.326	

* $p < .01$

Table 2

Group X Stimulus Type X Index-Finger

Means and Standard Deviations

GROUP

Stimulus Type	CA		MA		MR	
	MEAN	SD	MEAN	SD	MEAN	SD
SINGLE LETTERS						
Left	0.034	0.605	0.022	0.661	0.066	0.598
Right	0.039	0.670	-0.010	0.705	0.141	0.703
WORDS						
Left	0.356	0.777	-0.889	0.670	-0.095	0.560
Right	0.209	0.635	-0.052	0.737	0.051	0.680
BIGRAMS						
Left	0.255	0.776	0.197	0.711	0.114	0.649
Right	0.276	0.665	0.336	0.674	-0.738	0.706
CHINESE						
Left	-0.099	0.519	0.070	0.395	0.150	0.501
Right	0.092	0.582	0.097	0.377	0.132	0.503