particular prediction is not supported by the current literature which, as will be discussed later, generally indicates no changes in the involvement of the left hemisphere in language processing. Nevertheless, in the context of changing patterns of hemispheric involvement in the early years, it is possible to speculate about similar changes during the later years.

Hence, in general, there is a number of reasons to suspect that the two hemispheres do not develop in exactly parallel fashion and may be submitted to different processes during the life-span. Thus, a hypothesis of selective right hemisphere deterioration in the elderly falls within the already existing conceptualizations about hemispheric differences.

Physiological Evidence

In general, physiological and histological studies of the aging brain do not provide evidence that could support a hypothesis of right hemisphere dysfunction. However, one caveat is important when considering these studies. Most of the research is based on results from diseased brains or ones in which the premorbid health status was uncertain. Subjects who were considered neurologically healthy at the time of their death may have harbored pathological processes which could have become fatal at a later time. It is also difficult to distinguish between diseased brains and brains showing the effects of normal aging as the process of normal aging in the brain remains largely unknown. Nevertheless, I will briefly describe the major physiological changes which take place in the brain during the later years.

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**CHANGES WITH AGING IN RIGHT HEMISPHERE ACTIVATION
AS REFLECTED
IN BIMANUAL AND DIHAPTIC TASK PERFORMANCE**

by

DANIELLE FERRON

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Doctor of Philosophy
Department of Psychology
Carleton University
Ottawa, Ontario

May 15th

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"CHANGES WITH AGING IN RIGHT HEMISPHERE ACTIVATION

AS REFLECTED

IN BIMANUAL AND DIHAPTIC TASK PERFORMANCE"

submitted by

Danielle Ferron, B. A., M.A.

in partial fulfilment of the requirements
for the degree of Doctor of Philosophy

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Thesis Supervisor

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May , 1992

ABSTRACT

Clinical neuropsychological studies have shown elderly subjects to have deficits in visual-spatial processing, tactual perception and discrimination and in facial recognition, tasks that are thought to preferentially involve the right hemisphere. These findings have led to the hypothesis that the right hemisphere may be selectively disrupted with aging. More recent research using techniques such as dichotic listening, tachistoscopic viewing and dihaptic stimulation has produced inconsistent results but points to changes in the degree of involvement of the two hemispheres of elderly subjects in the processing of various types of information. However, much of this research is vitiated by methodological difficulties and by inconsistencies in the age and characteristics of the subjects.

The present study tested the hypothesis of right hemisphere disruption by assessing hemispheric involvement in three groups of older people aged 55 to 85, in two different tasks and compared the results to those of undergraduate subjects. The first task involved tactual perception and discrimination which required subjects to tactually explore nonsense shapes and discriminate them from distractor shapes. It was predicted that the left hand advantage which is normally obtained with dihaptic discrimination of such shapes would be diminished in the older subjects compared to younger subjects due to the hypothesized reduced activation or involvement of the right hemisphere. The second task involved finger tapping to two different rhythms with the two hands, one hand tapping twice for every tap in the other hand.

In young right-handers, performance has been reported to be better when it is the right hand that is leading (i.e. tapping twice), a finding that has been interpreted (Peters, 1987) in terms of hemispheric activation and consequent attentional bias. It was predicted under the hypothesis that the performance differential between right hand and left hand leading would be increased in older subjects because of diminished left hand performance.

The results on the dihaptic task were consistent with the hypothesis. Elderly subjects performed as well as younger controls with their right hand but left hand performance was significantly affected by age. In the middle groups (55 to 64 and 65 to 74 years old) the left hand advantage decreased or disappeared and in the oldest group (75 and over) the hand advantage was reversed. These results appear to indicate a decline in right hemisphere activation or function. Results for the two-one tapping task were not as clear-cut. Elderly subjects had a slower rate of tapping compared to younger subjects but they were not proportionately more impaired in the left hand leading condition, contrary to the hypothesis. However, elderly subjects showed an inordinate difficulty in controlling the left finger during the right hand leading condition. This probably contributed to overall slowing in the right hand leading condition. Moreover, the older subjects were impaired on a task of alternate tapping which suggests that subcortical processes may be involved. Results in general were indicative of right hemisphere underactivation due to possible callosal or subcortical dysfunction.

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I would like to dedicate this work to all my older subjects who touched me with their intelligence, wit and courage. As different as they were from one another, they all had : faith and energy to make the world a better place.

My gratitude also goes to my adviser, William G. Webster who provided patient support and gentle guidance.

Finally, I owe my husband many thanks for bearing with my ill temper and for being there all along this period.

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The majority of the cognitive changes reported in the elderly are associated with non-verbal abilities such as visual-spatial processing, constructional abilities, non-verbal abstraction and complex problem-solving skills. Deficits are also reported for tasks that have a speed component or that involve the division of attention. Language appears to be largely unaffected by aging and this extends to retention abilities where older people are shown to have deficits in visual retention but not in verbal retention. Other faculties which are not affected are mathematical abilities, short-term retention, verbal abstraction and deductive reasoning. This has been referred to as the classic pattern of intellectual aging (Botwinick, 1977).

Several theories have been put forward to explain such selectivity in the changes that accompany aging. Salthouse (1985) has argued that it is fluid intelligence and not crystallized intelligence that is affected by aging. Another theory proposes that some of the losses that are thought to be typical of the elderly are due to a selective deterioration or dysfunction of the right hemisphere (Goldstein & Shelley, 1981; Klisz, 1978; Farver, 1975; Botwinick, 1981; Albert, 1981; Albert & Kaplan, 1980; Filskov & Boll, 1981). The validity of the evidence for a right hemisphere dysfunction (the bulk of which came from clinical neuropsychology) has been questioned by researchers (Ellis & Oscar-Berman, 1989; Hochanadel & Kaplan, 1984; Obler, Albert, Goodglass & Benson, 1978) who have argued that the particular pattern of results shown by the elderly may be an artifact of testing procedures or of task demands rather than the effect of right hemisphere dysfunction. However, a number of more recent studies have examined laterality patterns in the elderly using experimental paradigms such as dichotic

listening, dihaptic stimulation and manual reaction times. Results from these studies have been inconsistent and provide only weak evidence regarding the hypothesis of right hemisphere changes. At least some of the inconsistency, however, may be attributed to methodological problems in the studies. In a substantive review of the effects of aging and alcoholism on cerebral asymmetries, Ellis and Oscar-Berman (1989) concluded that lateral perceptual asymmetries have not been shown to be different in the aged population and accordingly, that the hypothesis of right hemisphere dysfunction could not be supported. In the present author's opinion, the hypothesis of specific changes in right hemisphere functioning in the elderly has not been adequately tested and deserves further investigation.

Theoretical Basis for a Right Hemisphere Dysfunction

The hypothesis of selective right hemisphere dysfunction in older people implies that the two hemispheres develop differentially throughout life or that the hemispheres differ in such a way as to make one or the other more vulnerable to deterioration or dysfunction. In the next sections, I shall try to describe the various morphological and functional differences which exist between the two hemispheres and how these differences may be related to a greater vulnerability of the right hemisphere.

Differences Between the Hemispheres

Semmes, Weinstein, Ghent and Teuber (1960) were among the first to propose that the neural organization of the two hemispheres was different, the right being more "diffusely" organized than the left.

They based their suggestion on observations of patients with brain wounds which show that right hemisphere lesioned patients are more likely to show deficits in sensorimotor functions than left hemisphere lesioned patients, regardless of the site of the lesion. Semmes (1968) suggested that this could be accounted for by a more diffuse organization in the right hemisphere. Consistent with this hypothesis is the suggestion by Gur et al. (1980) who proposed that the larger proportion of white to grey matter in the right hemisphere may serve to allow more "across region processing" in the right hemisphere while a greater amount of "within region processing" would take place in the left. Thus, there may be structural and functional differences between the two sides of the brain which suggest that with aging, the two hemispheres may be submitted to qualitatively different processes.

There is also some evidence that the right hemisphere may be more susceptible to disease than the left; Carmon and Gambos (1970) have shown that arterial pressure is higher in the right hemisphere than in the left and may be at greater risk for cerebro-vascular incidents or for microscopic lesions.

Another line of evidence concerns the development of laterality patterns across the life-span. There is much research interpreted as showing that the lateralization of hemispheric functions increases during childhood years (Bryden, 1982). Brown and Jaffe (1975) proposed a model of increasing dominance of the left hemisphere over language functions with the right hemisphere becoming progressively less involved. According to this model, what would be predicted in old age is a larger left hemisphere advantage for verbal functions. This

particular prediction is not supported by the current literature which, as will be discussed later, generally indicates no changes in the involvement of the left hemisphere in language processing. Nevertheless, in the context of changing patterns of hemispheric involvement in the early years, it is possible to speculate about similar changes during the later years.

Hence, in general, there is a number of reasons to suspect that the two hemispheres do not develop in exactly parallel fashion and may be submitted to different processes during the life-span. Thus, a hypothesis of selective right hemisphere deterioration in the elderly falls within the already existing conceptualizations about hemispheric differences.

Physiological Evidence

In general, physiological and histological studies of the aging brain do not provide evidence that could support a hypothesis of right hemisphere dysfunction. However, one caveat is important when considering these studies. Most of the research is based on results from diseased brains or ones in which the premorbid health status was uncertain. Subjects who were considered neurologically healthy at the time of their death may have harbored pathological processes which could have become fatal at a later time. It is also difficult to distinguish between diseased brains and brains showing the effects of normal aging as the process of normal aging in the brain remains largely unknown. Nevertheless, I will briefly describe the major physiological changes which take place in the brain during the later years.

Histological Findings

Three major processes are evident at the macroscopic level in normal aging: loss of brain weight, increase in ventricular size and cortical atrophy. Brain weight starts to decline after the 5th decade, losing about 11 percent of its original weight by the 9th decade (Dekaban & Sadowsky, 1978). Ventricular size is found to increase very slightly between the 3rd and 7th decade and more rapidly thereafter. Roberts and Caird (1976) studied the brains of 66 normal aged subjects and found a significant increase in ventricular size compared to those of younger subjects. Autopsy material and findings obtained from CT scan studies show increasing cortical atrophy with age especially in the frontal lobes (Barron, Jacobs & Kinkel, 1976). Gyri become thinner and sulci are widened resulting in a general reduction in brain mass. None of these changes have been found to be more important or more prevalent in one hemisphere or in the other.

Microscopic changes are also seen in the aging process of the brain. These include neuronal loss, changes in the neuronal structure, lipofuscin accumulation in neurons, granulovacuolar degeneration and the appearance of neurofibrillary tangles and neuritic plaques. Neuronal loss has been found to be particularly significant in the superior temporal gyrus, the precentral gyrus and the striate cortex (Brody, 1955). Important cell loss has also been found in the hippocampus (Ball, 1977), the locus coeruleus (Brody, 1978) and cerebellum (Hall, Miller & Corsellis, 1975).

However, possibly more important than neuron loss are structural changes related to dendrites and synapses. Unfortunately, little is known about age-related morphological changes in the nerve body (Valenstein, 1981). Granulovacuolar degeneration, which is the appearance of small vacuoles containing a central granule, is sometimes seen in limbic structures of patients with senile dementia. It is also found with some regularity in the normal aged population in hippocampal neurons (Ball & Lo, 1977). Neurofibrillary tangles appear as double helical filaments which are arranged in an irregular fashion in the cytoplasm of neurons. Tangles have been reported by Dayan (1970) and Ball (1977) in the hippocampus of normal aged subjects. Neuritic plaques are composed of a central core of amyloid surrounded by granules and are usually found in supporting cells rather than in nerve cell bodies. Neuritic plaques have been found most often in the amygdala but also in the cortex, in the hippocampus and the basal ganglia (Ball & Lo, 1977).

Brain Imaging

Other methods which provide an insight into the changes that accompany aging are the measurement of cortical blood flow, electroencephalograms and event related potential recording.

Cortical blood flow.

Studies of cortical blood flow in aging subjects agree in revealing progressive decrease in cortical blood flow with age (Valenstein, 1981). Most affected areas are the frontal, parietal and temporal lobes.

EEG activity.

Valenstein (1981) reviewed the literature on EEG alterations in aging and summarized these changes as follows:

1. Alpha activity decreases gradually from the age of 60.
2. Beta activity becomes more prevalent during middle age although this increase becomes less evident after the age of 70.
3. Diffuse slow activity (frequencies slower than alpha) is more frequent in approximately 20 percent of healthy subjects over the age of 75. This activity has been correlated with intellectual deterioration.
4. Episodic high-voltage activity is seen in the temporal region in 30 to 50 percent of normal aged subjects. Sharp waves in the left hemisphere are sometimes associated with this activity.

It is important to note that the particular pattern of activity seen in some of the aged subjects may be the result or a concomitant effect of a change in degree of arousal or intellectual activity.

Evoked potentials.

An increase in latency of the early components has been found in several studies for somatosensory, auditory and visual potentials. Changes in amplitude in early components have been less consistent and show an increase in some studies and a decrease in others. Late components (P2 and P3) show a gradual increase in latency starting at the age of 15 (Goodin, Squires, Henderson & Starr, 1978). The contingent negative variation was also found by Loveless and Sanford (1974) to become progressively smaller in old subjects, as the interval between the first and second stimulus was increased. As for the changing patterns in EEG activity, the patterns in later component activity could

be related to changing levels of arousal and alertness in the older population.

This brief review of physiological changes in the aging brain suggests a number of conclusions. First, there is no indication from the studies that the right hemisphere is more affected by physiological aging than the left hemisphere. Most of these studies, however, have not specifically examined the question of whether changes were more prevalent in the right or the left hemisphere. Nevertheless, the gradient of deterioration seems to be in an anterior-posterior direction with more changes taking place in the frontal and temporal area than in the parietal and occipital. However, this is evident only in some of the processes taking place, namely neuronal loss and cortical atrophy. If there is any single structure that appears to be more affected than others it is the hippocampus which is implicated in most of the aging processes described in histological studies.

Secondly, there is a lack of agreement between the findings obtained from the various methods. This is not surprising considering the various stages of development at which these research methods presently are. This lack of agreement is probably an indication that aging involves several processes and that no single method can provide an adequate representation of aging. As a consequence, it is premature to assume, for example, that aging is predominantly a "frontal" phenomenon based on studies of cortical atrophy and neuronal loss only.

Finally, there is no agreement as to the relationship between intellectual status and the condition of the brain. For example, considerable cortical atrophy has been found in subjects with intact

intellectual functions while the reverse is also true eg. patients with impaired functions showing minimal or no shrinkage. The relationship between deviant responses on the EEG and intellectual status is also controversial. (Valenstein, 1981)

To conclude, it is premature to draw a relationship between the behavioural and cognitive changes seen in the elderly and the aging of the brain. It is instructive in this regard, to refer to animal models of brain aging.

Animal Models of Brain Aging

In recent animal models of aging, much importance has been given to the role of neurotransmitters and the neuroendocrine system in modulating behaviour in older animals (Corkin, Davis, Crowdon, Usdin & Wurtman, 1982). Barnes (1979) found that the maze learning speed of older rats was negatively correlated with the duration of long-term potentiation (LTP) in hippocampal synapses. Lynch (1985) points out that the shorter duration of the LTP effect in rats is associated with two other changes: a) an alteration in the shape of the synaptic connections and b) an increase in the number of sites that bind glutamic acid (which is thought to be a major neurotransmitter in the hippocampus). Lynch speculates that these two changes could be related to one underlying alteration: morphological changes in the spinal and terminal structure which could act to uncover glutamic receptors that had previously been buried in the synaptic membrane. Lynch also suggests the possibility of compensatory phenomena in brain aging. While post-synaptic field potentials have been found to be of shorter duration in older rats, they

also seem to be larger. This, according to Lynch, could reflect the increase in the number of glutamate binding sites in these rats. However, this increase in receptor density in specific sites could lead to a loss of physiological plasticity, the number of possible binding routes being limited by the loss of synapses. Lynch emphasizes that the causal link between these hypotheses is not demonstrated and that any of these events may happen in parallel rather than sequentially. This however, serves to illustrate the point that attempts to relate distinct processes of brain aging to specific cognitive changes fail to take into account the complexity of brain aging and the interrelatedness of these various processes. If one subscribes to Lynch's view of brain aging in rats, it is conceivable that what makes the difference between intellectual fitness and intellectual deterioration in the aged is not the degree of degeneration of the brain per se but the strength and efficiency of compensatory mechanisms.

An Activation Model of Right Hemisphere Dysfunction

In order to account for the complex changes that are seen in the elderly, it may be necessary to posit a number of different processes which interact together.

The deficits seen in the elderly on tasks thought to require the integrity in right hemisphere function could be the result of a diminished activation or underarousal of the right hemisphere. Two processes may be involved here: one to account for the disruption in level of hemispheric activation and a second one to account for the fact that it is the right hemisphere and not the left which is underaroused.

Concerning the second process, there are several differences (structural, organizational, and cerebrovascular) between the two hemispheres which could account for the fact that only the right hemisphere would be underaroused. For example, the right hemisphere has a higher white to grey matter ratio than the left hemisphere (Gur et al. 1980); it is also more susceptible to disease from increased arterial pressure (Carmon and Gambos, 1970). There are also suggestions that it may be more diffusely organized than the left hemisphere (Semmes, Weinstein, Ghent & Teuber, 1960). As for the first process, there are several candidates for this role. Frontal damage, because of its effect on attentional processes (Lezak, 1976) may cause an imbalance in the involvement of the two hemispheres. The corpus callosum, if damaged, could also disrupt the interaction between the two sides. Finally, limbic structures such as the hippocampus could also be involved because of their strategic role as a relay between perception and memory and as a regulator of selective attention (Lezak, 1976). However, it is important to remember that a number of parallel processes probably take place in aging and as a result, future research may not be successful in isolating the specific alterations that are the cause of the cognitive losses seen in the elderly.

In a recent review of the effects of aging and alcoholism on perceptual hemispheric asymmetries, Ellis and Oscar-Berman (1989) described two versions of the right hemisphere hypothesis. A strong form of the hypothesis would posit that some "important biological [...] changes occurring in the brain are themselves asymmetrically expressed". (p.129) The weak form of the hypothesis would state that "although

biological changes in the two sides are comparable in type and extent, functional mechanisms are, in fact, influenced to different degrees by these changes". (p.129) The strong form of the hypothesis is unlikely in light of the physiological evidence reviewed in an earlier section. The weak version, on the contrary, is compatible with the physiological evidence and with the theoretical models described and consequently, this is the perspective which is assumed in the present research.

Review of Research

Neuropsychological Findings

The first suggestions of selective right hemisphere dysfunction in the elderly were based on the pattern of deficits shown by older examinees in the various subtests of the Wechsler Adult Intelligence Test. There are several reports (Wechsler, 1958; Eisdorfer, Busse & Cohen, 1959) demonstrating that performance on the verbal scale remains stable in the elderly (Obler & Albert, 1985) and may even surpass that of younger subjects while scores on the performance scale tend to decline progressively with age (Botwinick & Storandt, 1974). Because most of the performance tests have substantial spatial component, they have been thought to tap predominantly into right hemisphere functions (Lezak, 1976; Searleman, 1977), this pattern of results has been interpreted by some as an indication of right hemisphere dysfunction. This interpretation was much criticized for not taking into account the effect of the speed requirements in the performance tests. It was later shown, however, that even when the speed requirements are removed from the tests, this pattern of deficits persists (Doppelt & Wallace, 1955; Storandt, 1977). It has also been found that the elderly are impaired in a number of other visuo-spatial tasks in which there are no speed factors, such as the Bender-Gestalt Visual Motor test (Gilbert & Levee, 1965), the Embedded Figures Test (Axelrod & Cohen, 1961), the Incomplete Figures Test (Danziger & Salthouse, 1978), figure drawings (Plutchick, Conte, Weiner & Teresi, 1978), the Benton Visual Retention Test (Arenberg, 1978) and tasks involving spatial rotation (Cerella, Poon &

Fozard, 1981). These are all spatial-visual tasks which are assumed to be processed predominantly by the right hemisphere.

Goldstein and Shelley (1975) explored the hypothesis that the cognitive changes seen in the elderly are similar to those seen in patients with diffuse brain damage. They compared young and old subjects with diffuse brain damage and young and old non-brain damaged subjects on a number of measures of cognitive, perceptual and motor skills. They factor-analyzed the various measures and, using a discriminant function analysis, classified their subjects into either young and old brain damaged or young and old non-brain damaged. The prediction was that, if the old subjects were more similar to brain damaged subjects than young subjects, they would be misclassified more often than the young subjects. They found that the misclassification rate was the same for both old and young subjects indicating that the older group was no more similar to brain damaged subjects than the young group was. However, a more detailed analysis of the various factors showed that the older group was similar to the brain damaged group on motor tasks but fared considerably better on the language tasks. The authors concluded that a model of diffuse brain damage could not account for the changes seen with advancing age and that more specific descriptions were needed to account for the changes. There are some problems in this study which compromise the validity of the results. The mean age of the older group (brain damaged and non-brain damaged) was 51.3 years and the total age range was 20 to 62. These subjects may have been too young in light of studies showing that intellectual decline (as indicated by WAIS scores) only starts around the seventh or eighth decade (Hochanadel & Kaplan,

1984). Furthermore, only 48.3% of the subjects (with or without brain damage) were correctly classified which puts into question the validity of the measures used. However, the study does point to the fact that the deficits seen in older people cannot be described as general and need to be analyzed in more specific terms.

Benton, Eslinger and Damasio (1981) administered a number of neuropsychological tests to a large group of healthy subjects aged from 65 to 84 years and the results were compared to those of normative samples. While they found that the elderly group had an overall failure rate that was significantly higher than the younger group, they also found that the majority of the older subjects (from 80 to 84 years old) failed on only one of the tests. Thus, they concluded that decline was apparent only in the oldest age group and was specific to certain functions. The highest percentage of failure was found in the Facial Recognition Test and in the Judgment of Line Orientation test, two tasks which are associated with right hemisphere processing. Moehle & Long (1989) obtained similar results. They administered the complete Halstead-Reitan battery to a group of elderly subjects and found that while performance was diminished in 6 out of 7 tests, impairment was most marked on tests which included a spatial component, such as the Tactual Performance Test. Deficits were least marked in tests which had a language component.

Other authors have more directly addressed the issue of right hemisphere dysfunction in the elderly. Farver (1975) administered the Boston Parietal Lobe Battery, which is thought to tap into both left and right parietal functions (Goodglass & Kaplan, 1972), and the Hooper

Visual Organization Test (Lezak, 1976) to normal elderly subjects. She found signs of impairment on tasks which are considered to reflect left hemisphere functioning such as right-left orientation, verbal finger localization and arithmetic. However, deficits were most marked on functions associated with the right hemisphere such as stick construction, three-dimensional block construction, clock setting, visual finger identification and the Hooper Visual Organization Test.

Schaie and Schaie (1977) compared scores on the Wechsler subscales of brain-damaged subjects with those of elderly healthy individuals. They found the rank order of the scores to be widely different in the two populations. However, the rank order scores of the elderly were found to be indistinguishable from those whose brain damage was right-sided. Unfortunately, this comparison of scores was based on scores obtained from two previous studies (Fitzhugh, Fitzhugh & Reitan, 1962 and Botwinick, 1977) and therefore the results must be viewed with caution.

Klisz (1978) reanalyzed the data reported in Reed and Reitan (1963a) where 31 tests from the Halstead-Reitan battery were used to discriminate between, on the one hand, young brain-damaged patients and young normal subjects and between, on the other hand, middle aged normals (aged 40 to 49) and older normals (50 years and older). Each test was categorized into one of 3 categories: sensitive to left hemisphere damage, sensitive to right hemisphere damage and sensitive to general impairment. It was found that the tests that best differentiated between young controls and young brain damaged subjects were, in order, general impairment indicators, tests sensitive to right hemisphere

dysfunction and tests sensitive to left hemisphere dysfunction. To distinguish between the middle-aged normals and the older normals, the tests with the most discriminating power were right hemisphere sensitive, with general impairment indicators and left hemisphere indicators being less important. It would appear then that the middle-aged and the older normal subjects were most different in their ability to perform in right hemisphere tasks. However, it is possible that those tests which are deemed to be sensitive to right hemisphere dysfunction are simply better discriminators. Klisz reports that there was indeed a tendency for right hemisphere tests to be more sensitive than left hemisphere tests in discriminating between young brain-damaged subjects and young controls although this trend was not significant. Of course, these results remain equivocal as they are based on previously obtained data.

Goldstein and Shelly (1981) used a similar method to classify a large group of neuropsychiatric and medical patients into left or right hemisphere dysfunction groups. The prediction was that the number of subjects categorized into the right hemisphere group would increase with the age of the patients. They tested 1,247 male patients (aged 20 to 70) on a wide variety of standard neuropsychological tests. To classify patients into right or left hemisphere groups, they used a localization key originally devised by Russell, Meuringer and Goldstein (1970). The key consists of a number of decision rules (such as Performance IQ greater or lesser than Verbal IQ by more than 10 points= left hemisphere and right hemisphere dysfunction, respectively) which allow for a classification of each subject into a left hemisphere group or a right

hemisphere group depending on the number of points accumulated for each side. The key is normally used to predict side of brain damage in patients in whom neurological damage is suspected. However, in this study, the actual number of points for one side or the other was the dependent variable rather than the side of prediction. They found that there was a significant increase with age in the number of right hemisphere points. There was also an increase in the number of left hemisphere points but this relationship was not significant. Since many of the subjects had a presenting condition of neurological disease, the investigators reanalyzed the results to see if the incidence of right hemisphere disease (as assessed by the neurological examination) was higher in the older groups than in the younger groups. There was no relationship between age and incidence of right hemisphere disease. Therefore, the greater frequency of right hemisphere points with increasing age is probably not an artifact of a greater incidence of actual right hemisphere pathology in the older groups. In the 'normal' group (patients presenting with non-neurological conditions), similar results were found i.e. a significant age effect for right hemisphere points, but a non-significant linear trend in left hemisphere points with age. The authors discussed the possibility that this increase in right hemisphere points could be due to the greater complexity of some of the right hemisphere tasks, such as the tests which comprise the Performance Scale of the Wais-R. However, as they point out, the discrepancy between Verbal IQ and Performance IQ was stable across all age groups, indicating no interaction between the complexity of the task and the age of the subject. Nevertheless, one cannot rule out the

possibility that the so-called right hemisphere measures are simply more vulnerable to any type of dysfunction, be it neurological, psychiatric or medical. Since all the 'normal' subjects had some presenting condition for which they had been referred to the hospital, the presence of illness or psychiatric pathology may have acted as a confounding variable. Another limitation is that the predictive validity of the localizing key used by the authors is unknown. As a result, these findings remain difficult to interpret.

Mittenberg (1988) sought to clarify some of the issues raised by these studies. He selected a number of neuropsychological measures which minimize overlearned material and speed requirements and which have demonstrated localizing ability. He administered these to 68 subjects aged 20 to 75. He found no specific impairment of right hemisphere functions in his elderly sample. The tests which were considered to be indicative of left hemisphere functioning were as affected by aging as tests associated with the right hemisphere. In fact, it was found that the most striking changes seen in the older sample were on tests associated with frontal functions. Mittenberg's work represents an attempt at eliminating confounding factors such as practice effects, novelty, complexity of tasks etc. Frontal measures, however, are sensitive to variations in fatigue, arousal and anxiety and when older subjects are tested this becomes a crucial consideration. Another difficulty with this study is the age of the subjects; as the oldest subjects were 75 years old, the majority of the subjects may have been too young to show any of the more specific deficits that are seen in older people.

There are several problems with neuropsychological investigations which purport to relate cognitive deficits in the elderly to a specific cortical area. Considering the fact that older normal subjects are used as controls in many studies of brain-damaged older patients, one cannot expect to find gross deficits when the same population becomes the population of interest. This expectation, however, appears to be present in research which supports the theory of right hemisphere dysfunction as well as in research which rejects it. Ellis and Oscar-Berman (1989) commented on a study where right hemisphere damaged subjects and alcoholics were compared with respect to the presence or absence of a left-sided neglect, which is normally considered an indication of right parietal damage (Bertera & Parsons, 1978). Since neglect was found to be absent in the alcoholic subjects, it was concluded that a hypothesis of right hemisphere dysfunction could not be supported. However, the presence of left-sided neglect is considered a sufficient but not a necessary condition to infer right sided brain damage and therefore, no conclusions can be made from the absence of this disorder. If any deficits exist, they are likely to be subtle and to be detectable only by comparison to normal subjects. This problem is compounded by the fact that cut-off scores are often used in neuropsychological practice to determine the absence or presence of a deficit. This practice is inappropriate for normal older subjects as their scores may be above the cut-off score but still significantly below that of younger subjects. Therefore, comparisons with brain-damaged populations are not likely to help in clarifying the nature of the dysfunction in the elderly.

Another problem concerns the comparability of the tasks used to assess right hemisphere and left hemisphere functioning. As mentioned previously, it is possible that tests that are used for one side are generally better discriminators than those used for the other side. Another reason why right and left hemisphere tests are not comparable is because of the very different nature of the tasks. The majority of left hemisphere tasks involve language and even those that appear to tap into other non-language functions (such as right-left discrimination or arithmetic) probably make use of some form of language processing. In general, neuropsychological studies of hemispheric functioning in the elderly are plagued with the same inferential difficulties that are seen in research on cognition in the elderly. In neuropsychological research as well as in studies on cognition, deficits that are found cannot be unequivocally attributed to a lack in the ability being tested. Moreover, many left hemisphere tasks tap into overlearned material which may be more resistant to the effect of aging or disease. So-called right-hemisphere tasks on the other hand, may require complex problem-solving skills or the ability to use task-specific strategies, in which the elderly have been found to be deficient (Salthouse, 1982).

In general, clinical neuropsychological research is limited in its potential to break new ground in this area. It can provide adequate descriptive accounts of deficits in the elderly and certainly characterizations of the elderly as showing frontal type deficits or right-sided deficits are probably equally valid. However, this type of research cannot confirm or disconfirm specific hypotheses concerning brain functioning in the elderly.

Experimental Studies of Lateral Dominance

Dichotic Listening

Hemispheric functioning in the elderly has been studied using methods of experimental psychology such as dichotic listening, and dihapctic stimulation. In 1973, Clark and Knowles used a dichotic listening task with subjects aged from 15 to 74 and examined the effects of age, ear of presentation, order of recall (1st or 2nd set of digits) and type of recall (oral or written report of digits) on their performance. Age had a significant effect on performance with the older groups performing worse than the younger. There was also a significant main effect of order of recall with performance being worse on the 2nd set than on the first. However, there was no interaction between age and order of recall, indicating no differential loss on the 2nd set of digits in the elderly. There was also a main effect of type of recall with more digits being remembered with written report. Again there was no age x type of recall interaction. These results seem to indicate that memory factors are not involved in the loss of accuracy seen in the older subjects. Ear of presentation had a significant main effect, with more items being recalled from the right ear than the left. In this case, however, there was an interaction of Age x Ear where the older group showed decreased accuracy in the left ear compared to the younger group. Thus, while the left hemisphere remained dominant for the older group, it appeared that the right hemisphere had lost some of its processing ability. This decrease could be interpreted as a diminished processing capacity for digits in the right hemisphere. However, the

validity of the study can be questioned since the authors did not verify the handedness of their subjects.

Shonfield, Trueman and Kline (1972) used dichotic listening with a sample of older subjects. In order to reduce the memory demands of the task, they used a recognition paradigm instead of the normal recall technique. The purpose of the study was to show that dichotic listening, when used with recall, tends to underestimate the processing capacity of aged subjects. The sample consisted of ten subjects in each of the decades from 20 to 50 and 60 and over. The variables of interest were age, ear, and first/second set of digits. There was a significant age effect in that there was an overall drop in accuracy with increasing age. They also obtained a significant effect for 1st/2nd set but no age x set interaction indicating that the older groups were not more influenced by the order of recall than the younger groups. There was, however, a significant age x ear interaction where the older people had higher right ear scores thereby increasing the discrepancy between right ear scores and left ear scores. The authors suggested that the lower accuracy in the left ear could be due to selective hearing loss and emphasized the need to reinterpret results of dichotic listening in terms of perceptual losses and not processing limitations. This study has been quoted by some researchers (Clark & Knowles, 1973; Johnson et al., 1979) as evidence for a loss in right hemisphere capacity notwithstanding the fact that the authors made no such claim themselves. Such an interpretation is not in fact, warranted. While there was a significant age x ear effect, there was no simple effect of ear of presentation in the younger group. This goes against most findings

obtained in dichotic listening which show a right ear advantage for verbal material (Bryden, 1982). This is not surprising, however, in light of the small number of subjects in each age group and the fact that the handedness of the subjects was not controlled for.

Elias and Elias (1976) presented their subjects (aged 17 to 77) with successive tones and words to be matched and examined the effect of age, sex and type of stimuli. They found that matching time increased with age (for words and tones) and also that reaction times were slower for tones than for words in all age groups. However, there was no interaction between age and type of stimuli, the difference in response time on the matching of tones (a right hemisphere task) and the matching of words (a left hemisphere task) not being greater in the older group than in the younger. This would appear to indicate unimpaired processing in the right hemisphere. However, since there was no comparison made between the two ears of presentation, it is not known to what extent the two tasks represent a valid measure of hemispheric preferences.

Johnson et al. (1979) presented subjects aged 44 to 79 years with dichotic digits in one task and, in a second task, with dichotic musical patterns that had to be identified. They found that the older subjects performed worse than the younger in reporting dichotic digits but that the decline was mostly in left ear performance. There was in fact no decline in right ear material. This would appear to support a right hemisphere dysfunction hypothesis. In the second experiment, where the subjects had to recognize musical notes, there was again a significant age trend but no difference between ear of presentation was found in any of the groups. The absence of an ear effect is in contrast with numerous

reports (Bradshaw & Nettleton, 1981) showing that musical stimuli are predominantly processed in the right hemisphere. However, musical stimuli can sometimes be processed in the left hemisphere and this is especially true of trained musicians who tend to process music sequentially and analytically (Bryden, 1982). Therefore, lack of control of musical training in the subjects may have confounded these results. Nevertheless, the older subjects did show a decrease in left ear reports of dichotic digits while for musical stimuli there was a decrease in both ears compared to younger subjects. These results are therefore consonant with a hypothesis of an underactivated or inefficient right hemisphere.

Borod and Goodglass (1980) also looked at the processing of verbal and musical stimuli by presenting their subjects aged 24 to 79 with musical tones to be matched and digits to recall. They found a significant right ear advantage for digits and left ear advantage for tunes. There was also a main effect of age where scores decreased with age for digits and tunes. There was no ear x age interaction in this task. The authors concluded that there was no greater impairment of the left ear in either task and therefore, that the hypothesis of right hemisphere dysfunction in the elderly could not be supported. They attributed the discrepancy between their results and those of other studies to the fact that they had performed an audiological screening of their subjects in order to verify their hearing capacity. In a later study, Borod, Obler, Albert and Stiefel (1983) assessed the perception of pure tones by male and female subjects aged 24 to 84 and found the right ear to be consistently superior in males and that this right ear

superiority in males increased with age. They concluded that the increase in right ear involvement in older subjects found in some earlier studies was likely due to differential hearing capacity in the two ears.

Ellis (1987) compared three age groups (25 to 39, 40 to 54 and 55 to 69) on their performance with dichotic stimulation. He used dichotic presentation of phonemes in one task to test left hemisphere processing and a task of tonal pattern discrimination for the right hemisphere. Perceptual laterality effects did not differ according to age in spite of the fact that neuropsychological testing had shown a selective decline in nonverbal abilities in the same subjects. Ellis concluded that nonverbal skills may be more vulnerable to the effects of aging but that functional asymmetries remain the same. However, these older subjects may have been too young to show any differences.

Hatta, Yamamoto & Mito (1984) presented elderly subjects (aged 65 to 91 years) and university students with dichotic digits. The results indicated a decline of scores in the aged subjects but no interaction between the degree of ear advantage and the age of the subject. In this study, the age of the older group may have covered too wide a span to detect changes that happen only after the eight decade.

The significance of results obtained from dichotic listening is uncertain. There are many inconsistencies between studies regarding the age and characteristics of the subjects and the nature of the task. Such inconsistencies are sufficient to explain most of the discrepancies found. Nevertheless, dichotic listening may not be an appropriate method for investigating age effects in hemispheric functioning. In their

extensive review of laterality patterns in the aging population and in alcoholics, Ellis and Oscar-Berman (1989) commented on the lack of convincing evidence obtained from dichotic stimulation studies. They concluded that laterality patterns were unchanged in alcoholics and in aged subjects and therefore a right hemisphere hypothesis could not be supported. This conclusion, however, is based on the expectation that aged subjects should demonstrate effects similar to those seen in patients with right hemisphere lesions, more specifically effects such as (a) a specific impairment in processing certain types of nonverbal auditory material, (b) a degradation of the characteristic left ear advantage for such non-verbal stimuli, and (c) an enhancement of the right ear (left hemisphere) advantage for processing verbal information (page 137). However, it is unlikely that normal elderly subjects would demonstrate such systematic changes. Since the elderly are reported to experience difficulty with competing stimuli and speed of processing, dichotic stimulation can only emphasize these difficulties and obscure lateral differences. For example, Robin and Royer (1989) presented their elderly subjects (aged 67 to 79) and young subjects with rapid successive tones in both ears simultaneously. The subjects had to decide if a sound consisted of one or two tones. They found that the elderly group needed a longer interstimulus interval to perceive the stimuli as separate. Since the subjects had normal hearing thresholds, the authors concluded that the elderly were impaired in the ability to process information, independent of sensorineural hearing loss. However, since the stimuli were delivered to both ears simultaneously, it is not known if the subjects would have performed differently in the two ears. While

dichotic stimulation may serve to reveal hemispheric differences in younger populations by pushing the brain to its ultimate capacity, it may by the same token also serve to obscure these differences in an elderly population. Unfortunately, absolute level of accuracy is not usually revealed in dichotic listening studies, making it impossible to evaluate the impact of floor or ceiling effects in the various groups tested.

Pointing to the numerous methodological flaws that are present in the above studies, Ellis and Oscar-Berman concluded that the hypothesis of right hemisphere dysfunction could not be supported. It is instructive to cite these authors on this matter: "Many of the studies reviewed here were unable to resolve the basic issues being addressed because they failed to show laterality effects in the control subjects or because the variance associated with laterality scores was too large to make group comparisons practicable. Without robust and stable asymmetries in normal controls, differential laterality effects across groups are virtually uninterpretable. Stimulus materials must be chosen so that they are easily manipulable [...] and possess fairly few dimensions, thus simplifying interpretation" (p.142). Ellis and Oscar-Berman have a valid argument but, to the defense of a right hemisphere hypothesis, similar methodological flaws are to be found in studies that report unchanged laterality patterns in the aged subjects as well as in those that report altered patterns.

Emotional Expression and Perception

Several studies point to the involvement of the right hemisphere in the perception and expression of emotion in normal populations (Borod & Caron, 1980; Suberi & McKeever, 1977; Ley & Bryden, 1979; Heller & Levy, 1981; Dekosky, Heilman, Bowers & Valenstein, 1980). Moreno (1987) examined the expression and perception of facial emotions in women aged 21 to 81 years. Since the emotional expressions of the women were judged to be more intense on the left side of the face, this was interpreted as indicating a right hemisphere dominance for emotional expression in all age groups. Older women expressed emotions as intensely as younger women but their productions were less accurate than those of their younger counterparts. For the perception of emotions, elderly women were also less accurate than the younger women. These results may be related to other findings showing deficits of facial recognition in the elderly (Benton, Eslinger & Damasio, 1981; Smith & Winograd, 1978; Ferris, Crook, Clark, McCarthy & Rae, 1980; Bartlett, Leslie, Tubbs and Fulton, 1989). However, the interpretability of the results of this study is reduced by the lack of comparison with another task measuring a different aspect of perception.

Tactual Perception

Another line of evidence for a possible dysfunction of the right hemisphere in the elderly is found in studies on tactual perception in the elderly. One commonly reported phenomenon is that the elderly perform differently compared to young or middle-aged groups on the Tactual Perception Test (TPT) (Goldstein & Braun, 1974; Bak & Greene,

1980; Price, Fein & Feinberg, 1980; Moehle & Long, 1989). On the TPT test, the examinee, who is blindfolded, is asked to fit blocks of wood of various shapes into the proper hole on a board. The dominant hand is tested first, followed by the non-dominant hand. The blindfold is then removed and, with the blocks and board removed from sight, the examinee is asked to draw the blocks in their proper location. There is normally a 30 to 40% improvement in performance from the dominant hand to the non-dominant hand. Slower or unimproved performance in the 2nd trial with the non-dominant hand is usually taken as an indication of brain dysfunction. The TPT test is used as a test of shape perception and discrimination and is presumed to be a right hemisphere task (Reitan, 1955; Lezak, 1976).

Goldstein and Braun (1974) compared groups from each decade from age 20 to 79 on the various measures of the TPT. They found a gradual increase in the number of reversals (slower performance in the left hand or no improvement) with increasing age. Bak and Greene (1980) compared two groups of older adults (50 to 60 years old and 67 to 86 years old) on several measures of the Halstead-Reitan Battery, including the TPT. On the TPT, the older group had significantly poorer scores for right hand performance, left hand performance and bimanual performance but were equal to the younger group on the Memory and Location subtests. It is not known from the data presented whether the older group showed significantly less improvement in the left hand than the younger group. However, the results do show that the poorer performance of the older group on the 1st and 2nd trial is not related to poor spatial memory. Price, Fein and Feinberg (1980) tested elderly retired teachers with the

TPT and found that 63% of the elderly fell in the impaired category when the right hand was tested and 89.8% when the left hand was tested. However, in the memory of block shapes and location of blocks on board subtests this rate fell to 12% and 77% respectively. They also identified a subgroup whose level of improvement from the right hand to the left hand was much lower than expected. They matched this subgroup to subjects whose improvement level was considered normal (39 percent improvement). They found these groups to be not significantly different on the Memory for blocks subtest. However, on a test of spatial organization, the impaired subjects had a significantly poorer performance than the normal group. The inferior left hand performance in this impaired group would seem to be related to poor visual-spatial skills and not to poor memory.

While the performance of the elderly on the TPT is interesting, it remains difficult to interpret. Several skills come into play in performing the TPT and they are not easily teased apart. The testing procedure tends to further complicate the picture. While the right hand is usually tested first, the left hand should in fact be dominant for this particular task since tactile perception is regarded as a right hemisphere task. Therefore, poor performance in the left hand could be due to faulty or slow processing in the right hemisphere or to inefficient transfer of learning from the right to the left hand. Had some of the subjects been tested in the reverse order (with the left hand first and right hand second) it would have been possible to ascertain the role of transfer of learning. Since all the subjects in

these studies were tested following the same sequence, no certain interpretation can be made concerning differences between the hands.

Two other studies measured tactual memory and tactual recognition in the elderly. Riege, Metter and Williams (1980) tested subjects aged from 20 to 85 on their ability to recognize previously explored wire shapes from an array of different shapes. They found a progressive decline in tactual recognition with age although groups had to be separated by 30 years in order for a difference to be significant. In all but the oldest group, more correct recognitions were made with the left hand (indicating right hemisphere dominance) but this difference diminished with age such that in the older group (from 70 to 84 years old) there was no difference between left and right hand performance. Hatta, Yamamoto and Mito (1984), using a similar procedure, obtained results that were inconsistent with these. They presented elderly subjects (aged 65 to 91) and undergraduate subjects with nonsense tactile stimuli and the subjects had to decide if successive stimuli were identical or not. Reaction times were longer and accuracy was inferior in the older subjects but there was no interaction between hand of response and age. The difference in results may have been due to the fact that in Riege et al.'s experiment, subjects had to memorize the shape of four different stimuli and after an interval had to recognize the four previously explored shapes from distractor shapes that were presented successively. In Hatta et al.'s experiment, stimuli had to be identified immediately after exploration. Thus, memory factors and the possible interference between stimuli may have played a significant role in Riege et al.'s experiment. Another source of difference is that Hatta

et al. presented the stimuli in a monohaptic fashion. As suggested by Witelson (1974), it may be necessary to use dihaptic presentation in order to obtain differential hand effects in tasks of tactual perception.

Motor Skills

Weller and Latimer-Sayer (1985) used a modified pegboard test to measure motor skills in elderly subjects. In this task, the subjects had to move the pegs (which had one painted end) from the top section of the pegboard to the bottom section while turning them over as they went, using each hand individually first and then both hands together. They found a positive correlation between age and time taken to complete the task with both the left hand and the right hand. They also found that as age increased, left hand completion time increased more than right hand completion time. Thus, the advantage of the right hand increased with age. However, the effect was partially obscured by the fact that the older group benefited more from practice with the left hand than did the younger group. Meudell and Greenhalgh (1987) tested the hypothesis of decreasing left hand skills in the elderly using accuracy of performance as a measure instead of speed of performance. They used the Square Tracing Test and the Fair Ground Test, two tests which measure visuo-motor coordination without speed requirements. In order to be able to compare with a speeded test, they also included the Modified Pegboard Test used by Weller and Latimer-Sayer. They found no selective deterioration of left-hand skills in the older group as there was no interaction of age x hand on the Square Tracing Test and the Fair Ground

Test. However, there was a significant difference in left hand performance on the Pegboard Test. The older subjects showed a greater increase in left hand time taken to complete the task and there was an hand x age interaction although the effect was small. These results are therefore consistent with those of Weller and Latimer-Sayer.

This small number of studies suggests the possibility of greater deterioration of left hand motor skills. However, the inconsistency of the results point to the fact that there are probably several confounding factors at play such as the effect of practice and the differential effects of speed and accuracy requirements. It may be that the elderly improve more with practice in motor tasks so that initial performance does not represent maximal performance. It is also possible that skills that are acquired later or less practiced in one hand may be more vulnerable to the loss of speed which accompanies aging. However, this explanation is not consistent with results indicating decreased tactual perception in the left hand in spite of the fact that the left hand is assumed to be superior for somatosensory perception. It is also possible that motor deficits are only seen when speed requirements are present. In general, studies using motor or somatosensory tasks show promise in the study of hemispheric dysfunction in the elderly but they need to be refined in order to allow for more conclusive interpretations. For example, speed and memory requirements need to be minimized and if tactual tasks are to be used, simultaneous stimulation in both hands is probably necessary in order to tap into hemispheric differences.

Reaction Time Studies

Rastatter and Lawson-Brill (1987) examined hand reaction times of aged subjects in response to linguistic stimuli presented to the left and right ears. The purpose of the study was to assess the degree of involvement of the right hemisphere in processing linguistic stimuli. Rastatter and Lawson-Brill reasoned that if, as suggested by Brown and Jaffe (1975), the degree of lateralization of language functions to the left increases with age, this should be reflected in a decreased engagement of the right hemisphere during language processing. Findings from this study seem to indicate that this was the case.

Rastatter and Gallaher (1982) had previously found that when younger subjects are presented monaurally with linguistic stimuli to the left or right ears, the fastest responses are made when the right hand is responding to stimuli presented to the right ear. This would be due to the direct access to the left hemisphere from the right ear to the right hand. Slowest reaction times are obtained when the stimulus is presented to the left ear or when a left hand response is required. According to Rastatter and his colleagues, these increases in reaction times are too large to be accounted for by interhemispheric transmission time. Instead they propose that the right hemisphere possesses limited linguistic competence and thus, its engagement (either through left hand response or left ear stimulation) causes an increase in processing time. This explanation implies a model of lateralization where the right hemisphere possesses some language competence rather than a

strict lateralization model where language functions are sequestered in the left hemisphere.

Concerning the older subjects, it was hypothesized that due to the purported loss of efficiency of the right hemisphere, the between hand differences would increase in older subjects. This would happen if the right hemisphere continued to be engaged, albeit with reduced efficiency, in the processing of language stimuli. Older subjects (aged 70 to 75) were therefore presented with verbal stimuli monaurally and were required to respond with their left or right hand. Reaction times were found to be significantly faster when the stimuli were presented to the right ear regardless of the hand used for responding. According to Rastatter and Gallaher, this would suggest that in this aged group, the left hemisphere was solely responsible for the processing of linguistic stimuli. These results must be regarded with caution as the comparison with younger subjects was not made within this study but with previously acquired results.

In a more recent study, Rastatter and McGuire (1990) measured vocal reaction times in older subjects in response to tachistoscopic presentation of abstract, concrete and nonsense words. The subjects had to indicate if the presented stimulus was a word or not. As with younger subjects, there was a significant field effect, in that right visual field stimulation obtained faster responses than left visual field stimulation. However, unlike the younger subjects, the older subjects showed a significantly greater number of false positive errors in response to left visual field stimulation. According to the authors, this reflects the decay in the stimulus trace as it is relayed

cross-callosally to the left hemisphere in order to be processed. This would be consonant with a model of increasing dominance of the left hemisphere over language functions which was proposed by Brown and Jaffe (1975). Moreover, Rastatter and McGuire suggest that the left hemisphere's capacity for linguistic processing may be altered. In younger subjects, a significant interaction had been obtained between type of word (concrete or abstract) and field presentation, e.g. abstract words were processed faster than concrete words in the left hemisphere while the reverse was true in the right hemisphere where concrete words were processed faster than abstract words. With the older subjects, there was an equal number of errors with concrete or abstract words presented to either field. Rastatter and McGuire attribute the absence of the field by word type interaction in older subjects to an information overload of the left hemisphere. The authors refer to Salthouse's (1985) cycle-time theory which postulates that any operation requiring central resources will be slowed in aged subjects, thereby giving rise to a division of attention and to a partial processing of the material. If such a model applies, it is reasonable to assume that patterns of responding such as those found in younger adults may not survive. The findings from this study are interesting in that they have implications for left hemisphere functions as well as for right hemisphere functioning. While left sided dominance over language functions is still present, it would appear that the style of linguistic processing in the left hemisphere may nevertheless be affected. The results of this study are indicative of the complexity of changes which take place in aging. The inconsistency found in research on aging

probably reflects the fact that specific changes may be concurrent with more general alterations. However, one word of caution is necessary concerning the methodology used by Rastatter and colleagues. The validity of the methodology rests on the assumption that interhemispheric transfer time is a stable measure that can be reliably deducted from the total time taken for cognitive processing. However, this is not necessarily the case. St-John, Shields, Krahn and Timney (1987) found that vocal reaction times in response to information relayed transcallosally were not very reliable. There was no correlation between hand reaction times and voice reaction times in the same individuals and furthermore, reaction times in females were less reliable than those obtained in males. It is to be expected that in older subjects, results may vary appreciably and as a result, the effects obtained by Rastatter and colleagues may in fact be due to increased interhemispheric transfer time and not to increased processing time within the hemispheres. Hence, these findings must be regarded with caution.

Conclusions

In general, the evidence at this time to support the theory of selective right hemisphere losses in the elderly is not compelling. Inferential and methodological difficulties have already been discussed in relation to neuropsychological findings. Research in lateral hemispheric processing consists of attempts at using one methodology or another and replications are scarce. Nevertheless, there is an

undeniable tendency in the elderly to show more right-sided than left-sided deficits and there is as yet no adequate explanation of this phenomenon. However, partial explanations have been offered and I shall try to address these in the following discussion.

The Role of Language

It has been argued by some (Ellis & Oscar-Berman, 1989; Ellis, 1987; Goldstein & Shelly, 1981) that left hemisphere functions are better preserved because language functions may be less vulnerable to the effects of aging. The overlearned quality of language would appear to make it less susceptible to deterioration. This is certainly true with some forms of senile dementia where the automatic aspects of speech are preserved while most other functions are severely affected. However, most of language is not overlearned and it may be that with regards to the normal elderly, deficits could be found if the more subtle aspects of language functioning were to be investigated. There are some indications that this could be the case. Elderly subjects do not appear impaired compared to older patients who have suffered brain insults but compared to younger subjects they show a number of subtle language deficits. They are found to be impaired in the comprehension of metaphors, the production of analogies and the comprehension of humor and of inferences (Brownell, Letourneau, Bihrlé, Powelson & Gardner, 1985). It is interesting that those are precisely the language deficits that have been observed in patients with right-sided brain damage (Brownell, Potter & Bihrlé, 1986; Bihrlé, Brownell & Powelson, 1986; Gardner, Brownell, Wapner & Michelow, 1983). Finally, many older people complain of difficulties in the retrieval of words and this has

been substantiated by research evidence (Light, 1988; Howles & Poon, 1985; Goodglass, 1980). Hence, the preservation of language is not uniform and certainly does not apply to some of the language functions for which the integrity of the right hemisphere is considered to be important.

Task Demands

Task characteristics such as novelty and complexity or the need to use a strategy to perform the task have been invoked as reasons why older people do not perform as well with "right hemisphere" tasks as with "left hemisphere" tasks (Ellis & Oscar-Berman, 1989). This is a reasonable argument in relation to many of the cognitive tasks that are used in research on aging. Also, many of the findings from clinical neuropsychological research could probably be accounted for in this manner. However, results obtained from studies of lateral dominance cannot be so dismissed. Techniques such as dichotic listening, tachistoscopic viewing, and dihapic stimulation equalize the difficulty of the task across the hemispheres and consequently, age by hemisphere interactions can be more readily attributed to differential hemispheric capacity or competence. Finally, some of the other right hemisphere deficits that are found in the elderly, such as deficits of facial recognition and emotional perception and expression, are in tasks that are neither novel nor complex and that are certainly well-practiced throughout the life-span.

The Frontal Hypothesis

Several researchers have suggested that the specific pattern of cognitive changes seen in the elderly is the expression of frontal deficits (Mittenberg, 1987; Ellis & Oscar-Berman, 1989; Hochanadel & Caplan, 1984; Craik, Morris, Morris & Loewen, 1990). There is superficial evidence that the frontal lobes may be selectively affected by neurobiological aging processes such as cortical atrophy and neuronal loss. However, as previously mentioned, the relationship between both cortical atrophy and neuronal loss and degree of cognitive deterioration is uncertain. There are other aging processes which do not appear to affect the frontal lobes in a differential manner (Valenstein, 1981).

There is still much controversy regarding whether aging subjects are predominantly impaired in frontal functions. Boone, Miller, Lesser, Hill et al (1990) found that older subjects were not more impaired on tests of frontal functioning than on other tests with localizing ability. Hochanadel (1991) administered 25 tests of neuropsychological functioning to 42 elderly subjects. An error-analysis approach was used to classify errors as indicative of right, left or frontal dysfunction. There was an age-related increase in errors indicative of frontal dysfunction. However, there was also a right side effect for males but not for females. The age at which the changes appeared was also different for men and women, the effects appearing later in women than in men. It appears that the question of frontal deficits is far from resolved and that factors such as gender may interact with the type of deficits found in older subjects. Tests that are used to assess frontal functions (such as the Wisconsin Card Sort, the Trail Making Test, the

Stroop Color Word Test) are notoriously sensitive to fatigue, degree of arousal, speed of response, etc. It is possible that, if the subjects tested are old enough to have difficulty with attention demanding tasks, then, in all likelihood, frontal deficits will be found.

The influence of gender

It has been known for some time (Bryden, 1982) that men and women differ significantly in the laterality patterns shown in tasks such as dichotic listening, dihapic perception and other experimental neuropsychological tasks. Women have generally exhibited smaller hemispheric differences and this has been interpreted as an indication that women's neuronal organization may be more diffuse than men's. However, in research on aging, few studies have specifically addressed the issue of the possible influence of gender on changes due to aging. While several studies have included males and females in the sample, few of these studies have looked for possible interactions between sex and age (with Hochanadel, 1991, being a notable exception). In light of Hochanadel's recent results, one may speculate that the lack of consistency regarding laterality changes in the aged could be due to the failure to analyze the effect of gender in a systematic manner.

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Rationale

The purpose of the present study was to assess hemispheric activity in three groups of older subjects by using two tasks which are thought to involve one or the other hemisphere preferentially. The first task involves the perception and recognition of nonsense shapes presented to both hands simultaneously. The second task requires the subjects to tap to two different rhythms simultaneously with the two hands.

The first task is based on reports in the experimental neuropsychological literature of better left than right hand performance in tasks of a tactile-spatial nature, specifically tactile perception and discrimination of shapes and tactile perception of line orientation (Corkin, 1979). These findings have been obtained with commissurotomed patients (Milner & Taylor, 1972) as well as with normal subjects (Dodds, 1978; Gardner, English, Flannery, Hartnett, McCormick & Wilhelmy, 1977; Flannery & Balling, 1979). These hand differences have generally been found to be larger or easier to obtain when stimuli are presented dihaptically rather than monohaptically (Witelson, 1974; Webster & Thurber, 1978). In addition, the effects are influenced by the strategy used to process the stimuli (i.e., holistic vs. sequential), associative value of the stimuli (whether it permits verbal labeling or not), hand used for recognition (same or different from that used for exploration), mode of response (vocal, visual or tactile) and length of interval from exposure to recognition testing (Hannay & Smith, 1979; Gardner et al. 1977; Denes & Spinacci, 1981). Analogous factors influence performance asymmetries in other competing stimulus paradigms like dichotic

listening and tachistoscopic recognition performance (Bryden, 1982) and so, not surprisingly, the reliability coefficients for somesthetic tasks are comparable to those obtained for these other paradigms (Varney, 1986). In this study, young controls and older subjects were tested dihaptically with nonsense shapes which they had to first feel and then discriminate from one another. It was expected that a left hand advantage would be obtained in younger subjects but that in older subjects this advantage would be attenuated or possibly even be reversed. It was felt that this task would be suitable for older subjects, as it contains relatively few dimensions (it is a simple recognition paradigm) and certain features (e.g. palpation time) can be easily manipulated to accomodate older subjects. Furthermore, such a task would help to clarify the issue of deficits in visual-spatial analysis in the elderly. Because the paradigm involves between-hand comparisons, this allows for a more refined analysis i.e. whether the deficits found in visual-spatial analysis are global in nature or more specifically related to the performance of one hand, namely the left hand.

The second task built upon reports in the literature of motor performance asymmetries between the hands that may reflect differential hemispheric activation or attention. Peters (1987) developed a task called 2:1 tapping in which the subjects tap a key twice with one hand for every tap by the other hand. He found that right-handers are better at this task when it is the right hand that is leading (tapping twice) and the left hand following (tapping once) than when it is the left hand that is leading. In contrast, left handers were found to have equal

facility performing with either hand leading. This pattern of results has been replicated by Webster (1990). Peters argued that the performance asymmetry of right-handers cannot be attributed to differential practice effects by the two hands. He claims that this asymmetry reflects a left hemisphere activation bias in right handers that is lacking in left handers. In right handers, the activation of the left hemisphere biases attention to the right body space, and this bias facilitates performance when the right hand is leading. In left handers, attention can be directed with equal facility to either lead hand. This account is similar to Kinsbourne's theory of selective attention which suggests that right handers focus attention in the right body space, thereby privileging left hemisphere processes (Kinsbourne, 1977). This interpretation of the left handers' performance is also in accordance with Annett's (1978) model of handedness which states that left handers lack the gene which predisposes right handers to a rightward shift. This task was considered to be suitable for testing older subjects as there are few dimensions to the task and speed requirements are minimal. Furthermore, because the influence of practice (and especially differential practice of the left hand) on such a task is assumed to be minimal, it was felt that the task would be particularly suitable for testing a hypothesis concerning age-related changes in hemispheric activation.

According to Peters' interpretation, if there were decreased activation of the right hemisphere with aging, one would expect to see the directional bias in 2:1 performance augmented. Performance when the

right hand in leading may remain stable in older subjects but performance when the left is leading should decline with age.

In summary, the hypothesis predicted opposite changes with age in the two tasks. On the dihaptic task, hand differences were expected to decline with increasing age, while on the 2:1 tapping task, hand differences were expected to increase with age. The two tasks were chosen for three main reasons: first, it was felt that the two tasks would be ecologically valid for both old and young subjects; second, since the rationale of the two tasks is based on within-subject comparisons, a more refined analysis of the deficits found is possible and third, the two tasks can be used as controls for one another (because opposite effects are expected in the two tasks), thereby making the results more solid and more readily interpretable.

As mentioned in the review of the literature, gender may have a notable influence on laterality changes with aging. Furthermore, males and females have been found to perform differentially in several tasks involving lateral preferences (Cioffi & Kandel, 1979; Flanery and Balling, 1979; Dawson, 1981; Lenhart and Schwartz, 1983). For this reason, equal numbers of males and females were included in each group and the influence of the gender variable was specifically analyzed.

In the first phase of the study, undergraduate subjects were tested and their performance analyzed to ensure that the expected hand effects could indeed be obtained in both tasks. In the second phase of the study, three older groups were tested and their performance compared to that of the younger subjects.

METHOD

Subjects

Four groups of subjects were included in the study. Group 1 consisted of sixteen right-handed undergraduate students (8 males and 8 females) between the ages of 18 and 30 years. They had been recruited from the university's introductory psychology course. The remaining three groups (groups 2, 3 and 4) were older subjects between the ages of 55 and 86 years. Sixteen subjects were from each of three decades: 55 to 64 , 65 to 74, and 75 and over with an equal number of males and females in each group.

The subjects in the three older groups had previously been participants in a study on the neurophysiological correlates of normal aging carried out at the Ottawa General Hospital. They were non-institutionalized, socially and physically active and had been recruited from a number of volunteer organizations.

The older subjects had been screened on the following criteria:

1. evidence of neurological illness in self-reported history and neurological examination;
2. evidence of generalized cognitive deficits (a score of less than 24 on the hospital's test of mental status) or of cognitive difficulties severe enough to warrant medical attention.

Left handed individuals were excluded from the study. The Edinburgh Handedness Inventory (Oldfield, 1971) was used to confirm self-reported right handedness (see Appendix A). A questionnaire was also administered to all subjects to ensure that no subject suffered from conditions that could impair intellectual or motor functions (i.e.

severe arthritis, kidney dysfunction, heart disease, neurological dysfunction) (see Appendix B). The questionnaire included questions designed to measure the degree of musical training of the subjects to allow for the exclusion of anyone with extensive musical instrument training. One subject was excluded for this reason.

A test of sensitivity to light pressure was administered to subjects in all groups to ensure that somatosensory functions were intact. Von Frey hairs were applied to the inside tips of the index and middle fingers of both hands. All subjects in the final sample had scores of 4 or less in both hands and both fingers indicating adequate sensitivity (Lezak, 1976) and therefore none was excluded on this criterion.

Because the two tasks included a minimum performance criterion, some subjects had to be eliminated from the study. Other subjects could not be included because they had failed to follow the instructions or could not understand the nature of the task. Furthermore, the subjects had to be successful in both tasks in order to be included in the sample. As a result, 35 percent of the subjects first tested in Group 4 could not be included in the final sample. In groups 2 and 3 however, the number of eliminated subjects was minimal and in Group 1, all the subjects tested were included in the final sample.

Table I summarizes some of the characteristics of the subjects: age, number of years of education, and score on the Handedness Edinburgh Inventory. The mean age was 24.0 for the younger group (Group 1), 61.3 for the 55 to 64 year old group (Group 2), 69.8 for the 65-74 (Group 3) and 78.6 for the oldest group (Group 4). Within each

group, there was no significant difference in the ages of males and females. Scores on the Edinburgh Handedness Inventory were analyzed with a two-way analysis of variance (with Age Group and Sex as factors) and no significant differences were found.

For the number of years of education, there was a significant effect of the Age group: $F(3,62) = 3.11, p < .05$ and of Sex: $F(1,62) = 4.28, p < .05$. The number of years of education decreased with age and was smaller in female subjects compared to males. However, correlational analyses indicated that number of years of education was not related to any of the dependent variables.

Table 1
Subject characteristics

Group	Sex	N	Age		Handedness (E. H. Q.)		Education (Number of years)	
			Range	Mean	Range	Mean	Range	Mean
1 (students)								
	M	8	20-30	23.0	.53-1.00	.79	15-17	16.4
	F	8	21-42	25.1	.33-1.00	.75	13-19	15.6
2 (middle-aged)								
	M	8	59-64	61.5	.47-1.00	.72	12-20	15.2
	F	8	57-64	61.0	.47-1.00	.76	11-18	14.8
3 (older)								
	M	8	65-74	68.9	.66-.91	.81	13-17	15.8
	F	8	68-74	70.8	.60-1.00	.74	13-19	14.9
4 (oldest)								
	M	8	75-86	79.6	.50-1.00	.85	12-20	14.6
	F	8	75-81	77.5	.71-.91	.83	09-16	12.3

Dihaptic Stimulation

Materials

Twenty nonsense shapes identical to those used by Flanery and Balling (1979) were used. All the stimuli had five or six sides and none could be easily labeled. The shapes were made of white rigid styrofoam board that was 1/2 cm thick and covered with a thin protective plastic film. They were glued in the center of rigid cardboard cards.

To prevent the subject from seeing the shapes, the hands were placed inside a curtained box. The box was open-ended allowing the experimenter to slide the stimuli from the back while the subject's hands rested inside the box. The floor of the box contained two frames into which the cards fit neatly thereby preventing movement of the shapes under the subjects' hands. The box which measured 36 x 28 x 23 cms was made of styrofoam board and its front was covered with a curtain allowing easy passage of the subject's hands.

For each subject, five pairs of forms were randomly selected as targets from the original set of 20 forms. The order of the shapes within the pairs was then reversed so as to obtain a total of 10 pairs to be presented dihaptically. Each pair was presented once when the recognition shape was identical and once when it was different, for each of the two hands. Thus, each pair of shapes was presented four times so as to obtain a total of 40 dihaptic trials. The recognition shapes in non-identical trials were randomly chosen from the remaining 10 shapes which had not been selected as stimuli shapes. The 40 trials were then randomly ordered for each subject, the only restriction being that the same two shapes were never presented in successive trials. Therefore, each subject received a unique combination of shapes and order of trials. The subjects were presented, in total, with 20 left hand trials and 20 right hand trials, half of which were identical trials and the other half non-identical trials.

Procedure

After being seated in front of the stimulus box and given a description of the task, the subjects were given two sample trials. They

were presented with two different shapes (one to each hand) and told to feel the shapes with their index and middle finger held together. It was emphasized that they should feel the two shapes simultaneously. They were allowed to feel the stimuli as long as they wished. The shapes were then removed and a single shape was presented to one of the two hands. The subject then had to make a decision regarding whether the shape presented to the one hand was identical or different compared to the shape that had previously been presented to that same hand. It was suggested that the best way to perform the task was to try to visualize or form a mental picture of the shapes. In one sample trial, the shapes were different and in the other, they were the same.

After the two sample trials, the subjects were shown some examples of shapes or combination of shapes which they would encounter. They were told that they would not be asked to compare two shapes which were mirror-images of one another or shapes that were identical but for their orientation. The subjects were then given six practice trials during which they received feedback about their performance. The subjects were given 10 seconds to feel the two stimuli shapes. The shapes were then removed and the experimenter presented the recognition shape to one of the two hands after lightly tapping on that hand to indicate that the shape would be presented to it. After five seconds, the shape was removed and the subject was asked to make a response; the subject was free, however, to respond before the five seconds were over. Verbatim instructions are found in Appendix C.

After the practice trials, the 40 experimental trials were started following the same procedure as for the practice trials. A

brief pause was introduced after 20 trials and older subjects were offered refreshments before resuming the task. Following completion of the task, the subjects were interviewed concerning the technique(s) which they may have used to perform the task. Their responses were recorded on a standard form designed for that purpose. (see Appendix D)

Dependent variables

The dependent variable was the number of correct responses in each hand, the maximum possible score being 20.

Two-One Tapping

Apparatus

The finger tap apparatus was similar to that used by Peters (1987) and Webster (1990). Two levers connected to microswitches were mounted 25 cm apart in a wooden base. The microswitches are connected to a multichannel event recorder which would be activated by the experimenter for each trial. A brief tone signaled the beginning of each trial and the recording stopped automatically after 10 seconds. Each tap was indicated by a pen deflection on the recording tape.

Procedure

Two-One Tapping

The two-one tapping task, being much shorter in duration than the dihaptic stimulation task, was always presented first to the subjects. The instructions given to the subjects were similar to those described in Peters (1987). Subjects were told that correct performance

consists of tapping with the two hands together once and then tapping with the leading hand once again alone. Faulty performance was defined as omitted or extra taps. The subjects were familiarized with the task with a demonstration by the experimenter and were allowed to practice for a few seconds in each hand. It was emphasized that they should try to tap as quickly as possible while avoiding making errors and that they should slow down if they started to make mistakes.

There were four blocks of two trials for each hand with each trial lasting 10 seconds. Half the subjects in each group received testing in the first block with the right hand leading and the other half started with the left hand leading. Subsequent blocks alternated between the right and the left hand leading. The subjects were told that, should they make a mistake the trial would be stopped and they would be instructed to start a new trial. The subjects had to produce at least one correct trial for each block. Subjects who could not produce one correct trial after four incorrect trials were eliminated from the study.

The first dependent variable for this task was the average rate of tapping in the correct trials in each block for each hand. Consequently, there were four repeated measures per hand (one measure per block). The second variable was a measure of accuracy obtained by calculating the ratio of total number of trials (correct and incorrect trials over four blocks) to number of correct trials over four blocks.

Simple Tapping

Since older subjects are known to show slowing in manual and motor tasks (Lezak, 1976), simple tapping rate (with the index finger) was also obtained for each hand. Two trials of 10 seconds each were taken for each hand, alternating between the hands for each trial. Subjects were asked to tap as fast as possible without stopping for the duration of the trial. The dependent measure was the number of taps produced in each hand during a 10 second trial, averaged over two trials.

Alternate Tapping

Two-one tapping requires coordination between the two hands and this aspect of the task could prove difficult for elderly subjects. For this reason, alternate tapping (tapping with the index finger, alternating between the hands) was measured with two trials of 10 seconds each. Subjects were told to tap as fast as they could while maintaining the alternation. The dependent measure was the number of taps produced by both hands averaged over two trials.

Appendix E contains the verbatim instructions for the three tapping tasks.

RESULTS

Dihaptic Stimulation

The subjects were presented in this task with pairs of nonsense shapes which they had to explore simultaneously and then compare one of the stimuli shapes to a recognition shape presented to the same hand. The accuracy of performance when tested with each of the two hands was then compared.

Young Controls

The mean accuracy scores for the right and left hand of the male and female subjects of Group 1 are shown in Table 2, along with corresponding data reported by Flanery and Balling (1979) for similar subjects.

The data from the present experiment were analyzed using a 2 (Recognition Hand) by 2 (Sex) analysis of variance. Comparison of these means shows that the results from the present study were almost identical to those obtained by Flanery and Balling.

Table 2
Accuracy scores obtained with the right and left hand of
undergraduate subjects in the Dihaptic Stimulation Task

Obtained in the present study

Group	Sex	N	Left hand		Right hand	
			Mean	S.D.	Mean	S.D.
1	M	8	18.50	1.51	16.87	1.45
	F	8	17.00	1.40	15.75	2.25
		16	17.75		16.31	

Reported in Flanery and Balling (1979) with similar subjects

M	8	18.90	17.00
F	8	17.40	16.40
		16	18.15
			16.70

Note: Maximum score is 20 in both studies.

A significant hand effect was obtained with the left hand performing at a higher level of accuracy than the right: $F(1,14) = 7.80$, $p < .02$. Thus, the left hand dominance in dihaptic perception and discrimination was confirmed with this group of subjects. Inspection of the means revealed that males performed better than females in both hands but the effect of Sex only approached significance: $F(1,14) = 3.81$, $p < .07$. This is also consistent with results from Flanery and Balling where males performed better than females although no significant sex differences were obtained.

Older Groups

Table 3 presents the means obtained by all four groups on the dihaptic stimulation task. An analysis of variance indicated a significant main effect of Age group: $F(3,56) = 4.56$, $p < .01$ with performance decreasing with age, and of Sex: $F(1,56) = 7.04$, $p < .01$

with males obtaining higher scores in both hands than females. There was no interaction of Age group and Sex indicating that males performed better than females in all age groups. There was no main effect of Hand but there was a significant interaction of Hand by Age group: $F(3,56) = 2.89$, $p < .05$.

Table 3

Accuracy scores for the left and right hand obtained by the four age groups in the Dihaptic Stimulation Task

Group	Sex	N	Left hand		Right hand	
			Mean	S.D.	Mean	S.D.
1 (students)	M	8	18.50	1.51	16.87	1.45
	F	8	17.00	1.40	15.75	2.25
		16	17.75		16.31	
2 (middle-aged)	M	8	17.00	1.51	15.75	2.54
	F	8	15.75	1.16	15.75	2.37
		16	16.37		15.75	
3 (older)	M	8	17.00	1.77	16.62	1.99
	F	8	15.62	2.19	14.62	1.92
		16	16.31		15.62	
4 (oldest)	M	8	14.50	2.20	16.00	2.20
	F	8	14.50	2.32	14.87	1.95
		16	14.50		15.43	

Separate analyses for the right hand and the left hand revealed that while there were no significant differences between the different groups in right hand performance there was a significant age effect in left hand performance: $F(3,56) = 2.89$, $p < .001$. Consequently, pairwise comparisons were carried out for left hand performance only. Only one

group. Group 4 (75 years old and over) performed at a significantly lower level of accuracy in the left hand compared to the control group. Group 2 and Group 3 were not significantly different from the control group or from one another. Thus, the age effect on the performance of the left hand can be attributed mostly to the lower performance of the oldest group. In fact, this group performed better using the right hand than the left hand although this difference only approached significance: $F(1,56) = 3.27, p < .07$. In summary, age had a significant effect on left hand performance but not on right hand performance, but this effect only appeared in subjects who were over 75 years old.

A chi-square analysis was carried out on the number of subjects in each group obtaining a left hand advantage, a right hand advantage, or equal scores using the two hands (see Table 4). Subjects were placed into right or left hand advantage groups if there was a difference of at least 1 between the scores of the two hands. Otherwise, they were classified in the equal hand group. A significant coefficient was obtained: Pearson $\chi^2(6 \text{ dfs}) = 13.66, p < .05$. The largest components were found in Group 1 (5.8) and Group 4 (6.9), the most important differences being found between those two groups. These results confirm those obtained from the analysis of variance and also highlight in a dramatic manner the differences among groups. Comparison of the frequencies for the different age groups shows that the proportions of subjects obtaining right hand and left hand advantages are neatly reversed from Group 1 to Group 4 with Group 2 and 3 occupying middle positions. While 75% of the controls obtained a left hand advantage,

only 44% of Group 2 and Group 3 and 19% of Group 4 obtained such an advantage. Right hand advantages were demonstrated by 12.5% of the controls, 25% of Group 2, 31% of Group 3 and 62.5% of Group 4. Therefore, a trend is clearly perceptible in these results.

Table 4

Frequencies of left and right hand advantages and equal hand performance in the dihaptic stimulation task in the four age groups

	Group 1 (students)	Group 2 (middle-aged)	Group 3 (older)	Group 4 (oldest)	Total
Left hand advantage	12	7	7	3	29
Right hand advantage	2	4	5	10	21
Equal hand performance	2	5	4	3	14
Total	16	16	16	16	64

Influence of Item Type

There are several reports (Potash & Jones, 1977; Dunziger & Botwinick, 1980) indicating that elderly subjects tend to exert more caution in tasks requiring decisions about the presence or absence of a stimulus and in tasks of discrimination between stimuli. In stimulus detection tasks, older subjects usually have a higher proportion of missed targets compared to false alarms. In tests of stimulus discrimination, elderly subjects are more cautious and tend to have more false negative answers compared to false positives. In order to ascertain that such an effect was not taking place, a separate analysis of variance was carried out to assess the effect of the type of item i.e. whether the stimuli presented in the item were different or

identical. A 4 (Age group) x 2 (Sex) x 2 (Hand) x 2 (Type of item) was used. These results are to be found in Table 5. As expected, the group effect as well as the sex effect were confirmed : $F(3,56) = 4.81$, $P < .005$ and $F(1,56) = 6.38$, $p < .02$ respectively. A hand by age group interaction was also obtained: $F(3,56) = 3.49$, $p < .05$. An effect approaching significance was found for Type of item: $F(1,56) = 2.98$, $p < .10$. Inspection of the means revealed that, in general, more errors were made in identical items. However, there was no interaction between Type of Item and Age group, indicating that the older subjects responded in a similar manner compared to the younger group on identical and different items.

Table 5
Accuracy scores obtained by all four groups on the positive and negative items of the Dihaptic stimulation task

Group	Sex	N	Negative Items		Positive Items	
			Mean	St.dev.	Mean	St.dev.
1 (students)	M	8	9.43	.69	8.24	1.54
	F	8	8.31	1.72	8.06	1.03
		16	8.87		8.15	
2 (middle-aged)	M	8	8.31	1.02	7.99	1.55
	F	8	8.25	1.51	7.50	1.22
		16	8.28		7.74	
3 (older)	M	8	8.43	1.33	8.37	1.10
	F	8	7.56	2.09	7.56	1.28
		16	7.99		7.96	
4 (oldest)	M	8	7.99	.96	7.12	1.76
	F	8	7.12	1.68	7.56	1.23
			7.55		7.34	

Influence of fatigue

Research on aging has also shown that older subjects are particularly vulnerable to the effects of fatigue. When the effect of fatigue is present, scores may vary across the duration of the task and accuracy may decrease towards the end of the task or in the second half of the task. For this reason, an analysis was carried out to ascertain the consistency of scores in the two hands between the first block of 20 trials and the second block. A 2 (Block) by 4 (Age group) analysis indicated no effect of 1st block/2nd block or any interactions with this factor. It would appear then, that the older subjects performed as well

in the second part of the task as in the first part and were comparable in this to the younger group. These results are in Table 6.

Table 6

Accuracy scores obtained in the first and second block of the
Dihaptic Stimulation Task (averaged over both hands)

Group	N	First Block		Second Block	
		Mean	St.dev.	Mean	St.dev
1	16	16.87	2.02	17.18	1.22
2	16	15.68	1.99	16.37	1.82
3	16	15.93	2.04	16.00	2.19
4	16	14.93	2.32	15.00	2.25
	64	15.85		16.14	

Correlational Analyses

In order to gain a better understanding of the performance of the older groups, a number of correlational analyses were performed using the older groups only. There was a positive but nonsignificant correlation (Pearson $r = .22$, $p < .10$) between the hand advantage obtained (right, left or equal) and combined accuracy in both hands in groups 2, 3 and 4 indicating that hand dominance was not related to total accuracy. This is similar to the correlation obtained for the same variables in the young controls ($r = .11$, $p > .10$). There was also no correlation ($r = -.045$, $p > .10$) between the size of the discrepancy between the hands and overall accuracy (in groups 2, 3 and 4 combined together) indicating that there was no floor or ceiling effect limiting the size of the discrepancy between the hands.

Since the number of years of education had been found to be significantly different in the various age groups, a correlation was calculated between the dependent variables and the number of years of education. No significant correlations were found between any of the variables and years of education.

Results of Debriefing

A debriefing session followed testing in order to find out if the subjects had used specific strategies to perform the task (see Appendix D). From the answers given, it appears that most of the subjects had used a variety of strategies i.e. visualization, verbal labelling, focusing on specific features, etc. Furthermore, a cursory analysis revealed that there was no systematic relationship between the strategy used and the hand advantage obtained by one individual. Moreover, there seem to be little relationship between the impression obtained by the subjects of their own performance (e.g. which hand had been superior, how well they had performed, etc.) and their actual performance. As a result, the information obtained from the debriefing was not formally analyzed.

Two-One Tapping

Young Controls

The first dependent measure was the tapping rate (the average number of taps produced in each block). These results, together with those reported by Webster (1990) for similar subjects are contained in Table 7. Visual inspection of the data reveals that the means from the two studies are very similar except for a slightly slower rate in the right hand leading condition in males in the present study compared to males in Webster's study.

Table 7

Tapping rates (number of taps per 10 second trial) obtained by undergraduate subjects when the left hand is leading and when the right hand is leading averaged over 4 blocks.

Obtained in the present study

Group	Sex	N	Left hand rate		Right hand rate	
			Mean	St.dev.	Mean	St.dev.
1	M	8	28.34	6.43	32.09	9.16
	F	8	27.67	6.64	29.67	7.78
		16	28.00		30.88	

Reported in Webster (1990) with similar subjects

	M	8	29.00		35.80	
	F	8	28.10		29.70	
		16	28.53		32.77	

A 2 x 2 x 2 x 4 analysis of variance was carried out with Lead hand, Sex, First hand tested and Block as factors. A significant Lead hand effect was obtained: $F(1,12) = 14.42, p < .005$ with faster tapping rates in the right hand leading condition than in the left hand

leading condition. There were no effects of Block or First hand tested indicating that practice had no effect, and that performance in the two conditions was not differentially affected by the order in which the two conditions had been tested. Although males performed better than females in both hands with both lead hand conditions, there was no effect of Sex and no Lead hand by Sex interaction. However, consistent with Webster's data, inspection of the means suggested smaller differences between the two hand conditions for females.

The second dependent measure was the ratio obtained by dividing the total number of trials attempted in one hand condition by the number of correct trials in that same hand condition. This ratio can vary from 1.00 to 4.00 (the maximum number of incorrect trials allowed in order to obtain one correct trial) and lower ratios mean more accurate performance. The ratios for the two lead hands are summarized in Table 6. Analysis of variance indicated that the results paralleled those obtained for tapping rate in that there was a significant Lead Hand effect: $F(1,14) = 7.67, p < .02$. There were no other significant factors and no interactions. These effects were similar to those obtained by Webster for a comparable measure (number of attempts to criterion). However, Webster obtained a significant sex effect with males requiring more attempts than females in order to reach the criterion. In the present case, males had more difficulty than females with the left hand leading but performed better than females in the right hand leading condition although this did not result in a significant Sex by Lead hand interaction (see Table 8).

Table 8

Ratios (ratio of total number of trials to number of correct trials when the left hand is leading and when the right hand is leading)

Group	Sex	N	Left hand ratio		Right hand ratio	
			Mean	St.dev.	Mean	St.dev.
1 (students)	M	8	1.78	.48	1.38	.33
	F	8	1.69	.53	1.53	.48
		16	1.74		1.45	

In summary, the effects reported by Peters (1987) and Webster (1990) have been replicated, confirming the stability of the paradigm.

Older Groups

Means and standard deviations obtained by the four groups on the first dependent measure (tapping rate) are presented in Table 9. A 4 (Age group) x 2 (Sex) x 2 (Lead hand) x 2 (First hand tested) x 4 (Block) analysis of variance was carried out. Since the factor of First hand tested was found to be non significant, it was dropped from further analyses. There was a main effect of Block: $F(3, 168) = 3.70, p < .02$ indicating an effect of practice but since there were no interactions involving this factor it was also dropped from the analysis. Subsequent analyses were based on the mean of tapping rates averaged over 4 blocks using Age group, Sex and Lead hand as factors. A main effect of Lead hand was obtained: $F(1, 56) = 50.77, p < .0001$ with all groups performing significantly better under the right hand leading condition than under the left hand lead condition. A main effect of Age group was

also obtained: $F(3,56) = 5.61, p < .001$. There was no effect of Sex and there were no interactions among any of the factors. It would appear that performance with the left hand leading was not differentially affected by aging compared to that with the right hand leading.

Table 9

Tapping rates (number of taps per 10 second trial, averaged over four blocks) obtained by the four age groups when the left hand is leading and when the right hand is leading

Group	Sex	N	Left hand rate		Right hand rate	
			Mean	St.dev.	Mean	St.dev.
1 (students)	M	8	28.34	6.43	32.09	9.16
	F	8	27.67	6.64	29.67	7.78
		16	28.00		30.88	
2 (middle-aged)	M	8	22.32	4.34	23.81	3.99
	F	8	26.53	5.53	28.57	5.48
		16	24.42		26.19	
3 (older)	M	8	21.76	4.33	22.98	5.15
	F	8	20.26	4.18	21.96	4.63
		16	21.01		22.47	
4 (oldest)	M	8	20.68	6.05	21.70	5.91
	F	8	23.75	5.50	25.68	5.56
		16	22.21		23.69	

Pairwise comparisons between groups were performed for the right hand leading and the left hand leading separately. For the right hand, there was no significant difference between Group 1 (students) and Group 2 (55 to 64) but differences were significant between Group 1 and

Group 3 (65 to 74): $F(1,56) = 14.84$, $p < .01$, Tukey's HSD Test, and between Group 1 and Group 4 (75 and over): $F(1,56) = 10.85$, $p < .01$, Tukey's HSD Test. No other comparisons were significant. Results were similar for the left hand in that the differences were significant only between Group 1 and Group 3: $F(1,56) = 13.13$, $p < .01$ and between Group 1 and Group 4: $F(1,56) = 9.00$, $p < .05$. Therefore, the youngest of the older subjects (Group 2) were not significantly different from the young controls in their tapping rate, but Group 3 and Group 4 were tapping significantly slower than the controls in both hand conditions.

A similar analysis (a 4 by 2 by 2 analysis of variance with Age group, Lead hand, and Sex as factors) was carried out on the ratio of total number of trials to number of correct trials. The means and standard deviations for this measure are found in Table 10.

Table 10

Ratios (ratio of total trials to correct trials totalled over four blocks) obtained by the four age groups in the Two-One tapping task.

Group	Sex	N	Left hand ratio		Right hand ratio	
			Mean	St.dev.	Mean	St.dev.
1 (students)	M	8	1.78	.48	1.38	.33
	F	8	1.69	.53	1.53	.48
		16	1.74		1.45	
2 (middle-aged)	M	8	1.85	.51	2.05	.86
	F	8	1.65	.57	1.39	.28
		16	1.75		1.72	
3 (older)	M	8	2.08	.84	1.56	.43
	F	8	1.44	.42	1.08	.09
		16	1.76			1.32
4 (oldest)	M	8	1.68	.30	1.78	.54
	F	8	1.84	.44	1.64	.76
		16	1.76		1.71	

Lead hand had a significant effect: $F(1,56) = 8.44, p < .01$

but there was no significant effect of Age group and this factor did not interact with any other. Thus, older subjects did not produce significantly more incorrect trials with either the right or the left hand leading. However, there was a significant sex effect: $F(1,56) = 4.36, p < .05$ with women performing at lower ratios (producing fewer incorrect trials) than men. With this measure, as well as with the speed measure, performance with the left hand leading was not more affected by aging than performance with the right hand leading and in fact the older groups performed as well as the younger groups.

An additional analysis was performed using number of incorrect trials produced under each hand condition. These results are presented in Table 11. Identical effects were obtained with this measure i.e. no significant group effect, but a significant Sex effect: $F(1,56) = 5.58$, $p < .02$ with females performing better than males, and a significant Lead hand effect: $F(1,56) = 11.40$, $p < .001$ with the left hand leading condition producing more incorrect trials.

Table 11

Number of incorrect trials (summed over four blocks) obtained by the four age groups when the left hand is tapping twice and when the right hand is tapping twice.

Group	Sex	N	Left hand leading		Right hand leading	
			Mean	St.dev.	Mean	St.dev.
1 (students)	M	8	4.87	2.64	2.87	2.64
	F	8	4.50	3.02	3.62	3.06
		16	4.68		3.25	
2 (middle-aged)	M	8	5.25	2.37	6.50	4.00
	F	8	4.12	3.27	2.75	2.12
		16	4.68		4.62	
3 (older)	M	8	6.87	4.15	3.62	2.61
	F	8	3.00	2.61	.62	7.44
		16	4.93		2.12	
4 (oldest)	M	8	4.75	2.12	4.50	2.44
	F	8	4.87	2.35	3.87	4.29
		16	4.81		4.18	

Relationship Between Speed and Accuracy

While older subjects obtained similar accuracy scores compared to younger subjects, they performed at a significantly slower rate than the younger subjects with either hand leading. To ascertain if there was a

trade-off between speed and accuracy in the older subjects, the correlation between tapping rate (averaged over the two hand conditions) and Ratio (over both hand conditions) was calculated for the older groups. Since a nonsignificant correlation was obtained ($r = -.016$, $p > .10$), it appears that the approach taken by the older subjects to the task was largely idiosyncratic and that as a group they did not sacrifice accuracy at the expense of speed. This correlation is similar to that obtained in the younger group for the same variables ($r = -.20$, $p > .10$).

Simple Finger Tapping

Means and standard deviations for simple finger tapping are shown in Table 12. The dependent measure is the number of taps produced in a ten second trial averaged over two trials for each hand. In simple tapping, the older groups were found not to perform at a significantly slower rate compared to younger subjects as there was no effect of Age group: $F(3, 56) = .63$, $p < .50$, nor of Sex. There was, however, a significant Hand effect: $F(1, 56) = 42.41$, $p < .0001$ with all groups having faster tapping rates with the right hand compared to the left hand. There were no interactions between any of the factors.

Alternate Tapping

A two-way analysis of variance (with Sex and Age group as factors) was carried out on the alternate tapping rates (given in Table 13), the dependent measure being the number of taps produced by the two hands in a ten second trial averaged over two trials. A significant Age effect: $F(3, 56) = 3.38$, $p < .02$ was obtained. Post-hoc comparisons indicated a significant difference between Group 1 and Group 4, but no other

comparisons were significant (Tukey's HSD: $p < .05$). There was also a significant Sex effect: $F(1,56) = 4.14$, $p < .05$ with women tapping more slowly than men in all the groups.

Table 12

Single finger tapping rates (number of taps produced in a 10 second trial, averaged over two trials) obtained by the four age groups in the left hand and the right hand

Group	Sex	N	Left hand		Right hand	
			Mean	St.dev.	Mean	St.dev.
1 (students)	M	8	50.25	8.64	51.68	8.02
	F	8	47.56	7.72	51.00	7.67
		16	48.90		51.34	
2 (middle-aged)	M	8	49.68	9.50	50.06	11.24
	F	8	45.12	8.39	48.50	11.17
		16	45.90		49.28	
3 (older)	M	8	48.00	4.56	52.00	9.4
	F	8	44.18	14.66	47.62	13.50
		16	46.09		49.81	
4 (oldest)	M	8	45.56	5.81	48.68	6.98
	F	8	42.43	6.72	46.18	8.75
		16	43.99		47.43	

Table 13

Alternate tapping rate (taps produced by the two hands in a ten-second trial, averaged over two trials) obtained in the four age groups.

Group	Sex	N	Mean	St. dev.
1 (students)	M	8	84.12	11.69
	F	8	76.00	13.43
		16	80.06	
2 (middle-aged)	M	8	72.62	13.91
	F	8	68.25	12.88
		16	70.43	
3 (older)	M	8	72.62	3.11
	F	8	67.75	16.66
		16	70.18	
4 (oldest)	M	8	70.75	14.22
	F	8	62.87	7.97
		16	66.81	

Correlational Analyses:

A correlation coefficient was calculated between the Two-one tapping rate (averaged over the two conditions) and simple tapping rate (averaged over both hands). A significant positive correlation was obtained ($r=.25$, $p < .05$) when all the groups were combined. However, when separate coefficients were calculated for each group, it appeared that this positive coefficient was mostly due to a correlation obtained in the youngest group ($r=.44$, $p < .10$). No correlations were significant for any of the older groups taken separately. It may be that for the young subjects, there is a speed component to the Two-one tapping task as well as an attentional component. This correlation however, may be

simply due to some characteristics of the younger subjects i.e. subjects that approach the task in a competitive manner probably tend to obtain high scores in both tasks while those that take a more relaxed attitude are probably slower in both tasks as well. For the older subjects, however, this was not the case since there was no correlation between the two tasks in any of the older groups.

There was a positive and significant correlation between the rate of Two-one tapping and alternate tapping ($r=.36$, $p < .05$) when all the groups were combined. However, this correlation is mostly due to the correlation obtained in Group 2 ($r=.50$, $p < .05$). All other correlations were non significant. There must be some degree of dissociation between the two tasks since Group 3 showed a decrease in Two-one tapping but not in alternate tapping. Group 4 was slower in both tasks but in that group the correlation was not significant between the two variables.

DISCUSSION

The goal of the present study was to test the hypothesis that underlying the cognitive changes associated with aging is a differential reduction of right hemisphere activity compared to left hemisphere activity. The approach taken involved a comparison of the performance of various age groups on two tasks for which one hemisphere or the other is believed to be dominant. The first task was one of tactual perception and discrimination and required older subjects to explore nonsense shapes presented dihaptically and then, to discriminate them from distractor shapes. A left hand advantage has usually been obtained in young normal subjects for this task (Dodds, 1978; Gardner, English, Flannery, Hartnett, McCormick, & Wilhelmy, 1977; Flannery & Balling, 1979; Witelson, 1974; Webster & Thurber, 1978), an effect interpreted as right hemisphere dominance for this task. It was predicted that, if right hemisphere activity decreases with age as hypothesized, then the left hand advantage normally obtained with younger subjects would be reduced or perhaps even disappear in the older groups.

The second task involved tapping to two different rhythms with the two hands i.e. tapping twice with one hand for every one tap with the other hand. With young normal subjects, performance has been reported to be better when the right hand is leading (tapping twice) than when the left hand is leading (Peters, 1987; Webster, 1990). Peters attributed this difference to an attentional bias to the right hand in right handers. The hypothesis predicted that, compared to younger subjects, older subjects would have proportionately greater difficulty performing

with the left hand leading than with the right hand leading and consequently, that the between hand discrepancy would increase.

Results with Younger Subjects

The purpose of including a group of young university students was to ensure that the dihaptic and 2:1 tapping effects reported in the literature and on which the present study was predicated would be obtained with the particular procedures used.

The dihaptic results from the young group indicated, in both males and females, that performance when testing the left hand was better than that when testing the right hand. There was no difference between male and female performance. The means obtained were almost identical to those obtained by Flanery and Balling (1979) with similar subjects. Studies using a dihaptic procedure to assess hemispheric differences have not always been successful in obtaining significant hand effects (Hannay & Smith, 1979). Inconsistent results using this method may have been due to a number of methodological problems such as the use of a small number of shapes for a large number of items, of shapes that can be easily labelled and of cross-modal matching. This replication with the younger subjects indicates that the hand effects reported in the literature could be obtained with the dihaptic procedure used and hence validates the rationale for the first task of the study.

In the 2:1 tapping task, a significant hand effect was obtained meaning that performance was better when the right hand was leading than when the left hand was leading. This effect was obtained in relation to both accuracy and speed of tapping. There was no effect of

Sex and no interaction of Sex with Lead hand. Thus, the effects reported by Peters (1987) and Webster (1990) were basically replicated. Although Webster had obtained a significant sex effect, the means obtained in this study were very close to those obtained by Webster.

When results of the simple finger tapping task were analyzed, tapping rate was found to be significantly faster with the right hand compared to the left, in both males and females. This is consistent with neuropsychological data on normals which shows faster tapping rates with the right index than with the left index (Lezak, 1976).

Because of the similarity of the data and of the effects obtained in this study and in comparable studies, the results appear to be replicable and to reflect stable differences in the performance of the two hands against which the results of the older groups can be compared.

Results from the Older Subjects

Dihaptic Stimulation Task

When the older subjects were compared to the young controls, a significant age effect was found for the left hand but not for the right hand. These results were consistent with the prediction that right hand performance would be stable across age groups but left hand performance would decrease with age. A second hypothesis predicted that between-hand differences would decrease with aging. This was clearly confirmed. Groups 2 and 3 (females especially) showed smaller differences between the hands than Group 1. The effect was demonstrated most dramatically in the case of the oldest males who actually had a reversed

pattern of hand superiority, i.e. a right hand advantage approaching significance.

The difference between Group 4 and the other groups may be of significance for understanding why several studies have failed to find any significant hemispheric differences in older persons. Few studies have used subjects older than 75 and even fewer have used subjects older than 80 years of age. Testing the very elderly may be difficult if not impossible with some of the tasks that are used in research on hemispheric differences, i.e. tasks such as dichotic listening and tachistosopic viewing where speed of processing is involved. In the dihaptic task, however, the duration of palpation time was set at a maximum (10 seconds) to ensure that older persons would have sufficient time to explore the stimuli. As a result, the older subjects generally performed well in this task. Many of them performed at levels higher or equal to that obtained by the younger subjects and all the subjects performed well above chance level. However, some subjects had to be eliminated because of their failure to follow instructions or to understand the nature of the task. Consequently, the findings related to this task are applicable only to subjects who are able to perform adequately in the task. A complete description of the reasons why subjects were eliminated in the different groups is to be found in Appendix F.

An analysis of the accuracy scores for the different item types (identical vs. different shapes) by the different age groups revealed no significant differences in the way that the older groups responded to the different items types compared to the younger group. Since, in

general, more errors were made in the identical items (although the factor of item type did not actually have a significant effect), there may have been a tendency on the part of the subjects to overprocess the stimuli and consequently to find differences where in fact the stimuli were identical. However, the fact that there was no interaction of this factor with any other factor indicated that older subjects did not have a different approach than younger subjects with identical or different items. Many subjects (including older subjects) found that item discriminability was high (non-identical stimuli were very different from one another) and reported that they had no difficulty in differentiating them provided that they could remember the shape of the target stimuli. Therefore, the difficulty of the task may have been more in the memorization of the stimuli. As a result, the effectiveness of the mnemonics used may have had a significant impact on the level of accuracy achieved by the subjects.

Also, fatigue seem to have had no significant effect on the older subjects since they performed as well in the last twenty trials compared to the first twenty and were similar in this to the control group. It remains to be explained why older subjects should have particular difficulty with dihapic shapes presented to the left hand and not with those presented to the right.

These results need to be interpreted in light of the fact that males performed somewhat differently compared to females in the different age groups. While there was a main effect of Sex and Age, there was no Age by Sex interaction, indicating that the difference between males and females was stable across age groups. Also, there was

no Age by Sex by Hand interaction, which would indicate no changes across age groups in the between-hand differences exhibited by males and females. However, this lack of interaction is probably due to the small number of males and females in each group. Inspection of the means reveals that females had smaller between-hand differences in all the age groups. Therefore, the interpretation of the results must take into account some possible differences between males and females in the changes that take place with age.

A commonly reported phenomenon in studies of lateral differences in haptic perception is that males perform better than females in such tasks and obtain larger between-hand differences (Cioffi and Kandel, 1979; Flanery and Balling, 1979; Dawson, 1981; Lenhart and Schwartz, 1983). According to Lenhart and Schwartz (1983), this superior performance and greater lateral differences in males are due to superior imagery coding abilities in males. This would be consistent with several reports indicating male superiority in visuospatial tasks in general (Maccoby and Jacklin, 1974). In the present study, males also showed a relative superiority in both hands compared to females but only in groups 1, 2 and 3. In Group 4, there was no difference between males and females. It may be that males of that age lose their ability to utilize imagery coding to process the information and hence lose both their advantage over females and their left hand advantage. One study by Hulicka and Crossman (1967) showed that younger subjects spontaneously use more imagery-related strategies than their older counterparts. In the present case, right hand performance remained stable perhaps due to continued access to left hemisphere strategies such as verbal coding or

labelling. It is also apparent that while younger females showed a small left hand advantage, this advantage disappeared in the older groups. If females are less proficient than males in spatial imagery (as suggested by Lenhart and Schwartz), this may be the reason for their generally lower scores and for the earlier loss of the left hand advantage, as was the case in this study.

Such an interpretation does not fit a strict localization model of brain functioning where processing is performed unilaterally by the right or the left hemisphere depending on the nature of the material being processed. However, it is consistent with a model of relative hemisphere superiority where both hemispheres have access to the material and are able to process it but one hemisphere is better equipped to process specific types of information. In this model, the right hemisphere would be more proficient at analyzing and remembering haptic shapes due to its access to imagery coding or similar strategies which are deemed to reside in the right hemisphere. Presumably, the left hemisphere also possesses some competence in dealing with haptic material and perhaps for this reason, older subjects were able to attain the same level of accuracy with their right hand as the younger subjects.

This possible loss of access to imagery coding may serve to explain many other changes seen in older subjects such as their difficulties with visual and spatial analysis (see review of the literature). These deficits are usually interpreted as a global impairment in processing visual or spatial material. However, comparison between the hands as in this study, allows a more specific

interpretation: older subjects may not be impaired in encoding or remembering visual or spatial information per se but perhaps have lost the use of the most efficient strategies in dealing with this type of information. This coincides with a qualitative view of aging where performance in the aged may be considered different but not necessarily inferior.

This hypothetical failure of the older groups to summon up visual imagery strategies could be due to a number of changes some of which are not mutually exclusive:

1. An increased attentional bias to the right which would tend to prime the left hemisphere. Right-handers may tend to show an increased preference for the right as they grow older.

2. An increased dominance of the left hemisphere over cognitive functioning. The dominant hemisphere would exert more inhibitory control of the right hemisphere.

3. A selective impairment of the right hemisphere which makes right hemisphere strategies inoperational or inaccessible.

4. If older people have less opportunities to make use of right hemisphere cognitive strategies, left hemisphere strategies may become more dominant.

The results from the 2:1 tapping task may assist in evaluating these alternative interpretations.

Motor Performance

The results of the older subjects on the 2:1 tapping task did not confirm the specific predictions made, i.e. that performance with the

left hand leading would be affected more by aging than performance when the right hand was leading and that, as a consequence, the discrepancy between the hands would increase with age. In fact, in the older subjects, tapping rate was slowed equally in both hands and the between-hands discrepancy was not different from that found in the other groups. As for tapping accuracy (as measured by the ratio of total trials to correct trials), it was not affected by age. It would seem then, that the left hand was no more impaired in older subjects than in younger subjects. However, the actual behaviour of the older subjects during the 2:1 task is of particular interest here. A sizeable proportion of the older subjects experienced considerable difficulty in coordinating the movement of the left index when the right index was tapping twice (right hand leading). The older subjects needed to be specifically instructed to remove their left index from the key at the same time as the right index and this had to be repeatedly demonstrated by the experimenter. In contrast, the same subjects did not experience any difficulty lifting their right index while tapping twice with the left. This element of the task, in itself, was the most problematic for many older subjects while it never posed any apparent difficulty for the younger controls. This unexpected observation was certainly consistent with the hypothesis that there would be left hand attentional impairments. The fact that the older subject showed equal slowing in both conditions can also be accounted for. Behaviourally, it would appear that if subjects were having difficulty in controlling the left finger they would have to allocate more attention to that finger thereby slowing the rate in the right hand leading condition as well.

Nevertheless, there are other possible interpretations of these results. For example, older subjects may be more cautious in performing such tasks and hence slow down in both hands. The less able hand may influence the other and therefore right hand performance may not represent peak performance in that hand. This would tend to eliminate any difference in the amount of slowing between the hands and to obscure possible interactions. It is to be noted in passing, and will be returned to later, that older subjects were no more impaired on the unimanual finger tapping with the left hand, suggesting that the effects observed with 2:1 tapping are not motoric in origin.

The representativeness of the older subjects is especially at issue in relation to the 2:1 tapping task. In the oldest group, 35 percent of the subjects originally tested could not learn the tapping task or could not perform at the set criterion and therefore had to be eliminated from the study. In Group 3 (65 to 74 years old), only one subject was unable to perform the tapping task while in groups 1 and 2, all the subjects were able to perform adequately. Thus, from Group 3 to Group 4, there was a sharp increase in the number of subjects who were unable to perform the task. It is important to note that most of the subjects that were unable to perform in 2:1 tapping performed well in the dihaptic task. Because this difficulty cannot be attributed to a general cognitive impairment, the inability to perform the task is of interest in itself and could be the topic of a future study. Had the methodology for this study allowed for all subjects to be included in the study (by not having a set criterion for performance), results may have been significantly different. Possibly, the subjects who were

eliminated may have provided further information concerning the apparent difficulty of the left finger in the 2:1 tapping task. In retrospect, the 2:1 tapping task was perhaps not an ideal measure of hemispheric involvement for older age groups as it does not permit a separation of performance factors from hemispheric effects. Some insight may be gained by examining the results obtained on the other two tapping tasks.

In simple finger tapping, the older groups were not found to tap significantly slower than the younger group and they showed a hand effect similar to that found in the young controls. The absence of any group differences in simple tapping is surprising in light of the numerous reports showing the decrease in speed of finger tapping with aging (Lezak, 1976). However, the reason for this may lie in the apparatus that was used. Simple finger tapping was measured with the same apparatus as for 2:1 tapping. Only minimal pressure is required to operate the lever on this apparatus and this may be somewhat less than what is required for the finger tapping device that is typically used in neuropsychological examinations. On the alternate tapping task, groups 2 and 3 performed similarly to the control group but Group 4 tapped significantly slower than the control group.

To summarize these results, the middle-aged group (Group 2) was not different from the controls in any of the tapping tasks. Group 3 was slower than the controls in 2:1 tapping and Group 4 was slower than the controls in both 2:1 tapping and alternate tapping. These deficits cannot be attributed to motor slowing since none of the groups showed any evidence of slowing in simple finger tapping. There was no correlation between 2:1 tapping rate and simple tapping rate for any of

2

A resolution test chart featuring patterns of vertical and horizontal lines of varying thicknesses and spacings. Each pattern is accompanied by a numerical value representing its resolution. The values are arranged in a grid-like fashion, with some values appearing in multiple locations. The values include 1.0, 1.1, 1.25, 1.4, 1.5, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.2, 3.6, and 4.0. The patterns of lines become increasingly dense and difficult to distinguish as the numerical value increases.

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the older groups. While there was a positive correlation in groups 1, 2 and 3 between alternate tapping and simple tapping (in order, $r=.55$, $p < .05$; $r=.43$, $p < .10$; $r=.77$, $p < .05$), there was no correlation in group 4 where a deficit was present in both tasks. It may be that up to a certain age, the alternate tapping task has a large speed component while for the oldest subjects this task presents a particular difficulty that goes beyond simple motor speed. There was a significant positive correlation between 2:1 tapping rates and alternate tapping (when all groups were combined) but this was mostly due to the correlation in Group 2, as all the correlations in the other groups were non-significant. Therefore, slowing in 2:1 tapping and in alternate tapping appears not to be related to simple motor slowing, nor does there appear to be any relationship between these two tasks (except in the case of group 2).

Perhaps the three tapping tasks can be conceptualized as being on a continuum of difficulty. The simplest of the three, single finger tapping, is not affected at any age. Alternate tapping, which requires precise coordination between the two hands, was slowed in the oldest group. Two-one tapping, where delicate interweaving of the movements of the two hands is necessary, showed the effects of aging at an earlier age (beginning in Group 3). A cautionary note is necessary here. Cross-sectional studies of aging are limited in the interpretations that can be made concerning the specific age at which some changes start to appear. The specific pattern of changes in performance across the various age groups may be a spurious effect due to the characteristics of the groups that were tested. Nevertheless, it is interesting to

speculate as to why the oldest group was slower in both 2:1 tapping and alternate tapping and not in simple tapping.

Stelmach, Amrhein and Goggin (1988) compared young controls and older subjects aged 67 to 75 years old on unimanual and bimanual tasks. Reaction time (time taken to initiate a movement toward a target) and movement time (time required to reach the target) were obtained for three different conditions : unimanual, bimanual symmetric (both hands going the same distance) and bimanual asymmetric (the two hands going different distances). It had previously been found that in bimanual asymmetrical movements, the hands adjust the speed of movement so as to terminate the two movements at the same time (Marteniuk & Mackenzie, 1980; Marteniuk et al. 1984). Older subjects were found to have significantly longer reaction times in all movement types compared to younger controls. There was no age by movement type interaction indicating that for all groups, unimanual movements required the least amount of preparation, bimanual asymmetric the most, and bimanual symmetric occupied a middle position. In movement time, however, the older subjects demonstrated proportionately greater increases for bimanual and for asymmetric movements. The older group took much longer completing bimanual movements even when symmetric and they were also much poorer at adjusting movement time when performing asymmetric movements as evidenced by greater differences in termination time between the hands.

While the tasks used by Stelmach et al. are not directly comparable to those used in the present study, a parallel can be drawn in the type of difficulty experienced by the older subjects in the two

studies. As in the Stelmach et al study, older subjects in this study were not impaired when the participation of only one hand was required. However, they experienced difficulty when movement was bilateral. In both studies, the older subjects had particular difficulty in performing tasks where different movements were required in the two hands. It is not known whether the subjects in Stelmach et al. would have performed differentially in the left hand compared to the right hand. However, the results invite speculation as to whether the deficits found in both studies are due to a common underlying difficulty with bimanual coordination. According to Preilowski (1972), bilateral motor coordination requires the integrity of the corpus callosum and especially of the anterior commissures.

However, other factors may be implicated here. In order to adjust a movement or to maintain a rhythm accross the hands, one must take various contextual cues into account and therefore asynchronous or asymmetric movements may also require proprioceptive feedback (see Kelso and Tuller, 1981 for a complete discussion of the importance of contextual cues in the dynamics of motor actions). According to Carmon (1970) damage to the right hemisphere can result in deficits in sustained motor performance, especially when a movement requires the integration of kinesthetic and proprioceptive feedback. If proprioceptive information is not being properly processed in older subjects, this could affect performance in bimanual tasks where proprioceptive cues are used to coordinate the movements of the two hands and also in dihaptic perception tasks where proprioception plays an important role in the encoding of the stimuli.

GENERAL DISCUSSION

In summary, the results of the dihaptic stimulation task were consistent with the idea of an underactivation of the right hemisphere in older subjects. However, this underactivation could be due to a number of reasons, some of which may be unrelated to neurological processes. For example, cognitively-based explanations (such as failure to summon right hemisphere strategies because of lack of opportunity to use such strategies) cannot be discounted on the basis of the results only. Also, the results need to be interpreted in the light of gender-related differences and possible interactions between sex and age.

The results from the 2:1 tapping task were not so clear-cut with respect to the hypothesis. The older subjects did not show a greater difference in performance between the left hand and the right hand conditions. Nevertheless, the informal behavioural observations force us to consider the possibility that the left hand may actually be more affected by aging than the right but that the methodology did not allow for this difference to emerge. Furthermore, slowing in alternate tapping in the oldest group point to the possible involvement of interhemispheric transmission in the deficits found (Wolff, Cohen & Drake, 1984; Preilowski, 1972).

A note is necessary regarding the representativeness of the subjects. Not having been drawn from the general population, the subjects may not be typical or representative of normal aging. None had major health problems (many appeared exceptionally healthy) and most were actively involved in community organizations. Consequently, the results of this study can be generalized to the aging population only

with caution. This selection bias however, ensured that disease and cognitive impairment would not contaminate the results. These results point to the fact that when healthy and active elderly persons are used in research on aging, deficits may be manifest only in the oldest of the subjects, i.e. after the age of 75. This appears to confirm other findings (Botwinick, 1977) showing that many cognitive abilities remain largely unaffected until the latter part of the eight decade.

It may be opportune now to relate these findings to those described earlier in the review of the literature. The deficits found in older people and that have been linked to a right hemisphere dysfunction are numerous and varied in nature. As discussed, there are deficits reported in tasks such as visual-spatial analysis (Gilbert & Levee, 1965; Axelrod & Cohen, 1961; Danziger & Salthouse, 1978; Plutchick, Conte, Weiner, Teresi, 1978; Arenberg, 1978; Cerella, Poon, Fozard, 1981), rod orientation (Benton, Eslinger & Damasio, 1981), perception and expression of emotion (Moreno, 1987), facial recognition (Benton, Eslinger & Damasio, 1981; Smith & Winograd, 1978; Ferris, Crook, Clark, McCarthy & Rae, 1989; Bartlett, Leslie, Tubbs & Fulton, 1989) and tactual perception and discrimination (Goldstein & Braun, 1974; Bak & Greene, 1980; Price, Fein & Feinberg, 1980; Moehle & Long, 1989). There is also some evidence for changes in the performance of the left hand in speeded motor tasks (Weller & Latimer-Sayer, 1985; Meudell & Greenhalgh, 1987) or in hand reaction times (Rastatter & Lawson-Brill, 1987). Neurologically, these various functions cover a wide area in the right hemisphere and as a result, the deficits cannot realistically be linked to neurological damage in the right hemisphere. Likewise,

cognitively-based explanations cannot suffice to account for such wide-ranging deficits affecting several different modalities. However, underactivation of the right hemisphere need not be related to neurological losses in that hemisphere. Such an underactivation could be caused by changes in other areas of the brain. For example, as mentioned in the review of physiological evidence for a right hemisphere dysfunction, changes in hemispheric activation could be related to losses in the frontal lobes, in the limbic structures or in the corpus callosum. This latter possibility is consonant with suggestions made by Cook (1984, 1986) concerning the role of the corpus callosum in regulating the inhibition and excitation of the hemispheres. In Cook's view, the anatomy of the two hemispheres is predominantly isomorphic and symmetrical such that structures in the two hemispheres are mirror-images of one another and are able to handle the same material but with differing degrees of efficiency. Furthermore, the two hemispheres are deemed to act together to handle complementary aspects of the same task. For example, the left hemisphere processes the core aspects of language while the right hemisphere handles the contextual or paralinguistic components of language. According to Cook, the callosum has a dual role: it serves to excite the hemisphere contralateral to the one already active in order to switch on the complementary aspects of a function and to inhibit those structures that are homotopic to the ones already engaged in the contralateral hemisphere, thereby preventing unnecessary duplication of processing. Cook's views are very novel and still in a speculative stage but they are provocative in that they reconcile the

apparently contradictory aspects of hemispheric specialization and the need for a more integrative view of hemispheric relations.

If such a model applies, then callosal dysfunction in the elderly may cause various disruptions in interhemispheric relations. For example, if the inhibitory mechanisms are not functional, the left hemisphere may compete with the right in handling material for which the right hemisphere is most competent. Alternately, if excitatory mechanisms are impaired, the engagement of the left hemisphere in language processing may fail to summon those aspects of language in which the right hemisphere is deemed to be superior. Thus, it is not necessary in this model to posit a specific dysfunction of the right hemisphere. This disruption could be related to an overactive left hemisphere or to a callosal dysfunction. For example, if, as suggested by Peters (1987), a right-sided bias is present in right handers, then this bias may increase with age, thereby making the arousal of the right hemisphere more difficult.

There are few findings pointing to a possible callosal dysfunction. The performance of older people on the TPT test is one example. When older people are tested on the TPT, many show no improvement from right hand scores to left hand scores, suggesting a deficit in transfer of training from one hand to the other (Goldstein & Braun, 1974; Bak & Greene, 1980; Price, Fein & Feinberg, 1980). However, the hypothesis of callosal dysfunction in the elderly has not been formally investigated. Neurological degeneration in subcortical areas appears to be mostly restricted to the basal ganglia and the limbic system although the corpus callosum has sometimes been implicated,

albeit infrequently (Valenstein, 1981). However, as previously mentioned, there need not be any correspondance between neurological losses and cognitive impairments. In fact, any amount of cortical damage is able to cause disruption in cross hemispheric communication (Heilman & Valenstein, 1985). Hence, the pattern of deficits found in our older subjects could be explained by either a dysfunction of interhemispheric transmission or by a right hemisphere dysfunction or a combination of both.

Nevertheless, before anatomical correlates can be established, finer-grained analysis are required to pinpoint more exactly the nature of deficits found in older persons. Studies of lateral differences involving within-subject comparisons can help in differentiating cognitive factors and hemispheric changes. However, effect sizes in these tasks are notably small and vulnerable to performance factors. This represents a particular problem with older subjects and possibly the goal of detecting changes in lateral differences may be irreconciliable with adapting the task to older subjects. Adding to the problem is the fact that, for a given task, the important components of the task and its correlates may vary across age groups. A case in point is the correlations obtained between 2:1 tapping and simple tapping in the different age groups. In the control group, there was a positive and significant correlation between these two tasks while there was no such correlation in any of the older groups. Because of this possible variability in what a task actually represents for the various age groups, the goal of achieving ecological and construct validity in research on aging is particularly challenging. As a result, tasks should

be chosen for their simplicity and for their ability to reveal basic differences between older and younger subjects. In this author's opinion, some of the issues concerning aging have been prejudged. It is often assumed for example, that older persons uniformly show increases in reaction time and slowing in simple motor tasks and many deficits in other tasks are attributed to this alleged slowing (Ellis & Oscar-Berman, 1989). Subjects in this study, however, showed motor slowing only when both hands were involved in coordinated action. Likewise, the distinction between initiation time and movement time is crucial if we are to investigate reaction times in the elderly.

The detection of age by task interactions in simple motor tasks may help in defining the nature of many of the losses seen in the elderly in this area of functioning. For example, a future study could elucidate the role played by timing and speed in unimanual and bimanual tasks by having subjects follow pre-set rates as was done in Wolff, Cohen and Drake (1984). Such a task should have the advantage of reducing the effects associated with subject strategies and differential speed-accuracy trade-offs. By eliminating a specific criterion of performance which all subjects have to satisfy, it would also allow for all subjects to be tested, including those who perform at very slow rates.

The use of more sensitive dependent measures (such as duration of tap and intertap interval stability as in Peters, 1989) would increase the chances of detecting differences between the two hands in different groups. Simple motor tasks such as simple finger tapping may reveal more about the performance of the two hands when more sensitive measures are

used. In 2:1 tapping, the issue of the 'stickiness' of the left index could be examined by comparing tap duration of the left finger when the right hand is leading and tap duration of the right finger when the left hand is leading.

The role of proprioception and of transmission of proprioceptive information across the corpus callosum also needs to be investigated. A task could be designed where left and right hand reaction times in response to a proprioceptive cue in the same hand or in the other hand could be measured. Obviously, the findings from this study raise many issues and no single study could resolve all of these issues. However, the basic questions to be answered would be whether, in simple motor tasks (preferably tasks that do not involve a cognitive component), the left hand is differentially affected by age and whether deficits are more pronounced when communication across the hemispheres is required.

To conclude, the results of the study, when considered in the broader context of the literature on cognitive and neurological changes with aging, leads to the conclusion that right hemisphere functions are selectively affected with aging. However, further work is necessary to delineate more closely the exact nature of the deficits found in the aged population, especially in relation to motor functions. Such work may clarify the role of interhemispheric communication in the deficits found in the aged population.

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Appendix A
EDINBURGH HANDEDNESS INVENTORY

108

Name _____ Date of Birth _____
Sex _____

PLEASE READ THESE INSTRUCTIONS CAREFULLY BEFORE STARTING.

Please indicate your preference in the use of hands in the following activities by putting + in the appropriate column.

****Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++.**

****If in any case you are really indifferent as to which hand you use, put + in both columns.**

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	LEFT	RIGHT
1 Writing		
2 Drawing		
3 Throwing		
4 Scissors		
5 Toothbrush		
6 Knife (without fork)		
7 Spoon		
8 Broom (upper hand)		
9 Striking Match (match)		
10 Opening box (lid)		
i Which foot do you prefer to kick with?		
ii Which eye do you use when using only one?		

(Please do not write in this space)

1

L.Q. = _____

Appendix B

Subject Questionnaire

SUB. NO. _____

- * Age: _____
- * Number of years of education (Including elementary and high school): _____
- * Is any member of your family left-handed ? NO ____ YES ____
If yes, please specify relationship _____
- * Have you ever received musical training ? NO ____ YES ____
Specify year(s) when you received this training: _____
When was the last time you have used your musical training for
any purposes ? Year: _____
- * Do you play a musical instrument ? NO ____ YES ____
Specify instrument(s) _____
When was the last time you played your instrument ? Year: _____
- * Have you ever had a head injury, stroke, heart attack or
neurological disease ? NO ____ YES ____ If yes, please underline.
- * Have you ever been diagnosed as suffering from multiple
sclerosis, diabetes, kidney dysfunction, heart condition ?
NO ____ YES ____ If yes, please underline.
- * During the last few hours, have you taken any medication such
as cold or allergy remedies (or any over the counter medication)
or antibiotics ? NO ____ YES ____

- * Do you presently suffer from a condition which requires the use of medication on a continual basis ? NO ____ YES ____
- * Do you suffer from any of the following conditions:
arthritis, paralysis, rhumatism, joint stiffness ?
NO ____ YES ____ If yes, please underline.
Has this condition had an effect on how well you can use
your hands ? NO ____ YES ____.

Thank you for providing me with this information. This information is necessary in order to ascertain the validity of the results of the study. Please be assured that this information will be kept strictly confidential.

Appendix C

Instructions for Dihaptic Stimulation Task

In this task, I will ask you to feel some shapes with your hands but without seeing them. I will present you with two shapes, one to each hand which you will feel with your fingers going around the outline of the shape like this. You can only use your two middle fingers to feel them, like this and keep them together, you cannot separate them. It is also important that you feel the two shapes simultaneously not one and then the other. Now, after you have felt the two shapes for 10 seconds I will remove them and I will present you with one shape to one of your two hands. But before I do that I will tap you on the hand to indicate to which hand I will present the shape. Then you will have 5 seconds to feel that shape. Now your job will be to decide if that shape is the same or different from the shape which you had felt in that same hand before.

While feeling the shapes, I want you to try to form a mental picture or visual image of the whole shape. In order to distinguish the shapes you do not need to remember all the details: what you need to remember is the general shape of it. I want you to concentrate on getting a picture of the whole shape. You may find at the beginning that this is impossible to do. However, it appears that our brain works in unconscious ways and our intuitions are often right. People often find when I tell them their score that they did a lot better than they ever thought they would.

But first I will show you how this is going to work and we will do quite a few practice trials before we actually start.

OK, just slide your hands through here, You see these frames: the shapes are always going to be placed around here. So all you need to do is to keep your fingers raised just over here and I will slide the shapes under your fingers and then you can just lower them. Now we will do a couple of examples. I will not be timing you for these.

Now, I want to show some combinations of shapes that you're not going to have to worry about. For example, these two shapes are always going to be different. Also, it will never be the case that this shape is going to be identical to this one. The two shapes that you are comparing and these two and you don't have to worry about whether this shape is similar to the left or the right. Also, another thing that will not happen is that this shape will never be a mirror-image of this one or the same shape but oriented differently. This is too difficult and many people cannot do it. So, when it is the same shape it is going to be placed in the same position and the same orientation.

OK, now we will do a few practice trials. This time I will be timing you. For the first shapes you will have 10 seconds to feel them. For the second shape you will have 5 seconds to feel the shape. However, you can if you wish make a response before the 5 seconds are over.

OK, now we will start the real trials. The difference now is that I will not be telling you whether you are right or wrong. OK do you have any questions ? Now remember: you have to feel the shapes simultaneously and it is important that you try to visualize the whole shape and make a mental picture of it.

There are quite a few trials in this task and you may at some time find that you are getting tired. What I normally like to do is to take a short break somewhere half-way through the task.

Appendix D

Debriefing questionnaire

Name: _____ Case no: _____

1. Were you using any particular strategy in order to feel the shapes and make a decision about them ?

-form a mental picture: yes___ no___

-concentrate on one feature or one side : yes___ no___

-give labels or associate with an object: yes___ no___

-other:

2. Did you feel that one of your hands was better than the other? R___ L___

3. Did you feel that there was enough time allowed for you to be able to visualize the shapes ? Y___ N___

4. Did you find that you were guessing most of the time ?
Y___N___

5. Did you start to recognize any of the shapes after a while ?
Y ___ N___

Did that help you ? Y___ N___

Did you change your strategy as a result ? Y___N___

Appendix E

Instructions for Tapping TasksTwo-one tapping

In this task, you will have to tap these two keys simultaneously using a certain rhythm: for each tap in one hand, you have to tap twice in the other hand. Now, you have to tap right here in order to get maximum sensitivity of the keys. The easiest way to do this is to tap with both fingers first and then once again with one finger. For example, if I were tapping twice in the right finger, I would go like this..... and if I were tapping twice with the left, I would go like this. How about trying it for a few seconds ?

Now, you should try to tap as fast as you can. Of course, I can tap faster since I am used to doing it and you may start by tapping more slowly. However, you should try to tap as fast as you can but without making mistakes. How about trying to see at what rate you can go. If you make a mistake just start over again. OK, good, now try with the other hand.

I will be using this machine to record your performance. For each trial, when I say "Ready", just position your fingers over the keys and when you hear the "Beep", start tapping and continue tapping until I tell you to stop. I will tell you for each trial which hand is going to be tapping twice. Now, should you make a mistake, just stop and we'll start the trial again. Do you have any questions ?

OK You will start tapping with your (right/left) hand tapping twice. At the sound of the beep, just start tapping.

Simple tapping

Now, I will ask you to tap one key with your index finger as fast

as you can without stopping. While you should try to tap fast it should also be a steady rhythm one that you can sustain for a few seconds. If this hurts in any way, please stop immediately. We will start with your right hand. Again, start at the sound of the beep and continue until I tell you to stop.

Alternate tapping

Now, you will have to tap alternating from hand to another and again as fast as you can. Make sure, however, that you do alternate between your two hands.

Appendix F

List of rejected subjects55 to 64 year old group

Subject	Sex	Reason for rejecting
L.B.	F	Equipment malfunction: did not call back to do task
J.C.	M	Had a negative score on the Edinburgh Handedness Inventory
L.P.	F	Difficulty performing tapping task because of arthritis
M.C.	F	Was not properly tested

65 to 74 year old group

J.C	M	Performed well in both tasks but had total hearing loss in right ear for 15 years. Gradual hearing loss since 1945.
G.L.	F	Could not perform tapping task with the left hand tapping twice. Performed dihaptic task well.
N.H.	M	Did not follow instructions for dihaptic task: explored with one hand and then the other.
J.P.	F	Was not properly tested; phone interruption in dihaptic task caused her to make 8 errors in a row.
J.Q.	F	Arthritis invalidated test results: left finger would stiffen unpredictably.

75 and over

E.B.	F	Could not perform tapping task; also, did not really understand instructions for dihaptic task.
M.O.	F	Could not perform tapping task: left finger would not lift from the key
S.C.	M	End of left index finger missing; could not learn either task.
J.H.	M	Could not perform tapping task; did well on dihaptic task.

J.H.	F	Could not perform tapping task but performed well on dihaptic task.
J.N.	M	Never really understood the nature of the task for the dihaptic task; performed well on tapping task.
N.H.	M	Could not do the tapping task; had had long-standing artherosclerosis (more than 15 years).

Appendix G

Consent Form

CARLETON UNIVERSITY

DEPARTMENT OF PSYCHOLOGY

INFORMED CONSENT FORM

TITLE OF EXPERIMENT: "Effects of aging on performance in manual and
tactile tasks"

INVESTIGATOR: Danielle Ferron

NAME OF PARTICIPANT: _____

I understand that this experiment will involve my making judgments about shapes and also tapping keys to two different rhythms with the two hands.

I understand that my participation is voluntary and that I may withdraw from the experiment at any time and for any reason.

I understand that my individual experimental data will be treated confidentially and that I will not be identified in any publication of the results,

signed: _____

date: _____

Appendix H

Debriefing

The purpose of this study is to see how the two sides of the brain work as people get older. Since the right side of the brain controls the left hand and the left side controls the right hand, we can measure the functioning of the brain by looking at the performance of the two hands in doing different types of manual tasks. In the task where you had to feel shapes with your hands, the left hand should perform better because it is the right side of the brain which is best in this type of task. In the tapping task, it is the right hand which should perform better when tapping twice because in right-handers, attention tends to be focused more on the right. The purpose of the study is to determine whether the two sides of the brain work in the same way in older people as in younger adults. More specifically, the study examines the hypothesis that in older adults, the right side of the brain becomes less involved in certain types of tasks, such as manual and tactile tasks. Therefore, should the right hemisphere of older adults be less involved, one would expect that the discrepancy of performance in the left and the right hand in the tapping task should increase (the left hand performing worse relative to younger controls. In the tactile task, the dominance of the left hand may disappear and the discrepancy between the hands may become smaller as a result.

Should you wish to have more information about this experiment or to discuss any aspect of it, please feel free to contact any of the following persons:

Appendix I

Letter sent to subjects to ask for participation in study

Department of Psychology
Ottawa General Hospital
501 Smyth Road
Ottawa, Ontario

You may recall your participation last year in the study on the effects of normal aging on the brain. Your help was very much appreciated. As you probably know, research is an ongoing endeavour and research on aging is crucial if we are to improve the quality of life amongst the elderly. A study in a vein similar to the one in which you participated will soon be undertaken by a Carleton University Ph.d. student. I would like to know at this time if you are interested in volunteering for this study. Testing would take place in the research labs of the Social Science Research Building at Carleton University and would require approximately 1 1/2 hour of your time. Transportation will be provided if necessary. You will find enclosed a self-addressed return card on which to indicate whether or not you wish to participate. Please feel free to contact me at if you wish more information. The person conducting the study is and she can be reached at

Again, I wish to thank you for your help in furthering research on aging,

Yours sincerely,

, M.A.
Psychometrist

END

22.12.92

FIN