INTRAHEMISPHERIC COMPETITION BETWEEN VOCAL AND UNIMANUAL PERFORMANCE IN RIGHT-HANDED, LEFT-HANDED AND INVERTED LEFT-HANDED SUBJECTS

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DEDICATION

This work is dedicated to the memory of my grandfather, Angus James Campbell, who shared with me the special skills of his many years, and encouraged the pursuit of academic achievement.

ABSTRACT

Levy and Reid (1976, 1978) propose that inverted left handers, that is, those left-handers who write with the tip of their pen pointed towards the bottom of the page, demonstrate ipsilateral hemispheric control over distal musculature responding. This theory of cerebral organization has not been well supported by empirical evidence, partly because of the failure of many studies to examine the complete musculature system involved in writing. The present study was proposed to study more of the musculature system involved in writing in the context of performing a dual task. Kinsbourne and Cooke's (1971) model of intrahemispheric competition states that dual task performance, compared to single task performance, will decrease (1) as the two competitive functions share the same cerebral space, and (2) as the concurrent activity increases in complexity. The theory further states that dual task performance will increase with practice.

Controlling for Familial Sinistrality, the present study compared the performance of right handed (n=20), left handed (n=20) and inverted left handed (n=20) male subjects during a Pursuit Rotor Test, which was hypothesized to parallel some of the motor behaviors involved in writing. Subjects completed this task while remaining silent or while repeating either a four word phrase or a four word alliteration.

Considering Levy and Reid's (1976, 1978) theory, it was hypothesized that (1) the performance of inverted left handers (ILH) without a history of Familial Sinistrality would show decrements in responding with their left hand under both interference conditions. ILH subjects with a history of Familial Sinistrality were predicted to demonstrate right hand response decrements during both interference conditions. (II) Left handed (LH) subjects without a history of Familial Sinistrality were predicted to demonstrate a right hand response

decrement under both levels of the interference conditions, whereas LH with a history of Familial Sinistrality were expected to show decreased left hand responding under both interference conditions. (III) Both right handed (RH) groups of subjects were proposed to demonstrate right hand decrements in responding under both interference conditions. The RH group with a history of Familial Sinistrality was also predicted to demonstrate a smaller left hand decrement under both the interference conditions. Based upon Kinsbourne and Cooke's (1971) dual-code theory, both interference conditions were hypothesized to interfere with and decrease the motor performance of subjects under the conditions listed in I, II and III above. It was hypothesized that the alliteration condition would decrease the performance more than the simple phrase condition.

Overall, the results did not support the predictions based upon Levy and Reid (1976, 1978) hypothesis. Neither group of left handed subjects (LH & ILH) showed any significant response decrements under concurrent verbal interference.

The overall performance of RH subjects demonstrated some support for the dual-task theory posited by Kinsbourne and Cooke.

Two out of a possible five groups of RH subjects demonstrated significant right hand response decrements under concurrent verbal interference. However, no difference in responding was found between simple and complex verbal interference.

Some qualitative results imply that some subtle differences do exist between LH and ILH subjects. Some limitations of the experiment are discussed as well as some future research topics.

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INTRODUCTION

A variety of approaches have been utilized to assess cerebral laterality. Behavioral testing, observation of neurologically injured patients, dichotic listening tapes, tachistoscopic recognition tests, the Wada test, electroencephalographic recordings and others have provided a comprehensive view of some brain-behavior relationships. Several measures which have been used as predictors of cerebral laterality include handedness, familial sinistrality, scores obtained on laterality questionaires and reaction time (RT) to lateralized visual, auditory and tactile stimuli.

Levy and Reid (1976, 1978) have suggested that the hand posture exhibited during writing is a possible predictor of cerebral laterality. Their results show that the hemispheric specialization of inverted left-handed subjects, that is, those who point the tip of the pen towards the bottom of the page while writing, is more closely matched to the performance of right handed subjects than to left handers who do not demonstrate an inverted hand posture while writing. These results have only been partially supported by other authors.

This research project measured differences in pursuit rotor performance under dual vs single-task performance among left handed and inverted left handed subjects in comparison with a control group of right handed subjects. Kinsbourne and Cooke's (1971) dual code theory states that dual task performance as compared to single task performance 1) decreases to the extent that the two functions share the same cerebral space, and 2) decreases as the concurrent task becomes increasingly difficult. Kinsbourne and Cook further hypothesized that performance increases with practice on dual tasks.

A task sharing design may be appropriate to explore Levy and Reid's (1976, 1978) theory. The rationale for this approach is partly based upon observations of the performance of inverted left handers. The inversion of the left hand is best observed during writing. While it is accurate to state that writing behavior utilizes fine motor movements of the distal musculature, a definition based solely on fine discrete movements does not take into account movements of the wrist or arm. This is important for understanding inverted left hand writing since the forearm generally moves towards the right side of the page in conjunction with fine movements of the distal musculature. Unlike Levy and Reid (1976, 1978) and others (Moscovitch & Smith, 1979; Smith & Moscovitch, 1979), a RT paradign was not used. This paradign, by definition, only accounts for immediate discrete fine motor movements; consequently, it does not lend itself to recordings of continuous activity. It is further possible that although contralateral motor control may be the most efficient neuroanatomical pathway in detecting and responding to the onset of a flash of light, a monaural tone, or a sensation of pressure, it does not necessarily preclude an ipsilateral feedback loop for anual task when thety such as writing. The results observed by Levy, Nebes, and Sperry, (1971) show that some of the errors in left hand responding of commissurotomy patients during verbal tasks were due to interference of the dominant verbal (left) hemisphere. The authors have suggested an ipsilateral feedback loop to account for these results. Perhaps the signifcance of the left hemisphere in the control of fine motor movements (Kimura & Archibald; 1974, Wyke, 1967, 1968, 1971) is utilized in such a feedback system especially for inverted left handed writers.

Any type of unique cerebral specialization of inverted left handed subjects has most often been reported in the visual or visuo-motor system for visually presented verbal material (Herron, Galin, Johnston & Ornstein, 1979, Levy & Reid, 1976, 1978; Moscovitch & Smith, 1979; Smith & Moscovitch, 1979). In the present study the specialization of a language hemisphere was determined by interference caused by competition of two separate functions which share the same cerebral functional space. A dominant cognitive function (expressive language) was coupled with a presumed recessive function (a unimanual task) to determine both the verbally specialized hemisphere and motor control of a continuous activity. If inverted left handers show a unique cerebral specialization between the verbally superior hemisphere and motor control hemisphere, it was hypothesized that this specialization would be evident in a demonstration of relationships in other modalities than visual.

Predictors of Cerebral Laterality

Neuropsychological Predictors. Cerebral laterality studies involving brain damaged patients are commonplace. Marked differences have been observed in aphasic symptoms for right handers versus left handers. Whereas language disorders have been consistently associated with lesions of the left hemisphere of right handed subjects (Gloning, Gloning, Haub, & Quatember, 1969; Hecaen & Piercy, 1956; McGlone & Kertesz, 1973; Zangwill, 1967) aphasic sympdoms have been observed in left handed subjects with damage to either hemisphere (Gloning et al, 1969; Goodglass & Quadfasal, 1954; Hecaen & Piercy, 1956; Hecaen & Sauget, 1971; Humphrey & Zangwill, 1952; Zangwill 1967). Zangwill (1979) observed that the incidence of crossed aphasia in right handers is in the 1 - 2% range. Such results are in accordance with the findings of researchers using the Wada (Wada & Rasmussen, 1960) technique, which induces the injection of sodium amytal into the intracarotid artery. These studies had determined that while approximately 90% of right handed subjects have speech represented in the left hemisphere, 48% of left handed and ambidextrous subjects are left dominant for speech, 38% are right hemisphere dominant and 14% indicate bilateral representation for speech (Branch, Milner, & Rasmussen, 1964; Wada & Rasmussen, 1960). Warrington and Pratt's (1973) results differ somewhat from the Wada research. Utilizing unilateral electroconvulsivetherapy and then testing for dysphasia the authors propose that approximately 70% of left handers have speech represented in the left hemisphere.

Case studies of commisurotomy and hemispherectomy patients also indicate the importance of the left hemisphere in expressive language functions. The right hemisphere has been shown to be deficient in the production of phonemes, comprehension and correction of complex auditory stimuli and writing (Dennis & Whitaker, 1976; Levy et al 1971; Zaidel, 1978a) Further, the right hemisphere has relatively little speech (Smith 1966; Zaidel 1978a) but intricate visual vocabulary and adequate auditory lexicons. (Levy et al 1971; Zaidel 1978a).

However, the right hemisphere demonstrates some capacity for language. When receptive language functions were examined in neurologically damaged patients, the results of some authors (Gazzaniga & Hillard, 1971; Zaidel, 1976 a,b) showed that receptive language is mediated by the right hemisphere when the two cerebral hemispheres are disconnected. Dimond (1980) in a review of right hemisphere language supports this position.

"Although the mute hemisphere may not express comprehension in speech and to a lesser degree in writing, it does nevertheless show a degree of comprehension of both written and spoken words". p. 334

Dimond makes this response in reference to studies where the left hand (therefore the right hemisphere) of right handed subjects was capable of choosing the correct article from a matrix of alternatives displayed pictorially after hearing the examiner explain what purpose the article served.

Therefore although the right hemisphere may not be capable of speech or written skills, it does demonstrate some comprehension of language when the mode of responding does not involve expressive verbal abilities.

The results of Sperry, Zaidel, and Zaidel (1979) indicate that the right hemisphere is almost as adept in demonstrating emotional responses to visually presented stimuli as is the verbal, that is, the left hemisphere. In some tasks which require interhemispheric transfer of verbal information the appropriate responses appear to be more dependent upon the left than the right hemisphere (Zaidel, 1979).

Behavioral Predictors: Laterality has also been predicted via tachistoscopic recognition tasks. Right handed subjects demonstrate a superiority of the left visual field (LVF) for the perception of geometric forms (Bryden, 1960; Kimura, 1969) but a right visual field (RVF) superiority for verbal material (Bradshaw & Gates, 1978; Bryden & Rainey, 1963; Hannay & Boyer, 1978; Mishkin & Forgays, 1952). Bryden (1965) reported inconsistent patterns in left handed performance, but Goodglass and Barton (1963) reported that LH subjects performed almost identically to their RH counterparts. Some of this research suggests that the manner of presentation influences the results. Variables such as spatial arrangement and duration of stimulus presentation (Kimura, 1959), the number of experimental trials and fixation instructions (Bryden & Rainey, 1963), nonsense forms versus geometric forms (Heron, 1957) have all produced significant results. As has ocular dominance (Bryden, 1959).

An interesting technique utilized to predict cerebral lateralization known as Dichotic Listening was pioneered by Kimura (1961a). In this technique different digits are presented simultaneously to each ear. The subject is instructed to report all information perceived and to guess if uncertain. The results showed that the contralateral auditory pathways were more effective than the ipsilateral in the perception of spoken verbal information.

Kimura (1961b) replicated these results with 120 neurologically impaired patients. A sub-group of 13 of the 120 patients was formed in which participants had right hemisphere dominance for language as verified by the Wada Test. The results showed that these patients perceived verbal stimuli more effectively through the left ear. The opposite results were found in patients who were left hemisphere dominant for language.

These results have been confirmed by additional research. A right ear superiority has been reliably obtained for verbal material (Bryden, 1965; Borowy & Gorbel, 1976; Curry, 1967; Know & Kimura, 1970) and a left ear superiority for non-verbal sounds (Curry 1967; Knox & Kinura, 1970) for right handed subjects. Left handers show greater variance (Bryden, 1965) and a slight reversal of superiorities (Curry, 1967).

Hemispheric Control of Sensory - Motor Responding. Contralateral hemispheric control of sensory-motor responding is well documented (Branch et al, 1964; Gazzaniga, Bogen, & Sperry, 1963; Kolb & Hishaw, 1980; Kreuter, Kinsbourne, &

Trevarthen, 1972; Levy et al, 1971; Smith, 1966; Wada & Rasmussen, 1960). Visual (Bradshaw & Gates, 1978; Bryden & Rainey, 1963; Hanney & Boyer, 1978; Mishkin & Forgays, 1952) as well as auditory (Kimura, 1961, 1967) stimuli are perceived more accurately through contralateral sensory pathways. One possible explanation for the better performance in response to verbal stimuli presented to the ear contralateral to the language dominant hemisphere is the anatomical evidence of a majority of sensory fibers which cross over the midline from the receptive organ to the contralateral hemisphere (Carlson, 1977; Kimura, 1967).

Left-handed subjects have shown some variance in hemispheric control of sensory-motor responding. In left handed subjects lesions of the left hemisphere have produced ipsilateral as well as contralateral deficits. For example, bilateral deficits following left hemisphere lesions have been reported for precision movements (Wyke, 1968), speed and accuracy of movement (Wyke, 1967), copying unfamiliar movements of the hand and arm (Kimura & Archibald, 1974), and acquisition of a bilateral co-ordination task (Wyke, 1971). In left handers, left hemispheric lesions have also produced ipsilateral apraxia (DeRenzi Pieczuro, & Vignolo, 1966). In a case study of a left handed subject, Zangwill (1954) reported agraphia with either hand following a left hemisphere glioma. Zaidel (1978b) has demonstrated that a more efficient ipsilateral feedback loop exists for the left hand - left hemisphere than the right hand - right hemisphere of commissurotomy patients. The subjects were able to name or point to objects placed in their left hand out of view. When an elbow restraint was utilized to prevent kinesthetic feedback the subjects still responded above chance with their left hand. Although the results could suggest the existence of simple lexicons in the right hemisphere, Zaidel interprets the findings as showing that fine motor movements of the fingers were involved in the tactile feedback loop. Liepmann's theory, (cf Kimura & Archibald, 1974) which states that the left hemisphere is the superior half-brain for the control of purposeful movements is in accordance with the results listed above.

Hand Posture Exhibited While Writing. Until recently, hand posture while writing has been ignored as a possible predictor of cerebral organization. But, more recently, Levy and Reid (1976, 1978) classified subjects by handedness, sex, and hand posture exhibited during writing. If the writing hand was above the line of script and the point of the pen was directed towards the bottom of the page, the subject was labelled as demonstrating a "hooked" or inverted writing posture. Conversely, if the writing hand was below the line of script and the point of the pen was directed towards the top of the page, the subject was described as showing a normal writing posture. Subjects were classified into three groups: right handed (RH), left handed (LH), and inverted left handed (ILH).

Levy and Reid had subjects participate in two tachistoscopic recognition tasks. In a consonant-vowel-consonant (CVC) recognition task, subjects were presented a

CVC tachistoscopically two degrees to the left or right of a single digit which served as the fixation point. After each trial subjects were to report both the CVC and the fixation digit. There were sixty trials per visual field. In the second task subjects were asked to detect a stimulus dot (a small white round stimulus) and designate the location of the stimulus within each visual field via a response card. The response card was comprised of twenty possible locations constructed in a 5 X 4 array. Twenty trials for both visual fields were recorded for each subject.

The results revealed that both the RH and ILH groups had superior RVF scores for the CVC recognition test and higher LVF scores on the dot location test. Group LH displayed reversed superiorities. Overall, groups RH and LH had higher scores than group ILH. Group ILH was less lateralized than both the other groups. Overall, males were superior to females on both tests.

These results suggested that subjects who exhibit a normal hand posture while writing have their linguistically specialized hemisphere located contralaterally to their dominant hand, while the hemisphere specialized for visuospatial functions is located ipsilaterally. Subjects who display a hooked posture have the reverse cerebral organization with the visuospatially superior hemisphere located contralaterally to the dominant hand and the linguistically specialized hemisphere located ipsilaterally. It might be noted that the performance of male ILH subjects in Levy and Reid's (1976, 1978) research was more consistent (than the females) with this description of laterality.

On the basis of these findings and previous work, Levy and Nagylaki (1972), Levy and Reid (1976, 1978) propose that ILH subjects control fine movements of the distal musculature through ipsilateral pathways. They suggest that this control is mediated by the uncrossed axons of the pyramidal tract.

Levy and Reid's model (1976, 1978) has not gone uncontested. Smith and Moscovitch (1979) designed a study to investigate and extend the model proposed by Levy and Reid. Smith and Moscovitch tachistoscopically presented RH, LH, and ILH subjects with the same CVC and dot location tests used by Levy and Reid. They also included a dichotic listening test as well as a RT task. The dichotic listening test consisted of six consonant-vowel syllables which were presented binaurally in sixty pairs. Subjects were instructed to identify both CVs on any given trial.

In the RT test subjects responded to a black stimulus dot in either the LVF or RVF by depressing a response key with the left index finger.

Of 200 experimental trials, one-half were catch trials in which no stimulus appeared. In the remaining 100 trials, the black stimulus dot was presented randomly and equally in either visual field. The results of the RT test show that inverted writers responded more quickly to a stimulus presented in the RVF whereas non-inverted writers responded faster to LVF stimulus. The CVs recognition task demonstrated that inverted writers performed optimally to stimuli presented in the visual field ipsilateral to their writing hand, while subjects with non-inverted writing posture demonstrated the opposite pattern of responding. The dot location test did not distinguish between any group, all subjects favoured the LVF. In the dichotic listening test all subjects demonstrated a superiority of the right ear.

In the second phase of this experiment a subset of the original sample was retested on the RT test using their right index finger. The dichotic listening test was modified so that the subjects only repeated the syllable which was best heard.

The results showed that, on the RT test, subjects with an inverted writing posture responded more quickly to a LVF stimulus whereas non-inverted writers exhibited shorter latencies to RVF stimuli. The dichotic listening test results showed that both groups of left handed subjects responded more accurately to stimuli presented in the left ear while the right handed group favoured the right ear.

Since Smith and Moscovitch found no conclusive results with either the dichotic listening or the dot location test, they suggest that inverted writers show a unique visual or visuo-motor cerebral organization. Unlike Levy and Reid (1976, 1978), the sex of the subject was not significant.

Moscovitch and Smith (1979) compared the RTs of RH, LH, and ILH subjects in three separate modalities. In the visual modality, subjects were to respond with a response key using the left or right hand as quickly as possible to the onset of a stimulus dot presented for 150 msec in either the RVF or LVF. Of 400 experimental trials, one-half were catch trials in which no stimulus was presented.

In the aural modality subjects responded to a 150 msec, 1000 Hz monaural tone presented after a latency of 1 second following a 300 msec, 350 HZ binaural warning signal. As in the visual tests, one-half of the 416 trials were catch trials. In the remaining trials the monaural tone was presented equally often to either ear. Subjects responded with their left hand on one half of the trials and with the right hand to the other half.

Responses to tactile stimulation were tested by requiring subjects to depress a response key with the left index finger following stimulation of the left middle finger by a tapered solenoid pin. Subjects were also required to respond with their right index finger following stimulation of their right middle finger. Four hundred trials were conducted in which half were catch trials.

The results from the study show that subjects with normal hand writing posture responded faster to stimuli presented in the same hand-field combination in all modalities. Further, the results suggested that this pattern of responding is also applicable to inverted writers for the auditory and tactile modalities but not in the visual modality. In the visual RT test, inverted writers responded more quickly to stimuli in the contralateral hand-field combination. The authors proposed that any difference between inverted writers and their normal counterparts is reflected by a unique specialization in the visual and/or visuomotor cerebral organization of the inverted writers.

But McKeever and Hoff (1979) have criticized the methodology utilized by Moscovitch and Smith (1979) and Smith and Moscovitch (1979) because the design confounded spatial compatibility and neuroanatomic pathways. McKeever and Hoff stated that the go/no-go paradigm displays a hugh field X hand effect which is not in accordance with previous work. To continue the investigation of ipsilateral cerebral control of inverted writers, McKeever and Hoff designed a simple RT paradigm. In this study, twenty-seven left handed undergraduates (twelve LH and fifteen ILH) responded with either the left or right hand to the onset of a white stimulus dot presented for 150 msec, 2.4 degrees to the left or right of a fixation point. A total of 34 trials were presented in nine blocks. Subjects responded to 162 trials with either hand.

Their results showed that both groups displayed a LVF superiority with both hands. The hand X field interaction was significant in the LH group, whereas only the main effect of field was significant in the ILH group. Homolateral (same field/hand combination) responses were significantly faster than heterolateral (opposite hand/field combination) responses for the LH group. The ILH group showed a tendency for faster heterolateral responses although this trend was insignificant. Sex of the subject and familial sinistrality were not significant.

McKeever and Hoff then calculated values of the right hemisphere sensory advantage (RSA or the tendency for the right hemisphere thereby LVF presentation superiority in response time resulting from visually scaning left to right) and transcallosal transmission time (TTT or the difference derived from heterolateral-homolateral response hand conditions suggestive of the latency required for the responding hemisphere to receive the signal from the sensory hemisphere via the corpus callosum). The RSA calculated by McKeever and Hoff for LH subjects was 3.0 msec and the TTT was 2.6 msec. When these values were applied to ILH subjects, a LVF superiority of 5.6 msec for left handed responding was predicted, as was a 0.4 msec LVF advantage for right hand responding. The results showed a 5.2 msec LVF superiority for left hand responding which was similiar to the prediction. However, the 6.2 msec LVF advantage reported for right hand responding was much larger than the hypothesized value. Based upon this evidence, the authors posit contralateral control of both left and right hand responding in the LH group and contralateral control of left hand responding in the ILH group. McKeever and Hoff further suggest that right hand responding to RVF stimulation in the inverted writers is determined not contralaterally but by two transcallosal relays. This hypotheses would predict a 5.6 msec LVF advantage for right hand responding which is quite similiar to the observed value of 6.2 msec. The authors further propose that there is a disconnection between the motor areas and visual areas of the left hemisphere of ILH.

The results of Moscovitch and Smith (1979) have also been debated by Bradshaw, Nettleton, and Spehr (1982). Extending Moscovitch and Smith's methodology, Bradshaw _et al_ included an additional manipulation in which subjects responded to stimuli in an arm-across-the-midline condition. Right-handed, left-handed and inverted-left-handed subjects responded by unimanually depressing a nasal or distal response key as quickly as possible in both the crossed and uncrossed field-hand conditions to a 100 msec flash of light in each visual field. Each hand responded to 123 trials in both the crossed and uncrossed conditions. The results show that the contralateral (hand-light) responses were faster than ipsilateral responses for the crossed (hand-key) condition. Conversely, the ipsilateral (hand-key) responses were more rapid than the contralateral responses for the uncrossed (hand-key) condition. The data for all three groups were almost identical.

McKeever and VanDeventer (1980) tested 65 left-handed subjects, 30 LH and 35 ILH, with a tachistoscopically presented letter masking task and a dichotic listening tape. The results did not indicate that handwriting posture was indicative of cerebral lateralization. Two subgroups, ILH females and LH males responded more accurately to both auditory and visual stimuli than LH females and ILH males. Levy and Reid's (1976, 1978) hypotheses would not account for the superior performance of the ILH females as they have suggested that inverted females are less lateralzed than males.

Lawson (1978) presented a face recognition task in which 157 RH and 69 LH subjects chose one of two composite faces which was perceived to resemble more closely a stimulus face.

The results show that while RH favour the half face presented in the LVF, left handers as a group do not prefer either field. Performance of the ILH males was consistent with predictions by Levy and Reid that is, that ILH males favoured the LVF, females responded in the opposite direction.

McKeever (1978) conducted a series of experiments to evaluate the relationship between familial sinistrality (F.S.) and hand posture exhibited while writing as possible predictors of cerebral laterality. McKeever placed 83 left-handed subjects along a continuum of inversion. If only the tip of the pen pointed towards the bottom of the page subjects were placed in the PEN group; if the subject bent their wrist along with the inverted tip they were classified as the WRIST group, and if subjects placed their hand above the line of script while showing the first two conditions as well, they were placed in the HAND group. Of the 38 males in this study 78.9% were classified as satisfying the PEN criterion, 34.2% satisfied the WRIST criterion and 31.6% satisfied the HAND criterion. The percentages for the 45 females in this sample were 43.3%, 15.6% and 11.1% for groups 1, 2 and 3 respectively. The above classifications were then divided dichotomously into inverted and non-inverted positive and compared with additional research (McKeever & VanDeventer, 1980). Since the incidence of percentages of inversion did not differ significantly, McKeever compiled four new groups of 47 ILH males, 38 ILH females, 15 LH males and 48 LH females. McKeever reported that the percentage of inversion increases as a function of F.S.

In Experiment II, 17 LH and 36 ILH viewed 180 stimulus trials binocularly in which a central fixation digit and a colored chip were simultaneously flashed in either the LVF or RVF. Subjects were instructed to report the color of the chip as well as the digit. The results, which were consistent with Levy and Reid's predictions demonstrated that ILH subjects responded 12.2 msec faster to stimuli in the RVF vs the LVF. The LH subjects responded only 4.0 msec faster to RVF stimuli than LVF stimuli and this difference in reaction time was not significant. The difference between ILH subjects, and LH subjects was observable only in the first 90 data trials.

McKeever then grouped the subjects as either stating a history of familial left-handedness (+F.S.) or no history (-F.S.). The +F.S. group closely matched the performance of tn-sequenced fasnion prepartore RFV stimuli) and the -F.S. group paralleled the performance of the L.H. group.

In Experiment III, 11 ILH and 14 LH responded to trials in which a word or words were presented binocularly in each field. The results indicated that the +F.S. group significantly favoured RVF stimuli whereas the -F.S. group did not. There was no difference in performance between the ILH and LH groups. McKeever proposed that F.S. may be at least as reliable a measure of cerebral lateralization as is hand posture while writing. These findings are not consistent with Levy and Reid's (1976, 1978) hypothesis that hand posture predicts which visual field subjects would prefer.

Tapley and Bryden (1983) evaluated the performance of 16 RH and 8 inverted right-handers (IRH) on several tasks. A handedness questionnaire and a dot test, developed by the authors, a dichotic listening test and the two visual tests reported by Levy and Reid were presented to all subjects. All subjects significantly favored the RVF for the visual nonsense syllables. No significant differences were observed for the visual dot location task. In the dichotic consonant-vowel, syllable task a significant right ear superiority and a significant ear by posture interaction were reported. Analysis of this interaction revealed that RH subjects demonstrated a right ear superiority whereas the IRH group did not. The groups did not differ on the handedness questionnaire. The IRH subjects responded more rapidly than the RH group using their right hand on the dot test. Overall, the data for the IRH subjects did not support the prediction of Levy and Reid's work.

Bradshaw and Taylor (1978) tachistoscopically presented single syllable words and non-words to 24 RH subjects, 24 LH +F.S. subjects and 24 LH -F.S. subjects. All subjects responded verbally, calling aloud the stimuli as rapidly as possible following a presentation of 150 msec duration in either visual field. Four hundred trials were administered to each subject.

The right handers responded more rapidly than the other two groups. Subjects responded more rapidly to stimuli presented in the RVF vs the LVF. A significant visual field by handedness interaction was found. Right handers favoured the RVF vs the LVF more than the LH +F.S. group. The LH -F.S. group did not respond differently to presentation in either visual field.

Bradshaw and Taylor then formed a group of 11 ILH subjects, of which 6 were selected from the LH +F.S. group and 5 from the LH -F.S. group. When compared to the remaining 37 LH subjects, the ILH group demonstrated a weaker RVF advantage. This is contrary to Levy and Reid's theory which would predict a significant RVF advantage for ILH subjects as compared to LH subjects.

Levy and Reid's work (1976, 1978) has been further investigated by Herron et al (1979). The authors employed both a dichotic listening test and ratios of electro-encephalograph (EEG) recordings from central (C_3, C_4), parietal (P_3, P_4) and occipital (O_1, O_2) leads during writing and several other tasks, assumed to require cognitive activity for RH, LH, and ILH subjects. The dichotic listening test consisted of 120 binaurally presented trials in which the subject was asked to repeat both syllables. All groups performed similiarly.

The EEG recordings were made during 30 second periods on each of the following tasks: block design, reading, speaking, writing and listening. The ratios of the EEG recordings between the hemispheres at the central and parietal leads showed that the speaking task and the block design task designated left and right hemispheres, respectively, for RH subjects. No such clearly defined relationship existed for either of the left-handed groups. The recordings from the occipital leads demonstrated that for the writing and reading tasks EEG activity in the right occipital area of the LH group is predominate relative to the RH and ILH groups. Consequently, for visual language tasks, Levy and Reid's (1976, 1978) theory was supported. No support was obtained for Levy and Reid's prediction of cerebral specialization for spatial perception since EEG activity was similar in both left handed groups. Herron et al (1979) found no support for ipsilateral motor control of writing in inverted writers at any lead pair. The authors speculate that the cerebral specialization of ILH subjects reported by Levy and Reid (1976, 1978), Moscovitch and Smith (1979) and Smith and Moscovitch (1979) may result from interactions between visual and verbal components of cognition.

Parlow (1978) examined both single and paired finger flexions of RH, LH and ILH subjects by requiring them to bend the middle joint of the finger after the experimenter touched the designated finger. Her results showed that, although both hands of all subjects were adequate in performing these tasks, the RH and ILH groups performed better with the left hand whereas the LH group favoured the right hand. Parlow speculated that the right hemisphere of the RH group was the visuospatially superior hemisphere and that the reverse was true for both groups of left-handers. Consequently, the superior performance of the left hand of the ILH group was assumed to be controlled by ipsilateral pathways.

Parlow and Kinsbourne (1981) tested LH and ILH subjects on a variety of unimanual tasks to ascertain any differences between hands. Tasks included; 1) a paired finger flexion task, 2) a static grip strength task, 3) a pursuit rotor task, 4) a repetitive single finger tapping task in both a silent and concurrent speech condition, and 5) a vertical arm tapping task. There were significant differences between the groups on three out of the five unimanual tasks. The LH group favoured the right hand vs the left in the paired finger flexion task, demonstrated a left hand advantage on the static grip strength task and showed a decrement in left but not right hand performance under the concurrent speech vs the silent condition of the repetitive single finger tapping task. No difference between hands was reported for the other two tasks. Both hands of the ILH group were relatively equal for all tasks. The authors stated that the performance of the LH group was the reverse of the performance expected of an RH group. This was not true for the ILH group which performed similiarly to the RH group.

The above studies have not indicated that hand posture while writing can be used as an indicator of cerebral lateralization. Indeed, the results of Bradshaw and Taylor (1979) are contrary to the predictions of Levy and Reid (1976, 1978). Other results indicate specialization in visual or visuo-motor functions (Herron et al, 1979; Lawson, 1978; Moscovitch & Smith, 1979; Smith & Moscovitch, 1979) or minor confirmation of ipsilateral cerebral control for ILH subjects (Parlow, 1978; Parlow & Kinsbourne, 1981). Several authors favor unique specialization not hypothesized by Levy and Reid (McKeever & Hoff, 1979; Tapley & Bryden, 1983). It would seem that the differences between LH and ILH subjects are not explicable in terms of one variable. Other research on ILH subjects have examined a developmental component of hand posture utilized in writing as well as a hypothesized deficit in selective cognitive tasks. These issues are discussed in Appendices I and II respectively.

The Dual - Task Hypothesis

Human performance can be influenced by either collaboration or competition between various functional spaces of the cerebral cortex (Kinsbourne & Hicks, as cited in Kinsbourne, 1978). Kinsbourne and Cooke (1971) had right handed subjects balance a dowel rod on their left or right index finger working under either a silent or verbal condition. In the verbal condition the subjects repeated a short sentence while balancing the dowel. Under the verbal condition balancing time significantly decreased for the right index finger but increased for the left. The authors theorized that dual task performance would decrease 1) as the concurrent task becomes increasingly difficult, and 2) to the degree that the two tasks share the same cerebral space; but would increase with practice. The dual task hypothesis has been fairly extensively investigated by a number of investigators using a variety of experimental techniques. The results of that research are mixed. The following section reviews the major findings of this body of work.

Hicks (1975) conducted a series of experiments to replicate and extend the work of Kinsbourne and Cooke. Hicks observed that concurrent verbalization decreased the performance of right hand balancing of right-handed males.

increased phonetic difficulty of the sentence, in the form of alliterations, produced a more pronounced decrement. Hicks also observed that interference occurred while the subjects hummed melodies during balancing trials, concluding that vocalic activity interferred with performance. Increasing the amount of practice before the inclusion of the verbal condition did not change the amount of interference. Left handed subjects with a history of familial left-handedness of any first degree relatives showed interference only with the left hand. Left handers without a history of familial sinistrality as well as right handers, with a history of familial left handedness, showed a decrease in performance with both hands under the verbal conditions.

Hicks, Provenzano and Rybstein (1975) introduced verbal interference in a bimanual sequential typing task as well as a unimanual typing task. Right handed subjects were shown a letter list and spoke it aloud or silently immediately before and while completing the typing task. There were significantly more errors in the bimanual task when the right hand was leading the sequence than when the left hand was the initiator. In the unmanual condition significantly more errors were recorded for the right handed responses. Both conditions produced interference although the magnitude of interference was greater during the vocal condition. As the redundancy of the verbal material increased, typing performance increased. The results also demonstrated interference with left hand performance. Hicks <u>et al</u> (1975) suggested that the cognitive tasks of remembering typing sequences and rehearsing letter strings are more demanding than the tasks employed by Kinsbourne and Cooke (1971) or Hicks (1975) and require involvement of both hemispheres.

Briggs (1975) conducted a study in which right handed subjects responded to a multi-limb tracking apparatus in either a silent or verbal condition. There was an signficant increase in right hand errors while the subjects repeated a passage of prose. Bowers, Heilman, Satz and Altman (1978) investigated the effects of a variety of types of interference while RH subjects were tapping their index finger as rapidly as possible. In the first experiment, subjects had to produce a string of words that began with a target letter presented to them by the experimenter. Both the left and right hands showed a significant decrease in performance under this concurrent verbal condition, but right hand performance was depressed almost twice as much as that of the left. The same results were obtained in Experiment II in which subjects, told that they would have to answer questions at the end, listened to a logical memory story while tapping. In Experiment III subjects read a logical memory story while tapping; right hand performance was significantly decreased from the control condition whereas the left hand was not. In Experiment IV the concurrent interference condition required subjects to observe snapshots of faces while tapping and then after tapping choose the 12 stimulus faces from an array of 24. This type of non verbal interference was not associated with a decrease in performance. Although as the stimuli were pictorially they would be assumed to interfer with the right hemisphere and therefore produce a left hand response decrement.

Lomas (1980) suggested that visual guidance of the hands may be a confounding variable in the preceeding research design. In an experiment in which RH subjects tapped a response key with distal arm movements the results showed a decrease in right but not left hand responding with concurrent verbalization vs a control condition only under the no visual guidance condition. There was no decrement in responding under the visual guidance condition. These same results were found for experiment II in which subjects finger tapped sequentially, under both a control and concurrent interference condition and both visual guidance and no visual guidance treatments. Thorton and Peters (1982) dispute the findings of Lomas reporting that both left and right hand responses of RH subjects were depressed under both visual guidance and no visual guidance conditions in a concurrent speech and sequential finger tapping experiment.

Rizzolatti, Bertoloni, and Buchtel (1979) had right handed subjects respond as quickly as possible to a flash of light in either the LVF or RVF under several interference conditions. In Experiment I the subjects counted backwards by 3's while anticipating the stimulus. The results show a LVF (right hemisphere) superiority for both hands. In Experiment II subjects tapped their fingers in an established sequence while anticipating the stimulus. Again, the results demonstrated better scores with LVF presentation regardless of what hand was tapping. In the third experiment subjects tapped their fingers in a non-sequenced fashion prepartore RFV stimuli) and the -F.Slus: No difference was found in responses to LVF or RVF presentations.

Boles (1979) presented a list of six words tachistoscopically to RH subjects who were told to remember the words, who then responded with each hand to 20 trials of dot arrays presented tachistoscopically. After a series of three experiments, Boles concluded that there was no significant field x hand interaction and consequently no support for Kinsbourne and Cooke (1971).

MacFarland and Ashton (1975) extended the results of Kinsbourne and Cooke (1971) with the addition of a spabial-verbal control condition, that is, a geometric problem requiring the assimiliation of digits and letters, as well as a control condition in which no mental activity was assumed to occur. RH subjects were required to perform both a concurrent verbal tasks, that is, simple mathathical problems, or finding hidden fiqure: or spatial tasks, while alternately depressing two response buttons. Under the verbal interference condition both hands showed a decrement in responses as compared to the no activity control. Under the concurrent spatial interference condition, both the left and right hand performances significantly decreased from the no activity control whereas neither hand differed between treatments under the spatial-verbal control condition.

Summer and Sharp (1979) investigated the effects of three types of interference (verbal, spatial and verbal-spatial) on the performance of right handed subjects in a bimanual sequencing task, a unimanual sequencing task and a single finger repetitive tapping task. All three types of interference were associated with poor performance for the left and right hands in the bimanual and unimanual sequencing tasks. But all interference conditions depressed only the responding of the right hand in finger tapping. Beaton (1979) designed an experiment in which right handed subjects unimanually sorted objects hidden from sight while tachistoscopically viewing digits presented in either the LVF, RVF or both. Subjects had to respond verbally when a target digit was presented. The results show that when the right hand was involved in the sorting tasks, the visual input produced a decrease in performance regardless of visual field. However, when the left hand was performing the sorting tasks only LVF material interfered with the sorting tasks.

Lomas and Kimura (1976) studied the effects of two separate concurrent verbal conditions on dowel balancing as compared to a silent control. Right-handed subjects recited either a nursery rhyme or produced non-speech vocalization (la-la) while balancing a dowel rod. Reciting the nursery rhyme did not result in a decrease in performance. Males performed significantly more poorly with both hands under the non-speech vocalizing condition as compared to the control condition. In Experiment II, RH and LH subjects were requested to tap their fingers in a designated sequence under the three treatments, that is, speech, non speech vocalizing, and control. The RH group showed a significant decrement in right hand responding under the speaking condition. Both hands of the LH group showed depression under both speech and non-speech vocalization as compared with the control condition. In Experiment III RH subjects were asked to perform sequential arm and repetitive finger tapping under the three treatments. Sequential arm tapping decreased during the speaking treatment. Interference in left hand and right hand responding was observed during the speaking trials when subjects repetitively tapped a single finger.

Sussman (1982) examined the rapid finger tapping performance of RH, LH and right handed stutters (RHS) under two verbal, and two spatial interference conditions. In the first verbal task subjects read a passage of prose while the second verbal task required subjects to count outloud by 3's. In the first spatial task the subjects were instructed to visualize letters of the English alphabet and remember letters with curved as well as straight segments. The second visual task required subjects to attend to a chimiric figure test in which five objects were contained. Subjects than had to choose an unfamiliar stimulus object from a new chimeric arrangement in which the five previous objects as well as the unfamiliar object was presented. For both verbal interference conditions RH subjects showed a decrease in right hand performance. The LH group showed smaller more symmetrical decreases for both hands during both verbal interference conditions. The RHS group demonstrated a marked decrease in right hand responses when required to count outloud by 3's but not while reading.

In the two spatial interference conditions the RH group showed symmetrical disruption of both hands under both conditions. The LH group showed a significant depression of left hand responses when requested to visualize segments of the English alphabet. The RHS group demonstrated a significant decrease in left hand responding during the alphabet visualization task and a pronounced right hand depression when asked to attend to a chimeric figure test. However it should be noted that both spatial tasks could be coded with verbal information. The letters of the alphabet are by definition verbal and the objects in the chimeric sorting tasks were everyday items such as a knife or hat. Therefore both verbal and spatial information were available to subjects.

Warshal and Spirduso (1981) had RH, LH and ILH subjects participate in a hand steadiness task and concurrently presented three words to the subjects. As the end of a trial the subjects were required to name the category which subsumed the words. For the RH and LH groups the preferred hand proved steadier than the non-preferred hand. This difference was smaller in magnitude but still significant for the ILH group. RH and ILH groups improved performance under the verbal load conditions for both hands. Under the same verbal load conditions, the LH group performed poorer during the non-verbal trials.

Bashore, McCarthy, Hefley III, Clapman, and Donchin (1982) in a series of experiments, measured the readiness potential (RP), a movement potential which is associated with a voluntary motor act, utilizing EEG recordings in response to either a unimanual dynamometer squeeze or to a writing response condition. In Experiment I, 8 RH, 8 LH and 8 ILH all demonstrated a larger RP in the hemisphere which was contralateral to the response hand performing the squeeze. In experiment II 6 RH, 6 LH and 11 ILH subjects without familial sinistrality squeezed the dynamometer and wrote either the words "he" or "hand" during experimental trials. As in Experiment I, the hemisphere contralateral to the response hand in either of the experimental response conditions demonstrated a larger RP that the ipsilateal hemipshere. However, four left-handed subjects showed a different pattern of response. Specifically, one LH and three ILH demonstrated a larger RP in the ipsilateral hemipshere furing the writing condition.

Experiment III used the same design as Experiment II with the exception that one IRH subject was tested. Overall the 6 RH, 1 IRH, 6 LH and 9 ILH subjects showed a large contralateral RP. Again, two ILH showed the reverse during the written task.

Other research has demonstrated a connection between verbal expression and manual activity. Kimura (1973, Exp. I) compared manual activity of right handed subjects during a verbal condition, in which subjects spoke on any topic for five minutes, to two silent conditions. In one silent condition, subjects wrote that last line of a limerick and in the other subjects studied complex designs to find a simpler geometric figure. Limb movements of the subject were classified into two major categories: 1) self-touching movements were defined as those in which the subject stroked his hair, touched his eyeglasses, etc., while 2) free limb movements were those in which no self-touching was involved. Significantly more manual activity was observed during the speaking condition. This difference was accounted for by the number of free movements of the right hand. The free movements were opposite the language hemisphere as verified by a dichotic listening test. No significant difference between right and left hands was found in free movements when subjects hummed.

Kimura (1973, Exp. II) used the same design with left handed subjects. The greatest number of free movements was made by the hand which was contralateral to the dominant verbal hemisphere as determined by a dichotic listening task. Left handed subjects, however, made significantly more absolute number of movements with the left hand regardless of which hemisphere was dominant for speech. Although the factor of hand dominance contributes to the number of free movements, Kimura suggested that speech is organized bilaterally in left handed subjects.

Summary The results of many of the above studies support Kinsbourne & Cooke's dual-code theory. The theory has been supported by replication of the dowel balancing experiment (Hicks 1975), and a variety of other motor tasks such as rapid finger tapping (Bowers et al 1978; Summers & Sharp 1979; Sussman 1982; Thornton & Peters 1982), bimanual or sequential tasks (Briggs 1975; Hicks et al 1975; Lomas & Kimura 1976), free movements of the hands (Kimura 1973 I, Kimura 1973 II), sorting tasks (Beaton 1979) and tachistoscopic recognition tasks (Rizzolatti et al 1979).

But other studies show contrary results by demonstrating a decrease in performance with both hands under the concurrent interference condition instead of the hypothesized right hand decrement (Boles 1979; Lomas & Kimura 1976; McFarland & Ashton 1975; Summers & Sharp 1979). Neither the hand steadiness measure (Warshal & Spirduso 1981) nor the measurement of readiness potentials, (Bashore et al 1982) provided support. In summary, data confirmatory of Kinsbourne & Cooke's dual-code theory are most often obtained when motor behavior of right handers is recorded under silent vs. verbal conditions.

As noted above (pages 2 and 3), a task-sharing design may be used to test the Levy and Reid (1976, 1978) hypothesis of ipsilateral cerebral control of the distal musculature of ILH subjects. To use the methodology employed by Kinsbourne and Cooke (1971) to investigate the dual-code theory, as a means of testing Levy and Reid's (1976, 1978) hypothesis of ipsilateral cerebral control, a continuous motor task which approximates the manual activities of writing behavior was selected. The combination of visual guidance, wrist and arm movements as well as the fine motor control of the distal musculature necessary to track a moving stimulus on a target platter satisfies the requirements for a suitable response to test this hypothesis.

Pursuit Rotor Research As A Method of Measuring Motor Skills

Kinsbourne and Cooke (1971) indicated that practice affects the performance of subjects under the dual-code hypothesis. A variety of variables which affect human learning such as reminiscence (Williams & Grbin, 1976; Horn, 1976), transfer of training (Boswell & Irion, 1975), mental rehearsal (Rawlings & Rawlings, 1974), reactive inhibition (Williams & Grbin, 1976; Hsu & Payne, 1979), or meditation (Williams & Herbert, 1976; Williams & Vickerman, 1976) have all been studied using a pursuit rotor apparatus. Williams and Grbin (1976) have further demonstrated that gross body movements necessitated by an oversized pursuit rotor apparatus are influenced by reactive inhibition, warm-up decrement and reminiscence. It would appear that the proposed specialization of motor behavior in inverted left handed writers would be detectable with such an apparatus when the unimanual continuous activity is measured while a task requiring activity in the dominant cerebral hemisphere is performed.

Purpose of The Study

The purpose of this study is to determine whether ILH subjects in a modality which parallels the motor responses of writing behavior is consistent with Levy and Reid's

(1976, 1978) hypothesis of ipsilateral cerebral control. While Levy and Reid's theory has been tested with a wide variety of experimental procedures, the studies have not been conclusive. An experimental design which examines a particular combination of finger, wrist and arm movements, and feedback loops may provide new information which is pertinent to Levy and Reid's work.

A task-sharing paradigm, as proposed by Kinsbourne and Cooke (1971), was used to record differences in the motor behavior of tracking a stimulus under different experimental conditions. The pursuit-rotor design permits examination of a period of continuous motor activity which utilizes much of the musculature system involved in writing behavior.

The experimental variables chosen for this study were handwriting posture, hand dominance, interference and familial sinistrality. In all handwriting posture groups, right-handers, left-handers, and inverted left-handers, all participants were males. Kolb and Whisha (1980) suggest that females are less lateralized than males regarding language functions. Levy and Reid (1976, 1978) found the clearest and most reliable support for their hypothesis in the results of male subjects. It is important to note that hand dominence, not right hand vs left hand, was considered in order to illuminate differences between experimental conditions for all groups. Three levels of verbal interference, none, simple, and complex, were selected since this type of interference has often been reported as significant. Familial sinistrality, no history of familial sinistrality vs. a history of familial sinistrality, was considered because:

> "... neuropsychological tests have shown that the cerebral organization of nonfamiamilial left-handers is lateralized in a way identical to that of right handed people, whereas familial left handers have more bilaterally represented verbal and non-verbal functions." (Kolb & Whishaw, 1980, pg. 174).

Similarly, Hick's (1975) results indicate that task sharing effects are influenced by familial left handedness. Nonfamilial left handers and right handers with a history of familial left handedness, show a decrease in performance with either hand during a concurrent verbal condition. Thus, familial handedness must be eliminated as a confounding variable before hand posture, exhibited while writing, can be used as an indicator of cerebral organization. Consistent with this design, McKeever (1978) has demonstrated that familial sinistrality is as least as reliable an indicator of cerebral lateralization as is hand position exhibited during writing.

A dichotic listening test was administered to all participants. This test was used to ascertain the verbally dominant hemisphere. It is only when the verbally superior hemisphere is determined that the response decrement results, obtained with a task-sharing paradigm, could be useful in assessing Levy and Reid's (1976, 1978) theory of ipsilateral cerebral control.

Thus this study using a novel experimental method, tested the Levy and Ried (1976, 1978) hypothesis of ipsilateral cerebral control of the distal musculature of ILH subjects.

Hypotheses (See Table I for a pictorial representation of the following hypotheses).

Hypothesis I

Based upon Levy and Reid's (1976, 1978) theory of ipsilateral cerebral control, Hypothesis I predicted that ILH subjects without a history of familial sinistrality would demonstrate decrements in responding with their left hand under simple and complex conditions of verbal interference, ILH subjects with a history of familial sinistrality were predicted to show a decrement in right hand responding under both verbal interference conditions.

Hypothesis II

LH subjects without a history of familial sinistrality were predicted to show depressed performance with their right hand under the verbal interference conditions while the LH group with a history of familial sinistrality were hypothesized to show a decrement in left hand responding under some conditions.

Hypothesis III

Both right handed groups were predicted to show decrements in right hand performance under both conditions of verbal interference. The RH subjects with a history of familial sinistrality were predicted to show a smaller decrement in left as compared to right hand responding under the two verbal interference conditions.

Hypothesis IV

Both simple and complex interference conditions were hypothesized to affect adversely performance. The complex verbal interference condition was hypothesized to cause the larger response decrement.

METHOD

Design:

The design used in this study was a split-plot factorial ($SPF_{32.23}$, Kirk, 1968). Two between group variables, Handwriting Posture and Familial Sinistrality, and two within group variables, Hand Dominance and Concurrent Interference were considered. See Appendix III for a conceptual layout of the design.

Subjects and Groups

Sixty-five male subjects were solicited by an advertisement placed in a daily newspaper and advertisements posted at Saint Mary's University campus. Subjects were screened during a telephone interview to eliminate those with severe visual or auditory problems. At the time of testing only three subjects were excluded from the sample because they exhibited a writing hand posture which was neither of normal nor inverted. In addition, two subjects did not meet criterion on the pursuit rotor task and were excluded.

The remaining sixty subjects formed the following six groups of ten subjects each:

1. Right Handed subjects without Familial Sinistrality that is any first degree relative such as mother, father and or sibling who exhibited left handedness, RH-:
2. Right Handed subjects with at least one first degree relative who exhibited left handedness, H+.
3. Left Handed subjects without any first degree relatives who exhibited left handedness, LH-.
4. Left Handed subjects with at least one first degree relative who exhibited left handedness, LH+.
5. Inverted Left Handed subjects without any first degree relatives who exhibited left handedness, ILH-.
6. Inverted Left Handed subjects with at least one first degree relative who exhibited left handedness, ILH+.

The mean age of the subjects was 27 years and the range was 17 to 67. Sixty percent of the subjects were between the ages of 17 to 25. All subjects reported normal hearing, and normal or corrected to normal vision. All subjects received five dollars for their participation in the study.

Test Instruments

The Edinburgh Inventory, The Maze Coordination Test, a Dichotic Listening Test and a Pursuit Rotor Test were used in this study. A description of each test follows.

The Edinburgh Inventory

This test (Oldfield, 1971) measures the degree of handedness demonstrated by the subject in a variety of everyday tasks. A laterality quotient for each participant from +1.00 complete right hand usage, to -1.00, Complete left hand usage may be caluculated. This test also permits the observation of hand posture exhibited while writing for each subject.

The Edinburgh Inventory consists of ten items which provide norms on the degree of laterality for 1100 normal subjects. Raczkowski, Kalat and Nebes (1974) tested 650 undergraduates and retested 47 approximately one month later with a handedness questionnaire which included 7 of the 10 Oldfield (1971) questions. Six of the 7 items demonstrated 90%, or greater, validity when item responses were cross-validated with individual performance tests. Bryden (1976) assessed 984 subjects using, in part, the Edinburgh Inventory. Having then collected a history of familial left handedness, Bryden observed the performance of subjects on the particular items and later retested the subjects. All the results including the statistical distribution of right and left handedness were then factor analyzed. The first five items of the Edinburgh Inventory were heavily loaded one main factor determined to be handedness.

The Maze Coordination Test

This test, which is incorporated as part of Trites (1977) Motor Steadiness Battery, was used to screen out subjects with motor control difficulties. Since tremors, Parkinson symptoms or rigidity of movement could make the scores of the pursuit rotor task confusing, any subject who did not meet a cutoff score was excluded from the sample. This cutoff score was the meanscore for 15 year old males (Knights, 1966).

A Dichotic Listening Tape

This test was constructed to determine the dominant verbal hemisphere for each subject. Previous research (Kimura, 1961) has demonstrated that the ear opposite the language dominant hemisphere, is more acute than the ear ipsilateral to the language dominant hemisphere.

The Pursuit Rotor Test

This test was used to measure performance during the two concurrent verbal conditions and the silent condition. This test was adopted because it has been demonstrated to be sensitive to variables which affect learning (Horn 1976; Rawlings & Rawlings 1974, Williams & Grbin, 1976), and it approximates the motor behavior of writing.

Apparatus:

A Photoelectric Rotary Pursuit (model number 30014), a repeat cycle timer (model number 51013), and a digital stop clock (model number 54030) all manufactured by The LaFayette Corporation were used during the Pursuit Rotor Test. A Sony stereophonic tape recorder (model TC-270) and Superex headphones were utilized in the Dichotic Listening Test. A Maze Coordination Platter and a digital timer manufactured by The LaFayette Corporation, and a Compass Instruments manual stopwatch were used during The Maze Coordination Test.

Procedure:

Handedness Questionaire

First, each subject completed the handedness questionnaire (Oldfield, 1971, See Appendix IV) to determine the degree of lateralization and their writing hand posture. Based upon Levy and Reid's (1976, 1978) experiments, an inverted hand posture was defined as one in which the subject placed his hand above the line of script, thereby directing the point of the pen towards the bottom of the page. Subjects who positioned their hand below the line of script and directed the tip of the pen towards the top of the page were defined as displaying a normal hand posture while writing.

The subject was placed in a familial sinistrality group if he reported at least one left-handed first degree relative.

Maze Coordination Test

Next, the subjects completed the Maze Co-ordination Test. The platter containing the maze was placed directly in front of the subject at his midline. Subjects were instructed to trace a path through a maze with a hand held stylus. The platter containing the maze was placed directly in front of the subject at his midline. The instructions for this test were given verbatim from Trites (1977, Appendix V). The dependent measures were (1) the time on boundry, and (2) the number of boundry hits. A cutoff score equal to the mean for 15 year old subjects, (Knights 1966), was used. Indeed no subject was excluded from the sample by this criterion.

Dichotic Listening Test:

On each trial the subject was presented with a set of three digits through the left channel of a set of headphones and a different three digit sequence through the right channel using a prerecorded stereo tape. The digits were presented in both ears at the same time but the same digit was never presented to both ears during any trial. The tape was stopped after each trial and the subjects were instructed to report, and to guess if uncertain, all digits heard regardless of ear.

After ten trials the tape was stopped. The subjects removed the headphones and reversed the position of the headphones so that the information through each channel would now be presented to the opposite ear. The tape was then rewound and ten more trials were presented.

The starting position of the channels of the headphones was counterbalanced within and across groups. All subjects received three practice trials to familiarize themselves with the test. The dependent variable, the number of correct responses per ear, was recorded for each trial.

Pursuit Rotor Task:

Subjects standing in front of a pursuit rotor apparatus practiced the task with each hand for two minutes. During the practice trials, subjects attempted to keep a 12.7 cm. hand-held stylus in contact with a 1.8 cm x 1.1 cm target area which revolved at 45 RPMs throughout a circle with a 30.5 cm diameter. Subjects were permitted full movement of the fingers, wrist, or arm which enabled them to keep the stylus on the target area.

Any subject who could not keep the stylus on the target area for a total of ten seconds out of the two minute practice trial with either hand was excluded from the sample. Two subjects did not meet the criteria and were excluded from the study.

Sixty experimental trials were presented in ten blocks of six, fifteen-second trials. Within each block, the following conditions were ramdomized: (1) right hand responding, no verbal interference (2) right hand responding, simple verbal interference (3) right hand responding, complex verbal interference (4) left hand responding, no verbal interference (5) left hand responding, simple verbal interference (6) left hand responding, complex verbal interference.

The target was stationary at the start of every trial. When the subject made contact with the target area of the pursuit rotor, the verbal signal "Ready" was given by the experimenter. After this signal, the trial was initiated after a 1,2, or 3 second delay. The target area always moved in a clockwise direction. The digital stopclock recorded time on target for 15 second trials.

On trials in which there was no verbal interference, the subjects were instructed to remain silent while tracking the target circle. During simple interference trials the subjects were required to repeat a four word sentence (Appendix VI) at least twice before the experimenter gave the verbal signal, and throughout the duration of the trial. In the complex interference trials the subject repeated a four word sentence in which each word began with the same letter (Appendix VII) in the same way.

Ten different simple and complex sentences were used. Each sentence was used four times throughout the experiment, twice with each hand. In both of the verbal interference conditions any sentence was coupled with both response hands within a block. The starting hand was counterbalanced within the across groups. The entire procedure, requiring one hour of a subject's time, was run in a single session.

RESULTS

All analyses of variance were executed with the ANOVA 7 computerized package (note II).

Explanation of Analyses:

Three, separate analyses of variance were computed on the data on The Pursuit Rotor Test and the scores on The

Dichotic Listening Test.

In Analyses I, The Pursuit Rotor Test scores, average time on target, and The Dichotic Listening Test scores, the average number of digits recalled, were analyzed using a mixed design, outlined in Appendix III. In both analyses the between group factors were (1) Handwriting Posture, RH, LH & ILH, and (2) Familial Sinistrality, - & +. In The Pursuit Rotor Test analyses, (1) Hand Dominance, that is, use of Dominant vs Non-Dominant hand, and (2) Interference, None, Simple & Complex, were the within subject factors; for The Dichotic Listening Test analysis, the only within subject factor was channel, Left & Right, that is, the ear receiving the verbal input.

In Analysis II, Familial Sinistrality was eliminated as a factor because this variable was not significant either as a main effect or in any interaction in the first analysis. The elimination of the Familial Sinistrality variable reduced the number of separate groups of subjects from six to three and consequently, the number of subjects per group increased f m 10 to 20. Handwriting posture; LH, RH, and ILH, as a between group factor was considered in analyzing the scores for both The Pursuit Rotor Test and The Dichotic Listening Test. The within subject factors for both The Pursuit Rotor Test Analysis and The Dichotic Listening Test analyses were identical to Analysis I.

In Analysis III, all subjects within the three hand writing posture groups were classified, using a median split, into laterality groups on the basis of their laterality quotient scores on The Edinburgh Inventory (Oldfield, 1971). Between group factors for both The Pursuit Rotor Test analysis and The Dichotic Listening Test Analysis were, (1) Handwriting Posture Group, RH, LH and ILH, and (2) Laterality Positive Laterality and Negative Laterality. Within subject factors considered when analyzing pursuit rotor scores were (1) Hand Dominance, that is the use of Dominant vs the Non-Dominant hands, and (2) Interference, None, Simple and Complex. The within subject factor, considered when investigating The Dichotic Listening Test score, was, once again, (1) Channel, that is, the Left vs the Right ears.

Analysis I

Pursuit Rotor Test

The overall analysis of variance of The Pursuit Rotor Task scores (Table II) indicated a significant main effect for Hand Dominance ($F(1,54) = 134.4620$, $p < .0001$); when subjects used their Dominant Hand, their mean contact with the stimulus target was 6.719 seconds (out of a 15 second trial) compared to 5.989 seconds with their Non-Dominant hand. Handwriting Posture was also significant ($F(2,54) = 3.3299$, $p < .0420$). Planned comparisons with Student T-tests indicated that RH subjects ($\bar{X} = 6.974$ seconds) tracked the target significantly longer than LH subjects ($\bar{X} = 5.714$ seconds) ($t(38) = 2.4371$, $p < .05$) but not ILH subjects ($\bar{X} = 6.375$ seconds) ($t(38) = 1.419$, $p > .05$). The Hand Dominance X Handwriting Posture Group interaction was also significant ($F(2,54) = 15.0874$, $p<.0001$); however, the Interference X Hand Dominance interaction was sizable but not significant ($F(2,108) = 2.8765$, $p<.0590$).

Analyzing the simple main effects of the Hand Dominance X Handwriting Posture Group interaction (Table III & Figure I), RH subjects were found to track the target stimulus significantly better with their Dominant, 7.578 seconds, vs. their Non-Dominant, 6.370 seconds, Hand ($F(1,54) = 19.1805$, $p<.01$). No difference in tracking by Dominant vs. Non-Dominant Hands was found in any group of left-handed subjects. Handwriting Posture was not significant in either the Dominant Hand or Non-Dominant Hand response conditions; all three groups performed relatively the same with their dominant hand and again, relatively the same with their non-dominant hand.

The Interference X Hand Dominance interaction (Table IV & Figure II) showed that all three groups performed better with their Dominant Hand in each Interference condition. The differences of .850, .653 and .687 seconds between Dominant vs. Non-Dominant response hands, respectively for No Interference: $F(1,108) = 14.8414$, $p<.01$; Simple Interference: $F(1,108) = 8.7592$, $p<.01$; and Complex Interference: $F(1,108) = 9.6951$, $p<.01$, were all significant. Interference was not significant for either the Dominant: $F(2,54) = .2495$, $p>.05$, or Non-Dominant Hand: $F(2,54) = .1985$, $p>.05$.

All Handwriting Posture Groups except LH+ tracked the target significantly better with their Dominant Hand (Table

V). The LH+ group did not show a preference for either hand.

The Interference X Hand Dominance interaction was significant $F(2,18) = 6.0306$, $p < .001$, for group RH+. Analyzing this interaction, (see Table VI and Figure III), the Dominant Hand was found to be significantly better at each level of Interference, (No Interference: $F(1,9) = 56.777$, $p < .001$, Simple Interference: $F(1,9) = 18.532$, $p < .001$, and Complex Interference: $F(1,9) = 25.641$, $p < .001$). Interference decreased pursuit tracking performance for the RH+ group when they used their dominant hand ($F(2,18) = 4.584$, $p < .05$. Under the No Interference control, this group spent a mean of 7.684 seconds on target, 7.186 seconds for Simple Interference and 7.192 seconds for Complex Interference.

Decomposition of the variable, Interference, indicated remarkable but insignificance results for the ILH- group ($F(2,18) = 3.3079$, $p < .0586$). The mean times on target for the No Interference, Simple Interference and Complex Interference was 6.341 seconds, 6.314 seconds and 6.060 seconds, respectively. Comparisons of these means by Duncan's Range Test (McGuigan, 1978) revealed no significant differences (R_3 (observed) = .281 at df=57 < R_3 (predicted) .991; R_2 (observed) =.027 at df=57 < R_2 (predicted) .873). The factor, Interference, did not effect the performance of any other Handwriting Posture Group.

Dichotic Listening Test

Table VII shows that the Channel X Handwriting Posture interaction was substantial but insignificant ($F(2,54) = 2.8672$, $p. < .0639$). For RH subjects, the mean number of digits recalled from the right channel, 2.700 out of a possible 3.00, was greater than the mean number recalled from the left channel, 2.401, out of a possible 3.00. For LH subjects there was better recall of material presented through the left, 2.495 vs. the right channel 2.183. No difference in recall between the right channel, 2.535, and the left channel, 2.596, was found for FLH subjects.

Analysis II

Pursuit Rotor Test

Analysis II, with the elimination of Familial Sinistrality as a factor, did not yield different findings from Analysis I. Again, Table VIII shows that Hand Dominance was significant ($F(1,57) = 136.125$, $p. < .0001$) as was Handwriting Posture Group ($F(2,57) = 3.458$, $p. < .05$). Again, the Hand Dominance X Handwriting Posture Group interaction was significant ($F(2,57) = 15.274$, $p. < .0001$). Similar to Analysis I, the Interference X Hand Dominance was noteworthy but insignificant ($F(2,114) = 2.899$, $p. < .0575$). Decomposition of these interactions replicated exactly the findings reported under Analysis I above:

All groups tracked the target significantly better with their dominant hand (Table IX). The difference in performance between Dominant and Non-Dominant Hands were

1.21 sec., 0.04 sec., and 0.58 sec. for the RH, LH, and ILH groups respectively.

The Interference X Hand Dominance interaction was significant for group RH. The decomposition of this interaction (Table X and Figure IV) showed that the right hand performance was superior at No Interference: $F(1,19) = 96.901$, $p.<.01$, Simple Interference: $F(1,19) = 45.650$, $p.<.01$, and Complex Interference: $F(1,19) = 58.690$, $p.<.01$. Concurrent verbal interference did not affect the performance of either the Dominant ($F(2,38) = 3.555$, $p.<.05$) or the Non-Dominant Hands ($F(2,38) = 3.734$, $p.<.05$).

Dichotic Listening Test

As was the case in Analysis I, Table XI shows the Channel X Handwriting Posture was remarkable but insignificant ($F(2,57) = 2.9354$, $p.<.0596$).

ANALYSIS III

Pursuit Rotor Test

The overall analysis of variance (see Table XII) of scores grouped according to Laterality, again, showed significant main effects of Hand Dominance ($F(1,54) = 136.6291$, $p.<.0001$) and Handwriting Posture ($F(2,54) = 3.7424$, $p.<.0292$). As well, the Hand Dominance X Handwriting Posture interaction reached significance ($F(2,54) = 15.3375$, $p.<.0001$). Once more the Interference X Hand Dominance interaction was sizable but insignificant ($F(2,108) = 2.9651$, $p.<.0542$). In addition, the Laterality X Posture interaction was significant ($F(2,54) = 3.4733$, $p.<.0370$).

The results show (Table XIII and Figure V) that RH subjects with Negative Laterality scores had higher mean tracking scores ($\bar{x}$ = 7.493 sec.) than those with Positive laterality scores ($\bar{x}$ = 6.454 sec.). This pattern was reversed for the LH and ILH groups where subjects in the Positive Laterality Groups (LH: $\bar{X}$ = 6.079 sec; ILH: $\bar{X}$ = 7.018 sec.) tracked the target better than those in the negative Laterality Groups (LH: $\bar{X}$ = 5.350 sec; ILH: $\bar{X}$ = 5.732 sec.).

When this interaction was decomposed (Table XIV) into simple main effects, no significant results were found. There were no significant differences between subjects with Positive vs. Negative Laterality scores for Right Handers: $F(1,54) = 0.424$, $p > .05$, Left Handers: $F(1,54) = 0.170$, $p > .05$, or Inverted Left-Handers: $F(1,54) = 0.650, p > .05$. Positive Laterality scores did not differentiate between Handwriting Posture Groups ($F(2,54) = 0.313, p > .05$; neither did Negative Laterality scores ($F(2,54) = 1.027$, $p > .05$).

All groups of subjects, except LH subjects with Negative Laterality scores, tracked the target stimulus better with their Dominant Hand (Table XV). Group LH with Negative Laterality scores showed no difference between responses with Dominant vs. Non-Dominant Hands.

The RH group with Positive Laterality scores achieved a significant Interference X Hand Dominance interaction ($F(2,18) = 5.2451$, $p < .01$). When this interaction was decomposed (Table XVI and Figure VI) a significant difference was found between Dominant and Non-Dominant Hand responses at No Interference: $F(1,19) = 46.46, p. < .01$, Simple Interference: $F(1,19) = 16.99, p. < .01$, and Complex Interference conditions, $F(1,19) = 26.37$, $p. < .01$. In all instances the performance of the Dominant Hand exceeded that of the Non-Dominant Hand. There was also a significant decrease in the responses of the Dominant Hand under the Simple Interference, $\bar{x} = 6.905$ sec., and Complex Interference, $\bar{x} = 6.901$ sec, conditions compared to the control condition ($F(2,18) = 7.820$, $p. < .01$).

The LH group with Negative Laterality scores showed a significant Interference X Hand Dominance interaction ($F(2,18) = 3.8548$, $p. < .0395$). The decomposition of this interaction, seen in Table XVII, did not show any significant simple main effects.

Dichotic Listening Test

The results of Analysis III (Table XVIII and Figure VII) are identical to Analyses I and II. Again the interaction of Channel X Handwriting Group was noteworthy but insignificant ($F(2,54) = 2.8925, p. < .0625$).

Laterality Quotient Results

The mean laterality quotients of each Handwriting Posture Group were analyzed by Duncan's Range Test. The results show that (1) both groups of RH subjects differed from all LH groups ($p. < .05$) and (2) LH+ subjects obtained laterality quotients which were significantly different from all the other LH groups ($p. < .05$). Table XIX shows that RH-subjects scored the most positive on this index (+.730) while LH + subjects attained the most negative laterality scores (-.795).

Qualitative Results

Some differences in the study deserve further comment. In attempting to assimilate data from all aspects of the study, there appear to be subtle yet noteworthy differences between LH and ILH subjects. On the Dichotic Listening Test the ILH subjects did not appear to demonstrate any ear preference for verbal stimuli. The results of the LH group, although insignificant, demonstrate a tendency for superior responding to left ear stimuli (see Table XX).

Secondly, the Edinburgh Inventory (Oldfield, 1971) Laterality Quotients produced interesting results. If the data from Table XIX are regrouped on the basis of Handwriting Posture, ILH subjects achieve a mean Laterality Quotient located between the RH and LH subjects. Although the ILH group attains a mean negative laterality score, the magnitude is less than that for their LH counterparts. The overall ranking of scores on The Pursuit Rotor Test also follows Handwriting Posture (see Table XX). Qualitatively, the ILH subjects are more successfuly than the LH subjects and more similar to the RH group.

DISCUSSION

Pursuit Rotor Test

All three analyses showed significant main effects for Hand Dominance and Hand Writing Posture. The interaction of

Hand Dominance X Hand Posture Group was also significant while the Interference X Hand Dominance interaction approached significance in all three analysis.

The significant effect of Hand Dominance is not surprising. In the task sharing literature reviewed in the introduction, subjects consistently obtained better performance with their Dominant vs. Non-Dominant Hands.

The effect of Handwriting Posture Groups was somewhat interesting. The performance of RH subjects was greater than that of LH but not ILH subjects. One possible explanation is that previous research utilizing task sharing procedures (Hicks, 1975; Lomas & Kimura, 1976, Sussman, 1982) reported smaller yet more symmetrical decrements in performance for LH vs RH subjects. The concurrent verbal interference may affect only the Dominant Hand of RH subjects but concurrent verbal interference affects both hands of LH subjects. Across all interference conditions, this would lead to RH subjects demonstrating better performance. But, the performance of RH subjects was not greater than ILH subjects. This is surprising as Levy and Reid (1976, 1978) have suggested that the performance ILHs in a task-sharing paradign, being more bilateral in their cerebral organization than other LH subjects, should be more adversely affected. However, the overall performance of ILH subjects was not significantly different from that of the RH group. This finding suggests that the performance of ILH subjects is similar to their RH counterparts as predicted by Levy and Reid (1976, 1978). Indeed the rank ordering across all conditions showed that the performance of ILH subjects was second only to the RH group and greater than LH subjects.

The significant interaction of Hand Dominance X Handwriting Posture Group is accounted for by the very large diffence in pursuit rotor tracking of RH subjects with their Dominant vs. Non-Dominant hand. No difference in Dominant and Non-Dominant hand performance was found on the other groups. This finding is consistent with previous research (Branch et al, 1964, Gloning et al, 1969, Hecaen & Sauget, 1971) which suggested that left handed subjects possess more bilateral cerebral organization than their right handed counterparts. The marginal significance of the Interference X Hand Dominance interaction may be accounted for by the superior performance of RH subjects when they used their Dominant vs. Non-Dominant Hand.

Each hypothesis of the study, outlined above, will be discussed separately:

Hypothesis I

The first hypothesis predicted a left hand response decrement in performance for ILH- subjects under both interference conditions compared to the control condition, and a decrease in right hand responding for ILH+ subjects under these same treatment conditions. The data did not support this hypothesis. In Analysis I the main effect of Interference approached significance for the ILH- group. The results suggest that any differences may be accounted for by the difference between the Complex Interference condition compared to both the Simple Interference and No Interference conditions. No other interactions of Hand Dominance X Interference results were significant.

Hypothesis II

Hypothesis II predicted a decrease in right hand performance for LH- subjects under both levels of the interference condition and a left hand response decrement for LH+ subjects. This hypothesis was not supported by the results although the Interference X Hand Dominance interaction for LH subjects with Negative Laterality scores was significant.

Hypothesis III

Right hand response decrements were predicted for both RH+ and RH- groups during both interference conditions. It was also predicted that RH+ subjects would show a smaller response decrement with their left hand than their right hand. Two separate groups of RH subjects did demonstrate the predicted right hand decrement. In Analysis I, RH+ subjects performed significantly better with their right hand in the control condition as compared to both levels of interference. The same results were found in Analysis III for RH subjects with Positive Laterality scores.

Hypothesis IV

It was hypothesized that both levels of interference would cause the specific response decrements listed in

Hypotheses I,II, and III above further, Hypothesis IV further predicted that the Complex Interference condition would cause a greater response decrement than Simple Interference. But no difference was found when subjects responded under the Complex vs. the Simple interference conditions. The Interference X Group RH interaction was significant indicating that the right hand of Group RH showed decreased performance during concurrent verbalization.

Dichotic Listening Test

Although the Dichotic Listening Test scores were consistent with predictions based on Levy and Reid, critical comparisons did not indicate significant differences.

The sizable but insignificant Channel X Group interaction, which was found in the three separate analyses, provides some support for Levy and Reid's (1976, 1978) work. The right ear advantage in RH subjects implies left hemisphere specialization for verbal input. The LH group obtained more correct responses from left channel input, suggesting right-hemisphere superiority in the perception of spoken verbal information (Kimura, 1961). There was no difference between ears in the perception of spoken verbal material for ILH subjects, which is consistent with Levy and Reid's (1976, 1978) suggestion that ILH subjects are less lateralized than either their LH or RH counterparts.

One reason for the failure to reach significance differences among these groups may be that the listening tape presented digits approximately one-half a second apart. Subjects may have had time to attend to each digit separately. If that is true, the tape was not useful in determining the dominant verbal hemisphere.

Qualitative Analysis Discussion:

Considering the data presented in the Qualitative results section, the two groups of left-handed subjects appear to be qualitatively different. Nonetheless, subtle differences can be noted on three separate measure. The differences between the LH and ILH subjects found in the results of the Dichotic Listening Test and Laterality Quotients suggests that ILH subjects have less hemispheric specialization than their LH counterparts. The rank ordering of performance on the Pursuit Rotor Test implies that this similarity between cerebral hemispheres many enhance overall performance. It may be the case that ILH subjects do respond differently than LH subjects, or perhaps there are unique cerebral specialization of the sort hypothesized by Levy and Reid (1976, 1978).

However, if contrary to Levy and Reid (1976, 1978), ILH subjects possess contralateral cerebral control over distal musculature responding, and given the fact that they show less hemispheric specificity than convential LH subjects, one should expect significant depressions of both hands during concurrent speech. This result was not found on the contrary, the performance of ILH subjects was superior to LH subjects. Therefore it is possible that ILH subjects may have somewhat mutually exclusive motor and speech areas of the cerebral cortex which would not be predicted to show interference.

GENERAL DISCUSSION

The task sharing design used in this study, should be justified as a test of Levy and Reid's (1976, 1978) theory of ipsilateral cerebral control of the distal musculature of ILH subjects. The performance of RH subjects on the Pursuit Rotor task under verbal interference, can be used to test this hypothesis. The neuroanatomic pathways of RH subjects have been well documented in previous research and the results of RH indicated the most consistent support for the Kinsbourne and Cooke (1971) dual-code theory. Consequently, if the predictions of Hypothesis III were fully confirmed, the task-sharing paradigm would appear to be useful. Unfortunately, not all the predictions were born out. In Analysis I only RH subjects with a history of Familial Sinistrality showed significant right hand decrements in responding during concurrent verbal interference. But, contrary to an Hypothesis III prediction, RH- did not demonstrate a smaller left than right hand response decrement.

Since the left hand decrement did not occur and since familial sinistrality was not found to be important, the results suggest that once familial sinistrality is removed the results may be more useful. Therefore after the removal of familial sinistrality as a variable, the RH+ group would only be predicted to demonstrate a right hand response decrement.

The above results demonstrate partial support for the Kinsbourne and Cooke (1971) model. However, contradictory results were found in the RH- group, who obtained the most positive Laterality Quotient +.730 as measured by the Edinburgh Inventory. These subjects were at least one generation away from left-handedness in any first degree relative. The dual-code theory, then, would predict a strong decrement in right hand responding under concurrent verbalization. But, this decrement was not found.

In Analysis II, which did not group RH subjects according to familial sinistrality, subjects did not show any response hand decrement under either level of the concurrent interference conditions. Analysis III demonstrated that RH subjects with Positive Laterality scores showed the predicted right hand response decrement under both levels of concurrent interference, but that RH subjects with Negative Laterality scores did not show this right hand response decrement.

The outcomes of the three analyses are not as divergent as they appear. First, the predicted right hand decrement occurred in two of a possible five groups of RH subjects. Second, individual subject characteristics may have obscured some differences. For example, the RH+ group, Analysis I, included five out of the ten subjects who were reclassified as RH, Positive Laterality scores, in Analysis III. The variability in the responses of RH subjects might be accounted for by those subjects with the more Negative Laterality scores. When the twenty RH subjects were considered one group in Analyses II, the subjects ranging in Negative Laterality scores, may have performed with wide differences. These large differences in performance would contribute to variance and diminish the liklihood of finding the difference to be significant.

If the laterality scores result in more homogeneous groups, than grouping on the basis of familial sinistrality, some support is obtained for the task-sharing theory of Kinsboure and Cooke (1971).

Analysis III, in which subjects were classified on the basis of their Laterality Quotient scores, may then produce the most reliable assessment of Levy and Reid's theory.

The performance of all groups of left handed subjects on the pursuit rotor test was very similar. No differences in responding across any level of interference for either response hand were found. The absence of any significant differences was surprising. Even if performance was not different in handwriting posture groups, the literature indicates a smaller bilateral decrement in responding under concurrent verbalization (Hicks, 1975; Lomas & Kimura, 1976; Sussman, 1982) for LH subjects than for RH subjects who most often show the strong right hand decrement. Perhaps a Pursuit Rotor Test was not a sufficently sensitive instrument to demonstrate the differences between these groups. More probable, however, is that left-handed subjects as a group demonstrate more bilateral cerebral organization than right handers and this lack of hemispheric specificity may, on a task-sharing paradigm, result in similar performance with right and left hands.

The similarity of performance under Simple and Complex Interference conditions was noteworthy. It was expected that having to repeat a sentence which included alliterations would be more cognitively demanding than reciting a simple four word phrase. The cerebral hemisphere responsible for responding to this demand should have been more less able to maintain maximum performance of the unimanual skill. But, in a debriefing period at the end of the experimental session many subjects stated that they found repeating the alliterations easy. It appeared during various stages of data collection that subjects learned to repeat the alliteration sentences in almost a melodic fashion and to direct their attention towards the pursuit rotor task. While the evidence is anecdotal, it appears that the alliterations were no more taxing than the simple phrases.

It is also possible that the task of tracking a target on a pursuit rotor at 45 rpms was not very difficult and that this easy task could not cause a difference in responding under the verbal interference conditions. But, other various and minimally demanding activities, such as repetitive finger tapping (Bowers et al, 1978), distal arm movements (Lomas, 1980) and unimanual sorting task (Beaton, 1979) have all produced decrements under a concurrent verbal condition. There is however, a difference between the pursuit rotor task and these other simple tasks. Subjects were required to watch the target as they traced its course. Lomas (1980) stated that decrements in performance may be more likely in a dual task condition when subjects do not monitor their behavior.

The significant Laterality X Group Interaction in Analysis III was noteworthy. RH subjects showed a pattern of responding across laterality groups which was opposite that of the LH and ILH subjects. The results suggest that RH subjects with Negative Laterality scores track the target stimulus longer than RH subjects in the Positive Laterality group. The RH subjects with

Positive Laterality scores had shown a decrement in performance with their right hand across interference conditions. The verbal interference may have caused the lower time on target for the RH subjects with Positive Laterality scores. Alternately, RH subjects with Negative Laterality scores may be somewhat more bilateral in their cerebral organization and may, therefore, perform tracking better with both response hands.

This same logic can be applied to both the LH and ILH groups. The best performance for both these groups was recorded by subjects in the Positive Laterality groups. Once again this suggest that left handed subjects who perform more activities with their non-dominant (right) hand outperform their counterparts who almost exclusively rely upon left hand responding. The subjects in the Positive Laterality groups may possess more bilateral motor skill development.

Two subjects who failed to achieve the cutoff score on the Pursuit Rotor Test were excluded from the sample. Both of these subjects exhibited an inverted hand posture while writing. This incidental finding even if based on only two subjects, is consistent with the results presented in Appendix III which states that ILH subjects demonstrate poorer performance on some neuropsychological tests then non-dominanted writers.

AN ALTERNATIVE EXPLANATION

In consideration of the findings of all three analyses, an alternate explanation to Kinsbourne and Cooke's (1971) dual-code theory is required to account for the inconsistencies noted between the hypotheses and results. Once again, the only groups who demonstrated any significant depression in performance during concurrent verbalization were the RH+ subjects in Analysis I, and the RH subjects with positive laterality scores in Analysis III. Nonetheless acknowledging the fact that concurrent verbal interference did not produce any decrement in performance in 13 out of a possible 15 groups of subjects, the problem still remains to explain the mechanism which accounts for the depression in scores noted for the above mentioned two groups of subjects.

If it is sited that RH subjects with Positive Laterality Scores are strongly right handed, then their similarity of performance compared to the RH+ group of subjects is surprising since each subject in the latter group had at least one first degree relative who was left handed. Further, the composition of the group RH subjects with Positive Laterality scores (Analysis III) included five of the ten subjects who were originally placed in the RH+ group in Analysis I. Consequently the results of the two groups of RH subjects may be due to a particular hemispheric specialization in light of the fact that these subjects demonstrated familial left-handedness.

This speculation can not be fully confirmed since otne research (Hicks, 1975) has showed that right handers with a history of familial sinistrality showed depression of both hands during concurrent verbalization. Nonetheless, in this particular study, a history of familial sinistrality is the most parsimonious explanation of the performance of the two groups of right handed subjects who showed depressed scores under concurrent verbalization.

LIMITATIONS OF THE STUDY

As mentioned earlier the results obtained from the Dichotic Listening Test present the most severe limitation interpreting subjects performance on the Pursuit Rotor Test. In order for the Dual-Task theory to be reliably utilized to assess Levy and Reid's (1976, 1978) theory, the linguistically dominant hemisphere must be determined. Since the results were remarkable but still insignificant, the inferences regarding language lateralization may only be speculative. In future research a dichotic listening tape which presents the digits in each ear at exactly the same time, may reduce error within this type of experimental design.

Left handers were classified dichotomously as exhibiting normal or inverted hand posture while writing. This classification, while consistent with Levy and Reid's work did not take into account the detailed differences in hand posture described by McKeever (1978). Subsequent research might separate groups along a continuum of hand inversion.

The use of cutoff score on the Maze Coordination Task to exclude subjects was consistent with previous research, (Knights, 1966), but the particular cutoff score on the Pursuit Rotor Task may have been too low. A higher cutoff score would include subjects who maintained more time on target during the control trials. Therefore the interference conditions may then show the hypothesized decrements.

Only the number of errors and not the time to complete the Maze Coordination Test was analyzed. If subjects traced the maze very slowly, they may have avoided errors and consequently not be eliminated from the sample.

The study may have one other problem. Subjects were permitted to move their fingers, wrist, elbows or arm while tracking the target. Levy and Reid's theory was supported by studies in which tasks involved discrete movements of the distal musculature. There may be various kinesthetic feedback loops operating anywhere from the arm to elbow, elbow to hemisphere, or elsewhere (Levy et al, 1971).

Future Research

Although the results of this study are inconsistent with Levy and Reid (1976, 1978), one is nonetheless aware of differences between hand writing posture groups of left-handed subjects. Perhaps one of the most interesting research avenues at this time is the deficit hypothesis stated above in Appendix II. Although Gregory and Paul (1980) and Gregory, Alley, and Morris (1980) state that the performance of ILH subjects fall within normal boundries, their performance was observed to be deficient in 21/32 measures of intellectual and neuropsychological test abilities as compared to LH and RH subjects.

Levy and Reid (1976, 1978) have stated that ILH possess more bilateral cerebral representation of verbal and spatial stimuli presented visually via a tachistoscope. This bilateral representation of cerebral function may interfere with rather than enhance the performance of tasks. Indeed some researchers (Gregory & Paul 1980, Gregory et al 1980, Todor 1980) have contributed data supporting this position.

Since, virtually, all the support for Levy and Reid's (1976, 1978) theory has been obtained in the visual or visuo-motor modality, hand posture exhibited during writing may not necessarily be indicative of ipsilateral cerebral control but only demonstrate a coping mechanism which aids subjects in the combination of linguistic and motor responses which comprise writing. Such coping skills must be at least somewhat beneficial since ILH subjects significantly outperformed both RH and LH subjects on the Trail Making Test (Gregory & Paul 1980). The inverted posture then may be more an adaptation which allows subjects to increase speed of responding, than an indication of unique hemispheric specialization.

If future research continues to collect additional neuropsychological data from ILH subjects, these new norms may indicate some usefulnesses in determining selective neuropsychological test abilities of ILH subjects.

Summary:

Although limited support was found for Kinsbourne and Cook's (1971) research on the dual code theory, the results did not support the hypothesis based upon Levy and Reid's (1976, 1978) theory of ipsilateral cerebral control of the distal musculature in inverted left-handed subjects. However, some qualitative differnces were observed between LH and ILH subjects.

TABLE I

Neuroanatomical connections and hypothesized interference pathways based upon Levy & Reid's (1976, 1978) research. A double line (=) indicates stronger interference than a single (–) line.

NO FAMILIAL SINISTRALITY
Presumed
Left Hemisphere Language

FAMILIAL SINISTRALITY
Presumed
Right Hemisphere Language

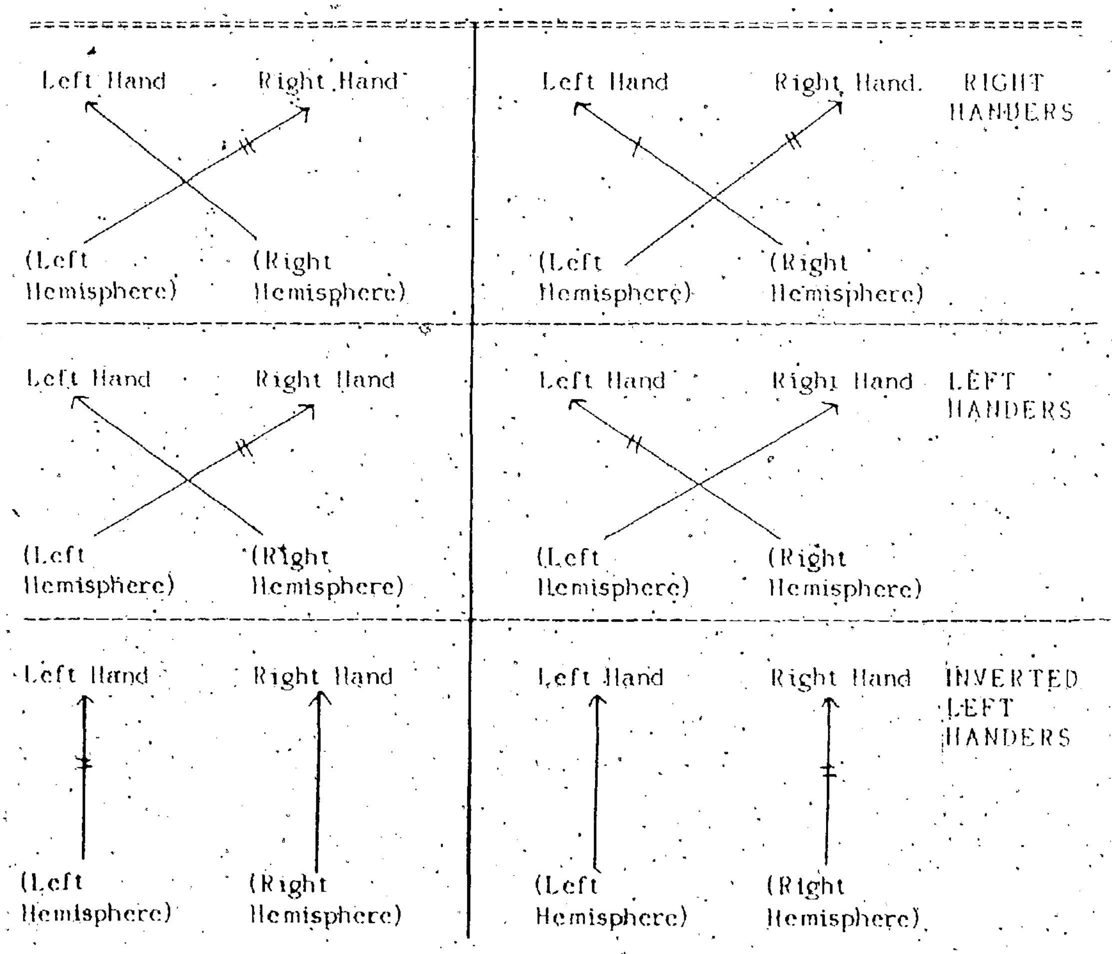

TABLE II

Analysis of Variance Source Table for Analysis I of The Pursuit Rotor Test computed from the mean scores of time on target in seconds (Interference (I), Hand Dominance (H), Familial Sinistrality (F.S.), Handwriting Posture Group (G)).

Source	Sum of Squares	Degrees of Freedom	F	P
1) I	0.5379	2	1.1048	0.3355
Error Term	26.2906	108		
2) H	47.9683	1	134.4620	0.0000
Error Term	19.2642	54		
3) FS	2.8249	1	0.1975	0.6627
Error Term	772.3607	54		
4) G	95.2549	2	3.3299	0.0420
Error Term	772.3607	54		
5) I X H	0.6643	2	2.8765	0.0590
Error Term	12.4712	108		
6) I X FS	1.0101	2	2.0747	0.1285
Error Term	26.2906	108		
7) I X G	0.6093	4	0.6257	0.6484
Error Term	26.2906	108		
8) H X FS	0.0777	1	0.2179	0.6475
Error Term	19.2641	54		
9) H X G	10.7647	2	15.0874	0.0000
Error Term	19.2641	54		
10) FS X G	9.6950	2	0.3389	0.7189
Error Term	772.3607	54		
11) I X H X FS	0.2017	2	0.8736	0.5766
Error Term	12.4712	108		
12) I X H X G	0.6120	4	1.3249	0.2644
Error Term	12.4712	108		
13) I X FS X G	1.2742	4	1.3085	0.2705
Error Term	26.2906	105		
14) H X FS X G	0.7441	2	1.0429	0.3606
Error Term	19.2641	54		
15) I X H X FS X G	0.3882	4	0.8404	0.5044
Error Term	12.4712	108		

TABLE III

Analysis of Variance Source Table for Simple Main Effects decomposed from significant H X G interaction in Analysis I of The Pursuit Rotor Test (H = Hand Dominance, G = Handwriting Posture Group).

Source	Sum of Squares	Degrees of Freedom	F
1) H of group RH	6.8417	1	19.1805
Error Term	19.2641	54	
2) H of group LH	0.7999	1	2.2425
Error Term	19.2641	54	
3) H of group ILH	1.693	1	4.7639
Error Term	19.2641	57	
4) G at Dominant Hand Responses	13.4324	2	.4695
Error Term	772.3607	54	
5) G at Non-Dominant Hand Responses	3.7961	2	.1327
Error Term	772.3607	54	

TABLE IV.

Analyses of Variance Source Table for Simple Main Effect decomposed from the significant I X H interaction in Analysis I of The Pursuit Rotor Test (I = interference, H = Hand Dominance).

Source	Sum of Square	Degrees of Freedom	F
1) H at no interference	3.6124	1	14.8414
Error Term	26.2906	108	
2) H at simple interference	2.1320	1	8.7592
Error Term	26.2906	108	
3) H at complex interference	2.3598	1	9.6951
Error Term	26.2906	108	
4) I at Dominant Hand Responses	0.1780	2	0.2495
Error Term	19.2641	54	
5) I at Non-Domianant Hand Responses	0.1417	2	0.1984
Error Term	19.2641	54	

TABLE V

Analyses of Variance Source Table for the Effect of Hand Dominance for all groups of subjects in Ananlysis I of The Pursuit Rotor Test (H = Hand Dominance, RH = Right Handed, LH = Left Handed, ILH = Inverted Left Handed, - = no. history of familial sinistrality, + = history of familial sinistrality).

Group	Source Q	Sum of Squares	Degrees of Freedom	F	P
1) RH-	H	27.4456	1	123.1444	.0001
Error Term		2.0059	9		
2) RH+	H	16.9369	1	95.2422	.0001
Error Term		1.6007	9		
3) LH-	H	2.6502	1	17.2336	.0028
Error Term		1.3840	9		
4) LH+	H	2.1622	1	2.3085	N.S.
Error Term		8.4297	9		
5) ILH-	H	3.8304	1	12.3050	.0067
Error Term		2.8016	9		
6) ILH+	H	6.5274	1	19.3101	.002
Error Term		3.0423	9		

TABLE VI

Analysis of Variance Source Table for simple main effects decomposed from the significant I X H interaction of group RH+ in Analysis I of The Pursuit Rotor Test. (I = Interference, H = Hand Dominance).

Source	Sum of Squares	Degrees of Feedom	F	P
1) H at no interference	10.095	1	56.777	.001
Error Term	1.600	9		
2) H at simple interference	3.295	1	18.532	.001
Error Term	1.600	9		
3) H at complex interference	4.559	1	25.641	.001
Error Term	1.600			
4) I at Dominant Hand Responses	1.632	2	4.564	.05
Error Term	3.221	18		
5) I at Non-Dominant Hand Responses	0.107	2	0.292	ns
Error Term	3.221	18		

TABLE VII

Analysis of Variance Source Table for Analysis I of The Dichotic Listening Test Computed from the mean scores of the number of correct responses per ear (Channel (C), Familial Sinistrality (FS) and Handwriting Posture Group(G)).

Source	Sum of Squares	Degrees of Freedom	F	P
1) C	0.0076	1	0.0231	0.8744
Error Term	17.8601	54		
2) FS	0.0091	1	0.0273	0.8637
Error Term	17.9169	54		
3) G	1.2769	2	1.9242	0.1540
Error Term	17.9169	54		
4) C X FS	0.0003	1	0.0008	0.9761
Error Term	17.8601	54		
5) C X G	1.8966	2	2.8672	0.0639
Error Term	17.8601	54		
6) FS X G	0.2335	2	0.3519	0.7100
Error Term	17.9169	54		
7) C X FS X G	0.5541	2	0.8377	0.5584
Error Term	17.8601	54		

TABLE VIII

Analysis of Variance Source Table for Analysis II of The Pursuit Rotor Test Computed from the mean scores of time on target in seconds (Interference (I), Hand Dominance (H), Handwriting Posture Group (G)).

Source	Sum of Squares	Degrees of Freedom	F	P
1) I	0.5379	2	1.0730	0.3462
Error Term	28.5748	114		
2) H	47.9683	1	136.1252	0.0000
Error Term	20.0859	52		
3) G	95.2550	2	3.4588	0.0371
Error Term	784.8809	57		
4) I X H	0.6643	2	2.8992	0.0575
Error Term	13.0611	114		
5) I X G	0.6093	2	0.6077	0.6612
Error Term	28.5748	114		
6) H X G	10.7647	2	15.2741	0.0000
Error Term	20.0859	57		
7) I X H X G	0.6120	4	1.3354	0.2602
Error Term	13.0611	114		

TABLE IX

Analysis of Variance Source Table for the effect of Hand Dominance for all groups of subjects in Analysis II of The Pursuit Rotor Test (H = Hand Dominance, RH = Right Handed, LH = Left Handed, ILH = Inverted Left Handed).

Group	Source	Sum of Squares	Degrees of Freedom	F	P
1) RH	H	43.7538	1	196.1929	.0001
	Error Term	4.2373	19		
2) LH	H	4.6000	1	9.2814	.0066
	Error Term	9.8261	19		
3) ILH	H	10.1792	1	32.1136	.0001
	Error Term	6.0225	19		

TABLE X

Analysis of Variance Source Table for Simple Main Effects decomposed from the significant I X H interaction of group RH in Analysis II of The Pursuit Rotor Test. (I = Interference, H = Hand Dominance).

Source	Sum of Squares	Degrees of Freedom	F	P
1) H at no interference	21.609	1	96.901	.001
Error Term	4.237	19		
2) H at simple interference	10.180	1	45.650	.001
Error Term	4.237	19		
3) H at complex interference	13.086	1	58.690	.0001
Error Term	4.237	19		
4) I at Dominant Hand Responses	1.742	2	3.555	N.S.
Error Term	9.312	38		
5) I at Non-Dominant Hand Responses	1.830	2	3.734	N.S.
Error Term	9.312	38		

TABLE XI

Analysis of Variance Source Table for Analysis II of The Dichotic Listening Test Computed from the mean scores of the number of correct responses per ear (Channel (C), Handwriting Posture Group (G)).

Source	Sum of Squares	Degrees of Freedom	F	P
1) C	0.0076	1	0.0236	0.8730
Error Term	18.4145	57		
2) G	1.2769	2	2.0040	0.1422
Error Term	18.1595	57		
3) C X G	1.8966	2	2.9354	0.0596
Error Term	18.4145	57		

TABLE XII

Analysis of Variance Source Table for Analysis III of The Pursuit Rotor Test computed from the mean scores of time on target in seconds (Interference (I), Hand dominance (H), Laterality (L), Handwriting Posture Group (G)).

Source	Sum of Squares	Degrees of Freedom	F	P
1) I	0.5379	2	1.0303	0.3616
Error Term	28.1915	108		
2) H	47.9172	1	136.6291	0.0000
Error Term	18.9384	54		
3) L	9.5323	1	0.7494	0.6053
Error Term	686.8855	54		
4) G	95.2062	2	3.7424	0.0292
Error Term	686.8855	54		
5) I X H	0.6698	2	2.9651	0.0542
Error Term	12.1981	108		
6) I X L	0.2783	2	0.5331	0.5939
Error Term	28.1915	108		
7) I X G	0.6131	4	0.5872	0.6759
Error Term	28.1915	108		
8) H X L	0.2141	1	0.6106	0.5560
Error Term	18.9384	54		
9) H X G	10.7581	2	15.3375	0.0000
Error Term	18.9384	54		
10) L X G	88.3609	2	3.4733	0.0370
Error Term	686.8855	54		
11) I X H X L	0.1049	2	0.4689	0.6328
Error Term	12.1981	108		
12) I X H X G	0.6122	4	1.3550	0.2534
Error Term	12.1981	108		
13) I X L X G	0.1015	4	0.0972	0.9801
Error Term	28.1915	108		
14) H X L X G	0.9521	2	1.3574	0.2651
Error Term	18.9384	54		
15) I X H X L X G	0.7224	4	1.5990	0.1787
Error Term	12.1981	108		

TABLE XIII

Mean time on target in seconds for Right Hand (RH), Left Handed (LH) and ILH (Inverted Left Handed) subjects in within the Positive Laterality (+Lat) or Negative Laterality (-Lat) scores for Analysis III.

	Time on Target	
Group	+ Lat	- Lat
1) RH	6.454	7.493
2) LH	6.079	5.350
3) ILH	7.018	5.732

TABLE XIV

Analysis of Variance Source Table for Simple Main Effects decomposed from the significant L X G interaction in Analyses III of The Pursuit Rotor Test (L = Laterality, G = Group, RH = Right Handed Subjects, LH = Left Handed Subjects, ILH = Inverted Left Handed Subjects).

Source	Sum of Squares	Degrees of Freedom	F	P
1) L at RH Scores	5.397	1	0.424	NS
Error Term	686.885	54		
2) L at LH Scores	2.171	1	0.170	NS
Error Term	686.885	54		
3) L at ILH Scores	8.269	1	0.650	NS
Error Term	686.885	54		
4) G at Positive Laterality Scores	3.982	2	0.313	NS
Error Term	686.885	54		
5) G at Negative Laterality Scores	26.131	2	1.027	NS
Error Term	686.885	54		

TABLE XV

Analysis of Variance Source Table for The Effect of Hand Dominance for all groups of subjects in Analysis III of The Pursuit Rotor Test. (H = Hand Dominance, RH = Right Handed, LH = Left Handed, ILH = Inverted Left Handed, + Lat = Positive Laterality Scores, – Lat = negative Laterality Scores).

Group	Source	Sum of Squares	Degrees of Freedom	F	P
1) RH +Lat	H	21.8890	1	86.5455	.0001
	Error Term	2.2763	9		
2) RH –Lat	H	21.8286	1	100.1648	.0001
	Error Term	1.9613	9		
3) LH +Lat	H	2.9659	1	5.8141	.0377
	Error Term	4.5911	9		
4) LH –Lat	H	1.8904	1	3.2863	N.S.
	Error Term	5.1771	9		
5) ILH +Lat	H	2.2815	1	6.8992	.0264
	Error Term	2.9792	9		
6) ILH –Lat	H	8.9861	1	41.3404	.0003
	Error Term	1.9563	9		

TABLE XVI

Analysis of Variance Source Table from Simple Main Effects decomposed from the significant I X H interaction of group RH with positive laterality scores in Analysis III of The Pursuit Rotor Test (I = Interference, H = Hand Dominance).

Source	Sum of Squares	Degrees of Freedom	F	P
1) H at no interference	11.752	1	45.461	.001
Error Term	2.276	9		
2) H at simple interference	4.297	1	16.990	.01
Error Term	2.276	9		
3) H at complex interference	6.670	1	26.374	.01
Error Term	2.276	9		
4) I at dominant hand responses	1.392	2	7.820	.01
Error Term	1.600	18		
5) I at non-dominant hand responses	0.277	2	1.275	ns
Error Term	1.600	18		

TABLE XVII

Analysis of Variance Source Table for Simple Main Effects decomposed from the significant I X H interaction of group LH with negative laterality scores in Analysis III of The Pursuit Rotor Test (I = Interference, H = Hand Dominance).

Source	Sum of Squares	Degrees of Freedom	F	P
1) H at no interference	1.922	1	3.342	NS
Error Term	5.177	9		
2) H at simple interference	0.055	1	0.095	NS
Error Term	5.177	9		
3) H at complex interference	0.578	1	1.005	NS
Error Term	5.177	9		
4) I at dominant hand responses	0.161	2	0.348	NS
Error Term	4.163	18		
5) I at non-dominant hand responses	0.712	2	1.541	NS
Error Term	4.163	18		

TABLE XVIII

Analysis of Variance Source Table for Analysis III of The Dichotic Listening Test Computed from the mean scores of the number of correct responses per ear (Channel (C), Laterality (L), Handwriting Posture Group (G)).

Source	Sum of Squares	Degrees of Freedom	F	P
1) C	0.0077	1	0.0234	0.8735
Error Term	17.6946	54		
2) L	0.0590	1	0.1782	0.6760
Error Term	17.8702	54		
3) G	1.2760	2	1.9279	0.1534
Error Term	17.8702	54		
4) C X L	0.1703	1	0.5196	0.5190
Error Term	17.6946	54		
5) C X G	1.8956	2	2.8925	0.0625
Error Term	17.6946	54		
6) L X G	0.2252	2	0.3403	0.7180
Error Term	17.8702	54		
7) C X L X G	0.5418	2	0.8268	0.5536
Error Term	17.6946	54		

TABLE XIX

The mean Laterality Quotients in a descending order from positive to negative for Right Handed (RH), Left Handed (LH) and Inverted Left Hand (ILH) subjects with either positive Familial Sinistrality (+) or negative Familial Sinistrality (-).

	Subjects					
	RH-	RH+	ILH-	LH-	ILH+	LH+
Laterality Quotient	+.730	+.674	-.524	-.556	-.650	-.795

TABLE XX

Qualitative results obtained from the mean number of digits correctly identified per Channel on the Dichotic Listening Test, the mean Laterality Quotients and the mean time on target in seconds on The Pursuit Rotor Test for Right Handed (RH), Left Handed (LH), and Inverted Left Handed (ILH) subjects.

Handwriting Posture Group	Dichotic Listening Test Left Channel	Right Channel	Laterality Quotients	Pursuit Rotor Test
RH	2.401	2.700	+ .052	6.575
LH	2.495	2.183	– .076	5.742
ILH	2.590	2.583	– .587	6.375

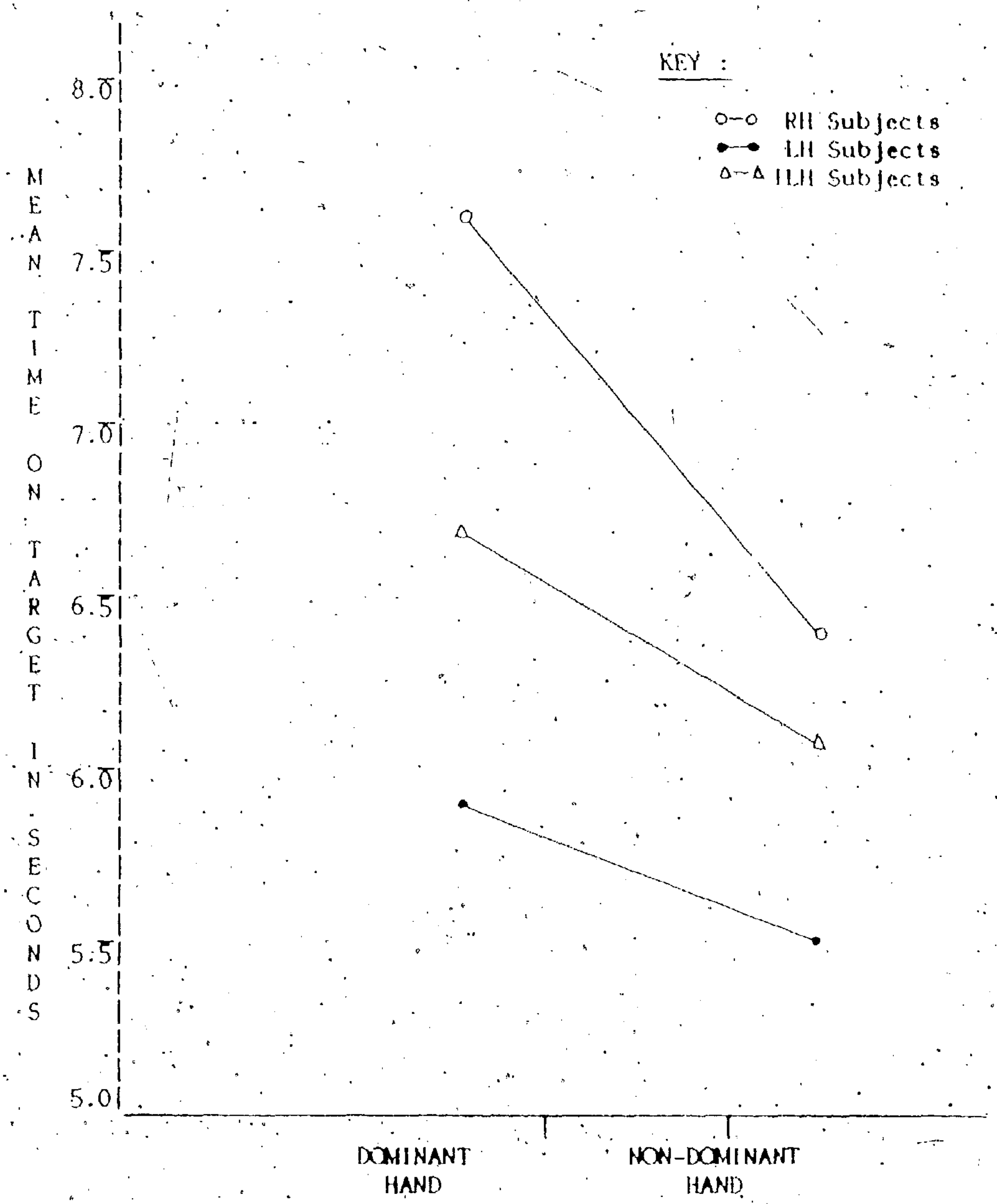

FIGURE 1 The mean time on target in seconds for right handed, left handed and inverted left handed subjecs with dominant vs. non-dominant hands.

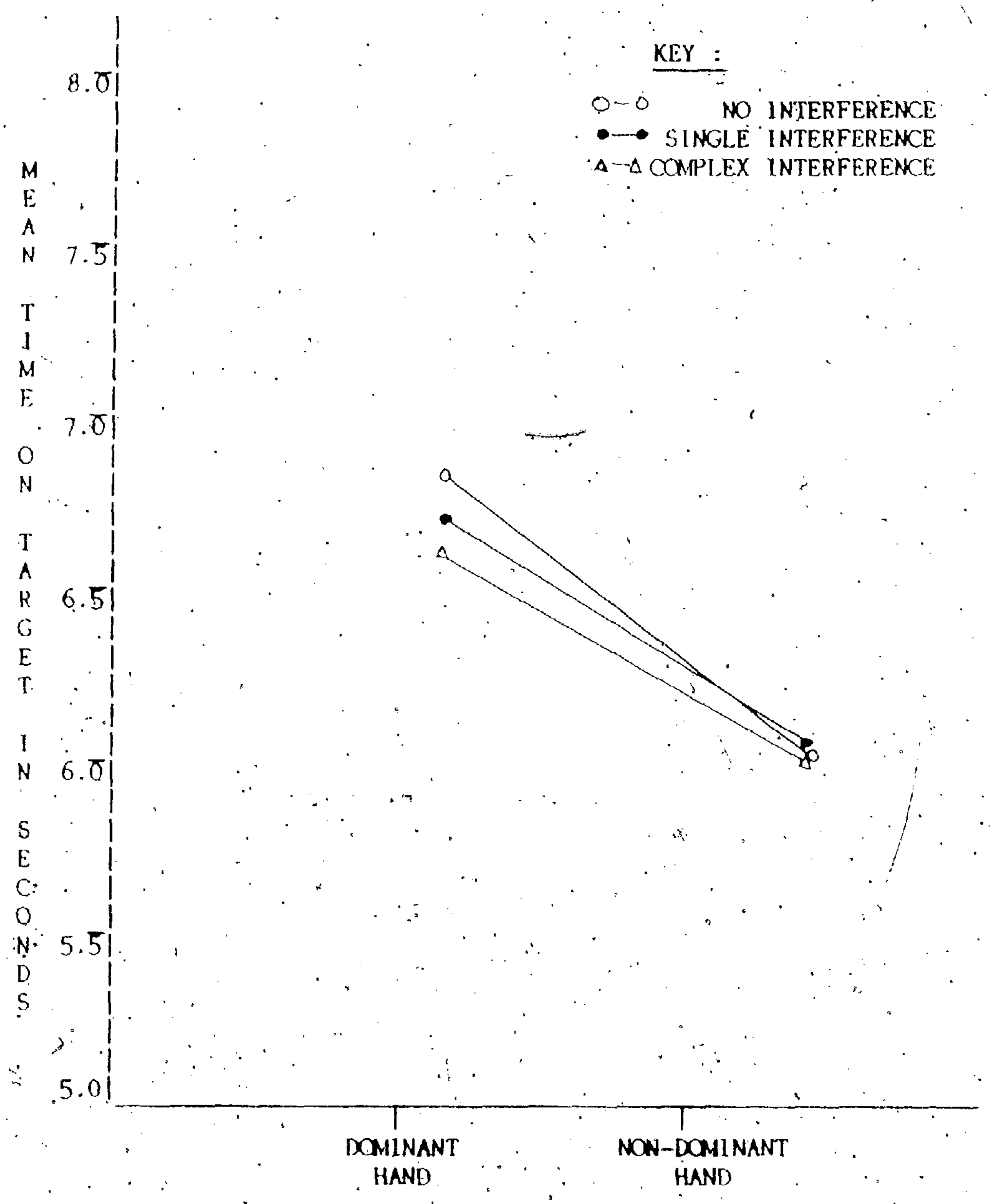

FIGURE 11 The mean time on target in seconds for the dominant and non-dominant hands of all subjects under the no interference, single interference, and complex interference conditions.

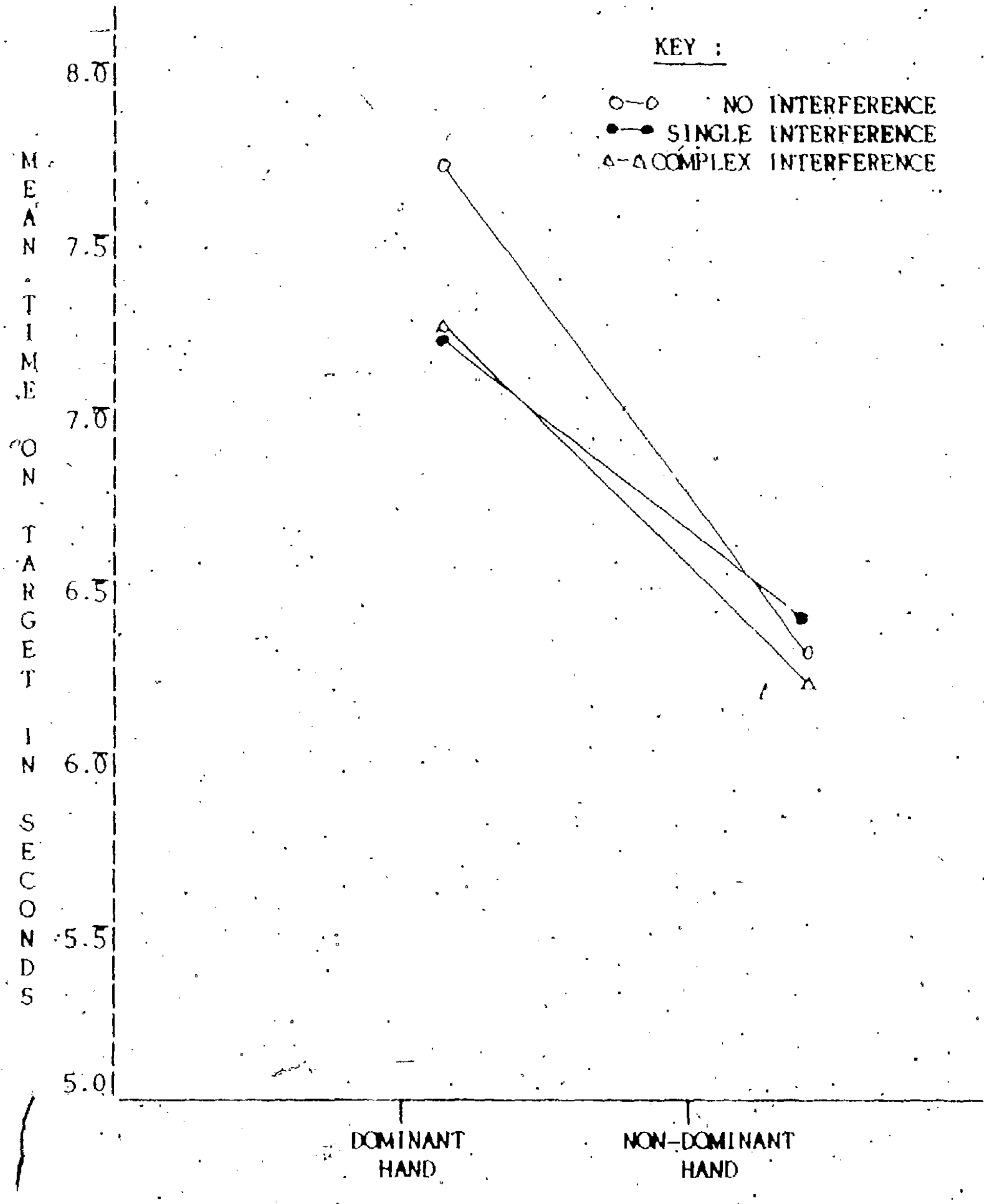

FIGURE III The mean time on target in seconds for the dominant and non-dominant hands of R.H. + F.S. subjects under the no interference, single interference, and complex interference conditions.

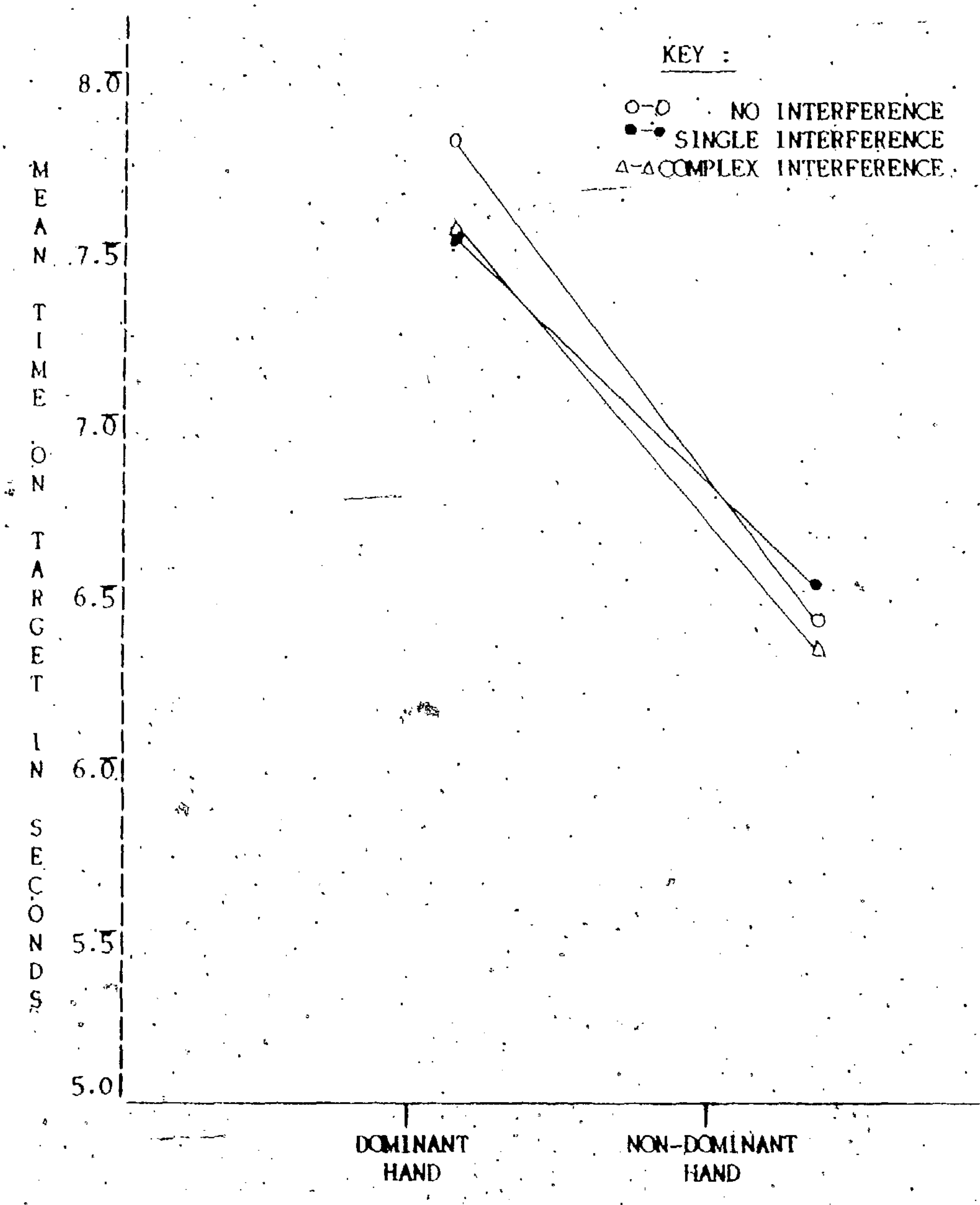

FIGURE IV The mean time on target in seconds for the dominant and non-dominant hands of RH subjects under the no interference, single interference and complex interference conditions.

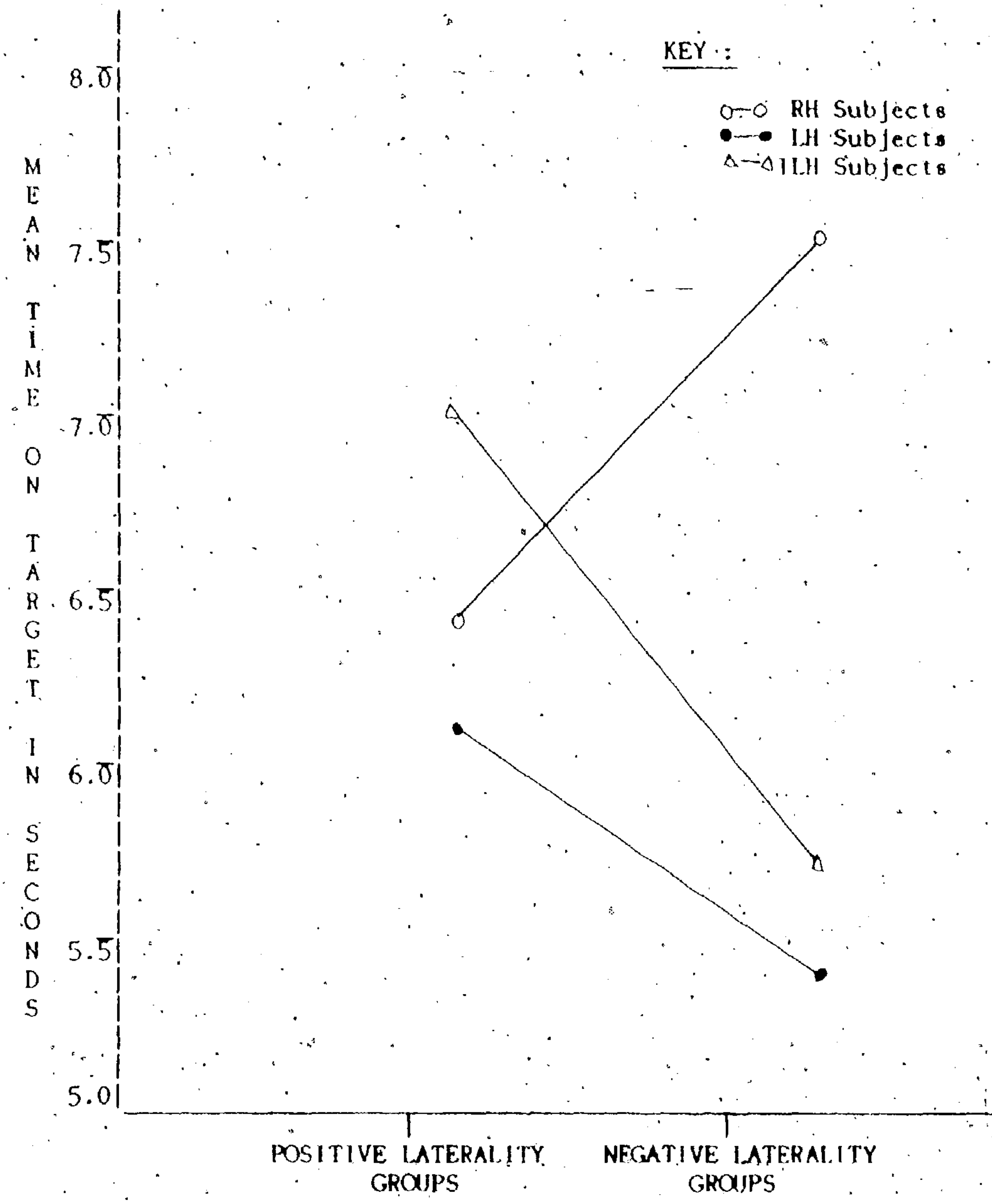

FIGURE V The mean time on target in seconds for right handed, left handed and inverted left handed subjecs as a function of grouping on laterality scores.

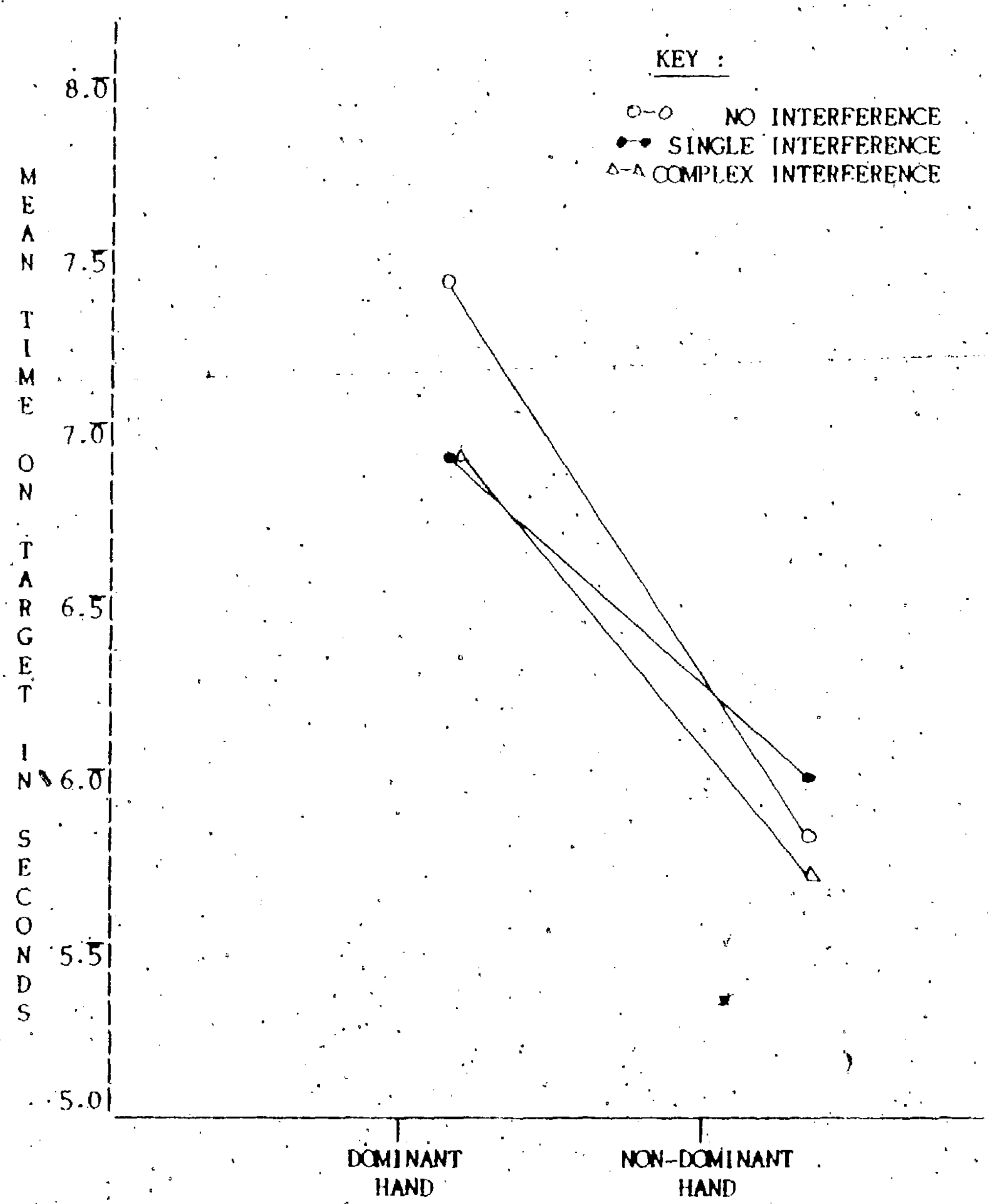

FIGURE VI The mean time on target in seconds for the dominant and non-dominant hands of RH subjects with positive laterality scores under the no interference, single interference, and complex interference conditions.

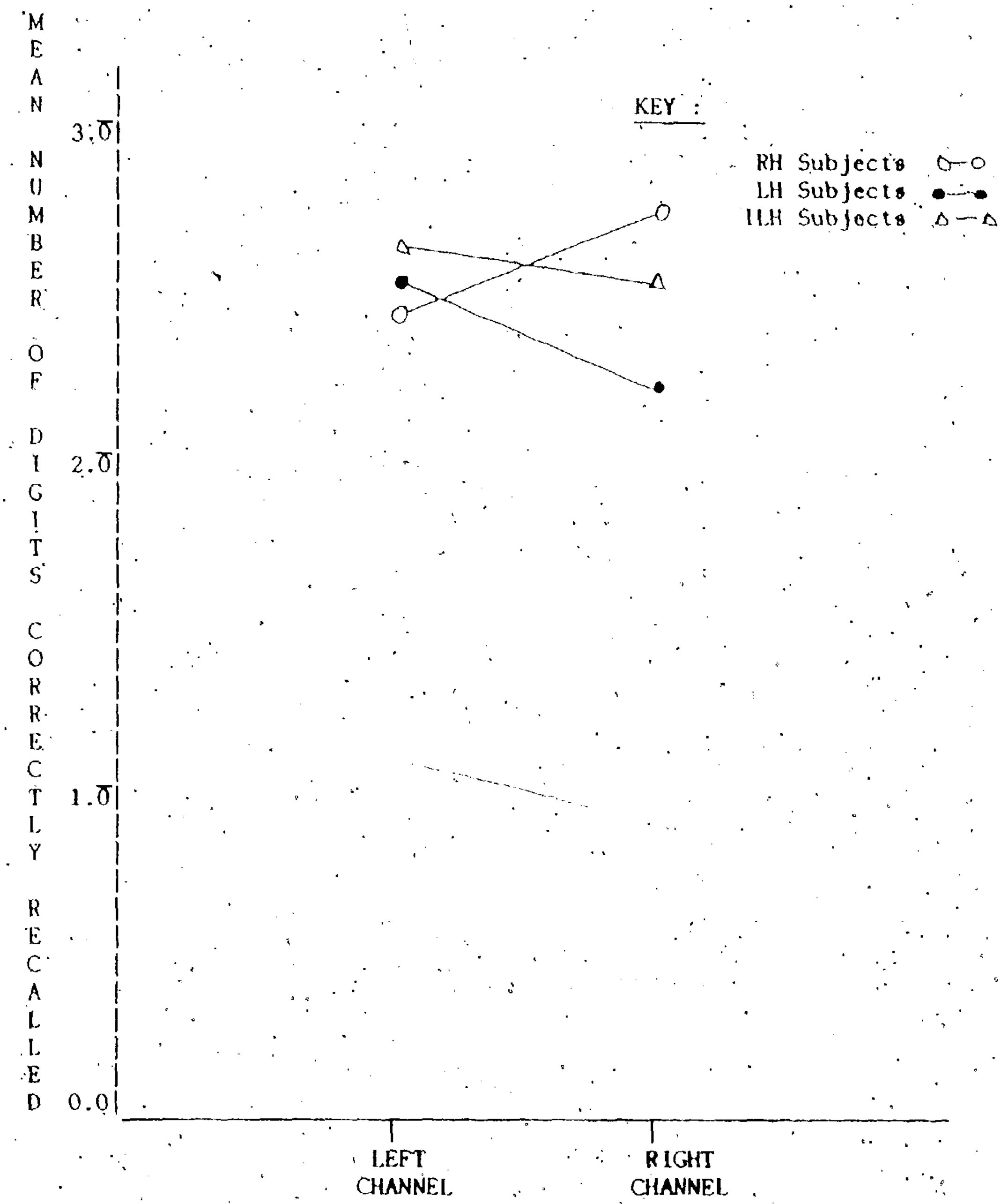

FIGURE VII The mean number of digits correctly recalled per channel for right-handed, left-handed, and inverted left-handed subjects.

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Note I. Personal Communication, Dr. Murray Schwartz, Psychology Department, Saint Francis Xavier University, Antigonish, N.S. It has been Dr. Schwartz's observation that females can not balance a dowel Rod for a long enough duration to satisfy a control condition.

Note II. The Anova 7 Computerized Analysis of variance was developed by J.K. Mewhart of Queens University.

APPENDIX I

Normative Data on Hand Posture Exhibited While Writing

Surveys with children suggest that inversion of the hand while writing is associated with development. Allen & Wellman (1981) found that females are closer to the normal hand position than males at every age and that children switch to a normal handwriting position as they age. They also observed that children with normal handwriting posture had achieved higher reading scores than ILH children.

Peters & Pederson (1978) agree that more males are inverted than females, but state that there is an increase in the percentage of inversion with increasing age. Coren & Porac (1979) found that approximately one half of left handed writers show hand inversion while writing. The likelihood of the normal handwriting position in right handers is ten times more probable than inversion. The authors further suggest that inversion decreases with age.

In a sample of twelve ambidextrous subjects Combs et at (1979) , did not observe any child demonstrating an inverted posture while writing. But this finding does not challenge the conclusions of the research cited above which indicates that ILH subjects as more ambidextrous than their LH counterparts.

APPENDIX II

Neuropsychological Deficit Hypothesis

Several authors have indicate that ILH subjects are deficient in the results shown by several neuropsycholical tests. Gregory et al (1980) administered the Space Relations test from the Differential Aptitude Test (Bennet, Seashore, & Wesman, 1974) to 64 LH, 20 ILH and 64 RH subjects. The ILH group performed significantly more poorly than either of the RH or LH groups. The authors suggest that the relatively bilateral performance of the ILH group in Levy & Reid's research is indicates that ILH have less efficient spatial reasoning abilities.

Todor (1980), studied the sequential motor ability of LH and ILH female subjects. Subjects were instructed to alternatively tap between two targets as rapidly as possible for 10 seconds duration at four levels of difficulty, as determined by target size and speed of trials. The performance of the LH group was superior to the ILH group. For the dominant hand significant differences were found between the LH and ILH groups on only the two highest levels of difficulty. When subjects responded with the non-dominant hand the performance of the LH group was always superior.

Gregory & Paul (1980) assessed the performance of 12 RH, 12 LH and 12 ILH male subjects in a variety of neuropsychological tests. All subjects were given the Finger Tapping Test, the Category Test, the Tactual Performance Test, the Speech Sounds Perception Test, The Trail Making Test (parts A,B, and T) from the Halstead - Reitan battery as well as the Wechsler Adult Intelligence Scale, the Name

Writing Test, and the Television Test. The overall results showed that the ILH group scored more poorly than the LH and RH groups on 21 out of 32 sub-categories. One remarkable finding was that although ILH subjects were slower with their dominant hand as compared to the other groups, their non-dominant hand was superior to the two other groups on the Television Test ~~and~~ the TPT form board. The authors propose that this may be suggestive of some ipsilateral cerebral control. Positive Familiarity Sinistrality resulted in worsened scores for the ILH group but did not affect the scores of the LH group.

$\alpha\gamma_{ik}$ effect that represents nonadditivity of effects α_i and γ_k : (H x FS)

$\pi_{m(ik)}$ constant associated with person m who is nested under ik : (C)

β_j effect of treatment j : (RH)

$\alpha\beta_{ij}$ effect that represents nonadditivity of effects α_i β_j. : (H x RH)

$\beta\gamma_{jk}$ effect that represents nonadditivity of effects β_j and γ_k : (RH x FS)

$\alpha\beta\gamma_{ijk}$ effects that represents nonadditivity of effects α_i, β_j and γ_k : (H x Rh x FS)

$\beta\pi_{jm(ik)}$ effect that represents nonadditivity of effects β_j and $\pi_{m(ik)}$: (RH x C)

δ_l effect of treatment l : (I)

$\alpha\delta_{il}$ effect that represents nonadditivity of effects α_i and δ_l : (H x I)

$\gamma\delta_{kl}$ effect that represents nonadditivity of effects γ_k and δ_l : (FH x I)

$\alpha\gamma\delta_{ikl}$ effect of nonadditivity of effects α_i, γ_k and δ_l : (H x FS x I)

$\delta\pi_{lm(ik)}$ effect that represents nonadditivity of effects δ_l and $\pi_{m(ik)}$: (I x C)

$\beta\delta_{jl}$ effect that represents nonadditivity of effects β_j and δ_l : (RH x I)

$\alpha\beta\delta_{ijl}$ effect that represents nonadditivity of effects α_i, β_j and δ_l : (H x RH x I)

$\beta\gamma\delta_{jkl}$ effect that represents nonadditivity of effects β_j, γ_k and δ_l : (RH x FS x I)

$\alpha\beta\gamma\delta_{ijkl}$ effect that represents nonadditivity of effects α_i, β_j, γ_k and δ_l : (H x RH x FS x I)

$\beta\delta\pi_{jlm(ik)}$ effect that represents nonadditivity of effects β_j, δ_l, and $\pi_{m(ik)}$: (RH x I x C)

$\epsilon_{o(ijklm)}$ experimental error

APPENDIX IV

EDINBURGH HANDEDNESS INVENTORY

Surname...................... Given Names..............................

Date of Birth...................... Sex..........

Please indicate your preferences 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 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 to 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)		

g. Which foot do you prefer to kick with?

h. Which eye do you use when using only one?

L.Q. | Leave these spaces blank | DECILE

MARCH 1970

APPENDIX V

Instruction to the Test

Maze Co-ordination Test

The stand is placed at the edge of the table and the maze is placed in the middle of the stand, midline of the patient. The lead from the machine is connected to the terminal which should be in the lower right hand corner of the maze. The stylus is connected to the machine. The following instructions are given:

IN THIS TEST, YOU ARE TO TAKE THIS STYLUS (the stylus is shown to the patient) AND PUT IT IN THIS OPENING HERE. (Examiner demonstrates by placing the stylus in the middle of the lower right hand opening.) AND MOVE IT ALL THE WAY THROUGH THE MAZE UP TO HERE (Examiner points out the upper left hand opening). THE IDEA IS TO GO THROUGH THE MAZE **WITHOUT** TOUCHING THE SIDES. GO THROUGH THE MAZE ABOUT THIS FAST. (Examiner demonstrates the exact method and speed for approximately one quarter of the length of the maze. The power source should be off).

IF YOU GO TOO FAST, YOU WILL MAKE EXTRA MISTAKES, REMEMBER, THIS IS NOT A SPEED TEST, I DON'T WANT TO SEE HOW FAST YOU CAN GO, BUT HOW **CAREFULLY**, WITHOUT TOUCHING THE SIDES, YOU CANNOT REST YOUR HAND OR ARM ON YOUR SIDE OR ON THE STAND,(Examiner demonstrates each position) OR BRACE IT IN ANY WAY. TRY IT FIRST **WITH** YOUR (DOMINANT) HAND. DO YOU HAVE ANY QUESTIONS? PLACE THE STYLUS IN THE OPENING HOLE. BEGIN.

Two trials are administered with the dominant hand, followed by two trials with the nondominant hand.

APPENDIX VI

1. She wears new clothes.
2. Boys play soccer often.
3. Linda eats ripe bananas.
4. Most jokers talk loudly.
5. Walruses swim in oceans.
6. Green turtles crawl slowly.
7. Most mothers bake cookies.
8. Some mothers bake cookies.
9. Nighthawks fly over trees.
10. Peacocks are colourful birds.

APPENDIX VII

1. She sells sea shells.
2. Baby boys bounce balls.
3. Linda likes licking lemons.
4. Jolly jokers jest joyously.
5. Walruses won't wash windows.
6. Tired turtles tilt timbers.
7. Every elephant eats eggs.
8. Many mothers make muffins.
9. Nervous nighthawks nest noisily.
10. Pretty peacocks parade proudly.

APPENDIX III

The proposed design is a split-plot factorial with two between group variables (Handedness and Familial Sinistrality) and two within group variables (Response hand and Concurrent Interference). The notation for this design is $SPF_{pr.qu}$ where :

p = levels of a_i = (3) (Handedness(H): Left Handed; Right Handed, Inverted Left Handed)
q = levels of b_j = (2) (Dominant Hand, Non-Dominant Hand)
r = levels of c_k = (2) (Familial Sinistrality (FS): + FS, -FS)
u = levels of d_l = (3) (Concurrent Interference (I): no verbal interference, simple verbal interference, complex verbal interference)
n = levels of s_m = (10)
The design is then a $SPF_{32.23}$.

A schematic presentation of the data is as follows:

	b_1	b_1	b_1	b_2	b_2	b_2
	d_1	d_2	d_3	d_1	d_2	d_3
ac_{11}	s_1	s_1	s_1	s_1	s_1	s_1
ac_{12}	s_2	s_2	s_2	s_2	s_2	s_2
ac_{21}	s_3	s_3	s_3	s_3	s_3	s_3
ac_{22}	s_4	s_4	s_4	s_4	s_4	s_4
ac_{31}	s_5	s_5	s_5	s_5	s_5	s_5
ac_{32}	s_6	s_6	s_6	s_6	s_6	s_6

This linear model for the design is as follows: (The notation is taken from Kirk, 1968)

$$x_{ijklm} = \mu + \alpha_i + \gamma_k + \alpha\gamma_{ik} + \pi_{m(ik)} + \beta_j + \alpha\beta_{ij} + \beta\gamma_{jk} + \alpha\beta\gamma_{ijk} + \beta\pi_{jm(ik)} + \delta_l + \alpha\delta_{il} + \gamma\delta_{kl} + \alpha\gamma\delta_{ikl} + \delta\pi_{lm(ik)} + \beta\delta_{jl} + \alpha\beta\delta_{ijl} + \beta\gamma\delta_{jkl} + \alpha\beta\gamma\delta_{ijkl} + \beta\delta\pi_{jlm(ik)} + \varepsilon_{o(ijklm)}$$

where:
μ = grand mean of treatment populations
α_i = effect of treatment i : (H)
γ_k = effect of treatment k ; (FS)