1988

Asymmetrical Sensory and Motor Patterns in Individuals with Inverted and Noninverted Handwriting Postures

James Brian Pope
College of William & Mary - Arts & Sciences

ASYMMETRICAL SENSORY AND MOTOR PATTERNS
IN INDIVIDUALS WITH
INVERTED AND NONINVERTED HANDWRITING POSTURES

A Thesis

Presented to

The Faculty of the Department of Psychology

The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

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by

J. Brian Pope

1988

APPROVAL SHEET

This thesis is submitted in partial fulfillment of

the requirements for the degree of

Master of Arts

J. Brian Pope

Author

Approved, April 1988

Herbert Friedman, Chair

Peter Derks

E. Rae Harcum

Ellen Rosen

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ACKNOWLEDGEMENTS

The writer wishes to thank Professor Herbert Friedman, under whose guidance this research was conducted, for his advice and criticism throughout the course of the research and the preparation of this manuscript. The author is also indebted to Mr. Robert Bower who wrote the computer program that made this investigation possible. Finally the authors would like to thank his parents, James R. Pope and Linda Pope, for their patience and financial support during the preparation of this manuscript.

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ABSTRACT

Hemispheric asymmetry patterns in individuals having the left-noninverted, left-inverted, and right-noninverted handwriting postures were evaluated. Tachistoscopic tests requiring motor responses of the left and right hands were used to evaluate asymmetry patterns for verbal and spatial stimuli (in the visual sense modality), and tests involving the discrimination of tactually presented normal and mirror-inverted words and letters were used to evaluate asymmetry patterns in that modality. No significant effects were observed for the tachistoscopic verbal and spatial tests, but the test involving discrimination of mirror-image words yielded significant sex differences according to handwriting posture--with left-noninverted males taking the most time to discriminate whether a word was mirror-inverted or not. Right-noninverted males responded most quickly on this task, and left-inverted males took an intermediate amount of time. Response times of the female subjects did not significantly differ according to handwriting posture, thus indicating a greater likelihood of bilateral language organization in left-handed females. The widely discrepant response times of males on this task are suggestive of bilateral language organization. It is possible that programs for the control of the writing hand may be dissociated from the hemispheric centers dominant for language recognition and/or speech. There did not appear to be such dissociation in female subjects. The observed male-female differences may reflect a testosterone-mediated differentiation of cerebral asymmetry patterns for language, with the degree of inferred dissociation (of writing programs from language recognition and/or speech centers) being affected by high levels of testosterone produced in males during fetal development. Other possibly significant factors such as stressful birth and/or brain injury to one or the other hemisphere were also considered as having an influence on subsequent handedness, but seem insufficient in explaining the greater degree of inferred lateral dissociation.

ASYMMETRICAL SENSORY AND MOTOR PATTERNS

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INTRODUCTION

The use of handwriting posture as an independent variable in experiments designed to test underlying neuroanatomical organization has yielded surprising and interesting results. The first study in this category used both left-, and right-handers classified into four groups in terms of hand position during writing (Levy & Reid, 1976).

Insert Figure 1 about here

The specific characteristic of hand position in writing (handwriting posture) used to classify subjects into groups was the degree of inversion/noninversion of an individual's hand while writing. An individual has an inverted handwriting posture if his/her hand is oriented above the line of writing and the pen points toward the bottom of the page--giving the hand a somewhat hooked appearance. The inverted handwriting posture is quite common in left-handed individuals (especially males), but is rare in right-handers. Levy (1984) estimates the incidence of the inverted writing posture to be approximately 70% in males and 45% in females. A noninverted handwriting posture is characterized by the hand being oriented below the line of writing and the pen pointing toward the top of the page. Noninverted handwriting postures are more common in left-handed females than in left-handed males.

Early evidence of different asymmetry patterns in left-, and right-handers. Earlier research in this area has shown that left-handers have a great deal of heterogeneity with respect to asymmetries of tachistoscopically or dichotically presented functions. McKeever, Van Deventer, and Suberi (1973) compared groups of left-handers with and without a history of familial sinistrality on a tachistoscopic word-recognition task. They found that left-handers with a history of left-handedness (familial sinistrals) showed a right visual field (RVF) advantage and superior performance whereas the nonfamilial sinistrals showed no such asymmetries. The implications of this study are that lateralization (for verbal-type processing) may be radically different in familial versus nonfamilial sinistrals, and that verbal-type processes that are typically colateralized to the same hemisphere in right-handers may be laterally dissociated in left-handers.

Gloning, Gloning, Haub, and Quatember (1969) found that lateralization of reading, writing, and calculation did not predict lateralization for speech in an observation of 57 (40 right-handed and 17 left-handed writers) non-right-handed neurological patients who were tested for various neurological disorders. Non-right-handed was a term used by Gloning, et al. to describe individuals who write with the right hand, but are left-handed for tasks other than writing. They found that lesions contralateral to the writing hand were significantly associated with disorders such as agraphia, alexia, and disorders of calculation. Levy (1982) hypothesizes that reading, writing, and calculation may be colateralized to the same hemisphere whereas speech lateralization is unrelated to the asymmetry of these functions, so that in terms of lateralization patterns, left-handers (in general) are not the exact opposite of right-handers. Motor control of the writing hand in left-handers is hypothesized by Levy to be laterally dissociated from lateralization for speech, whereas right-handers are much more likely to have speech and writing represented in the same hemisphere. For example, left-handers could have motor control for writing represented in the right hemisphere and speech represented in the left.

Major studies using handwriting posture classification. Levy and Reid (1976, 1978) added much more precision to the study of cerebral asymmetries in left-handers by classifying left- and right-handed subjects into inverted and noninverted handwriting posture groups and using a tachistoscopic nonsense-syllable identification task to test for hemispheric dominance in verbal processing, and a tachistoscopic dot-location task to test hemispheric dominance in spatial processing. Stimuli for each task were presented randomly in the right and left visual fields of each subject. A right visual field (RVF) advantage (in accuracy and latency of response) would indicate a left hemisphere superiority, and a left visual field (LVF) advantage would indicate a right hemisphere superiority. Levy and Reid found that for subjects having the right-non-inverted (RN) handwriting posture there was a right visual field (RVF) superiority on the verbal task (reading of tachistoscopically presented nonsense syllables), and a left visual field (LVF) superiority on the spatial task (locating tachistoscopically presented dots). Individuals having the left-inverted (LI) handwriting posture displayed the same direction of perceptual asymmetries as did the RN subjects, but of smaller magnitude. Individuals having the left-noninverted (LN) handwriting posture showed a left visual field (right hemisphere) advantage on the verbal task and a right visual field (left hemisphere) advantage on the spatial task. Thus, LI and RN individuals are presumed to be lateralized alike (for perception of visually presented verbal and spatial stimuli), and opposite to LN individuals.

The findings of Levy and Reid (1976, 1978) that LI individuals are left-hemisphere dominant for recognition of visually presented verbal stimuli have been relatively well supported in the literature. The most common test for differences in functional asymmetries in individuals the LN, LI, and RN writing postures was the comparison of differences in the speed of responding (either verbally or manually). One of the first of these studies (Smith & Moskovitch, 1979) found support for the findings of Levy and Reid, but used only left-handed subjects.

Smith and Moskovitch used tachistoscopic nonsense-syllable and dot location tasks very similar to those used by Levy and Reid. They found that on the nonsense syllable identification task that 14 out of 15 LI subjects showed an RVF (left hemisphere) advantage and 12 out of 15 LN subjects showed an LVF (right hemisphere) advantage. On their dot-location task, LI subjects had an LVF (right hemisphere) advantage but the LN subjects showed no significant visual field asymmetry. The one RI subject used in this study showed a large LVF advantage on the syllable-identification task, but also an LVF advantage on the dot-location.

In a similar study, McKeever (1979) compared LI and LN subjects on two tachistoscopic tasks. One task involved unilateral and bilateral word recognition, and the other involved color-naming latencies for color patches presented tachistoscopically. On the word recognition task, no differences between handwriting posture groups were seen, but LI subjects showed a significant RVF advantage on the color-naming task.

McKeever and Hoff (1979) compared LI and LN subjects on a manual reaction-time task (responding as quickly as possible to turning off a light which is turned on in either the RVF or LVF). Subjects used either the right of left hand to respond to a total of 162 LVF and 162 RVF trials. The subjects with the LN writing posture showed a left visual field (LVF) superiority in both left and right hand responding. Subjects with the LI writing posture had the same LVF superiorities as the LN subjects and also had faster reaction times. McKeever and Hoff also found a significant homolateral (stimulus presented on same side as writing hand) superiority for LN subjects and a nonsignificant heterolateral superiority for LI subjects. Even though the heterolateral advantage for the inverters was not significant, the two groups of left-handers did differ significantly from each other.

Using a somewhat more elaborate experimental design, Moskovitch and Smith (1979) measured the differential reaction times of the left and right hand (of LN, LI, and RN subjects) to sensory signals appearing in the left or right visual field. They found that RN and LN subjects showed a homolateral (signal presented on same side as writing hand) reaction-time superiority, and that LI subjects showed a heterolateral superiority--suggesting that the left-inverters relied on neural pathways ipsilateral to the writing hand in response to visual signals.

Other methods of lateralization assessment. Differences in lateralization for visually presented verbal and spatial stimuli between individuals having the LN, LI, and RN writing postures have also been evaluated through the use of some simple (noninvasive) neuropsychological tests. For instance, Gregory and Paul (1980) administered a test involving the speed of writing the word television with the dominant and nondominant hands. They found that RN subjects were faster with the right hand, LN subjects were faster with the left hand, and LI subjects (like the right-handers) were faster with the right hand even though they normally wrote with the left hand.

Dabbs and Choo (1980), on the basis of previous research which indicated that cerebral blood flow is greater to the right hemisphere than to the left in right-handers, measured blood temperature over the left and right ophthalmic arteries as an index of blood flow to the left and right cerebral hemispheres, respectively. The found that RN and LI subjects were similar in having greater inferred blood flow to the right hemisphere (based on higher blood temperature over the right ophthalmic artery), whereas LN subjects had greater inferred blood flow to the left hemisphere.

Studies of asymmetries in EEG alpha activity have also produced similar results. Herron, Galin, Johnstone, and Ornstein (1979) compared patterns of EEG alpha suppression (recorded from occipital leads) in subjects with the LN, LI, and RN writing postures. They also found that LI and RN subjects were similar in asymmetry and opposite to the LN subjects.

Possible mechanisms of motor control (of the writing hand). The studies cited up to this point all indicate some difference in cerebral organization with respect to the lateralization of general verbal abilities and the lateralization of motor programs for writing in left-handers having inverted and noninverted writing postures. The studies that test right-handers as well as left-handers according to their handwriting posture (Levy & Reid, 1976, 1978; Moskovitch & Smith, 1979; Gregory & Paul, 1980; and Dabbs & Choo, 1980) indicate that left-inverters are lateralized differently from left-noninverters, and that right-noninverters were lateralized much like left-inverters--except that asymmetries were smaller in left-inverters. To this end, Levy and Reid (1978) speculated that Levy's (1974) hypothesis that control of the writing hand in individuals with the inverted handwriting postures is mediated via a neural pathway ipsilateral to the writing hand was indeed correct. In other words, individuals with the left-inverted writing posture would have motor control of the writing (left) hand represented in the left hemisphere. This arrangement would explain how left-inverted and right-noninverted individuals can be lateralized alike and yet write with different hands, but it does not sufficiently explain the inverted or <u>hooked</u> hand posture manifest in some (mostly male) left-handers.

One possibility is that writing movements in those left-handers with language specialization in the left hemisphere (left-inverters) nonetheless have writing movements programmed in and controlled by the right hemisphere. This would mean that this type of left-handed individual is more <u>laterally dissociated</u> with regards to language and motor specialization--having verbal (word or syllable identification) abilities lateralized to the left hemisphere, but writing lateralized to the right hemisphere. Geschwind (1975) suggests that the superiority of the dominant hand lies not in greater strength but greater skill, which must in some way reflect a superiority of the opposite hemisphere controlling that hand. The hemisphere dominant for handedness is a storehouse of the learning involved in the acquisition of motor skills. In the case of a normal right-hander using his left hand, the left hemisphere (the repository of detailed information concerning movements) is likely either to direct completely the right hemisphere or at least to contribute to the smaller store of learning on the right. If this is the case, then much of the skill of the left hand (in an RN individual) may be borrowed from the left hemisphere across the corpus callosum. It is hypothesized in the present study that similar mechanisms may underlie motor control of the writing hand in LI and possibly LN individuals. For instance, writing movements in LI individuals may be controlled by the left hemisphere through the right, whereas in LN individuals the primary encoding of programs for motor control of the writing hand is in the right hemisphere and the left hand is controlled directly from there.

In a clinical study, Heiliman, Coyle, Gonyea, and Geschwind (1973) evaluated a left-handed man who had sustained an extensive area of damage affecting the right motor and premotor regions and adjacent areas--exactly those areas whose destruction on the left typically leads to aphasia and right-sided paralysis. This patient did develop a severe left-sided paralysis but did not develop any language disorder, suggesting that his intact left hemisphere was dominant for language (e.g. recognition and speaking). He demonstrated, however, an apraxia (disorder of learned movement) in his unparalyzed right arm. This apparent paradox is resolved if one assumes that the right hemisphere is the source of the programs for motor action. When these programs are destroyed, the patient responds incorrectly (to verbal commands) with his right hand.

McKeever and Hoff (1979) hypothesized a functional or anatomic <u>disconnection</u> of left hemisphere visual from left hemisphere motor areas within the left hemisphere. A stimulus which is presented to the RVF of an LI individual would first be represented in the visual area of the left hemisphere, then transferred transcallosally to the right hemisphere, and then transferred transcallosally back to the left--a double transcallosal relay. McKeever and Hoff found this to be the most plausible explanation for their finding that response latencies were slower for LI individuals in RVF than in LVF conditions (255.0 msec. (RVF) as compared to 249.8 msec. (LVF) for the left hand and 257.1 (RVF) compared to 250.9 (LVF) for the right hand). Another possibility is that a certain subset of left-handers have both language specialization and motor control of the left hand lateralized in the right hemisphere (left-noninverted), and that the left hand is controlled directly from there.

Levy (1974), and Levy and Reid (1978) hypothesize that motor control of the writing hand in individuals with left hemisphere language specialization but who write with the left hand (left-inverters) could be mediated via a neural pathway ipsilateral to the writing hand. This hypothesis is based in part on Hecaen and Sauget's (1971) finding that agraphia with right hemisphere lesions in left-handers was much less common than agraphia with left hemisphere lesions in either right- or left-handers. Levy (1982) finds this extremely difficult to reconcile with the idea that in all left-handers, the right hemisphere is crucial for control of the left hand during writing, either as the central programmer or as a relay station. Levy, however, goes on to point out that it may be possible to encompass the Hecaen and Sauget observations within a transcommissural hypothesis.

Levy (1982) goes on to speculate that the distribution of fiber types in the ipsilateral and contralateral pyramidal tracts may be atypical in LI individuals. Levy suggests that fibers controlling visuo-motor reactions of the hands may have an abnormal predominance in the uncrossed pathways. This abnormal predominance of motor control in the uncrossed pathways in LI individuals may be the result of a partial blockage of midline development in the embryonic and/or fetal period which results in partial callosal dysgenesis and a partial failure of pyramidal decussation.

Levy's speculations are controversial in the sense that control of the writing hand may be mediated via <u>uncrossed</u> rather than by <u>crossed</u> motor pathways. The alternative hypotheses (Geschwind, 1975; McKeever and Hoff, 1979) explain the occurrence of the inverted writing posture without hypothesizing motor control of the writing hand via a motor pathway ipsilateral to the writing hand. One could infer from these hypotheses that an individual whose verbally dominant hemisphere is the left hemisphere and who writes with the left hand (a left-inverter) does so because the verbal information is encoded (at least partially) into writing movements in the left hemisphere, and then transcallosally transferred to the right hemisphere--which controls the left hand. In this case, language specialization is still in the left hemisphere but control of the writing hand is mediated via a pathway contralateral to the language-specialized (left hemisphere).

<u>Evidence for differing asymmetry patterns in response to tactual (spatial) stimuli according to sex and handedness</u>. Witelson (1974), in a study using male right-handers, found that simple linguistic tactile stimuli (such as letters) were processed more efficiently with the left hand (right hemisphere). The results of this study were interpreted as an indication that linguistic stimuli presented tactually must be analyzed in a spatial code and then translated into a verbal code. In another study, Witelson (1976) used a tactual test involving simultaneous palpation of non-meaningful shapes (dichaptic stimulation) designed to assess the relative participation of the two hemispheres in spatial processing in 200 neurologically intact, right-handed boys and girls (6-13 yrs.). Tactile shape discrimination depends mainly on the right hemisphere in adults. It was found that boys, but not girls, responded most efficiently to the tactile (spatial) stimuli with the left hand. This study indicates a right hemisphere specialization for processing of spatial information in males but not in females. Witelson found that boys performed in a manner consistent with right hemisphere specialization for processing of spatial information as early as the age of 6. Girls showed evidence of bilateral representation until the age of 13. These results suggest a sexual dimorphism in the neural organization underlying spatial perception during a major period of childhood and also a possible sex difference in neural plasticity during development.

Klein and Rosenfield (1980) in a dichaptic stimulation study similar to that of Witelson (1976) found a slight, but nonsignificant, left-hand advantage in both boys and girls in responding to letters. Hatta, Yamamoto, Kawabata, and Tsutui (1981), in a study using raised-surface outlines of familiar objects, found a significant left-hand superiority in children who were 12 years old, but not in children who were between the ages of 8 and 10. They suggest that this reflects a developmental trend with hand asymmetry emerging between 10-12 years of age. From the age of 12 on, the left hand (right hemisphere) is thought to be superior in the processing of tactual (spatial) stimuli.

Lenhart and Schwartz (1983) attempted to determine the role of subject strategies and sex differences in tactile discrimination asymmetries for the processing of ambiguous, nonlanguage shapes. One coding instruction (verbal description or naming) was employed to prompt left-hemisphere processing, whereas a second condition (imagery instructions) was designed to engage the right hemisphere. They found a clear left-hand advantage for males given imagery coding (but not verbal coding), but not for females. This finding was interpreted as an indication that males have peculiar access to or utilization of right-hemisphere imagery codes. Females appear to exhibit relatively limited capacity to utilize or gain access to imagery codes for tactile discrimination, regardless of side of hemisphere.

Nagae (1985) investigated handedness and sex differences in terms of the manner in which verbal and spatial information is processed because previous studies have obtained conflicting results concerning this problem. They compared verbal and spatial abilities in right- and left-handed males and females to test the hypothesis that sinistrals and females are less lateralized for visuo-spatial functions than are dextrals and males. They used a task which involved recall of the identity of letters and their positions in a 5 by 5 square matrix. The results of the letters and positions recall test, in general, indicate that left-handed males are inferior to right-handed males in terms of the recall of positions (but not letters), whereas females (both left- and right-handers) performed the recall of letters and positions equally well. This supports other research indicating that left-handers are less laterally differentiated than right-handers and suggests that because verbal function in left-handers is shared by both hemispheres, the right hemisphere component of linguistic ability interferes with (right-hemisphere) visuospatial processing, and as a consequence left-handers performed worse than right-handers on the recall of positions.

The results found by Nagae (1985) are somewhat in conflict with those found in a study by Sanders, Wilson, and Vandenberg (1982) which also tested for sex and handedness differences on spatial tasks. The spatial tasks involved mental rotation of objects in 3-D space and mental rotation of objects in cards in 2-D space. They found that left-handed males had higher spatial scores than right-handed males, whereas left-handed females in all groups had lower spatial scores than did right-handed females. Males (as a group) had higher spatial scores than did females. Thus left-handed males may have an advantage in the processing of spatial information when it is presented as a mental task but not when the same sort of processing is forced to take place tactually.

In the present study, tactual discrimination tasks involving discrimination of raised surface, mirror-inverted words and letters were used to evaluate differences in cerebral asymmetry patterns in subjects according to sex and handwriting posture. The rationale for using a task of this type was that shared components of spatial and linguistics processing in each hemisphere of left-handers would generate a greater deal of confusion between mirror-inverted words (and letters) and their counterparts in normal orientation. This confusion is inferred from the slower reaction times that left-handers may exhibit. Another possible source of confusion may lie in Geschwind's (1975) suggestion that motor control of writing in left-handers is directed by the left hemisphere through the right. If this is the case then left-handers may become confused (as inferred from relatively slower reaction times) between the program for motor control of writing which is transmitted to the right hemisphere from the left hemisphere and the program which may already be present in the right hemisphere but for some reason is nondominant.

This study investigated the viability of both hypotheses of motor control of the hand during writing by using tachistoscopic-type visual tasks which required motor rather than verbal responses. Presumably, tasks which require motor responses are more indicative of underlying cerebral motor control than tasks which require verbal responses. Two kinds of tasks are used in the present study: visuomotor and tactual discrimination. The visuomotor tasks used here involve basically two components. These components are the identification of tachistoscopically presented stimuli (words and arrows), and an appropriate motor response (measured as reaction time) selected for a specific visual stimulus. Response time is thus a measure of a cognitive response selection component as well as the time it takes to produce the motor response.

Predicted outcomes for the present study. In this study, patterns of asymmetry on sensory and motor tasks in college undergraduates having the LN, LI, and RN writing postures would allow testing of Levy's (1974) and Levy and Reid's (1976, 1978) hypothesis that left-inverters may have language specialization in the hemisphere ipsilateral to the writing hand (the left hemisphere) as well as the alternative hypothesis (Geschwind, 1975; McKeever & Hoff, 1979) that the writing hand is controlled by the right hemisphere even though visual recognition of (and speaking of) language is lateralized to the left hemisphere. If motor control of the writing hand in LI subjects is mediated via an ipsilateral motor pathway (from the left hemisphere), then reaction times of the left hand for verbal tasks in heterolateral (right of fixation) conditions (or for homolateral conditions when responding with the right hand) would be the fastest response conditions. For spatial tasks, LI subjects will have shorter reaction times with the right hand in heterolateral conditions or with the left hand in homolateral conditions. If writing movements in left-inverters are programmed in the left hemisphere and transcallosally transmitted to the right (as Geschwind suggests) then the LI subjects will have longer reaction times when responding with the left hand to verbal stimuli in homolateral conditions, and longer reaction times when responding with the right hand to spatial stimuli in homolateral conditions--because the neural impulse will have to travel a longer distance. Similarly, LI subjects should have greater difficulty than LN and RN subjects in distinguishing between letters, and words, and their mirror reversals. All models assume that RN individuals have left hemisphere verbal (and right hemisphere spatial) asymmetry patterns and would have the largest (most clearcut) asymmetries.

In short, four major propositions were tested in the following series of experiments: (1) to determine if LN individuals differ from LI individuals on asymmetry measures as an attempt to replicate the research indicating that LI individuals have language specialization in the left hemisphere whereas LN individuals have language specialization in the right hemisphere; (2) to determine if males differ from females on the same asymmetry measures in order to assess any sex differences according to handwriting posture; (3) to test Levy's (1974) hypothesis that the left hemisphere controls the writing hand in LI individuals; and (4) to test Geschwind's (1975) suggestion that left-handers (in general) have left hemisphere dominance for language recognition and speaking but right hemisphere dominance for (the motor programs for) writing.

Method

Subjects

A total of 66 university undergraduates participated in the study and received class credit for their participation. Eleven men and eleven women were included in each of three groups defined according to handedness and handwriting posture (left-inverted [LI], left-noninverted [LN], and right-noninverted [RN]). Subjects were informed only that left- and right-handers were being tested on computerized tasks of visual and tactual perception, and all subjects had normal or corrected vision.

Design and Procedure

Subject selection and questionnaire items. Potential subjects signed up for the study if they believed their hand position in writing matched one of those depicted in a diagram (Levy & Reid, 1976) illustrating the LI, LN, RI, and RN writing postures.

The subjects who signed up were then screened through a phone interview before being scheduled for laboratory sessions. Upon arrival to a laboratory session, a potential subject was asked to fill out a questionnaire designed to assess handwriting posture (both pictorially and verbally), handedness patterns for 12 common activities, eye dominance, and history of familial sinistrality. The pictorial aspect of the handwriting posture assessment consisted of the subject choosing the simple line diagram (Friedman, 1983) which most closely matched his/hers.

Insert Figure 2 about here

Handwriting posture was also categorized on the basis of four questions (Levy, 1984) designed to also assess the angle of paper tilt when writing, whether the pen points toward the bottom of the top of the page, whether the hand is held above or below the line of writing, and where others might describe his/her writing posture as being hooked.

Insert Table 1 about here

Handedness patterns for common activities were measured with seven questions from Crovitz and Zener (1962) and four newly devised questions.

Insert Table 2 about here

Eye dominance was assessed with a simple pointing test. Subjects were asked to fixate on a spot (an X) on a chalkboard approximately eight feet away (using the index finger of the right and then the left hand. The X was situated between a series of equally spaced numbers--with the numbers one through five being positioned to the left of the X and the numbers six through ten being positioned to the right of the X. Subjects were told to alternatively close each eye while maintaining the pointing position and to report which number the finger was pointing at.

Insert Table 3 about here

History of familial sinistrality was evaluated simply by having subjects check the appropriate spaces on the questionnaire.

Insert Table 4 about here

After completing the questionnaire, subjects were asked to fill out a Psychology Department Consent Form.

Insert Table 5 about here

Experimenter evaluation of a potential subject's handwriting posture occurred during this time. The consent form was always oriented in a straight up-and-down position prior to a subject's being seated at a desk and filling it out. In addition to the Levy (1984) criteria, the tendency of individuals having inverted writing postures to hold the paper with the nonwriting hand positioned to the left of the writing hand in the case of left-inverters, and to the right of the writing hand in the case of right-inverters was determined (Guiard & Millerat, 1985). If a potential subject's handwriting posture was ambiguous (in between inversion and noninversion), the session was ended and the subject was given credit for coming to the laboratory.

Visuomotor tests. After completing the questionnaire and consent form, the tachistoscopic visuomotor tasks began. Subjects were seated on a stool (with adjustable height) in front of the testing apparatus (viewing screen and computer keyboard), familiarized with the equipment, and given a test of tapping speed. The tapping test consisted of a start signal being presented on the viewing screen, and the subject then being required to tap the space bar of the computer keyboard as fast as possible with the left hand (for five trials), and the with the right (for five trials). This was done to insure there were no appreciable differences in motor responding between the left and right hands.

The visuomotor tests consisted of both verbal and spatial tasks. The verbal visuomotor task required subjects to discriminate whether a word (tachistoscopically presented to either the left or right of fixation) was a noun or a verb and then to make the appropriate (noun or verb) response as quickly as possible. This was accomplished (through the use of a computer program) by first requiring subjects to verbally report on a single digit (200 msec. duration followed by a

300 msec. mask) appearing at fixation. Subjects were required to verbally call out the single digit as soon as they saw it. At the time concurrent with the digit being masked out, a word (containing from three to six letters) was tachistoscopically presented (at a presentation length predetermined during practice trials) lateral to the fixation point. The words were presented, one at a time, on either the far-left or far-right (16.5 degrees lateral to fixation) of the viewing screen (17 inches wide by 13 inches high). A total of 40 words were used. 20 of these words were unambiguous verbs (most often or only used as verbs), and 20 were unambiguous nouns.

Insert Table 6 about here

The duration times of the tachistoscopic word presentations ranged from 90 msec. to 130 msec.--with stimulus presentations being split into eight blocks of five trials (four blocks for each hand). The reaction-time responses for the noun-verb discrimination were recorded by having a subject press certain keys on the computer keyboard to terminate the timing sequence. If the left hand was the responding hand (for a certain block of five trials) and the word was a verb, the subject responded by hitting the letter A on the computer keyboard. If the word was a noun, the subject responded by hitting the letter D. If the right hand was the responding hand and the word was a verb, the subject responded by hitting the letter L. If the word was a noun, the subject responded by hitting the letter J. Timing started as soon as a word was presented on the viewing screen and was terminated when the subject hit the letter. Response times for each stimulus for each hand were printed out and the mean response times for each hand at left (homolateral condition) and right (heterolateral condition) of fixation were recorded. Errors for each hand at homo- and heterolateral conditions were also recorded.

The spatial visuomotor task required subjects to match the direction of a tachistoscopically presented directional arrow by using a joystick-like device. The directional arrows were approximately two inches long and pointed in only one of eight directions (0, 45, 90, 135, 180, 225, 270, and 315 degrees). These were presented in one of three positions (top, middle, bottom) on either side of the screen at 16.5 degrees lateral to fixation. To insure maintenance of fixation, subjects were required to fixate on a digit in the center of the screen (as with the verbal task) and verbally call out that digit. The manner in which the fixation digit was presented was the same as with the verbal task. The duration of the tachistoscopic presentation of the directional arrows was predetermined during practice trials and ranged from 80 to 115 msec. Stimulus presentation was split into eight blocks of five trials (four blocks for each hand). The device used to match the direction of the tachistoscopically presented arrows was a box (six inches by six inches by five inches) with a metal lever used to complete an electrical circuit in one of the eight directions. Subjects held the lever with the left hand for four blocks of five trials and with the right hand for four blocks of five trials and alternated in this fashion until all trials were completed. The task of the subject was to move the lever in the same direction as the arrow presented on the viewing screen and to touch the electrical contact for that direction in the lever box--match the direction of the arrow.

Timing began as soon as the arrow was presented on the viewing screen and ended as soon as contact was made in the lever box. Response times for each stimulus for each hand were printed out and the mean response times for each hand at left and right of fixation were recorded. Errors for each hand at left and right of fixation were also recorded.

Tactual discrimination tests. The tactual discrimination tests had both recognition and discrimination components. Subjects had to both recognize a word which was presented on the viewing screen (at above detection threshold--usually 200 msec. or above) and make a response by palpating a raised-surface word which was the same word as the one presented on the viewing screen. Subjects also had to discriminate as to whether or not the word they were palpating was a mirror-image of the word presented on the viewing screen. The raised-surface words were mounted on wood squares (four inches by four inches) and the letters of the words were approximately one inch tall by three quarters of an inch wide. These letters were made from wire approximately 2 millimeters thick. These word squares were placed in a button device with places for two squares to be placed lateral to one another. One side of this button device contained a raised-surface word, and the other side contained a blank wood square. Subjects were instructed to press down on the word if it was normal (non-mirror-image), and to hit the blank square on the other side of the device if the word was a mirror-image of the one presented on the viewing screen. The button device was covered by a box with a hole big enough for subjects to reach in a palpate the word, but not big enough for the word to be seen. This covering box was also open on one side so the experimenter could change the raised-surface word/blank combination from trial to trail. Trials were reset by the experimenter and subjects were cued by the experimenter that a trial was ready to begin. There were ten raised-surface words altogether, and each word was presented four times (twice normal and twice mirror-imaged) for a total of 40 trials--20 for each hand. The timing sequence began as soon as the stimulus word was presented on the viewing screen and was ended when the subject depressed the word in the button device. The response times for the left hand responding to a normal word, the left hand responding to a mirror-imaged word, and the right hand responding to normal and mirror-imaged words were recorded--as were the mean response times and the number of errors for each of these conditions. The words used in this task are shown in Table 7.

Insert Table 7 about here

The letter-recognition/discrimination task was structured just like the word recognition/discrimination task except that four single capital letters (C, J, P, & R) and their mirror-images were used. Subjects were also not cued by the viewing screen or the experimenter as to which letter would be used on a particular trial. The subjects were instead familiarized with all four letters used at the beginning of the task. The beginning of each trial was communicated verbally to each subject. Subjects were presented with each letter four times--twice for the normal letter and twice for its mirror-image. Response times were recorded for the left hand responding to a normal letter, the left hand responding to a mirror-imaged letter, and the right hand responding to normal and mirror-imaged letters. The number of errors for each of these conditions was also recorded.

Results

Handedness inventory. The handedness inventory was used to classify subjects into handwriting posture groups for later comparison. There was no difficulty in filling the LN, LI, and RN male groups as well as the LN and RN female groups, but it took a much greater effort to find subjects for the female LI group.

Analyses of variance with two between-group factors--sex (male, female), and handwriting posture (LI, LN, and RN) were carried out on each of the 12 items on the inventory. This was done primarily to determine whether the items on the inventory discriminated between left-, and right-handers (in general), and to determine whether any of the items discriminated between individuals with the LI and LN writing postures. All items on the handedness inventory were coded on a scale of 1 to 5 for analysis with 1 being that the left hand is always used for the task described in an item and 5 being that the right hand is always used.

A distinct pattern emerged on several of these items--with significant main effects for all ($df = 2, 60$, and $p < .001$ at least), for handwriting posture and no significant main effect for sex or sex by handwriting posture interaction. The items found to be consistent with this pattern were: item a (throwing a ball), b (picking up a straight pin from the floor), d (holding a hammer while nailing), e (holding a tennis racket while playing), h (holding scissors while cutting), i (operating a hand-held calculator), and item j (giving commands to a dog by pointing). The source of the significant main effects for handwriting posture for all these items was the difference between left- and right-handers. No significant differences were found between subjects with the LI and LN writing postures, and for each of these items it was noted that LN subjects were not as left-handed as RN subjects were right-handed. The responses of the LN subjects for these items ranged from 2 to 3 (on the 1 to 5 point scale) whereas the RN subjects ranged between 4 and 5. Subjects with the LI writing posture generally responded in the same range (2 to 3) as the LN subjects on these items. Figure 3 represents the mean of the handedness inventory scores for all of these items as a function of sex and handwriting posture.

Insert Figure 3 about here

For item c (holding a toothbrush while brushing), there was a significant main effect for handwriting posture, $F\ (2, 60) = 122.332$, $p < .0001$, and the main effect for sex approached significance, $F\ (1, 60) = 2.909$, $p < .10$. The source of the significant main effect for handwriting posture was again the difference between left- and right-handers, and the source of the effect for sex was that males tended to be more right-handed than the females.

Insert Figure 4 about here

Again no difference was observed between the LI and LN writing postures, but LI and LN males did average around two for this item, whereas female LI and LN subjects averaged around 1.3. It could be that this item is not very useful for discriminating between LI and LN subjects because individuals probably would have much less of a tendency to use either hand for such a task. A significant main effect for handwriting posture was also observed for item f (holding a pen when drawing pictures) with subjects also responding as being either left-handed or right-handed, but not responding with either hand.

Item g (holding a fork while eating) yielded a significant main effect for writing posture, $\underline{F}$ (2, 60) = 106.448, $\underline{p} < .001$, and a significant sex by writing posture interaction, $\underline{F}$ (2, 60) = 4.793, $\underline{p} < .05$. The source of the significant main effect for handwriting posture was the difference between left- and right-handers. In this case, subjects tended to all be more left-handed--probably reflecting a cultural bias toward holding one's fork in the left hand.

Insert Figure 5 about here

Item k (turning the knob on a combination lock) also had a significant main effect for handwriting posture, $\underline{F}$ (2, 60) = 10.755, $\underline{p} < .0005$. In this case, however, LI males made more right-handed responses than left-handed ones (averaging about 3.5). LN males average about three for this item--indicating that as a group they use both hands about equally for such a task. LI females averaged about 2.5 and LN females averaged about three for this item. Right-handed males and females averaged about 4.5.

Insert Figure 6 about here

Item 1 (drumming your fingers on a table top) yielded no significant differences either according to sex or handwriting posture. It appears that for this item subjects use both hands about equally. Eye dominance and history of familial left-handedness also yielded no significant main effects or interactions, but the sex by handwriting posture interaction for familial sinistrality approaches significance, F (2, 60) = 4.136, $p < .10$, indicating a difference in familial sinistrality according to handwriting posture. The source of this difference appears to be the difference between the number of left-handers in one's family between LN and RN subjects--with LN males having the greatest number of left-handers in their families, and RN females having the least. LI males tended to have fewer left-handers in their families than LI females. The eye dominance scores were not affected significanly according to sex and handwriting posture. Also, most subjects were right-eye-dominant regardless of handwriting posture. Eye dominance scores were also used as a third between-subjects factor (in addition to sex and handwriting posture) in a separate analysis of variance for the handedness inventory measures. None of the main effects or interactions were significant. However, for all measures, the mixed eye dominance (neither right nor left eyed) group were more left-handed than either the right-eye-dominant or the left-eye-dominant groups.

The test of tapping speed was coded on a 1 to 5 scale--with 1 being the left hand responding at least 20 percent faster and 5 being the right hand responding at least 20 percent faster. In this test, significant main effects were found for sex, *F* (2, 60) = 6.364, *p* < .005. The source of the main effect for writing posture was that subjects with the RN writing posture tapped faster than subjects with the LI and LN writing postures. No significant difference between LI and LN subjects was found. The source of the main effect for sex was that males were faster with the right hand as compared with the left hand, and females were faster with the left hand compared to the right.

Insert Figure 7 about here

Visuomotor tests:

Verbal task. An analysis of variance with two between-subjects factors--sex (male, female) and handwriting posture (LI, LN, and RN)--and one within-subjects factor--response condition (homolateral for left and right, and heterolateral for left and right) was carried out to determined whether the three-way interaction among these factors was significant. The differences in response times between LI and LN subjects in heterolateral and homolateral response conditions were of primary interest. It would be predicted according to Levy's hypothesis that LI subjects would respond faster in heterolateral conditions with the left hand (as opposed to homolateral), and that RN subjects would respond faster in homolateral conditions with the right hand. No significant interactions or main effects were observed. However, response times for predicted fastest conditions according to handwriting posture are roughly as would be predicted according to Levy's hypothesis. Handwriting posture group means (for response time) at each response condition are summarized in Figure 8. Predicted and actual fastest response conditions for handwriting posture groups are summarized in Table 8.

Insert Figure 8 and Table 8 about here

As can be seen, the actual fastest response conditions for the handwriting postures (even though nonsignificant) are roughly as predicted according to Levy's model. LN females, LI males, and RN males and females all responded as would be predicted.

Spatial task. An analysis of variance with two between-subjects factors--sex (male, female) and handwriting posture (LN, LI, and RN)--and one within-subjects factor--response condition (left homolateral and heterolateral, and right homolateral and heterolateral) was carried out to determine whether the three-way interaction among these factors was significant. The differences in response times according to handwriting posture in homolateral and heterolateral response conditions for both hands (handwriting posture by response condition interaction) was of primary interest. A significant main effect was found for sex, F (1, 60) = 17.469, $p < .0005$, indicating differences in response times according to sex--with the source of this effect being that males of all handwriting postures responded faster than females of all handwriting postures. A significant handwriting posture by response condition interaction was also observed, F (6, 180) = 2.36, $p < .05$, indicating that response times at each of the response conditions differed according to handwriting posture. Handwriting posture group means (for response time) at each of the response conditions are summarized in Figure 9, and predicted and actual fastest response conditions for each handwriting posture group are summarized in Table 9.

Insert Figure 9 and Table 9 about here

As can be seen, the fastest response conditions are as predicted in Levy's model only for the LI group. The LN and RN groups seem to be responding as if this were a verbal task.

Tactual word task. An analysis of variance with two between-subjects factors--sex (male, female) and handwriting posture (LI, LN, and RN)--and one within-subjects factor--response condition (left hand responding to normal and mirror-imaged words, and right hand responding to normal and mirror-imaged words) was carried out to determine whether the three-way interaction among these factors was significant. For this task, the sex by handwriting posture by response condition interaction was significant, F (6, 180) = 2.74, $p < .05$, indicating at least two separate processes going on which influence the source of the interaction.

Insert Figure 10 about here

Males differ more according to handwriting posture--with the main effect for handwriting posture being significant, F (2, 60) = 5.134, $p < .01$, and females differing more according to response condition--with the sex by response condition interaction also being significant, F (3, 180) = 2.697, $p < .05$. Both of these factors contribute to the source of the three-way interaction. The primary factors contributing to the source of the significant three-way interaction--the significant main effect for handwriting posture, and the significant sex by response condition interaction--are difficult to explain, but one major pattern seems to emerge for both males and females. On the whole, left-noninverters tend to respond more slowly than right-noninverters and left-inverters. This pattern is far more pronounced in the male subjects--who seem to be the source of this effect. This task is also quite different from the <u>verbal</u> and <u>spatial</u> visuomotor tasks in that responses of the left and right hands at homolateral and heterolateral response conditions cannot be compared or predicted according to Levy's model. This is because there are no homolateral or heterolateral response conditions per se, but conditions designed to produce <u>confusion</u> of mirror-images. Since such confusion is a condition likely to produce errors, the number of errors at each response condition was analyzed to help define the effects observed in this task.

<u>Error analysis for tactual word task</u>. An analysis of variance with two between-subjects factors--sex (male, female) and handwriting posture (LI, LN, RN)--and one within-subjects factor--number of errors per response condition (left hand responding to normal and mirror-imaged words) was carried out to determine whether the number of errors in each of the response conditions was related (directly or inversely) to the significant effect for handwriting posture found to be a major source of significant sex by handwriting posture by response condition interaction. Significant effects for handwriting posture, $F\ (2,\ 60) = 3.30$, $p < .05$, and response condition, $F\ (3,\ 180) = 5.29$, $p < .005$, indicating that subjects significantly differed on the amount of errors

made according to handwriting posture, and that subjects significantly differed in the number of errors made according to response condition. These effects are summarized in Figure 11.

Insert Figure 11 about here

It can be seen that male LN subjects (the ones who responded most slowly) also made the fewest errors, and that male RN subjects (the ones who responded most quickly) made the most errors. Male LI subjects made an intermediate number of errors, and this pattern also seems to be evident in the female subjects--although to a much lesser degree. Table 10 summarizes the response conditions where fewest errors were made.

Insert Table 10 about here

It can be seen that RN subjects responded most accurately to mirror-imaged words with the right hand, and that LI subjects responded differently as to how few errors they made--with males responding more accurately in the left-normal and right-mirror-imaged conditions and the females responding more accurately in the right-normal condition. Response conditions where the most errors were made were with the <u>left</u> hand for all subjects. RN males responded least accurately in the left-mirror condition, whereas females responded least accurately in the left-normal condition.

<u>Tactual letter task</u>. An analysis of variance with two between-subjects factors--sex (male, female) and handwriting posture (LI, LN,

and RN)--and one within-subjects factor--response condition (left hand responding to normal and mirror-imaged letters, and right hand responding to normal and mirror-imaged letters) was carried out to determine whether the three-way interaction among these factors was significant. This interaction was not significant but the sex by response condition interaction, F (3, 180) = 3.181, $p < .05$, was significant as well as the main effect for response condition, F (3, 180) = 4.533, $p < .005$. These effects are summarized in Figure 12.

Insert Figure 12 about here

It appears that males have roughly the same pattern of responding as in the tactual word task--e.g. LN males respond most slowly and RN males respond most quickly, with the LI group in between. The pattern of responding is somewhat different for the females--with the main difference between the males and females being that LN females respond faster than LN males. Table 12 summarizes the response conditions where the fewest (and most) errors were made.

Insert Table 12 about here

As can be seen, no pattern of error-making seems to exist, and the correspondence with Table 10 is quite low.

Discussion

In this study, differences were found between the LN and LI males and females. With regard to possible mechanisms of motor control, this study generally supports the suggestion that motor control of writing in some left-handers is mediated through the contralateral hemisphere via crossed motor pathways (Geschwind, 1975; McKeever & Hoff, 1979). However, Levy's (1974) hypothesis of ipsilateral control cannot be ruled out due to the nature of the tasks. The set of predictions for each model (for each task used in this study) are summarized in Table 12.

Insert Table 12 about here

The results of the spatial visuomotor task are consistent with Levy's ipsilateral control hypothesis only for LI subjects. The LN and RN subjects responded in opposite fashion from what would be predicted by Levy's hypothesis. On this task, the LN group responds fastest with the left hand when the stimulus is in the left visual field. This suggests either the possibility of a right hemisphere spatial superiority in the LN subjects (which is the opposite of what would be predicted according to Levy) or that the task was poorly designed with respect to assessing hemispheric asymmetries in the processing of spatial stimuli. This is because the task involved both recognition of the spatial stimulus (direction arrow) as well as choosing an appropriate motor response (based on the perceived direction of the arrow). The motor response is thus based on a certain amount of <u>decision time</u> which may have been different for each subject, thus confounding any analysis of perceptual asymmetries. It was also noted that no significant effects were observed on the verbal visuomotor task for what are most likely similar design difficulties.

Insert Figure 9 about here

For the tasks involving confusion of mirror-inverted words and letters, Levy's (1974) ipsilateral control hypothesis would predict that there should be no significant difference in the amount of confusion of conflicting writing programs (as inferred from slower response times) between the LI (and RN) and LN groups. This is because Levy's model tacitly assumes a dominant language hemisphere (left in LI and RN and right in LN) with little or no bilateral representation. IN this study, it was hypothesized that confusion would be the result of bilateral language representation with little or no language dominance. Longer response times (greater confusion) would be the result of having to make a choice based on similar language information/abilities being encoded in each hemisphere. According to Geschwind's (1975) contralateral control hypothesis, it is LI individuals who should demonstrate more of this confusion (as indicated by slower response times in this study). No conclusive support was found for either of these hypotheses.

Insert Figure 10 about here

In the tactual word confusion task, it was found that male subjects differed more according to handwriting posture with the LN group having (by far) the slowest response times--with the LI group being in between and the RN group being the fastest. The response times of the female subjects differed more according to response condition--with the LN and LI groups differing slightly according to whether the word was mirror-inverted or not. The RN group responded with very little variation over response condition (and also tended to respond fastest in both the male and female groups). An unexpected finding was that LN subjects in general (but especially the males) responded so slowly--e.g. showed the greatest amount of confusion of mirror-inverted words (as inferred from response time).

This result could be interpreted as supporting Levy's (1974) suggestion that motor control in the LI individuals is mediated via an ipsilateral pyramidal pathway because the LI group (especially the males) responded faster than the LN group. If this result were interpreted without reference to the RN group, then the LI group could be thought of as responding in a more <u>neurally efficient</u> (following a shorter motor pathway) manner than the LN group.

This is not a complete picture, however. The RN group on this task responded fastest, and thus in the most neurally efficient manner. This effect was most pronounced in the male subjects. Thee response times for the female RN subjects did not differ as much according to handwriting posture. The RN and LI groups were relatively close in their response times and the LN group was slowest. This result could perhaps be better interpreted as supporting Geschwind's contention that some language functions are represented bilaterally in left-handers and that motor control of the writing hand is directed by the left hemisphere through the right. A motor control mechanism similar to this could be used to explain the response times of both groups of left-handed males. The difference in response times between the LI and LN groups could be due to differing amounts of primary language encoding (e.g. recognition to speech) relative to encoding of motor programs for writing in each of the cerebral hemispheres. According to this interpretation, LI males may have such functions as language recognition and speech encoded primarily in the left hemisphere, whereas the programs for the motor control of writing may be encoded primarily in the left hemisphere and transferred to the right hemisphere via the commissures for output or these programs may be primarily encoded in the right hemispheres of these individuals (or some combination of both of these asymmetry patterns). LN males should be more likely to have primary encoding for language recognition and speech in the right hemisphere as well as primary encoding of motor programs for writing, and this encoding pattern is more likely to be represented equally in both hemispheres relative to LI males. Thus, LN males could be illustrating more confusion of mirror-inverted words on this task because of conflicting programs (for writing as well as language recognition and speech) in each hemisphere.

The tactual letter task was designed to be a test of spatial processing in the tactual sense modality. Results were less clearcut than those of the word task and were in the opposite direction of that predicted. However, the letters used may have been poor spatial stimuli because they were very similar to the verbal stimuli used on the tactual word task. This is because most subjects tended to respond to the verbal stimuli (words) only by palpating the first couple of letters.

There are basically two major findings of interest in this study. One is that both groups of left-handers (LN and LI) tend to be less left-handed than right handers are right-handed. This is supported by differences in the distribution of handedness inventory scores among the handwriting posture groups--with both groups of left-handers responding nearer the middle of the five-point scale (indicating some degree of mixed or shared hand usage) and right-handers responding as using their right hand for virtually everything. This is also supported by response times on the tactual word task in which the LN and LI groups take longer to discriminate mirror-inverted words than the RN group, indicating that they are less left-handed than the RN group is right-handed.

The other significant finding is that males and females differ significantly on the tactual word task. The fact that the LN males (and to a lesser degree the LI males) took longer on average to discriminate mirror-inverted words than did the LN and LI females suggest the possibility of different patterns of underlying cerebral asymmetry between these groups of males and females. If the male LN and LI subjects responded as they did because of confusion caused by shared representation of language abilities and/or writing programs in each hemisphere, then it could be inferred that LN individuals are less right-hemisphere-dominant than RN individuals are left-hemisphere-dominant. It is more difficult to make similar inferences from these results about cerebral motor control in the LI males because the response times of this group were intermediate to the LN and RN groups. Levy's (1974) hypothesis that motor control of writing hand in this group is from the ipsilateral hemisphere did not receive conclusive support from the LI males who were much slower at discriminating mirror-inverted words than the RN males. The Levy and Reid (1978) and the Moskovitch and Smith (1979) studies were interpreted by those investigators as an indication that LI and RN individuals are lateralized alike with respect to language specialization, but the tasks these investigators used measured ability to identify nonsense syllables and to turn off a dot (presented in the left or right visual field) respectively. When specialized processing mechanisms are engaged (such as in discriminating a mirror-inverted word from a word in its normal orientation) the pattern of lateralization in LI males (as inferred from response time) indicates this group has more bilateral representation of language abilities than Levy and Reid (1978) and Moskovitch and Smith (1979) had concluded.

The fact that males and females differed significantly according to handwriting posture and response condition on the tactual word task suggests that left-handedness in males and females may be influenced by different factors. Geschwind (1984) and Geschwind and Galaburda (1985) suggest that the high levels of testosterone secreted by the male fetus during the course of intrauterine life may selectively inhibit the development of the cortex on the left side. As the fetus develops, it is the left hemisphere of the cortex which develops first. If the development of the left hemisphere is slowed in relation to the right, then the individual may be more likely to show anomalous cerebral dominance (e.g. bilateral representation of language)--instead of the usual left hemisphere dominance manifest in approximately 90 percent of the population. Thus high levels of testosterone in utero may be an important factor in accounting for the high levels of left-handedness in males. This hypothesis is one good way to explain the slower responses of the LN (and to a lesser extent the LI) males on the tactual word task--if one takes slower responses in these groups to be an indication of anomalous cerebral dominance. This model also suggests that the left hemisphere is evolutionarily predisposed for the control of language abilities in humans.

Geschwind's is not the only model which may help to explain the unexpected findings of this study. Satz, Orsini, Saslow, and Henry (1985) delineate a clinical syndrome which they term the pathological left-handedness syndrome. This syndrome is primarily associated with early brain injury in some manifest left-handers. This syndrome is believed to be caused by a hemisphere lesion that is predominantly left sided (or bilateral asymmetric) which onsets before age six, and encroaches upon the critical speech zones of the frontotemporal/ frontoparietal cortex. This syndrome may include any or all of the following features: shifts in manual dominance, trophic changes in the extremities, transfer of hemispheric speech, and/or intrahemispheric reorganization of visuospatial cognitive functions. It is difficult to draw any conclusions on how this syndrome may relate to left-handers because handwriting posture was not assessed as a part of their neurological assessment procedures. It would, however, be a good idea for handwriting posture to be assessed in future studies of this type since it is easy to evaluate and could provide more complete information as to the nature of cerebral motor control than is now presently available.

Birth stress may also have an influence on asymmetries of cerebral motor control and anomalous hand dominance. Liederman and Coryell (1982) found that six week old infants with a history of perinatal complications lacked the rightward headturning bias of those children without a history of perinatal trauma. Children with a history of perinatal complications were also deviant with reference to the duration of a postural reflex and its degree of lateralization. Liederman and Coryell suggest that perinatal complications may delay the establishment of volitional hand use as well as increase the probability of left-handedness. These investigators interpreted their data as supporting Satz's (1972) model of pathological left-handedness (of which Satz et al.'s (1985) model is an expanded version). Unfortunately, Satz et al. also fail to distinguish between the LN and LI writing postures.

The possibility is raised here that the differences found here between LN and LI individuals are due to differing mechanisms of motor control (of the writing hand) underlying the LI and LN writing postures--especially in male subjects. LN individuals have been found to be less lateralized with respect to language representation than RN individuals (which makes sense according to Geschwind's testosterone hypothesis), but most likely still have language representation and motor control of the writing (left) hand lateralized to the same (right) hemisphere. According to either hypothesis, the LI are anomalous--either in having motor control mediated via uncrossed pyramidal tracts or in having language and motor control in different hemispheres. This anomalous condition may result from high intrauterine testosterone levels or some other birth stress or trauma early in life and may reflect a greater sensitivity of males to the type of stressors that influence the development of left-handedness.

In conclusion, this series of experiments indicates that lateralization patterns of LN individuals for language specialization and motor control of the writing hand are not mirror images of RN patterns. This finding was interpreted as reflecting that LN (and to a lesser extent LI) individuals have bilateral representation of language abilities whereas RN individuals are highly lateralized. Differences were also found between male and female subjects which may reflect differences in brain lateralization due to the LN (and to a lesser extent LI) males being exposed to high levels of testosterone during the course or intrauterine life. It was also found that LI males took longer to make mirror-image discriminations of raised-surface words than did the RN males, but less time to make this discrimination than the LN males. This was interpreted as being an indication that language specialization and motor control of the writing hand in LI males is not completely lateralized to the left hemisphere.

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Figure 1. Handwriting Posture Diagrams from Levy and Reid (1976).

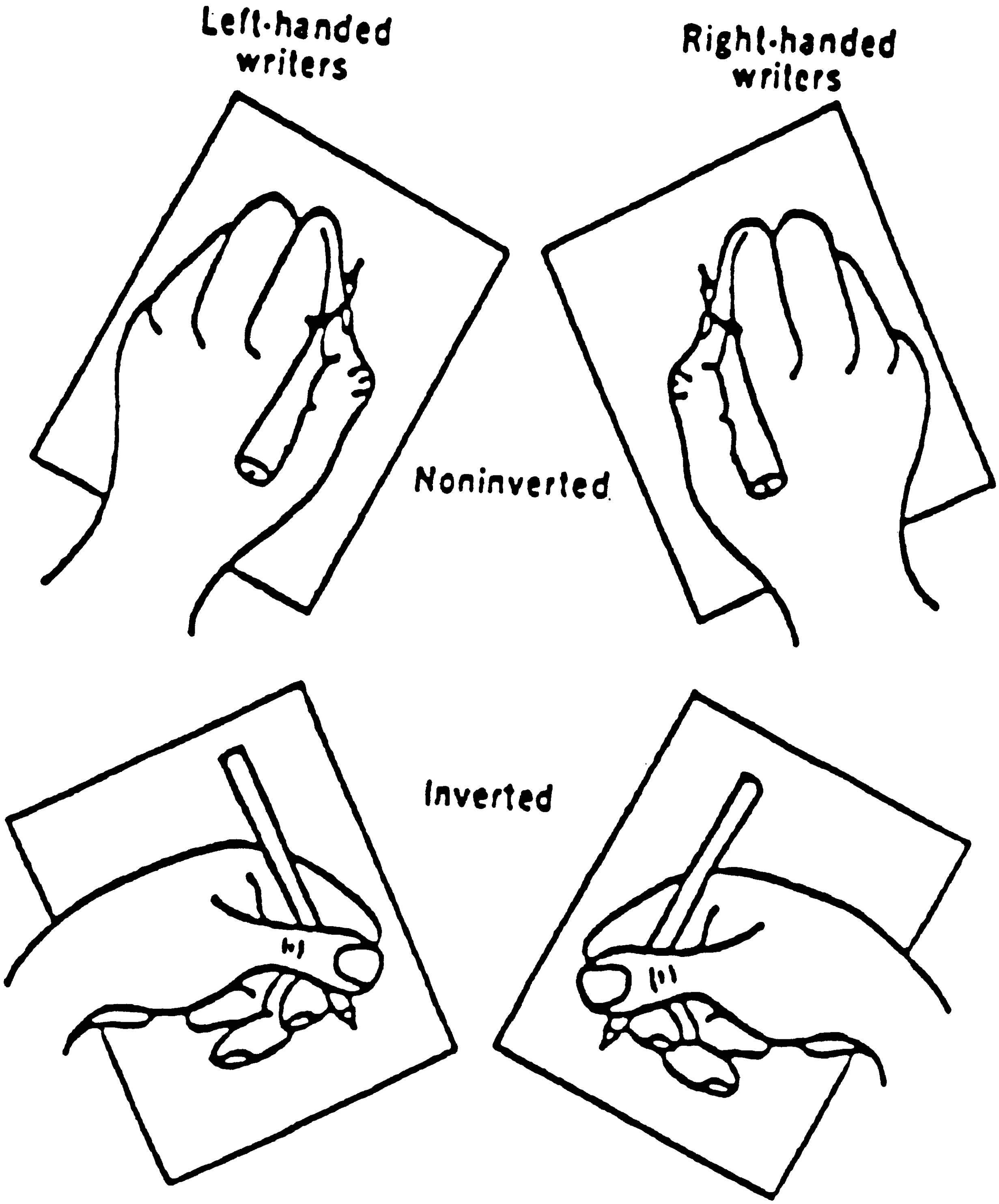

Figure 2. Pictorial Handwriting Posture Assessment.

Please <u>circle</u> the appropriate answers.

Which of these diagrams best matches your handwriting posture?

pen (arrow) and hand position shown relative to forearm

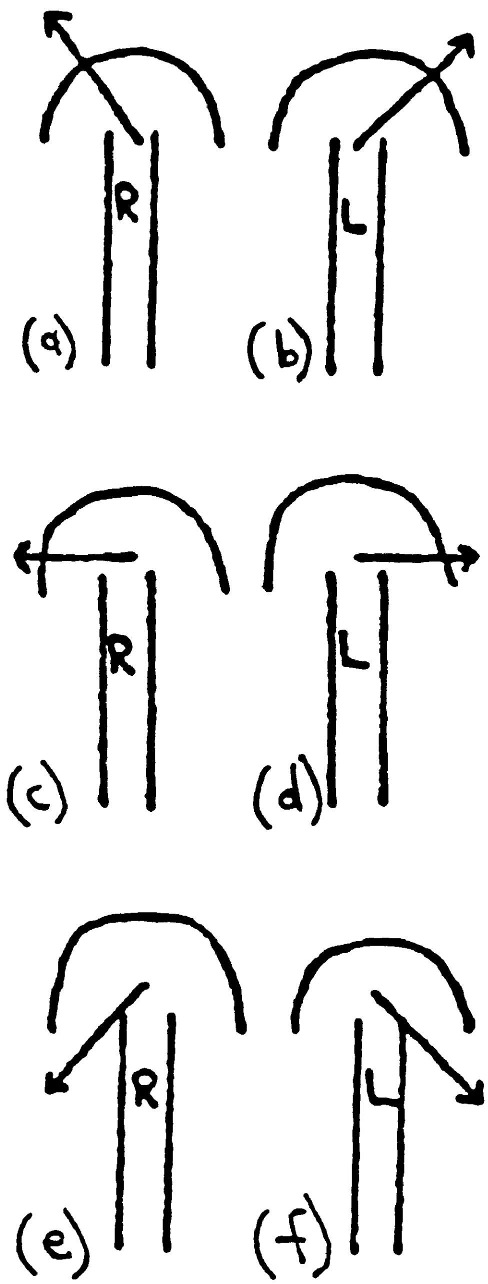

Table 1. Verbal Handwriting Posture Assessment (Levy, 1984).

When I write, I turn the paper so that:

a) The bottom, left corner points toward me.

b) The bottom, right corner points toward me.

c) The paper is straight up and down.

d) The paper is sideways with the top of the paper to my left.

e) The paper is sideways with the tope of the paper to my right.

When I write, it is usually the case that:

a) The tip of my pen points toward the bottom of the page.

b) The tip of my pen points toward the top of the page.

When I write, my hand is held:

a) Above the line of writing.

b) Below the line of writing.

I think most people who look at my hand posture would describe it as being:

a) Somewhat unusual and might say it was "hooked."

b) The same hand posture that most right-handers use.

Table 2. Handedness Patterns for Common Activities.*

Which hand do you use for the following tasks (L or R) and is that hand used all the time (A), most of the time (M), or are both hands used equally (C)?

*a) throwing a ball					
b) picking up a straight pin from the floor	LA	LM	E	RM	RA
*c) holding a toothbrush while brushing	LA	LM	E	RM	RA
*d) holding a hammer while nailing	LA	LM	E	RM	RA
*e) holding a tennis racket while playing	LA	LM	E	RM	RA
*f) holding a pen when drawing pictures	LA	LM	E	RM	RA
*g) holding a fork when eating	LA	LM	E	RM	RA
*h) holding scissors while cutting	LA	LM	E	RM	RA
i) operating a hand-held calculator	LA	LM	E	RM	RA
j) giving commands to a dog by pointing	LA	LM	E	RM	RA
k) turning the knob of a combination lock	LA	LM	E	RM	RA
l) strumming your fingers on a table top	LA	LM	E	RM	RA

* = Crovitz & Zener (1962) items

all others are original items

Table 3. Eye Dominance Test.

EYE DOMINANCE TEST

1) Stand at the X on the floor next to the orange chair.

With both eyes open, use your right index finger to point at the "X" on the chalkboard in front of you. Close your right eye. Write down the number your finger is pointing at in the space provided.

____

With your left index finger, point again with both eyes open. Close your left eye. Write down the number your finger is pointing at in the space provided.

____

Table 4. Checklist for History of Familial Left-Handedness.

HISTORY OF FAMILIAL LEFT-HANDEDNESS

Please check the appropriate space if that particular family member is (was) left-handed. If more than one, then indicate number.

Father _____ Mother _____

brother(s) _____ sister(s) _____

grandfather (paternal) _____ grandfather (maternal) _____

grandmother (paternal) _____ grandmother (maternal) _____

Table 5. Consent Form and Writing Posture Check.

COLLEGE OF WILLIAM AND MARY

Psychology Department Consent Form

The general nature of this experiment on *Handwriting Posture and Cerebral Organization conducted by Brian Pope has been explained to me. I understand that I will be asked to answer some questions about my handedness and do some tasks on a computer. I further understand that my responses will be confidential and that my name will not be associated with any results of this study. I know that I may refuse to answer any question asked and that I may discontinue participation at any time. I also understand that any grade, payment, or credit for participation will not be affected by my responses or by my exercising any of my rights. I am aware that I may report dissatisfactions with any aspect of this experiment to the Psychology Department's Research Ethics Committee. My signature below signifies my voluntary participation in this experiment.

____________________ ____

Date Signature

*underlined portions are what subjects had to fill out.

Table 6. Stimulus Words for Verbal Visnomotor Task.

Nouns		Verbs	
1.	Clock	1.	Think
2.	Room	2.	Give
3.	Road	3.	Hear
4.	Wood	4.	Save
5.	Hair	5.	Lose
6.	Bed	6.	Listen
7.	Heart	7.	Ask
8.	Street	8.	Spend
9.	Girl	9.	Deny
10.	House	10.	Decide
11.	City	11.	Enter
12.	Earth	12.	Send
13.	Dog	13.	Seek
14.	Food	14.	Extend
15.	School	15.	Eat
16.	Tree	16.	Let
17.	Corn	17.	Admit
18.	Animal	18.	Sing
19.	Car	19.	Fail
20.	Heart	20.	Argue

Table 7. Words Used in Tactual Discrimination - Word Task.

*each word and its mirror-image used twice.

1. cat
2. girl
3. dog
4. bed
5. bird
6. help
7. desk
8. car
9. run
10. talk

Figure 3. Average of mean scores on handedness inventory (items a, b, d, e, h, and i) as a function of sex and handwriting posture.

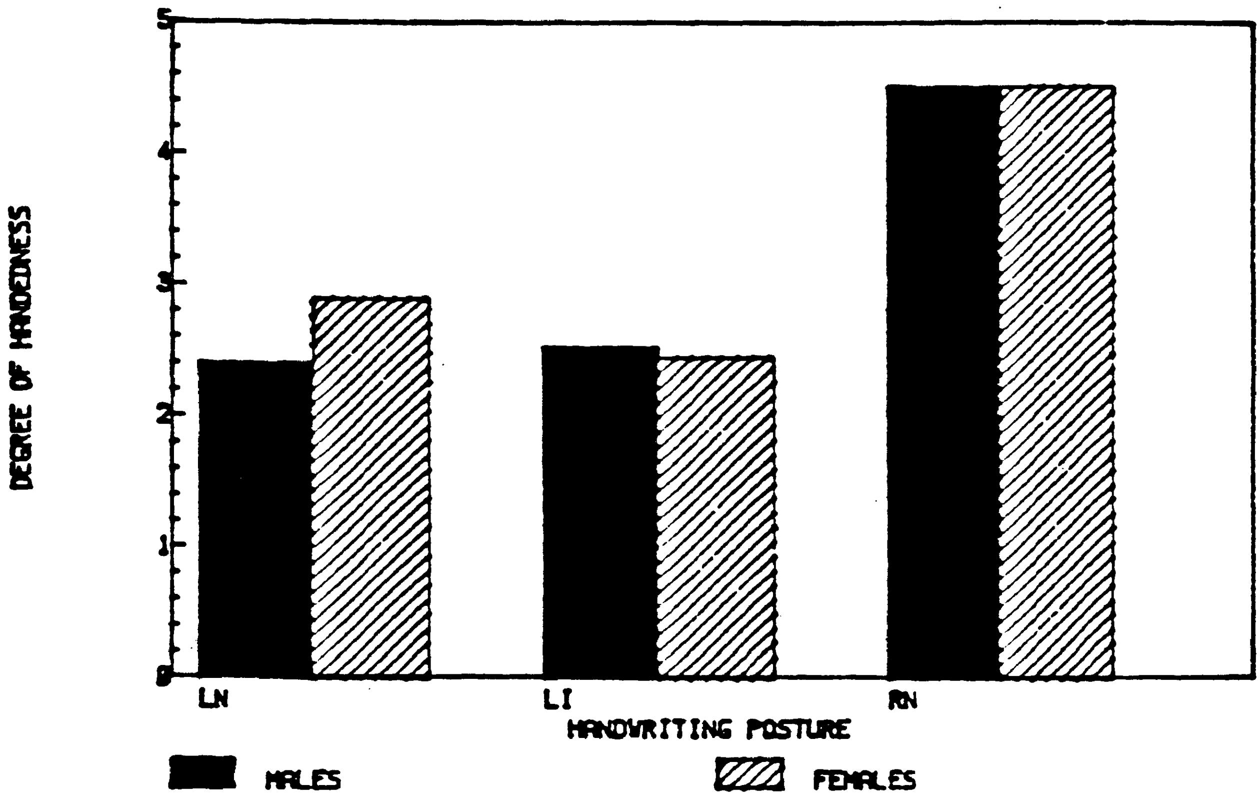

Figure 4. Mean scores on handedness inventory for item c (holding a toothbrush while brushing) as a function of sex and handwriting posture.

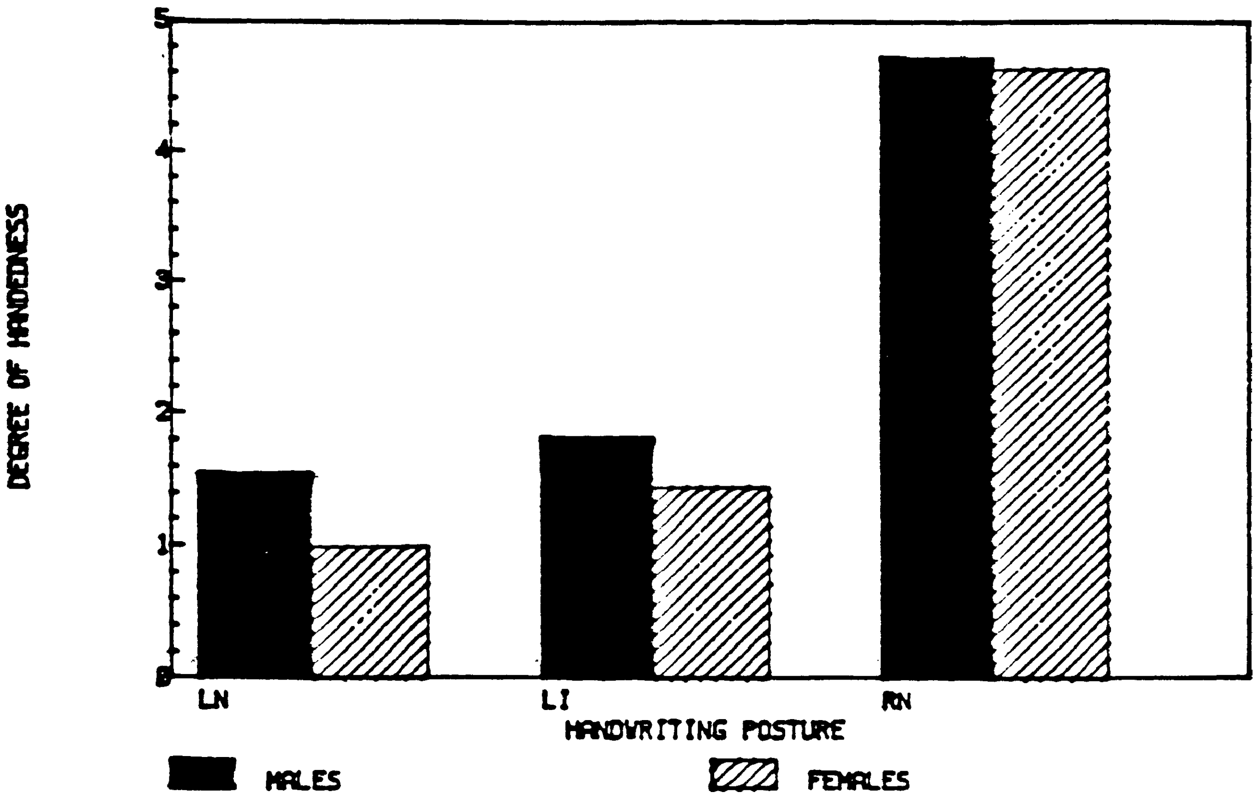

Figure 5. Mean scores on handedness inventory for item g (holding a fork while eating) as a function of sex and handwriting posture.

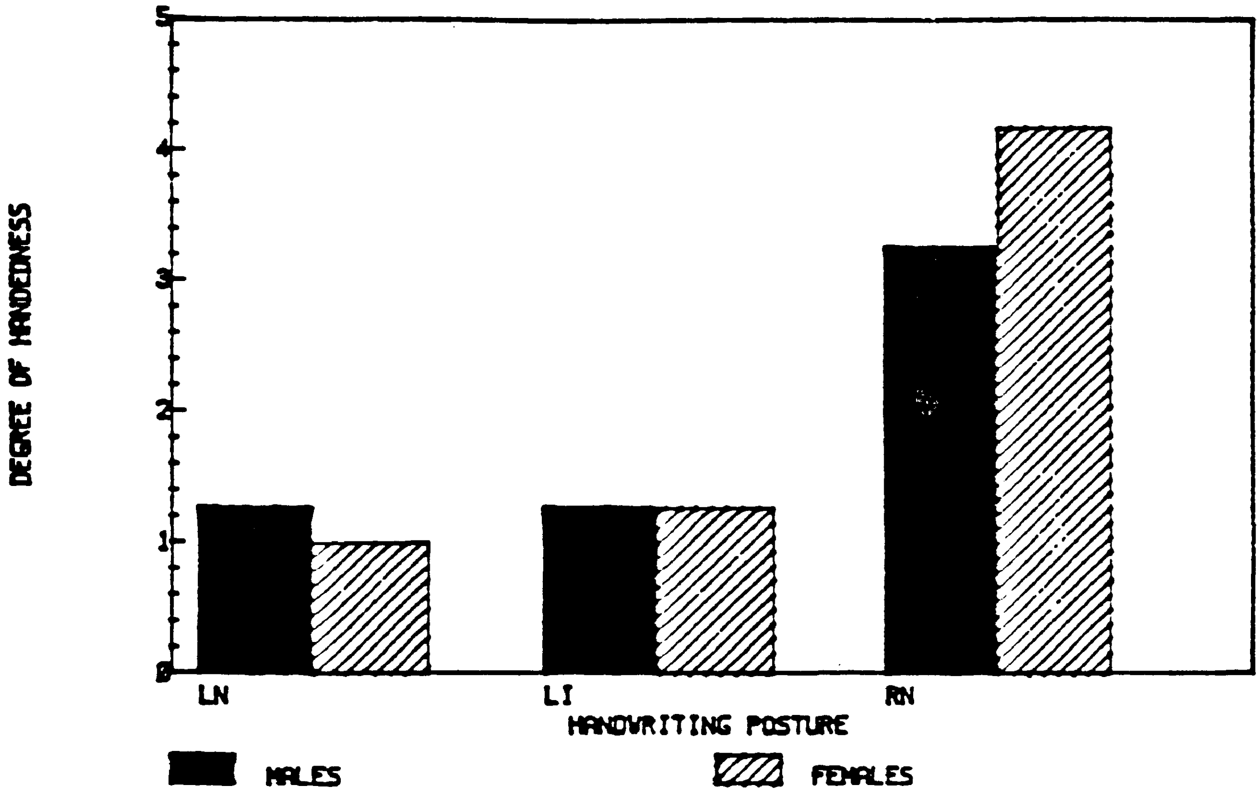

Figure 6. Mean scores on handedness inventory for item k (turning the knob on a combination lock) as a function of sex and handwriting posture.

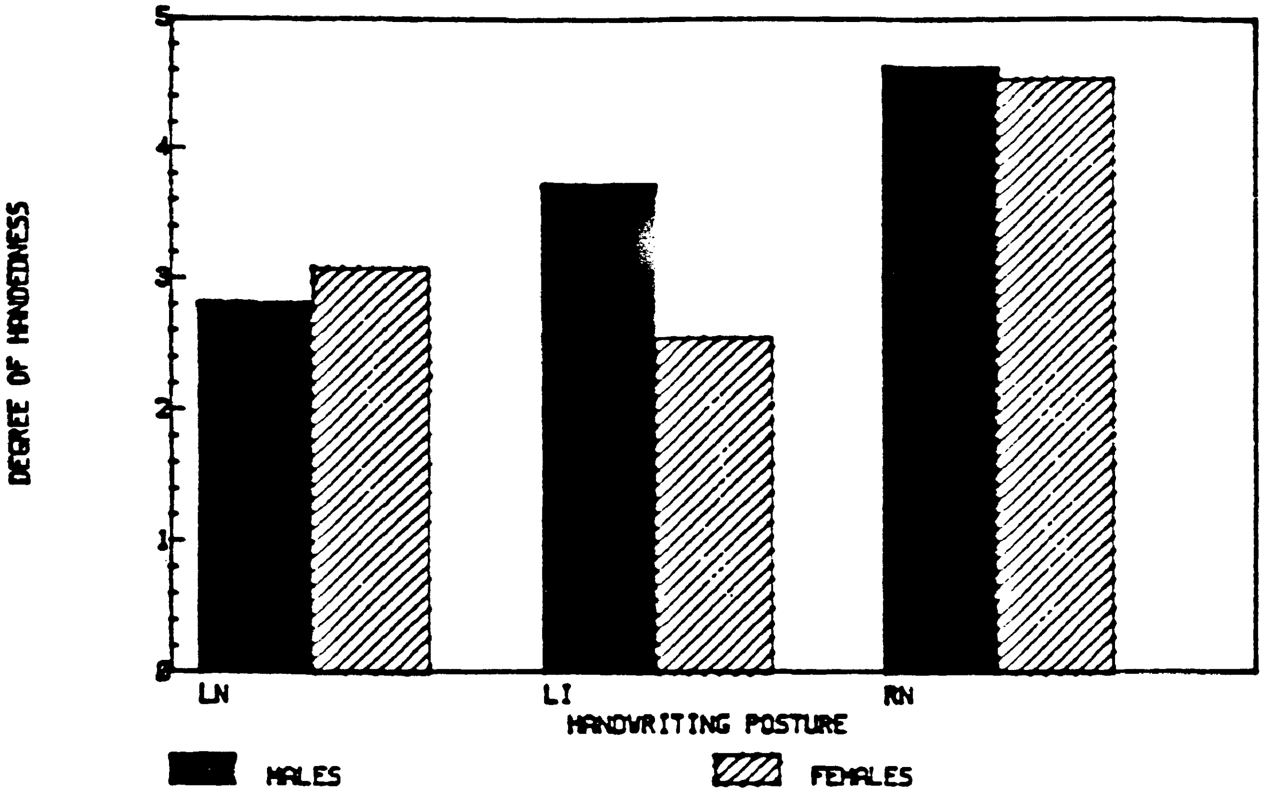

Figure 7. Mean Tapping Speed scores as a function of sex and handwriting posture.

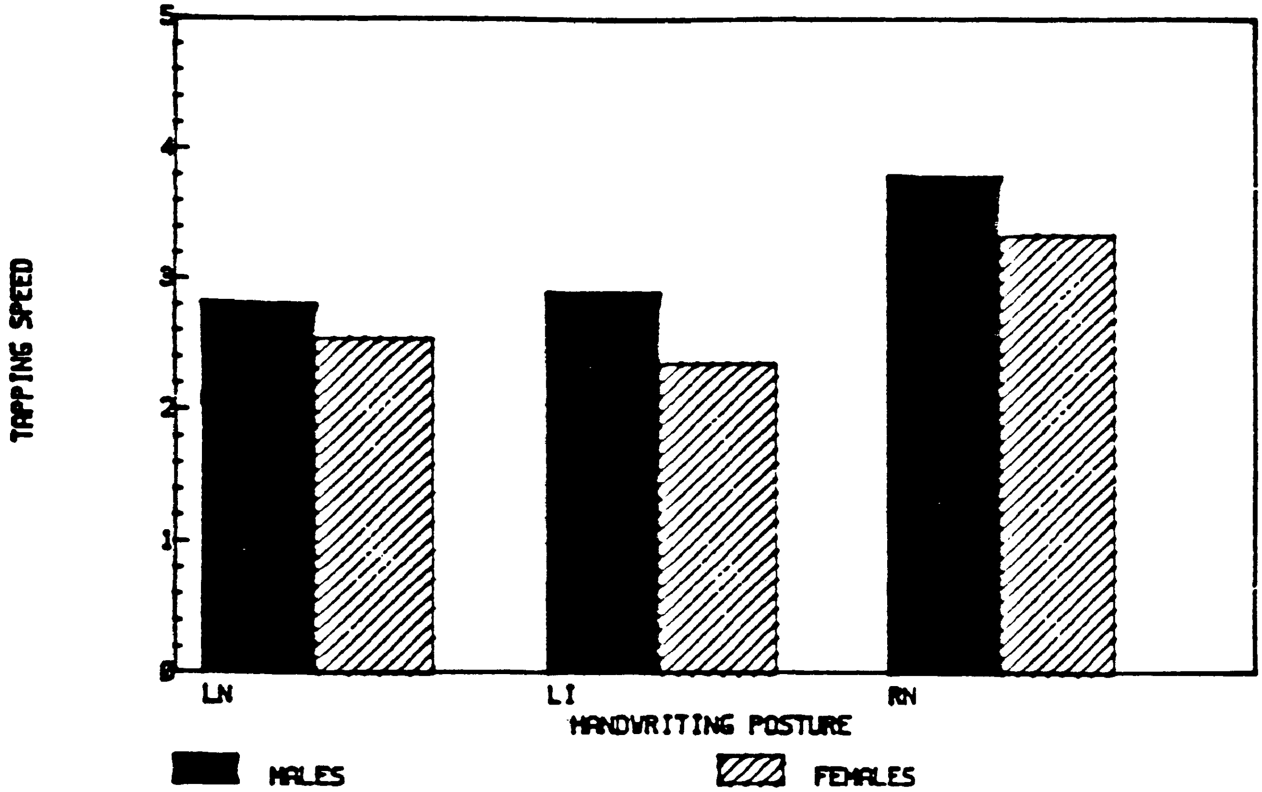

Figure 8. Mean response time on the <u>verbal</u> visnomotor task as a function of sex, handwriting posture, and response condition (left homolateral and heterolateral, and right (homolateral and heterolateral).

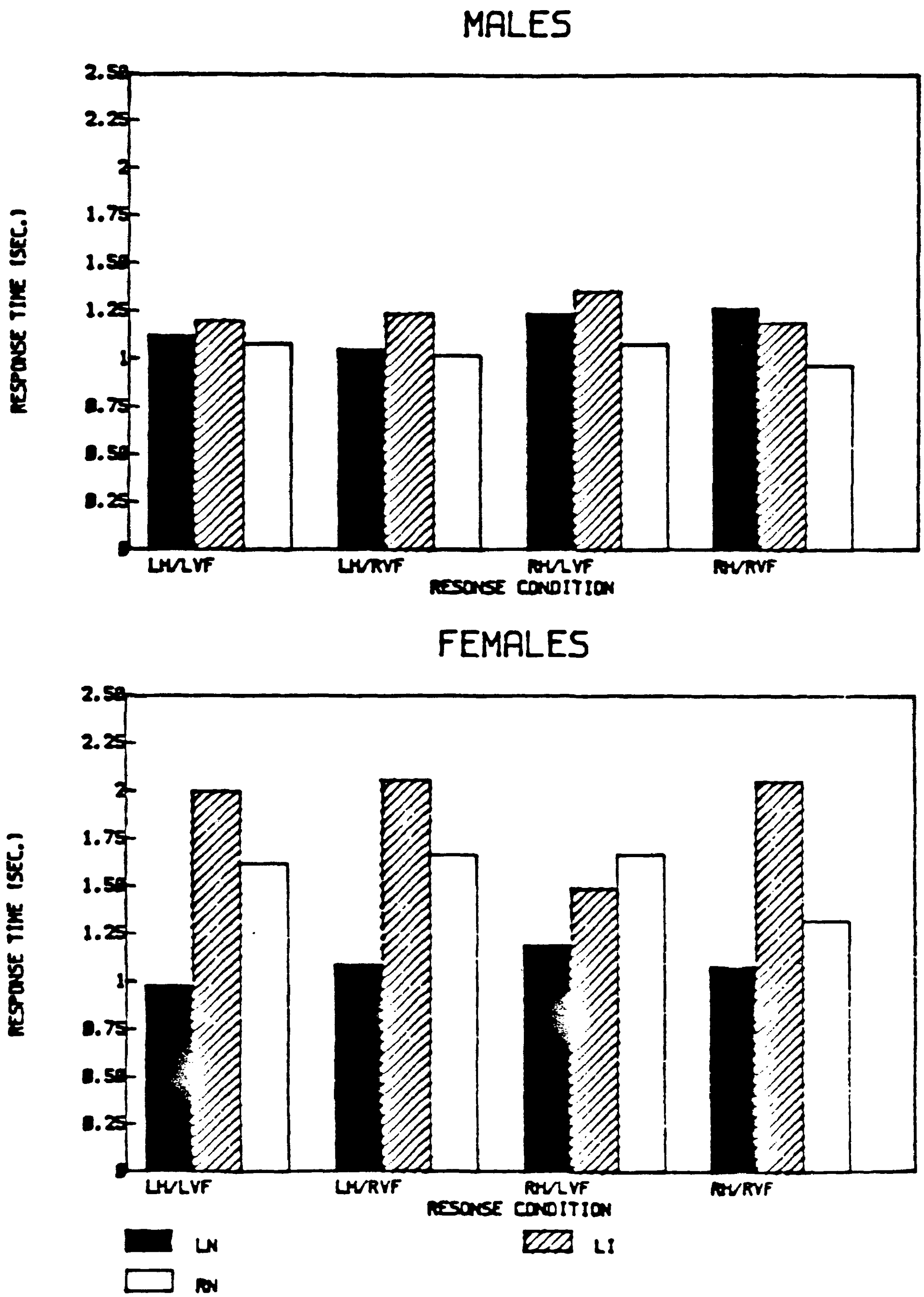

Table 8. Predicted and actual fastest response conditions in verbal visnomotor task (according to Levy's model) as a function of handwriting posture.*

handwriting posture	Predicted fastest response condition	Actual fastest response condition males	Actual fastest response condition females
LN	LL	LR	LL
LI	LR or RR	RR	RL
RN	RR	RR	RR

* The abbreviations of LL, RR, RL, RR signify left hand responding to a stimulus in the left visual field, left hand responding to a stimulus in the right visual field, right hand responding to a stimulus in the left visual field, and right hand responding to a stimulus in the right visual field respectively.

Figure 9. Mean response times on the spatial visnomotor task as a function of sex, handwriting posture, and response condition (left homolateral and heterolateral, and right homolateral and heterolateral).

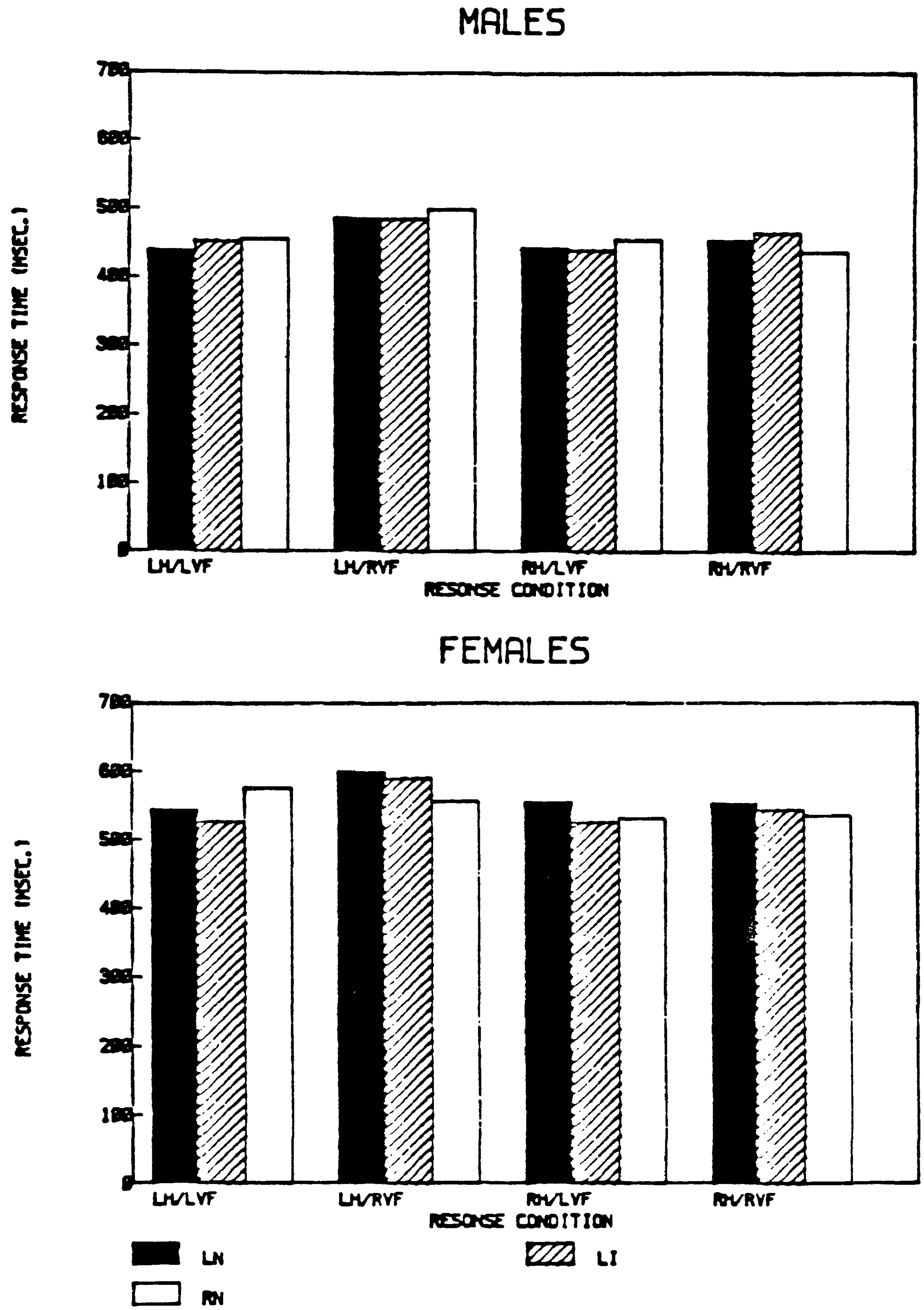

Table 9. Predicted and actual fastest response conditions acording to ipsilateral control model (in <u>spatial</u> visnomotor task) as a function of handwriting posture.

handwriting posture	Predicted fastest response condition	Actual fastest response condition	
		males	females
LN	RR	LL	LL
LI	RL; LL	RL	RL; LL
RN	LL	RR	RL

Figure 10. Mean response times for <u>males</u> and <u>females</u> on the tactual word task as a function of sex, handwriting posture, and response condition.

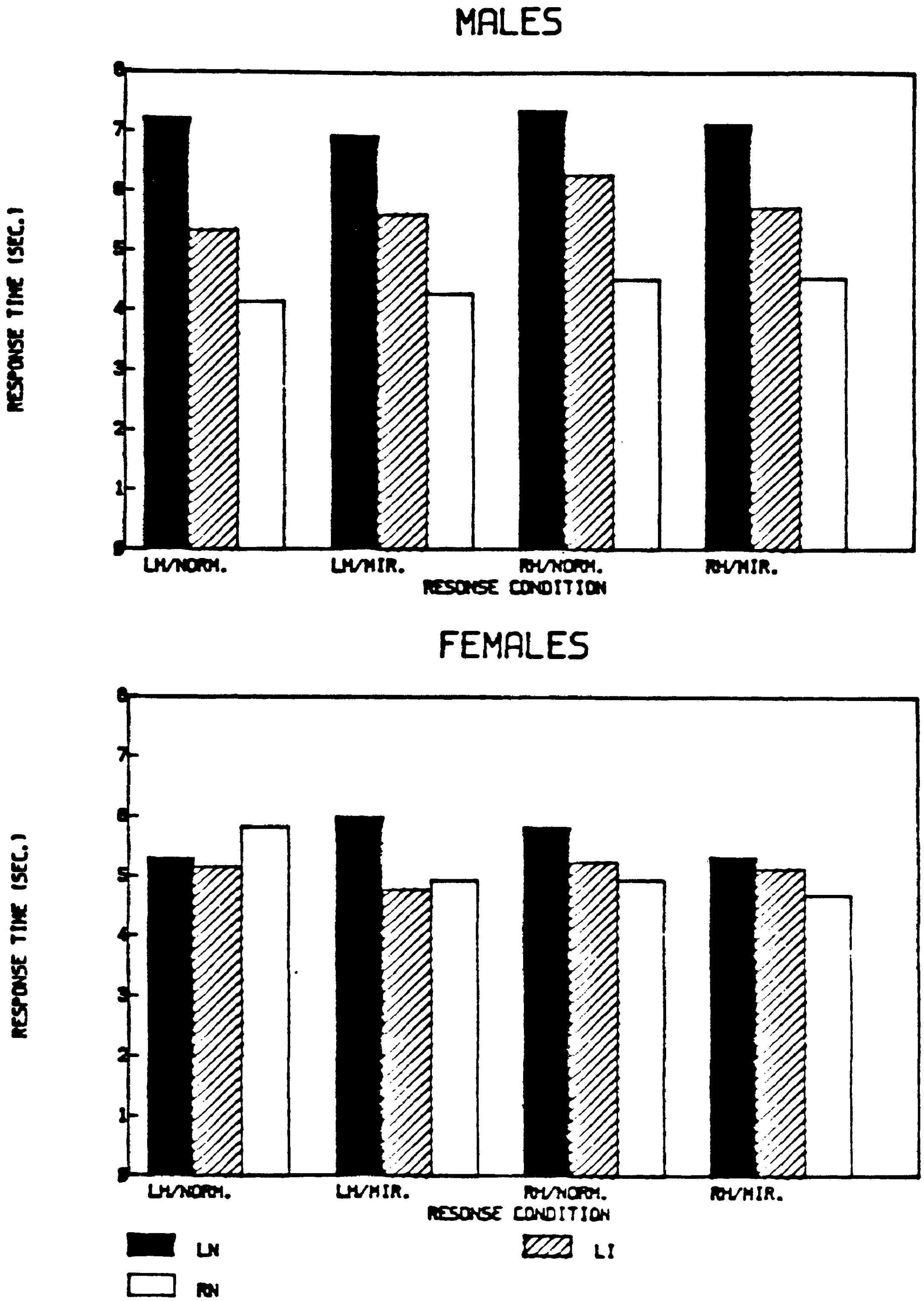

Figure 11. Mean number of errors for <u>males</u> and <u>females</u> on the tactual word task as a function of sex, handwriting posture, and response condition.

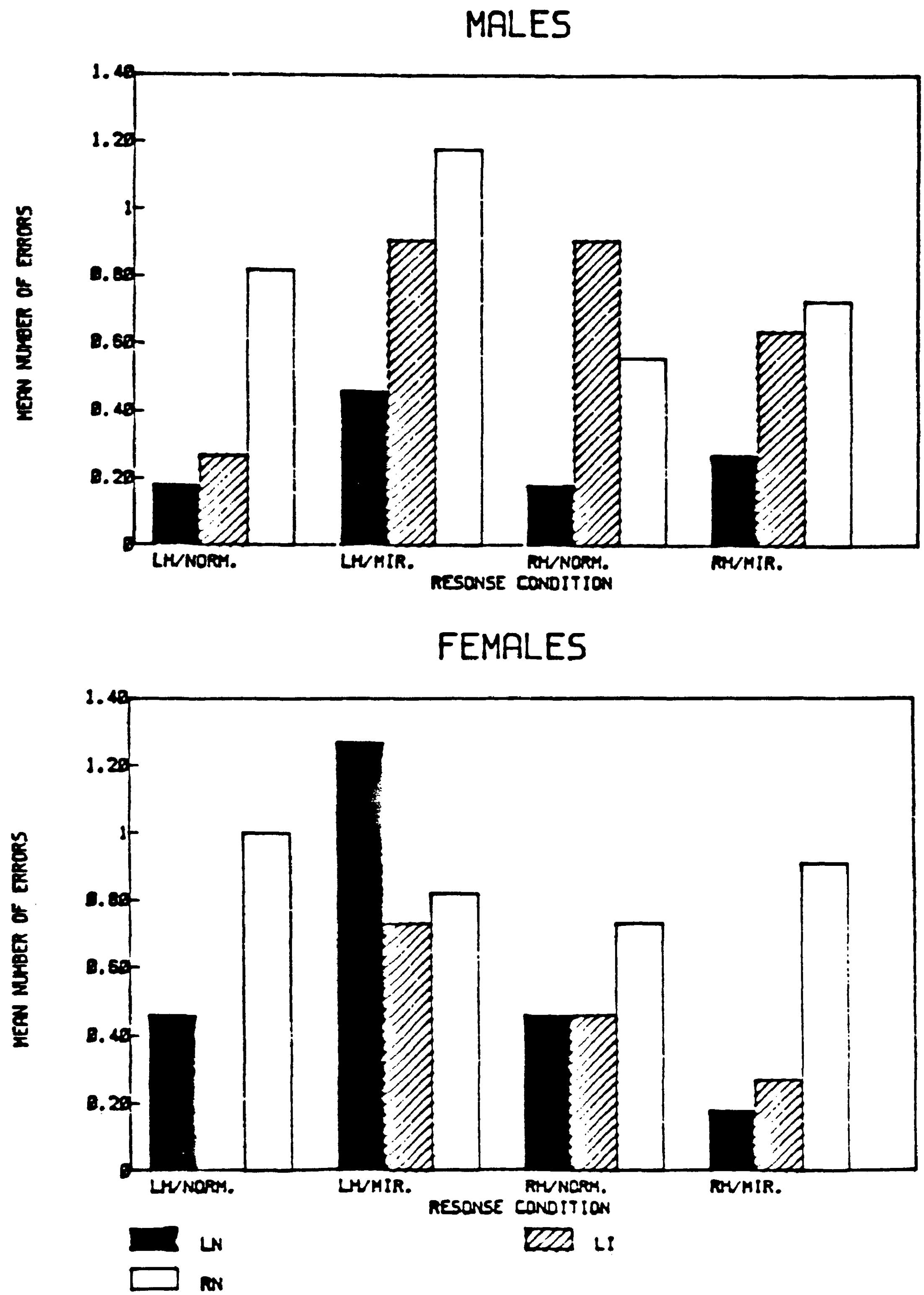

Table 10. Response conditions where fewest and most errors were made as a function of sex and handwriting posture.

handwriting	males		females	
posture	fewest	most	fewest	most
LN	L norm; R mir	L mir	R norm	L mir
LI	L norm	L mir; R mir	L norm	L mir
RN	R mir	L mir	R mir	L norm

Figure 12. Mean response times for <u>males</u> and <u>females</u> on the tactual letter task as a function of sex, handwriting posture, and response condition.

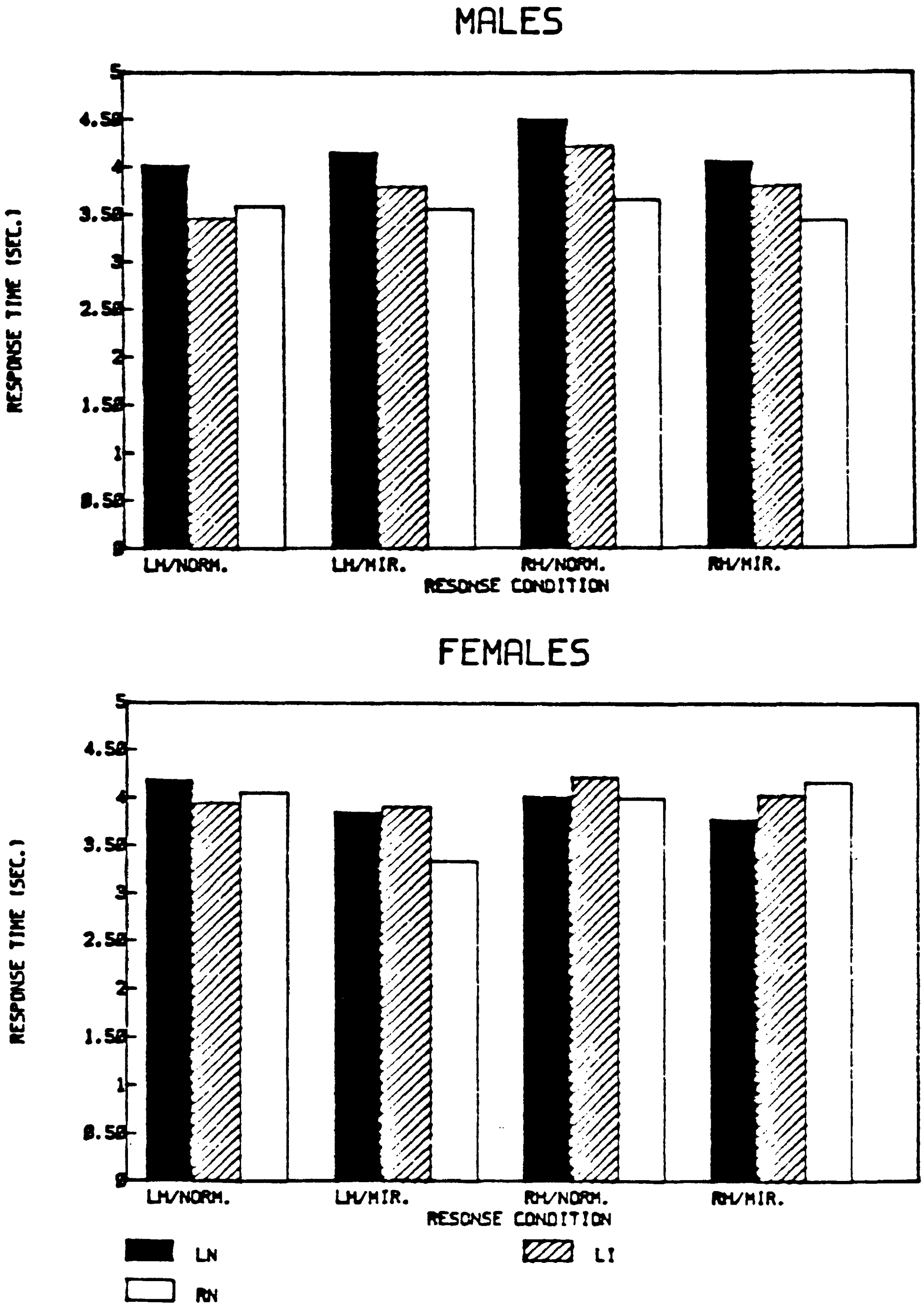

Table 11. Response conditions where fewest and most errors were made as a function of sex and handwriting posture.

handwriting	males		females	
posture	fewest	most	fewest	most
LN	L mir	R mir	R mir	L mir
LI	L mir; R norm	R mir	L mir; R mir; R norm	L norm
RN	R mir	L norm	L mir & R norm	L norm

Table 12. Summary of predictions according to Levy's (1974) ipsilateral control hypothesis (in Li individuals) Geschwind's (1975) hypothesis of contralateral control.

	Ipsilateral	Contralateral
Distribution of hand use according to writing posture:	LI with left hemisphere language should respond about the same as LN with right hemisphere language.*	LI less lateralized in the sense that both hemispheres are actively involved in motor control.*
Verbal Visnomotor task:	LI faster in heterolateral conditions with the left hand or homolateral conditions with the right hand.	LI slower than LN (and RN) in heterolateral conditions with the left hand.
Spatial Visnomotor task:	LI faster with right hand in heterolateral conditions of left hand in homolateral conditions.	LI slower than LN (and RN) with the right hand in heterolateral conditions.
Confusion of mirror-inverted words and letters (inferred according to response time):	There should be no significant difference in the amount of inferred confusion between the LI (and RN) and LN groups. Discrimination should be equally quick for all groups.	LI should demonstrate more inferred confusion because of possible competition between motor programs for writing which may already be present in the right hemisphere and those transmitted from the dominant (left) hemisphere.

* In the ipsilateral control hypothesis it can be safely assumed that LN is the exact opposite of RN and also that cerebral control of the writing hand is different in LI and LN individuals, whereas the contralateral control hypothesis allows for greater bilateral representation of language abilities. Thus, in this model LN is not the exact opposite of RN.

VITA

JAMES BRIAN POPE

Born in Greenfield, Indiana, May 11, 1962. Graduated from Greenfield-Central High School in that city, May 1980, B.A. DePauw University, 1984.

In August 1984, the author entered the College of William and Mary as a graduate assistant in the Department of Psychology.