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HEMISPHERIC SPECIALIZATION IN CHILDREN:
NEUROPSYCHOLOGICAL EVIDENCE IN A SAMPLE OF CHILDREN WITH
UNILATERAL BRAIN LESIONS

by
Kevin L. Barclay

**Thesis submitted to the faculty of Graduate Studies and
Research in partial fulfillment of the requirements for the
degree of
Master of Arts**

**Department of Psychology
April, 1991
Carleton University
Ottawa, Canada**

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ABSTRACT

The purpose of this study was to investigate the neuropsychological sequelae of unilateral lesions in children. Its unique contribution to the literature was the careful selection of subjects with short lag times between lesion onset and testing and the unequivocal identification of side of lesion. Neuropsychological measures included a subgroup of tests from the Halstead -Reitan battery and Halstead's modifications for young children (Knights, 1985). Subjects were identified by reviewing medical files of the Neurosurgical Unit at the Children's Hospital of Eastern Ontario. Only cases with clearly lateralized lesions identified by the neurosurgeon through CT Scan, EEG and surgical observations were considered. Twenty-nine subjects met this criteria. Sixteen of these subjects had no known neurological history (negative history) prior to rapid onset of the present lesion. The fifteen remaining subjects had long standing seizure histories (positive history) which were treated by excising the seizure focus.

Results from the neuropsychological tests revealed that the left lesioned young subjects (mean age 13) showed patterns similar to adult findings; significant deficits in verbal skills (VIQ) relative to performance skills (PIQ) as determined on the WISC-R. Relative deficits were determined by subtracting PIQ from VIQ creating the VIQ-PIQ difference score. Right lesioned subjects with no known neurological history prior to onset of the

lesion showed significant deficits in the Tactual Performance Test (TPT) location scores as compared to their left lesioned counterparts. Right lesioned subjects with negative neurological histories also showed VIQ - PIQ difference scores that were significantly higher (positive) than their left lesioned counterparts (high negative). Results for left and right lesioned subjects with long standing seizure disorders indicated results similar to left lesioned subjects with negative histories; a deficit in VIQ relative to PIQ. In fact, right lesioned subjects with longstanding seizure disorders had lower (high negative) VIQ-PIQ difference scores than any group and showed significantly better performance on the TPT location score than their left lesioned counterparts. Paired t-tests indicated that male left lesioned subjects with negative neurological histories had significant differences in VIQ and PIQ while their female counterparts did not. Although a between sex groups comparison did not reach significance, the t-tests imply a greater lateralization of language functions for males than females, which is in support of adult findings. The results are illustrated by four case studies which portray the significant interaction between history and side of lesion. Results are discussed in terms of the possible potential for differential reorganization of the left and right hemispheres. Recommendations are offered for further research to clearly delineate the subject population if a better understanding of the development of hemispheric specialization is to be realized.

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TABLE OF CONTENTS

	Page
Abstract	i
Acknowledgements	iii
List of Tables and Figures	v
List of Appendices	vi
Introduction	1
Review of the Literature	
Studies with Normal Adults	2
Studies with Normal Children	4
The Study of Children with Lateralized Lesions	8
Lesions Suffered in Infancy	9
Lesions acquired in Childhood	13
Co-factors in the Study of Hemispheric Specialization	21
Sex Differences as a Co-factor	22
Other Co-factors	25
Neuropsychological Assessment and Hemispheric Specialization	28
Wechsler Intelligence Scales	29
Other Neuropsychological Tests	31
Reliability and Validity of Neuropsychological Tests	32
Purpose of the Present Study	35
Statement of Hypotheses	37
Methodology	
Subjects	38
Neuropsychological Assessments	41
Statistical Analyses	44
Results	
All Subjects	46
Subjects with Negative Neurological Histories	49
Sex Differences	53
Age Effects	55
Comparing Groups with Different Neurological Histories	58
Case Studies	64
Discussion	
The VIQ-PIQ Difference Scores	77
Other Components of the Neuropsychological Assessment	82
Age Effects	84
Sex Differences	86
The History Factor	88
Summary and Conclusions	91
References	93
Appendices	108

LIST OF TABLES

	page
Table 1	
Test according to functional localization in a hemisphere	42
Table 2	
Hemispheric assignment of aphasia items	43
Table 3	
Statistical Analyses	45
Table 4	
Subject variables for the study sample	47
Table 5	
Review of findings for each hypothesis	63

LIST OF FIGURES

Figure 1	
Mean VIQ and PIQ Scores For left and Right Lesioned Subjects with Negative Neurological Histories	52
Figure 2	
Mean VIQ-PIQ Difference Scores for Left and Right Lesioned Groups by Sex	57
Figure 3	
Mean VIQ-PIQ Difference Scores for Left and Right Lesioned Groups by History	62

LIST OF APPENDICES

i)	Lesion description for each subject	109
ii)	Significant One-way ANOVAs All subjects together (n=29)	110
iii)	One-way ANOVA, VIQ -PIQ difference score Subjects with negative neurological histories (n=16)	114
iv)	Other significant statistical analyses Subjects with negative neurological histories (n=16)	115
v)	Significant paired t-tests	118
vi)	Two-way ANOVA VIQ-PIQ difference scores lesion by history, all subjects (n=29)	120

INTRODUCTION

Since Broca's seminal report (1865) that damage to the left anterior lobe causes expressive speech dysfunction, there has been extensive interest in the functional asymmetry of the cerebral hemispheres. Over the course of the last century, the development of modern neurophysiology and the paradigm shift that allowed the acceptance of psychology from its philosophical roots into the realm of neurology, have allowed researchers from the continuum of brain and behaviour sciences to examine the intricate relationship between localized brain areas and specific functional behaviours. The developmental course of the brain and behaviour relationship from infancy through to adulthood has provided a vast area of study for researchers anxious to understand the basis of this complex and intricate association.

REVIEW OF THE LITERATURE

Studies with Normal Adults

By far the most popular method of study of hemispheric lateralization in normal individuals is the Dichotic Listening Task pioneered by Doreen Kimura (1961). In this task the subject is presented with two different auditory signals at the same time, one arriving at each ear. The subject is then required to make some identifying response. In general, accuracy for speech related material is better in the right ear, whereas accuracy for non-speech materials is better in the left ear (Bryden, 1982). Although the ascending auditory pathways are relatively complex, there is strong evidence that the crossed pathways have a greater number of fibers and faster transmission speed than do the ipsilateral connections (Majkowski et al., 1971; Rosenzweig, 1951). Information is transmitted to both auditory cortices from each ear, however the pathways suggest that more information is more quickly and accurately received by the contralateral cortex. In normal adults, a strong right ear advantage for meaningful words (Satz, Achenback & Fennel, 1967) for nonsense syllables (Curry & Rutherford, 1967) and for numbers (Bryden, 1967) suggests a left hemisphere superiority for verbal stimuli.

In the visual mode similar asymmetries have been demonstrated indicating a left hemisphere superiority for

various forms of verbal material (Bryden, 1983).

Tachistoscopic presentation of laterally positioned stimuli has been a popular method of investigating hemispheric asymmetries for visual material (Bradshaw & Nettleton, 1983; Segalowitz, 1983). While being asked to fixate on a central point, subjects are briefly presented with lateralized visual stimuli. Due to neural connections complementary to those described in the auditory pathway, the right visual field advantage for verbal material has been attributed to the superior ability of the left hemisphere to perform language functions (Bradshaw, Nettleton & Taylor, 1981; Bryden, 1982; Kolb & Wishaw, 1980; Merikle et al., 1971). A variety of verbal stimuli have demonstrated the right visual field advantage including mirror oriented english words (Isseroff, Carmon & Nachshon, 1974) vertically oriented words (Bryden, 1970; Kershner & Jeng, 1972) and Hebrew words (Carmon et al., 1976). Such studies, taken together, exemplify the salient features of the right visual field advantage for verbal material.

While the left hemisphere demonstrates a significant involvement in language functions, the right hemisphere can demonstrate a significant involvement in visuo-spatial functions (Bryden, 1982). The association between visuo-spatial functions and the right hemisphere has a history that dates back to Hughlings Jackson (1876) and his work that paralleled Broca's with patients who suffered brain

damage. The tachistoscopic methodology described above has often been employed in the study of right hemispheric superiority for visuo-spatial tasks (Bryden, 1982; Kolb & Whishaw, 1980). The evidence regarding visuo-spatial tasks, however, is not as concretized as that regarding language tasks, in part because of the contradictory evidence defining the nature and number of distinct spatial abilities (Johnson & Meade, 1987).

Studies with Normal Children

In searching for the bases of hemispheric specialization, researchers have turned to younger populations. By establishing the developmental pattern of hemispheric specialization, researchers hope to isolate the influential factors that contribute to the patterns of hemispheric specialization seen in adults.

There is evidence that lateralization of function is present at very young ages, if not from birth (Dennis & Whitaker, 1977; Moscovitch, 1977; Molfese, Freeman & Palermo, 1975). Molfese (1977) has summarized the literature representing the neurophysiological asymmetries seen in the infant brain. Best and Glanville (1978) have demonstrated cerebral asymmetries in speech and timbre discrimination by infants as young as three months. Because of the infants'

limited ability to respond overtly, a number of studies have utilized electrophysiological response to stimuli to investigate hemispheric specialization. One such study, carried out recently, utilized facial signs of emotion to elicit electroencephalogram (EEG) asymmetries from 10 month old infants (Fox & Davidson, 1988). In this study, the researchers utilized a standard stranger and mother approach paradigm including a brief separation from the mother. In one condition, a stranger with a neutral facial expression would approach the infant in the mother's presence. In a second condition the mother would approach the infant with a smiling expression. In a third condition, the stranger would approach with a neutral expression while the mother was absent. During each of the approach sequences, infant behaviour, including facial expression, was videotaped. EEG was recorded from the left and right frontal and parietal scalp regions to compare with previously established adult findings (Davidson et al., 1979; Tucker et al., 1981). Artifact-free periods of EEG were extracted that were coincident with expressions of joy, anger and sadness as elicited by the infant and coded from the video tape. Facial expressions associated more frequently with the approach of the mother were also associated significantly with left frontal activation of the EEG. Facial expressions associated with the stranger were associated significantly with right frontal activation of

the EEG. This asymmetrical electrophysiological response to positive (mother) and negative (stranger) emotional stimuli is also seen in adults (Davidson, 1984; Leventhal & Tomarken, 1986). Although there are methodological difficulties with scalp recorded EEGs in that the asymmetries could be generated by the facial expressions themselves (Davidson, 1984), the similarities between the adult and infant findings nevertheless point to a very early, if not congenital, development of this particular asymmetry.

Other interesting response paradigms have been utilized by researchers to examine laterality in normal infants. For example, Entus (1977) used the nonnutritive high-amplitude sucking paradigm to the discrimination of novel verbal (consonant-vowel syllables) and non-verbal (musical notes) stimuli presented in the Dichotic Listening Task. Infants between 22 and 140 days of age exhibited a significant increase in the rate of sucking when a syllable was presented to the right ear and a musical note to the left ear.

Another example of interesting response paradigms can be seen in a study by Glanville, Best and Levenson (1977) who used heart rate to examine asymmetries in three month old infants. They found a greater recovery of the cardiac orienting response when a new speech stimulus was presented

to the right ear as opposed to the left ear. A novel musical note produced greater response recovery when it was presented to the left ear. These positive findings for infants, however, can be matched with as many negative findings in the current literature leading some researchers to summarize the evidence as inconclusive (Hahn, 1987).

In the formative years of ages two to four, further evidence can be found to support the early development of hemispheric specialization (Witelson, 1987). At this age, the standard Dichotic Listening Task has produced positive results reflecting the pattern of hemispheric specialization similar to that seen in adults; left hemisphere specialization for verbal material and right hemisphere specialization for visual spatial material (Ingram, 1975; Kinsbourne & Hiscock, 1977; Nagafuchi, 1970).

In older child populations, more convincing and abundant results are to be found in the literature that firmly establish the existence of this familiar pattern of hemispheric specialization similar to that seen in adults (Hynd & Obrzut, 1977; see Hahn, 1987, for a recent review). The consistency of these results may reflect an increase in functional laterality corresponding to an increase in age or it may simply reflect a more reliable and cogent methodology suited to the ability of the subjects to respond. This difficulty in interpretation of the results has led to an ongoing debate between researchers who feel

that patterns of hemispheric specialization in normal populations develop with age versus those who see the patterns as invariant from birth. This debate rages in the current literature (see Witelson, 1987; and Bullock, Liederman & Todorovic, 1987) and likely will for some time until rigorous methodology is developed to examine more closely the neurophysiological and neuropsychological correlates of brain-behaviour relationships in the normal subject.

The Study of Children with Lateralized Lesions

As the seminal developments in neuropsychology owe their foundations to the study of brain lesioned individuals, the current state of the art similarly relies heavily on the study of groups of individuals who have suffered brain lesions. Through the comprehensive assessment of these individuals, direct information is revealed regarding the complex relationship between brain and behaviour. The study of individuals with lateralized brain lesions has largely focussed on the study of adults until very recently. The paucity of evidence for pediatric populations is due in large part to the fact that the neurological syndromes relevant for such study occur with low frequency in children (Knights & Stoddart, 1984; Witelson, 1987). Nonetheless, researchers continue to probe

the brain-behaviour relationships further as more controlled techniques and better delineated populations are defined.

Lesions Suffered in Infancy

For some time, it has been demonstrated that children suffering left hemisphere lesions at a very early age do not suffer the same language deficits as the adult populations with the same lesions (Annett, 1973; Witelson, 1987; Woods & Carey, 1979).

Maureen Dennis and colleagues (Dennis & Kohn, 1975; Dennis, Lovett & Wiegel-Crump, 1981; Dennis & Whitaker, 1976) have examined closely the development of hemispheric specialization through the study of children who have undergone hemidecortication for intractable seizures. For the subjects in these studies it is often difficult to determine age of lesion onset, however, these comprehensive studies reflect the complex interplay between neural plasticity and early functional specialization. Specifically, Dennis has found that even a massive loss of left hemisphere tissue by hemispherectomy may leave the Verbal Intelligence Quotient (VIQ) unaffected while causing other persistent deficits in the use and understanding of both oral and written language (Dennis, 1985). Dennis' comprehensive study of 407 children with neurological damage also found no evidence to support the classical theory of

development of hemispheric specialization, implying that a more complex relationship with intervening variables may be at work.

Some recent reports continue to support the hypothesis of neural plasticity in the infant brain. For example Bergman et al. (1984) used a Dichotic Listening Task to examine the patterns of hemispheric specialization in a young population who demonstrated congenital or infantile hemiplegia. The subjects who had demonstrated a left hemiplegia in early life demonstrated a left ear attentional advantage for verbal material (the reverse of the traditional adult findings). This recent study confirmed previous findings that demonstrate the reorganization of hemispheric specialization following early brain damage (e.g. Goodglass, 1967).

This recent study also illustrates some of the fundamental difficulties that have plagued investigations of hemispheric specialization to this day. Firstly, the behavioural manifestation of hemiplegia is taken as prima facie evidence of brain damage in the contralateral hemisphere. Although this is a likely assumption, more direct links to the neurological substrate of the behavioural manifestation should be demonstrated before confidence in the existence of the lesion is established.

Secondly, comprehensive reports on the etiology

underlying the hemiplegia are required if confidence is to be established regarding the likely site of the brain lesion. In the Bergman et al. study, 23 of the 28 hemiplegic subjects represented congenital cases with no etiologic diagnosis. Of those with an etiologic diagnosis, three represented cases that could implicate bilateral brain damage (acute encephalopathy associated with pertussis immunization, acute meningoencephalitis, and cases of sepsis, meningitis and dehydration) and only two cases presented etiologies indicative of lateralized damage (dermatic signs of neurofibromatosis and a case of cerebrovascular accident). As another example of this issue, Hecaen's (1976) frequently cited article also suffers from a difficulty with the etiology of its young subjects. Of the 26 brain lesioned subjects, 16 had an etiology of cranial trauma, a very common form of childhood neurological damage. Although the lateralization of the lesion was confirmed by surgery and/or the results of clinical, radiological and electroencephalographic testing, Hecaen admits that "in the cases of traumatic etiology, we are unable to completely exclude a lesion of the other hemisphere" (p. 118). Difficulties illustrated in these studies are characteristic of the difficulties faced by all researchers who investigate the relationship of hemispheric specialization in the lesioned brain in young subjects (Witelson, 1987). Fortunately, with the modern development of brain imaging

techniques becoming relatively commonplace in the clinical setting (Gur, 1985) it is hoped that neurophysiological evidence will accompany behavioural evidence to determine the site of lesion in the brain.

In contrast to many of the aforementioned studies, other studies have demonstrated the innate qualities of hemispheric specialization as seen in subjects who suffered brain damage in infancy. For example, when Woods and Carey (1979) carefully assessed children with early left hemisphere lesions, they demonstrated significant language deficits that had persisted. These specific deficits were overlooked by standard clinical aphasia testing. In addition, researchers have also demonstrated greater deficits in syntactic comprehension (Kiessling, Denckla & Carlton, 1983; Vargha-Khadem, O'Gorman & Watters, 1985) and deficits in praxic ability (a skill traditionally assigned to the left hemisphere in adults) (Nass, 1983) for left versus right perinatal damage.

Still other recent reports examine the complex relationship between age of onset, site of lesion and reorganization after lesion in the developing brain. These reports (see Satz et al, 1988) implicate an important developmental milestone at age three that predicts the course of intra versus inter-hemispheric reorganization. These reports also exemplify the effects that lag time

between lesion and assessment of function may have on hemispheric specialization.

Upon initial inspection it may appear that these two lines of evidence, neural plasticity versus early hemispheric specialization, represent conflicting paradigms. It is important to realize that studies, such as those described above, often examine behaviour after an extensive lag time from lesion onset. Therefore, these studies do not necessarily reflect hemispheric specialization at the time of onset. They may reflect hemispheric specialization at the time of testing and they may reflect differential plasticity of the hemispheres but further speculation should be considered an extrapolation from the evidence. Present studies have not clearly supported one paradigm over the other. In addition, It is important to recognize that the two views of early hemispheric specialization and neural plasticity may be considered complementary rather than contradictory if a fuller understanding of the developing brain is to emerge (Witelson, 1987).

Lesions Acquired in Childhood

Difficulties described in finding subjects for infant studies of hemispheric specialization persist throughout childhood. In comparison to adults, children suffer far less frequently from the kinds of neurological insults which are

unilateralized to a specific cerebral hemisphere. In adult populations, the overwhelming majority of subjects in studies of hemispheric specialization have suffered a cerebral vascular accident (CVA) while the remainder of subjects usually have a lateralized brain tumour (e.g. Inglis et al., 1982; McGlone, 1978; Snow, 1987). In pediatric neurological patient populations, CVA is seen on occasion in the perinatal period however it very rarely occurs during childhood. In addition, although brain tumours do occur in childhood, they most often occur in lower brain regions where the infiltration is bilateralized (Bigler, 1984). The vast majority of childhood neurological cases represent diffuse, bilateralized brain damage (Knights & Stoddart, 1984) that does not provide a useful population for the study of hemispheric specialization. Nonetheless, a number of studies have overcome this difficulty to some extent and are summarized here.

Dichotic listening tasks are often used in the study of children with lateralized brain lesions. For example, Woods (1986) employed this methodology in a recent study of 29 subjects who demonstrated evidence of lateralized cerebral lesions. The dichotic stimuli used were similar to those developed initially by Kimura (1961) and represented verbal material. On indices of laterality (see Marshall, Caplan & Holmes, 1975), a significant difference was demonstrated

between children with left brain lesions (n=16) and children with right brain lesions (n=13) for a right ear advantage with the verbal stimuli ($t=2.81$, $p < 0.01$). The right lesion group demonstrated a right ear advantage larger than the left lesioned group and comparable to the control group (laterality indices, right lesioned group = 0.217, left lesioned group = -0.036, controls = 0.311). On a case by case basis, ten of the thirteen subjects demonstrated a clear right ear advantage. In contrast, only six of sixteen left lesioned subjects demonstrated a clear right ear advantage. In fact, within the left lesioned group, two subjects demonstrated a clear left ear advantage. In addition to these groups of children with an average age of onset equal to about 6 years (range 1 to 15), Woods also looked at two groups of subjects with infantile hemiparesis with an age of onset prior to one year. In this early lesioned group, he could not find any significant differences between the left hemiparetic subgroup and the right hemiparetic subgroup. The average lag time between lesion and testing was about 9 years for the late lesioned group (range 2 to 22) and about 16 years (range 9 to 24) for the early lesioned group, making the average ages of all groups about 16 at the time of testing.

From these results, Woods postulates that the "lack of a consistent lesion effect following early lateralized brain lesions is due to the greater degree of functional

reorganization that takes place after such lesions" (p. 303). The groups that suffered later lesions demonstrate the pattern of hemispheric specialization observed in brain lesioned adults.

It is important to note, however, that all the subjects in this study were selected on the basis of hemiparesis. As mentioned earlier, it is highly likely that these subjects suffered a brain lesion contralateral to the hemiparesis but it does not rule out the possibility that a bilateral lesion may exist. In fact 10% of Wood's subjects did demonstrate mild motor deficits contralateral to the hemiparesis indicating some bilateral cerebral involvement. In response to this concern, Woods has stated fairly that "the overwhelming preponderance of the neurological impairment remained contralateral" (page 304).

The early and late lesioned groups differed on functional asymmetry but they also differed in etiology. Of the early lesioned group, 11 of 21 have an etiology not necessarily indicative of a lateralized lesion (difficult labour and delivery, premature birth, postmature birth, idiopathic etiology). In addition, 7 of the remaining 10 early lesion cases had a diagnosis of seizures and hemiparesis although it is not indicated if the seizures were localized. This leaves 3 of 21 early lesion cases with an etiology indicative of a lateralized lesion

(porencephaly, and Sturge-Weber syndrome). On the other hand, 23 of the 29 late lesioned subjects had an etiology indicative of a lateralized lesion (thrombosis, embolism and arteriovenous malformation). Three of the remaining cases were described as having "other focal lesions" (p. 304) and the final three as having a "question of postnatal trauma". Of course, these differences in etiology reflect the differences in neurological insults typically suffered by these two populations. In some cases EEG and angiography were used to determine site of lesion, Nonetheless, the etiologies associated with bilateral lesions must be taken into account when considering the lack of lateralization demonstrated by the early lesioned population. By identifying clearly localized lesions Woods' sample does offer an impressive rigour. Barring direct evidence from CT scans, which were not available for this sample at the time of onset, and considering that verification of lesion site was available on some subjects through EEG and angiography, Woods' study represents further evidence for the existence of hemispheric specialization in childhood. What will continue to be at issue with studies such as Woods' is the lag time between lesion and testing (Witelson, 1987).

Other studies have used populations in which testing was carried out relatively close to the time of lesion onset. For example, Hecaen (1976) reports on 26 subjects with cortical lesions (17 left, 6 right, 3 bilateral) who

were assessed for a variety of language disturbances. As expected, the percentage of left lesioned cases with a language disturbance was high (88%). Hecaen also considered the percentage of right lesioned cases suffering language disturbances as being high (33%) although this may be an artifact of clinical sampling; referrals of right lesioned children may be fewer because language deficits are not as prominent in these children and those who are referred are the most seriously impaired and demonstrate language deficits along with other serious impairments. Language deficits are often seen as more serious impairments than visuo-spatial or other cognitive deficits. In addition to these considerations, one of the two right lesioned subjects demonstrating aphasia was left handed. As will be discussed later, the sometimes atypical pattern of hemispheric specialization in left handers must be considered when making assumptions about typical hemispheric specialization in a subject sample (Bryden, 1982).

Longitudinal assessments in the Hecaen study revealed the striking ability for recovery of language function in children even after following lesions of the left hemisphere. Hecaen concluded that the analysis "appears to indicate a relative hemispheric equipotentiality which permits the transfer of language representation to the opposite hemisphere in the case of unilateral lesions in

childhood" (p. 114). At the time of publication, Hecaen commented briefly on the persistence of some language deficits but his focus was on equipotentiality of the hemispheres. Later, upon re-analysis, Hecaen recanted the emphasis on equipotentiality for an emphasis on early hemispheric specialization (Hecaen, 1983; Witelson, 1987). This shift of focus illustrates the sensitivity of such studies to the qualitative interpretation of the author. As well, it demonstrates the likelihood that early hemispheric specialization and equipotentiality of the hemispheres may cooperate in the development of language.

Many of the aforementioned studies did not have the luxury of lesion site verification afforded some of today's researchers through the use of the CT scan. One such recent study examined spoken syntax in children with acquired unilateral lesions (Aram, Ekelman & Whitaker, 1986). In this study, Aram and colleagues examined the spontaneous speech of lateralized brain lesioned subjects on a variety of measures. The subjects were culled through chart review of 1400 children seen at a children's hospital for cardiac catheterization or cardiac surgery over the course of five years. From this population, eight left and eight right lesioned children with negative neurological histories prior to lesion were identified through the use of CT scan. Although the right and left lesioned groups could not be compared directly because of age differences, they were

matched with controls from the original 1400 who were concordant for age, sex, race and presence or absence of cyanosis. The CT scans allow for a much finer definition of the lesion site and indicated fully unilateralized lesions. Intrahemispheric location of lesions, while uncontrolled, was relatively comparable between groups. Left hemisphere lesioned subjects performed more poorly than matched controls on a wide variety of spoken language measures. Right hemisphere lesion subjects performed more poorly than matched controls on a measure of errors in simple sentences though the majority of measures showed no difference between these subjects and their controls. This study provides evidence for the development of hemispheric specialization in this young group however, because the right and left lesioned groups could not be matched for age and/or balanced for sex, a somewhat cautious interpretation is required when comparing the groups. Although average ages of onset between groups was close (left lesioned = 1.5, right lesioned = 1.7) the left lesioned group contained only 2 subjects over the age of 6 months while the right lesioned group contained 5 subjects over the age of 6 months. The comparable average group ages result from the inclusion of one subject with age of onset of 6 years in the left lesion group while all other subjects in the study have an age of onset 3 years and under. Upon inspection of Aram and colleagues' tabulated

data, it appears that the pattern of deficits, although more pronounced for the 6 year old, is similar to that seen for the other members of the left lesion group. While offering further evidence for the existence of hemispheric specialization at an early age, this study also demonstrates the complex interweaving of co-factors such as age and sex which must be considered when examining children with lateralized lesions. By verifying the site of lesion through CT scan, by reporting the actual age and sex of each subject, by providing well matched controls and by offering a caution when comparing the different lesion groups, this study demonstrates a level of sophistication and rigour rarely seen in previous literature.

Co-factors in the Study of Hemispheric Specialization

As the previously mentioned studies illustrate, the complex multi-factorial nature of relevant subject variables has provided a significant obstacle to the researcher attempting to investigate the development of hemispheric specialization. These difficulties are exacerbated in the study of clinical populations where subject numbers remain small and little opportunity exists to match and/or balance samples of independent groups. Nonetheless, through a thorough description of a carefully selected sample, consideration of all relevant co-factors and an exhaustive

search of the literature, it is hoped that clinical research will contribute to the growing understanding of the lateralized functions attributed to the individual hemispheres.

Sex Differences as a Co-factor

Since the late 1960s, researchers have begun to recognize the significant role that sex differences may play in hemispheric specialization (Khan & Cataio, 1984). Many studies have demonstrated sex differences in normal adult subjects with regard to hemispheric specialization. For example, researchers have demonstrated sex differences in auditory perception tasks (Lake & Bryden, 1976; Piazza, 1980) and in visuo-spatial tasks (Kimura & Durnford, 1974; Tucker, 1976). These studies demonstrate a greater lateralization of function in the hemispheres for males and a more bilateral representation of function in the hemispheres for females. In contrast, there is a fair representation of negative results regarding sex-differences in the literature leading some researchers to conclude that sex differences can be attributed to methodological confounds (see Fairweather, 1980; Kinsbourne & Hiscock, 1977). Although such methodological confounds do exist in some of the clinical literature, there has amassed a large

body of evidence using adult subjects to support a more bilateralized representation of functions in females. For example, many studies have reported that aphasia following left hemisphere damage occurs more often in males than females (Brust et. al, 1976; McGlone, 1980; Messereli et. al, 1976). This evidence suggests that because language is more lateralized in the left hemisphere in males they will suffer greater language loss following comparable left hemisphere lesions than women. Although this may represent an over-simplification, (see Kimura, 1987) it has become a major consideration in studying adult populations who have suffered lateralized brain lesions.

Sex differences also provide an avenue of approach when considering the development of hemispheric specialization. If sex differences play a part in the patterns of hemispheric specialization in adults and similar sex differences can be demonstrated in young populations, then this provides evidence that patterns of hemispheric specialization may not vary greatly through development. Sex differences have been demonstrated in some studies of the cognitive abilities of younger subjects. For example, a male advantage in spatial abilities has recently been demonstrated in a large sample of school aged children by Johnson and Meade (1987). Although this male advantage has been regularly demonstrated in adult populations, Johnson

and Meade demonstrated it reliably in samples of children as young as 10 years of age. They did not, however, reliably demonstrate the sex difference in younger age groups. It is important to realize that although sex differences are demonstrated in this and several other studies of spatial abilities (Bouchard & McGee, 1977; Freedman & Rovcagno, 1981; Newcombe & Bandura, 1983; Orsini et al, 1982; Samuel, 1983), they do not necessarily relate to hemispheric specialization. They simply indicate a difference in performance not in hemispheric specialization. On the other hand, understanding the development of sex differences in spatial ability may provide a better understanding of possible critical milestones in the development of sex differences in other neuropsychological concepts such as hemispheric specialization.

Gordon (1983) looked more closely at hemispheric specialization and sex differences in a younger population through the use of the dichotic listening task. In this study, Gordon found sex differences for the older children (mean age = 13.0) but not for the younger children (mean age = 9.4). These results illustrate that adolescence may be an important time for the development of sex differences in hemispheric specialization (see Waber, 1977).

Sex differences have been found in younger populations. For example, Jones and Anuza (1982) found a strong right visual field advantage for accurate identification of the

sex of faces presented tachistoscopically to young boys age three and four. Girls of the same age did not demonstrate the same strong field advantage for this task. The pattern for both sexes is similar to that seen in adult subjects on the same task.

The aforementioned studies do indicate some interesting sex differences in the study of hemispheric specialization in younger populations. Obviously further study will be required to understand this co-factor and its relation to hemispheric specialization in the very young. As it has been made clear in previous sections that a paucity of clinical studies exists involving children with lateralized lesions, it need only be reiterated that these same studies rarely considered sex as a factor worthy of scrutiny.

Other Co-factors

The relationship between gender and hemispheric specialization has led researchers to investigate the co-factors of hormonal environment and chromosomal aberrations. Individuals with Turner's Syndrome (karotype 45X0) and individuals with Klinefelter's Syndrome (karotype 47XXY) have been examined in an effort to understand the influence that sex-related genes may have on hemispheric specialization. Turner's Syndrome subjects have demonstrated less

hemispheric lateralization of language functions than controls (Cordon & Galatzer, 1980; Money, 1964; Netley & Rovet, 1982a). Netley and Rovet (1982b) also studied a group of Klinefelter's Syndrome subjects who demonstrated a greater lateralization of functions than controls on a verbal dichotic listening task and on a spatial dichaptic task, indicating a reversal of the trend found in Turner's syndrome subjects.

Individuals who have been exposed to atypical hormonal environments have been examined to better understand the influence that sex-related hormones may have on hemispheric specialization. For example, Buffery and Gray (1972) studied a group of male subjects stricken with Kwashiorkor disease (a protein deficiency corresponding with a low level of androgen and consequently an elevated level of estrogen) who demonstrated superior verbal abilities and deficient spatial abilities reflecting the pattern that mimics that which is seen in females. Hines and Shipley (1984) further investigated the relationship between hormonal environment and hemispheric specialization by comparing females who were exposed to Diethylstilbestrol (DES) prenatally to their non-exposed sisters and to males. DES, a synthetic estrogen, was used by mothers for a short time in the 1960s to protect against spontaneous abortion. Hines and Shipley found a strong negative correlation on right and left ear scores in a dichotic listening task for the exposed females and males

(indicative of hemispheric specialization for language) as compared to the unexposed sisters. These results suggest the importance of the prenatal hormonal environment on the development of hemispheric specialization. It is important to remember that all the aforementioned groups of atypical subjects differ from normals in a great many ways (Bigler, 1984; Hines & Shipley, 1984; Khan & Cataio, 1984; McGlone, 1980) and should therefore be considered cautiously.

Handedness deserves careful consideration in the study of hemispheric specialization. Although the pattern of hemispheric specialization for dextrals is becoming well delineated by current research, the pattern for sinistrals is poorly understood (Bryden, 1982). Dextrals represent the majority of the population and hence are represented in the majority of reports in which almost every subject demonstrates speech localized in the left hemisphere (Strauss & Wada, 1983). Sinistral subjects demonstrate a less clear pattern with percentages of left hemisphere speech dominance ranging from 50 - 70 % (Rasmussen & Milner, 1977; Strauss & Wada, 1983). This unclear pattern of hemispheric specialization and the fact that the incidence of sinistrality is rare have led to their exclusion, intentional or unintentional, from studies of hemispheric specialization. With the development of more sophisticated studies, the description of lateral preference is becoming

more comprehensive (Bryden, 1982; Strauss & Wada, 1983) and the pattern of hemispheric specialization of sinistrals is becoming better understood (McKeever, 1986).

Along with handedness, familial patterns of sinistrality have also been investigated in current literature in relation to hemispheric specialization. For Example, Hardyck (1977) suggests that familial sinistrality effects hemispheric specialization for language while other researchers have found that familial sinistrality interacts with sex to influence spatial ability in right handers (McKeever et. al, 1983). In further demonstration of the complex interrelations between these variables, McKeever (1986) examined and found a significant interaction between a measure of androgyny, sex and familial sinistrality on a spatial task. Although the comprehensive review of each of these cofactors is beyond the scope of the current paper it is clear that they must be taken into account when considering the study of hemispheric specialization.

Neuropsychological Assessment and Hemispheric Specialization

As many of the subjects of the aforementioned studies are culled from clinical populations, standard neuropsychological tests have played an important role in delineating hemispheric specialization. Although these tests are applied in the clinical setting for the purpose of

identifying cognitive impairments, they can be utilized to identify the likely neurological substrate of the cognitive impairment. Coupled with information collected from neurophysiological examinations, the neuropsychological assessment can help to profile the cognitive sequelae associated with lateralized brain lesions.

Weschler Intelligence Scales

By far the most popular elements from the neuropsychological assessment for the study of hemispheric specialization are the Weschler Intelligence scales. In adults, the Verbal Intelligence Quotient (VIQ) and Performance Intelligence Quotient (PIQ) differences on the WAIS and WAIS-R have been used to imply corresponding lateralized brain lesions. A high positive VIQ - PIQ difference would suggest a right hemisphere lesion while a high negative VIQ - PIQ difference would suggest a left hemisphere lesion. Several studies have used the VIQ - PIQ difference to demonstrate the association of neurologically identified lateralized lesions to specialized abilities of the hemispheres (Bornstein, 1983; Bornstein & Matarazzo, 1982; Klove, 1974; McFie, 1975). In addition, sex differences have been found in the VIQ - PIQ differences of subjects with unilateralized lesions suggesting a more

lateralized hemispheric specialization for males versus females (Inglis et al., 1982; McGlone, 1980; Sundet, 1986). Nonetheless, many clinicians recognize that the VIQ - PIQ difference should only be considered as indicative of lateralized lesions if accompanied by other neuropsychological and neurophysiological evidence (Bigler, 1984; Chelune, Ferguson & Moehle, 1986; Russell, 1979).

VIQ - PIQ differences on the WISC-R have also been used as an indication of lateralized brain damage in children. Some researchers have suggested that a VIQ of 10 points greater than a PIQ is indicative of lateralized lesions of the right hemisphere while a PIQ 10 points greater than a VIQ could indicate lesions of either hemisphere (Rudel, Tueber & Twitchell, 1974). More recently, Riva and Gazzaniga (1986) examined early and late lesioned subjects with respect to VIQ - PIQ differences. They found that the late and early right hemisphere lesioned groups demonstrated PIQ scores significantly lower than controls while only the early left lesioned group demonstrated VIQ scores significantly lower than controls. The late left lesioned group did not differ from controls on either PIQ or VIQ. The previously mentioned confound of etiology may play a role in the different results for the early and late lesioned groups however this study coupled with a number of negative or conflicting results (Annett, 1973; Kohn & Dennis, 1974; Reed & Reitan, 1969) indicate that a VIQ - PIQ difference must be

interpreted very cautiously in the younger clinical subject. Another recent study indicated that in the general (non-neurological) population even a large VIQ - PIQ difference (beyond the 90th percentile averaging about 23 points) was not significantly associated with a positive neurological history for children (Moffitt & Silva, 1987). On the other hand, VIQ - PIQ differences of this magnitude are regularly associated with serious intellectual impairments (Bloom et al, 1986). In general, VIQ - PIQ differences must be considered along with other neuropsychological and neurophysiological evidence if a clear understanding of lateralized lesions in children is to develop.

Other Neuropsychological Tests

Other neuropsychological tests have played a role in the understanding of lateralized lesions. For example, the Aphasia Screening Test has been used to estimate the extent of both left and right hemisphere damage through its measures of aphasic and apraxic deficits (Reitan, 1979). Although a standardized scoring system is not widely agreed upon, the test does provide evidence for hemispheric specialization; left hemisphered lesioned individuals show

greater deficits on verbal items while right hemisphere lesioned individuals show greater deficits on non-verbal items (Snow, 1987).

For the most part neuropsychological tests have been developed, standardized and studied for the purposes of understanding lateralized lesions in adult populations. For example, the Category Test and the Tactual Performance Test (TPT) have been considered the most sensitive general indicators of brain damage in adults (Reitan, 1955b). More specifically, the difference between the dominant and non-dominant hands on the TPT has strong implications for lateralization of lesions as does the Finger Oscillation Test (Jarvis & Barth, 1984). Unfortunately, most references to younger populations are extrapolations from these adult findings. Nonetheless, as pediatric neuropsychology gains a firm foothold and as more and more clinical studies are performed, it is hoped that the neuropsychological assessments useful in suggesting the site of lesion in adults will be helpful in confidently understanding the location of lesions in the young brain.

RELIABILITY AND VALIDITY OF NEUROPSYCHOLOGICAL TESTS

Studies have been performed to examine the reliability and validity of various components of the neuropsychological

test battery. For example, Kaufman has reviewed extensively the interpretation of VIQ - PIQ differences in test scores on the WISC-R. He reports that both the VIQ and PIQ are stable and reliable across age groups and that the 90% confidence level is within ± 6 points on the VIQ and ± 8 points on the PIQ (Kaufman 1979, p. 24). On the other hand, Kaufman describes the VIQ - PIQ difference scores as "notoriously unreliable". Statistical significance for the difference score is 12 points at the $p .05$ level and 15 points at the $p .001$ level. Kaufman feels that a difference of 12 points is worthy of explanation.

Kaufman also points out, however, that there could be many varied explanations for a difference score of this magnitude. He adds that, by examining data on normal children, it can be seen that VIQ - PIQ differences of 17 points could not be considered abnormal by any reasonable statistical standard (Kaufman 1979, p. 25).

In a comprehensive multivariate analysis of FSIQ, VIQ and PIQ Dennis (Dennis 1985) reports that even in a large sample of brain injured children, the IQ scores do not correlate with any specific cluster of the 100 medical history variables that were examined. By using the multivariate approach, Dennis has examined the IQ scores without the restraint of an a priori hypothesis. These results again indicate cautious interpretation of the VIQ-PIQ differences. It is important to note that, of the 407

subjects studied, only 54 (13%) had etiologies that were clearly lateralized with an additional 58 (14%) having evidence suggesting lateralization of brain injury. The remaining subjects represented a wide range of neurological insults not necessarily lateralized. The heterogeneity of the population must be taken into account when considering the lack of identification of lateralized test scores with a particular cluster. Nonetheless, Dennis' sample does reflect the breadth of clinical diversity faced by the neuropsychologist and therefore the cautions indicated by that sample should be weighed heavily when faced with individual assessments. Although beyond the scope of the present paper, Dennis' report leads to the questioning of the concepts of PIQ and VIQ as distinct components of intelligence and that many other as yet not tested elements may be more accurate reflections of verbal and visuo-spatial abilities.

Sensorimotor tests from the neuropsychological test battery were recently examined by Francis and colleagues (Francis, Fletcher and Rourke, 1988) on a large sample of primarily learning disabled children. In this study, they found no discriminant validity of the left handed or right handed scores within this population of children whom had no record of frank brain injury. The more significant factor that was revealed in the study was complexity of task rather

than lateralization of task. As a result, Francis and colleagues concluded that, in future studies of learning disabled children using a factor analytic approach, the left handed and right handed scores should be collapsed into a single more reliable index. Francis and colleagues also go on to point out that, in brain damaged populations, there could still be validity in separating left and right scores as this population was not used in the present study. What this study does offer for researchers studying brain damaged populations is that a statistically significant discrepancy in lateral sensorimotor tests should not be considered as necessary or sufficient to imply neurological impairment without other supporting evidence; and that the lateral sensorimotor tests offer no more discriminant validity than other components of the neuropsychological test battery.

PURPOSE OF THE PRESENT STUDY

This study was intended to investigate the effects of unilateral brain lesions upon neuropsychological functioning in children. Groups of young subjects with physiologically identified lateralized lesions were compared to better understand the relationship between side of lesion and functional deficit in children. Therefore, a group of children with right hemisphere cortical lesions were compared to a group of children with left hemisphere

cortical lesions on various components of the neuropsychological assessment to examine the possible functional effect of lateralized lesions. Other factors such as age and gender were also be considered in the comparison. Subject numbers did not permit a comparison between left and right handed subjects, therefore only right handed subjects were analyzed. As well, each lesion was clearly delineated by the neurophysiological evidence so that functional deficits are confidently related to the side of lesion.

As evidenced by the previous review of literature, studies to date have not clearly identified the side of lesion nor have they typically taken gender, handedness and age differences into account. By investigating the side of lesion to the fullest and by considering all of the aforementioned co-factors, it was hoped the present study would contribute to the current body of research regarding the development of hemispheric specialization.

STATEMENT OF HYPOTHESES:

Hypothesis One

It is hypothesized that a group of children with neurophysiologically identified unilateral left hemisphere lesions will demonstrate greater negative Verbal IQ - Performance IQ difference scores than a comparable group of children with neurophysiologically identified unilateral right hemisphere lesions.

Hypothesis Two

It is hypothesized that the left lesioned children will demonstrate a greater deficit on neuropsychological tests that reflect language functions than the right lesioned children.

Hypothesis Three

It is hypothesized that the right lesioned group will demonstrate greater deficits on neuropsychological tests that reflect visuo-spatial functioning than the left lesioned children.

Hypothesis Four

It is hypothesised that the lesioned children groups will demonstrate sex differences similar to those seen in adult groups reported in the literature; a greater demonstration of lateralized deficits is hypothesized for the male lesioned children as compared to the female lesioned children.

Hypothesis Five

It is hypothesized that the older lesioned children will demonstrate greater lateralized deficits than the younger lesioned children.

METHODOLOGY

Subjects

Subjects were culled from a review of medical files recorded at the Children's Hospital of Eastern Ontario (CHEO). Medical files of patients identified with a suggestion of lateralized brain lesions and who were seen for neuropsychological Assessment were reviewed. Etiologies that lead to lateralized brain lesions in children usually have serious cognitive and behavioural implications

therefore it is assumed that all possible children with such etiologies have been assessed at the Neuropsychology Laboratory. The Neuropsychology Laboratory at CHEO performs extensive neuropsychological assessments on children for whom the assesment may disclose relevant diagnostic or prognostic information. The central core of the assessment battery is based on the Halstead-Reitan tests and Reitan's modifications for young children (Knights, 1985). The complete battery of tests is administered by rigorously trained psychometrists over the course of a day. The battery includes tests of motor, sensory, psychomotor, spatial, expressive and receptive language, memory and reasoning abilities. Detailed descriptions of the entire battery and testing procedure are available (Knights & Norwood, 1979).

An exhaustive search of the medical records revealed that 56 separate neuropsychological assessments were performed on 29 individual children who met the following criteria:

- 1) A lateralized brain lesion that had been identified through CAT Scan, surgery and E.E.G. by the neurosurgeon.
- 2) A complete neuropsychological assessment had been performed.
- 3) A FSIQ of 60 points or over.
- 4) The neuropsychological assessment was performed in close chronological proximity to the neurological confirmation of

the lesion site.

5) The subject was right handed.

Left handed subjects were not included in the analysis because only 4 were available. Therefore the left handed subjects could not be studied as a group and their inclusion with the right handed subjects would only add to variability and lack of interpretive power for the right handed group.

Subjects were identified as either left lesioned or right lesioned by the attending neurosurgeon according to CAT scan, EEG reports and surgical confirmation as evidenced in the medical file. Only subjects with a clearly lateralized cortical lesion were used. Subjects with long standing neurological histories prior to the onset of the lesion were examined separately in the study.

The rigorous subject selection criteria excluded cases such as closed head injury or encephalitis where the brain damage may not be clearly lateralized. Etiologies that may demonstrate clear lateralization included intracerebral haematoma, tumour, cyst, and arteriovenous malformation. In each case the site of the lesion had been verified through neurophysiological or neuroradiological means. In many cases the treatment course included surgery to resect the lesion and consequently surgical notes provided the verification of the lesion site. Etiologies for the left and right lesioned group were comparable (see lesion descriptions, appendix I).

The primary group of study consisted of those cases

with a negative neurological history prior to the onset of a frank neurological insult. There were 16 right handed subjects whom met this criteria. The remaining 13 right handed subjects had suffered long standing seizure disorders prior to the identification and removal of the epileptogenic focus. Because the ability to determine age of onset for the second group is difficult, they were examined separately as a sub-group following a full group analysis.

Neuropsychological Assessments

Neuropsychological assessments have been completed by trained psychometrists at CHEO as part of the neuropsychological services provided to patients referred to the Neuropsychology laboratory described above. Standardized test procedures are followed according to the Knights-Norwood Neuropsychological Test Administration Manual (Knights & Norwood 1979). The tests relevant to the study of hemispheric specialization and focussed on here are:

1) Weschler Intelligence Scales for Children- Revised (WISC-R)

VIQ, PIQ, and individual subtests

2) Pegboard Test

3) Tactual Performance Test (TPT)

Dominant & Non-dominant hands, Memory, Location

4) Finger Agnosia Test

5) Finger Tip Writing Test

6) Aphasia Screening Test (AST)

The above tests represent a wide range of language, spatial perceptual, sensory and motor tests that may reflect hemispheric specialization according to the left and right designations in table 1.

TABLE 1**Tests according to functional localization in a hemisphere**

<u>Left Hemisphere</u>	<u>Right Hemisphere</u>
WISC-R Verbal IQ (Language)	WISC-R Performance IQ (Spatial)
Pegboard test -Right Hand (Motor)	Pegboard Test -Left Hand (Motor)
TPT -Right Hand (Motor)	TPT -Left Hand (Motor) TPT Memory, Location (Spatial)
Finger Agnosia Test -Right Hand (Sensory)	Finger Agnosia Test -Left Hand (Sensory)
Finger Tip Writing -Right Hand (Sensory)	Finger Tip Writing -Left Hand (Sensory)

The Aphasia Screening Test (AST) contains items that are sensitive to both left and right hemispheric functioning. For further investigation the AST items that discriminate between left and right lesions were assigned to

the left and right hemisphere according to evidence in the current literature (Snow, 1987). The error scores on the left and right assigned items were summed to create lateralized total scores. This provided an opportunity to validate the AST concepts as they are understood in current clinical practice. The items were assigned to left and right hemispheres according to Table 2.

Table 2

Hemispheric assignment of aphasia items

left Hemisphere	Right Hemisphere
Name Square	Copy Square
Spell Square	
Name Cross	Copy Cross
Spell Cross	
Name Triangle	Copy Triangle
Spell Triangle	
Name Baby	
Write Clock	
Name Fork	
Read "7 SIX 2"	
Read "M G W"	
Read "See the black dog"	
Repeat "Triangle"	
Repeat "Massachusetts"	
Repeat "Methodist Episcopal"	
Write "Square"	
Read "Seven"	
Repeat "Seven"	
Repeat "He shouted the warning"	
Explain "He shouted the warning"	
Compute $85-27 =$	
Compute $17 \times 3 =$	
Name a "Key"	Demonstrate Use of a Key
	Draw a Key

Other AST test items that confound left hemisphere and right hemisphere functioning were not included in the left

and right total scores as they do not provide conceptual or practical relevance for comparisons of unilateral functioning (Snow, 1987).

Statistical Analyses

Because of the numerous co-factors, a multivariate approach to data analysis would have been the most appropriate choice. Unfortunately, the number of subjects required for such an approach was not available (Pedhazur, 1982).

Various one-way ANOVAs were performed with sex and side of lesion as individual independent variables and all the aforementioned neuropsychological test scores as the dependent measures. The difference of VIQ - PIQ and also AST Left - Right scores were calculated and examined as dependent measures. The absolute value of VIQ - PIQ was also used as a dependent measure when collapsing lesion groups and examining sex differences alone. The correlation between age and absolute value of VIQ - PIQ difference was also analyzed. Table 3 Summarizes all statistical analyses performed.

Table 3
Statistical Analyses
Planned

<u>Analysis</u>	<u>Independent Variable</u>	<u>Dependent Variable</u>
One-way ANOVA	Lesion Side	Each Neuropsychological Test
One-way ANOVA	lesion side	VIQ-PIQ difference
One-way ANOVA	lesion side	AST Left - Right
One-way ANOVA	Sex	VIQ-PIQ difference
Correlation	Age	Absolute value of VIQ-PIQ difference

Post Hoc Analyses

<u>Analysis</u>	<u>Independent variable</u>	<u>Dependent variable</u>
Paired t-test	within lesion groups	VIQ-PIQ differences
Paired t-test	within sex by lesion groups	VIQ-PIQ differences

All analyses were performed using SPSS/PC+ version 2.0.

In addition, 4 case study reports were documented which profile the interaction between the factors of lesion (left, right) and prior neurological history (positive, negative).

RESULTS

ALL SUBJECTS

Taken as a group, the total of 29 subjects represent all cases of neurophysiologically identified lateralized brain lesions in right handers. This larger group is comprised of 15 left lesioned subjects and 14 right lesioned subjects. The age at testing of the subjects in each lesion group were comparable (grand mean = 13.5 years, range 2.9 - 21.4). All relevant subject variables have been summarized in Table 4. Subjects were group according to factors relevant to the hypotheses. In addition, during the collection of subject information, a factor regarding previous neurological history surfaced that became relevant to the present study. From the original 29 subjects, 16 had no neurological history prior to rapid onset of the lesion under study (negative history). The remaining 13 subjects had long standing seizure disorder histories (positive history) which prevent the identification of age at lesion onset. Therefore these groups have been analyzed separately following the full group analysis.

Table 4 **hemispheric specialization**
Subject variables for the study sample

Group	Subject Number	Age at Testing	VIQ	PIQ	FSIQ	VIQ-PIQ
Negative history, left lesioned females	1	13.17	85	82	83	3.00
	2	15.90	85	98	86	-3.00
	3	13.19	87	98	98	-11.00
	4	10.98	92	100	94	-4.00
	5	9.88	109	111	111	-2.00
Mean		11.21	92	96	95	-4.00
S.D.		4.99	10	11	11	5.41
Negative history, left lesioned males	6	12.32	75	92	82	-17.00
	7	14.90	78	93	84	-15.00
	8	13.42	102	130	117	-28.00
	9	16.72	113	120	116	-7.00
Mean		14.35	92	109	100	-16.72
S.D.		3.91	18	19	20	8.66
Negative history, right lesioned females	10	14.14	73	54	61	19.00
	11	11.00	87	77	81	10.00
Mean		12.59	80	66	71	14.50
S.D.		2.20	10	16	14	6.36
Negative History, right lesioned males	12	15.86	74	72	71	2.00
	13	6.87	85	82	82	3.00
	14	9.29	109	96	100	13.00
	15	14.84	108	114	112	-4.00
	16	8.12	113	114	115	-1.00
Mean		11.00	98	96	96	2.20
S.D.		4.08	17	19	19	6.98
Positive history, left lesioned females	17	17.81	84	91	86	-7.00
Mean		17.81	84	91	86	-7.00
S.D.						
Positive history, left lesioned males	18	14.70	80	73	67	-13.00
	19	12.16	84	73	78	9.00
	20	13.27	101	96	99	5.00
	21	12.19	90	121	105	-11.00
	22	7.74	100	124	114	-1.00
Mean		12.61	88	98	93	-10.00
S.D.		2.41	17	24	20	17.11
Positive history, right lesioned females	23	16.39	70	86	76	-16.00
	24	17.34	82	106	91	-24.00
Mean		16.86	76	96	84	-20.00
S.D.		0.67	8	14	11	5.06
Positive history, right lesioned males	25	13.78	78	91	83	-13.00
	26	21.39	80	88	83	-4.00
	27	17.02	81	96	88	-15.00
	28	13.14	91	90	80	1.00
	29	15.89	81	104	91	-23.00
Mean		16.71	82	94	86	-11.00
S.D.		3.96	5	6	4	8.89

There were no significant differences found between the two lesion groups on VIQ, PIQ or FSIQ or with respect to the VIQ-PIQ difference scores. Only one subtest of the WISC-R, Object Assembly, revealed a significant difference ($F = 7.08$, $p < 0.05$, $df = 1,27$). Left lesion subjects had a higher mean scaled score than right lesioned subjects ($\bar{X} = 11.0$, 8.2 respectively). All other subtests revealed no significant differences. Paired t-tests revealed that left lesioned subjects had VIQ scores significantly lower than their PIQ scores ($\bar{X} = -10.0$, $t = -3.37$, $p < 0.05$). Right lesioned subjects did not have a significant difference between their VIQ and PIQ ($\bar{X} = -4.2$, $t = -1.18$, $p > 0.05$).

There were no significant differences found in any area of the AST nor in total AST score. The aphasia left and right scores, sub-totalled according to Table 2, did not reveal statistically significant differences. The left lesioned score, the right lesion score and the difference score between left and right all indicated no significant differences. In addition, most AST items indicated a lack of homogeneity of variance due to low error rates. In this regard, the AST items may serve well as pathognomic signs for clinical interpretation but they do not demonstrate the variability needed for meaningful statistical analyses.

In this total sample of subjects, only two other components of the neuropsychological tests under study revealed significant differences between left and right

lesioned subjects. TPT right handed time scores were significantly longer for right lesioned subjects than for left ($F = 6.21$, $p = 0.05$, $df = 1,23$; $\bar{X} = 6.97$, 4.47 minutes respectively). Also, significantly more errors were made by right lesioned subjects on the finger agnosia test of the right hand ($F = 5.71$, $p < 0.05$, $df = 1,25$). Right lesioned subjects made on average 2.50 errors compared to left lesioned subjects who made on average 0.50 errors. In the case of the finger agnosia test, however, there is a violation of homogeneity of variance due to low error rates for most subjects (Cochran's $C = 0.941$, $p < 0.001$). In the case of TPT right handed scores, the homogeneity of variance is also violated by the upper limit set on time scores of 15 minutes (Cochran's $C = 0.86$, $p < 0.05$). In addition, another caution must be offered regarding these two results in that some subjects were not tested on these components. subjects may have not been tested because of obvious motor deficits or an inability to concentrate and complete the assessment. The subjects that did not complete these tests were from both the left and right lesioned groups, therefore the biasing effect may be minimal. In general, however, these two results must be considered very cautiously.

Subjects With Negative Neurological Histories

In cases where the subject has a long standing

neurological history (involving a seizure disorder) the age of onset of lesion can not be clearly identified, which confounds any discussion regarding the development of hemispheric specialization. Therefore, analyses were performed separately on those subjects who had negative neurological histories prior to the onset of lesion. Such cases include various tumours, tuberous sclerosis and intracerebral haematoma.

Nine left lesioned subjects and seven right lesioned subjects met this criteria. The ages of the two groups were comparable (mean = 12.1, range 2.9 - 16.7).

There were no significant differences found between the left and right lesioned subjects on VIQ, PIQ or FSIQ. The VIQ - PIQ difference score was found to be highly significant with the left lesioned group having a higher negative mean score of -10.0 as compared to the right lesioned group with a mean score of 5.7 ($F=12.14$, $p < 0.05$, $df = 1,15$). The range and mean values for each lesion group are depicted in Figure 1.

Paired t-tests were performed to examine whether lateralized lesions led to significant differences in VIQ versus PIQ within both the left and right lesioned groups. Left lesioned subjects showed significant differences between their VIQ and PIQ ($\bar{X} = -10.0$, $t=-3.28$, $p < 0.05$) while right lesioned subjects did not ($\bar{X} = 5.71$, $t = 1.74$,

$p > 0.05$). These results indicate that only left lesions are related to significant relative deficits in functions associated with the affected hemisphere. Therefore, the significant differences between left and right lesioned groups result from significant left lesioned relative deficits as compared to non-significant right lesioned relative deficits.

the only subtest of the WISC-R that revealed a significant difference between lesioned groups was the Object Assembly test, with the left lesioned subjects having higher scores than the right lesioned subjects ($F = 7.59$, $p < 0.05$, $df = 1, 14$; $\bar{X} = 11.22, 6.86$ respectively).

No items of the AST nor the total AST score revealed any significant differences between the two lesion groups. Similarly the AST-Left, AST-Right and the difference score between left and right were all found to be non-significant.

Only one other component of the neuropsychological test battery revealed significant differences between the left lesioned and right lesioned groups. the Left lesioned group scored significantly higher on the location component of the TPT than right lesioned group ($F = 5.10$, $p < 0.05$, $df = 1, 11$; $\bar{X} = 4.14, 1.17$ respectively).

Figure 1

**Subjects with Negative Histories
Mean VIQ & PIQ scores by Lesion Group**

Lesion Group

N=16

SEX DIFFERENCES

Sex differences in lateralized test scores were examined by performing an ANOVA on the magnitude of VIQ - PIQ difference scores of the core group of right handed subjects with negative neurological histories. This group included seven females and nine males. Mean ages of the male and female groups were comparable. It is not appropriate to simply compare between sex groups on any tests that are sensitive to lateralized lesions because the number of left and right lesioned subjects within each sex group is not balanced. Therefore, differences between sex groups on tests sensitive to lesion side would be dependent upon differences in the ratio of left lesioned to right lesioned subjects within the sex group. Because FSIQ is an average of VIQ and PIQ, it is sensitive to both left and right lesions. Therefore, it is appropriate to consider FSIQ as a control for comparing general functional abilities of each of the sex groups. FSIQ was found to be comparable between males and females.

Ideally, the VIQ - PIQ difference scores could be analysed as a two-way ANOVA with sex and side of lesion as factors. However, each of the lesion by sex groups were too small and imbalanced to be examined using this analysis.

To further investigate the potential sex effect, an analysis of absolute values of VIQ - PIQ differences was

performed. By considering absolute values, the analysis collapses lesion groups together thereby reducing the biases of unbalanced cells and increasing the cell count to an appropriate level for analysis. Absolute values provide a measure of the magnitude of difference between VIQ and PIQ. According to Hypothesis four, males with lateralized lesions were expected to have greater magnitude of difference between VIQ and PIQ than females. This analysis, however, yielded a non-significant result indicating that there were no significant differences in the magnitude of VIQ - PIQ differences for right handed males and females with negative neurological histories.

Sex differences were examined in the larger group of subjects, including those with a positive neurological history, but once again, cell counts were too small and imbalanced to perform the appropriate two-way ANOVA. Therefore, another analysis of VIQ-PIQ difference magnitudes was performed. Again, no significant differences were found in the magnitude of VIQ - PIQ differences for males and females.

Since the total left lesioned group showed significant VIQ - PIQ differences in the initial paired t-test analyses, it was appropriate to examine the sex effect within all left lesioned subjects as a one-way ANOVA with sex as the independent factor and VIQ - PIQ difference scores as the dependent variable. This ANOVA indicated that VIQ - PIQ

difference scores approached significance, with males having a higher negative score than females ($F = 2.03$, $p < 0.05$ $df = 1, 14$, $\bar{X} = -13.33$, -5.00 respectively). In addition, paired t-tests indicated that male left lesioned subjects had significant differences between their VIQ and PIQ ($\bar{X} = -13.33$, $t = -2.94$, $p < 0.05$) while left lesioned females did not ($\bar{X} = -5.00$, $t = -2.48$, $p > 0.05$). Neither right lesioned males nor right lesioned females indicate a significant difference between VIQ and PIQ ($\bar{X} = -4.7$, $t = -1.42$, $p > 0.05$; $\bar{X} = -2.8$, $t = -0.27$, $p > 0.05$, respectively).

In summary, the results partially support the hypothesis that males indicate greater lateralized deficits than females. Although an ANOVA directly comparing male and female within the left lesioned subjects did not reach significance, the more sensitive paired t-tests indicated differences showing that males in this lesion group had significant relative deficits between their VIQ and PIQ scores while the females did not. Figure 2 depicts the range and mean VIQ-PIQ difference scores for each sex by lesion group.

AGE EFFECTS

Magnitude of VIQ-PIQ differences may also be used to examine expected age effects on the lateralization hypothesis. To do so, analyses were performed correlating age at testing with absolute value of VIQ - PIQ differences.

According to Hypothesis Five, older subjects should have greater magnitude VIQ-PIQ difference scores than younger subjects because functions should be more lateralized in older subjects. Whether considering all cases (n=29) or only those with a negative neurological history (n=16), the correlation between age and VIQ-PIQ magnitude was found to be non-significant.

FIGURE 2

Male and Female Lesion Groups Mean VIQ-PIQ difference Scores

N = 29

COMPARING GROUPS WITH DIFFERENT NEUROLOGICAL HISTORIES

In reviewing the above results it becomes clear that differences exist between subjects who have a long standing neurological history prior to identification and removal of lesion (positive history) versus those with no known neurological history prior to identification and removal of lesion (negative history). Subjects with negative histories showed significant differences between left and right lesioned groups on the VIQ-PIQ difference scores. In contrast, when subjects with positive histories were included in the analysis, the differences between left and right lesioned groups were no longer significant. Further consideration of the positive history subjects revealed that all have had long standing seizure disorders. In general, all subjects had lateralized lesions of the brain identified and resected, however, those with long standing seizure disorders may have had lesions related to the seizure disorder that developed long before testing and surgery. Therefore, it is difficult to determine the time of lesion onset for this group. The distinction between subjects with long standing seizure disorders versus those with negative histories prior to rapid onset of lesion is a useful one when considering the methodological confounds of studying lateralization. The following analyses compared the history groups in an effort to investigate this confound.

There were 16 subjects with negative histories and 13

subjects with positive histories included in the following comparative analyses. There were no significant differences between the two history groups on FSIQ. There were significant differences between the two groups in mean age at testing ($F = 4.35$, $p < 0.05$, $df = 1,28$). The group with longstanding seizure disorders was older than the group with negative histories (mean age = 15.0, 12.1 years, respectively).

Examination of the positive history group alone revealed no significant differences on any of the individual tests studied.

The most notable difference between the subjects with negative histories and those with positive histories is that the latter showed no significant differences between left and right lesioned groups on VIQ - PIQ difference scores. As reported earlier, subjects without long standing neurological histories showed a highly significant difference between left and right lesioned groups on the VIQ - PIQ difference scores. Paired t -tests revealed that left lesioned subjects with positive neurological histories showed no significant differences between their VIQ and PIQ ($\bar{X} = -5.0$, $t = -2.48$, $p > 0.05$) while right lesioned subjects actually showed significant differences in the reverse of expected findings ($\bar{X} = -14.0$, $t = -2.96$, $p < 0.05$).

The positive versus negative history factor can be

directly examined by performing a two-way ANOVA on the VIQ-PIQ difference scores with side of lesion (left, right) and neurological history (positive, negative) as independent factors. This ANOVA reveals a significant main effect for history ($F = 4.18$, $p < 0.05$, $df = 2,28$). Positive history subjects had a higher negative VIQ - PIQ difference score ($\bar{X} = -12.15$, $n = 13$) than those without longstanding histories ($\bar{X} = -3.13$, $n = 16$). Most importantly, there is a significant interaction between history and side of lesion ($F = 6.27$, $p < 0.05$, $df = 1,28$). Right lesioned subjects without longstanding seizure histories are the only subjects that have a positive VIQ - PIQ mean difference score ($\bar{X} = 5.7$, $n = 7$). Left lesioned subjects without longstanding seizure disorders, left lesioned subjects with longstanding seizure disorders and right lesioned subjects with longstanding seizure disorders all have negative mean VIQ - PIQ difference scores ($\bar{X} = -10.0$, $n = 9$; $\bar{X} = -10.0$, $n = 6$; $\bar{X} = -14.0$, $n = 7$, respectively). Multiple comparisons of group means using the least squares difference procedure revealed that right lesioned subjects with negative histories are significantly different from all other groups at the $p < 0.05$ level. No other comparison reached significance.

These analyses revealed that only subjects without longstanding neurological histories demonstrate the expected patterns of hemispheric specialization; relative verbal

deficits associated with left hemisphere lesions and visuo-spatial deficits associated with right hemisphere lesions. Subjects with long standing seizure disorders tend to show VIQ deficits relative to PIQ performance, regardless of side of lesion. Figure 3 depicts the range and mean VIQ-PIQ difference score for each history by lesion group.

FIGURE 3**Positive and Negative History Groups
Mean VIQ-PIQ Difference Scores** **N=29**

Table 5 summarizes the results of the present study in relation to each hypothesis.

Table 5

Summary of hypotheses and related results

Hypothesis	Decision	Evidence
1) Left hemisphere lesions will result in greater negative VIQ-PIQ difference scores than right hemisphere lesions.	Supported	<ul style="list-style-type: none"> ● In the negative history group, left lesion subjects had significantly greater negative VIQ-PIQ difference scores than right lesioned subjects.
2) Left hemisphere lesions will result in deficits on neuropsychological tests related to language.	Not Supported	<ul style="list-style-type: none"> ● No significant differences found between lesion groups on VIQ or language related AST items.
3) Right hemisphere lesions will result in deficits on neuropsychological tests that reflect visuo-spatial functioning.	Supported	<ul style="list-style-type: none"> ● Significant differences found between all left and right lesioned subjects on TPT components and on the object assembly subtest.
4) Subjects will demonstrate sex differences similar to adults: males will show greater lateralization than females.	Partially Supported	<ul style="list-style-type: none"> ● No significant differences found between males and females in the magnitude of VIQ-PIQ differences. ● The comparison of VIQ-PIQ difference scores between male and female left lesioned subjects approached significance. ● Paired t-tests showed significant differences between VIQ and PIQ for male left lesioned subjects but not for female left lesioned subjects.
5) Older children will demonstrate greater lateralized deficits than younger children.	Not Supported	<ul style="list-style-type: none"> ● No correlation between age and magnitude of VIQ-PIQ difference scores.

CASE STUDIES

To better understand the clinical profile of the subjects in the analysis, the following four representative case studies are offered. By offering the additional clinical information relevant to hemispheric specialization, it is hoped that a better understanding of the clinical profile will be achieved. The cases selected represent the differences found with respect to lesion side and long standing neurological history. All male right handed subjects were chosen so as to avoid the potential for confounding handedness and sex within the illustration of lateralized deficits.

CASE ONE

LEFT SIDED LESION, NEGATIVE NEUROLOGICAL HISTORY

Age at testing: 13 years Sex: Male Handedness: Right

History: History negative prior to rapid onset of lesion related symptoms (headaches, poor attention). Choroid plexus papilloma excised from left temporal area. Surgery carried out one month after initial assessment. WADA test indicated speech and immediate memory in left hemisphere.

Pegboard

Dominant (right): 60 seconds Non-Dominant: 75 seconds*

WISC-R

VIQ: 102 PIQ: 130 FSIQ: 117 VIQ-PIQ: -28

Lowest Subtest(s): Arithmetic 7

Highest Subtest(s): Block Design 17

Aphasia Screening Test

Total Errors: 3

1 error in expressive aphasia*

Tactual Performance Test

Dominant(right)	3.16 minutes	Total	6.33 minutes
Non-Dominant	2.18 minutes	Location	5 correct placements
Both	0.99 minutes	Memory	7 correct placements

Finger Agnosia Test

Right 1 error* Left 2 errors*

Finger Tip Writing

Right 6 errors* Left 4 errors*

* below norms

PICTORIAL REPRESENTATION OF LESION

(based on CAT scan or surgical notes)

Lateral View

Coronal Section

Case One Summary

Case one represents an example of specific deficits following lateralized brain damage. It can be seen that language deficits are evident following this localized left hemisphere lesion. The lowest subtest score is in Arithmetic, a skill usually associated with the left hemisphere in this age group. On the other hand, superior performance is seen in the Block Design subtest. This pattern is reflected throughout the verbal and performance subtests as indicated by the VIQ - PIQ difference.

The Aphasia Screening Test also supports a diagnosis of left hemisphere damage as errors indicate expressive aphasia. Again, the skills here are usually associated with left hemisphere functioning.

The pattern of results offered on other tests are not as clear. As expected, no deficits are seen on the TPT. However, deficits are seen for the left hand (right hemisphere) on the more basic tests of motor and sensory functioning. An unexpected result is seen on the Pegboard test as the left hand performance is below norms. The Finger Agnosia Test and the Finger Tip Writing test show performance on both hands that is below norms. The subject does show a greater deficit on the right hand on the Finger Tip Writing test which would be expected. Taken together, the above results implicate a higher level temporal left hemisphere cortical lesion possibly concomittant with a

lesion closer to midline and lower.

Follow up information was also available on Case one through an assesment carried out 2 months after surgery. This assesment indicated persistent deficits in language skills relative to visuo-spatial skills. The difference between VIQ and PIQ persisted although it had decreased (VIQ 96, PIQ 114, FSIQ 103). TPT performance decreased to below norms in most areas, while Finger Agnosia scores improved to normal. Errors on the Finger Tip Writing test persisted.

Taken as a whole, Case one exemplifies the verbal deficits expected with a lateralized lesion of the left hemisphere. Beyond the higher level cortical functions, the picture becomes less clear. As the lesion involved the choroid plexus it is possible that areas of the brain closer to the midline and phylogenically lower were also involved. Nonetheless, the pattern of results reflected in higher level cortical functions are consistent with a hemispheric specialization hypothesis. The adolescent age of the subject does not allow this case to shed much light on the developmental course of hemispheric specialization as most researchers recognise that puberty may likely be the critical developmental period.

CASE TWO

RIGHT SIDED LESION, NEGATIVE NEUROLOGICAL HISTORY

Age at testing: 9.25 years Sex: Male Handedness: Right

History: Negative neurological history prior to onset of lesion related symptoms (headaches, one grand mal seizure). Right temporal lobe ganglioma excised 1 week after assessment. WADA indicated language and memory in left hemisphere.

Pegboard

Dominant (right): 69 seconds Non-Dominant: 71 seconds

WISC-R

VIQ:109 PIQ:96 FSIQ:100 VIQ -PIQ:+13

Lowest Subtest(s): Picture Arrangement 8

Highest Subtest(s): Comprehension 12

Aphasia Screening Test

Total Errors: 10*

4 errors in Left-Right discriminations*

Tactual Performance Test

Dominant(right)	8.08 minutes	Total	17.14 minutes
Non-Dominant	3.66 minutes	Location	2 correct placements*
Both	5.40 minutes*	Memory	1 correct placements*

Finger Agnosia Test

Right 3 errors* Left 0 errors

Finger Tip Writing

Right 4 errors Left 3 errors

* below norms

PICTORIAL REPRESENTATION OF LESION
(based on CAT scan or surgical notes)
Lateral View Coronal Section

Hemispheric Specialization

Case Two Summary

Case two also represents an example of lateralized deficits consistent with right hemisphere lesion. Comparison of VIQ and PIQ scores indicates a relative deficit in the performance tests that rely on visuo-spatial functioning. As an example, the lowest subtest score is the Picture Arrangement test. On the other hand, verbal functioning appears unaffected by the lesion as exemplified by the high subtest score in Comprehension. In addition, performance on the TPT is below norms indicating a visuo-spatial deficit. As well, the greatest deficits on the AST were in the left-right discrimination questions, a skill at least partially dependent upon visuo-spatial functioning. All of these findings are consistent with a lesion of the right hemisphere.

The more basic areas of sensory and motor functioning are not as clear. For example, although the left hand score on the pegboard is slower as expected, the difference between left and right is not as great as would be expected. Also, the finger Tip Writing scores indicate errors on both sides (although within normal range), and the Finger Agnosia test shows below normal performance for the right hand while left hand performance is normal. The Finger Agnosia test actually indicates a reversal of predicted results.

Case two also offered additional information in the way of a follow-up assessment undertaken 5 months after surgery.

Hemispheric Specialization

At this time the difference between VIQ and PIQ had shown a decrease while the FSIQ stayed the same (VIQ 98, PIQ 102, FSIQ 100). For the most part, errors committed in other areas of the previous assesment persisted.

In general, Case two again represents a classic example of the pattern of higher functioning deficits expected with a lateralized lesion in the right hemisphere. As this subject is only age nine, case two gives support to the hypothesis that hemispheric specialization occurs at a relatively young age.

CASE THREE

LEFT SIDED LESION, POSITIVE NEUROLOGICAL HISTORY

Age at testing: 8 years Sex: Male Handedness: Right

History: Seizure history since age 3. Resection of left inferior and posterior temporal lobe grade III astrocytoma 2 cm in diameter. Testing occurred 1 week prior to surgery. WADA indicated speech in left hemisphere while memory showed up bilaterally.

Pegboard

Dominant (right): 40 seconds Non-Dominant: 31 seconds

WISC-R

VIQ: 103 PIQ: 124 FSIQ: 114 VIQ -PIQ: -21

Lowest Subtest(s): Comprehension 8

Highest Subtest(s): Block design 15

Aphasia Screening Test

Total Errors: 1

1 error in body orientation*

Tactual Performance Test

Dominant(right) 2.68 minutes Total 9.58 minutes
Non-Dominant 5.65 minutes Location 5 correct placements
Both 1.25 minutes Memory 2 correct placements

Finger Agnosia Test

Right 0 errors Left 2 errors

Finger Tip Writing

Right 5 errors* Left 5 errors

* below norms

PICTORIAL REPRESENTATION OF LESION
(based on CAT scan or surgical notes)
Lateral View Coronal section

Case Three Summary

Although Case Three has a longstanding seizure disorder that began at a young age, the pattern of deficits shown here are consistent with a lateralized lesion of the left hemisphere. Although VIQ results are slightly above age norms, the VIQ score is 21 points below the PIQ score. Consider also that the lowest subtest score is comprehension. These results coupled with a normal performance on the TPT indicate a localised lesion of the left hemisphere.

The AST result is not necessarily consistent with a left hemisphere lesion in that the only error was in body orientation, a visuo-spatial task. As well, although within normal range, more errors were made by the left hand in the finger agnosia test. The Finger Tip Writing test was consistent with a left hemisphere lesion as was the pegboard result.

In general, these results point to a lesion of the left hemisphere. Although the subject is young, the long standing seizure history poses a problem for clear interpretations of the developmental course of hemispheric specialization in this case. If an invariant lesion is assumed at age 3, then the results presented in this case may represent the developmental course of a past lesion. On the other hand, the results may reflect a new lesion unrelated to the original seizure disorder. Nonetheless, whether the focus

Hemispheric Specialization

is on a past lesion or a present lesion the subject does indicate hemispheric specialization at a pre-pubertal age.

Follow-up information was also available for Case Three from an assessment carried out 4 months after surgery. Again the VIQ - PIQ difference was diminished yet the FSIQ remained relatively the same (VIQ 106, PIQ 120, FSIQ 113). General improvement was also seen in other areas. For example errors in the AST, Finger Tip Writing and Finger Agnosia decreased. Again, the hoped for prognosis of improved abilities and decreased divergence of lateralized scores is reflected in this case.

CASE FOUR

RIGHT SIDED LESION, POSITIVE NEUROLOGICAL HISTORY

Age at testing: 14 years Sex: Male Handedness: Right

History: Long standing seizure history prior to assessment. Cat Scan revealed a hypodense area in the right temporal lobe at time of assesment. Two years later a Grade III malignant astrocytoma was removed from right temporal lobe. Surgery was followed by radiation. At that time, the WADA test indicated speech and memory in left hemisphere.

Pegboard

Dominant (right): 78 seconds* Non-Dominant: 98 seconds*

WISC-R

VIQ: 81 PIQ: 104 FSIQ: 91 VIQ -PIQ: -23

Lowest Subtest(s): Arithmetic 5

Highest Subtest(s): picture arrangement 12

Aphasia Screening Test

Total Errors: 2

1 dyscalculia error*

Tactual Performance Test

Dominant(right)	7.08 minutes*	Total	13.65 minutes*
Non-Dominant	4.58 minutes*	location	6 correct placements
Both	1.99 minutes*	Memory	6 correct placements

Finger Agnosia Test

Right 5 errors* Left 3 errors*

Finger Tip Writing

Right 4 errors* Left 3 errors*

* below norms

PICTORIAL REPRESENTATION OF LESION

(based on CAT scan or surgical notes)

Lateral View

Coronal section

Hemispheric Specialization

Case Four Summary

Case four represents, for the most part, a reversal of expected findings. Although most components of the TPT do support a diagnosis of right hemisphere lesion the VIQ and PIQ scores are reversed. This subject shows none of the expected visuo-spatial deficits on the PIQ subtests. On the other hand, greatest deficits are shown on VIQ subtests. This case is representative of other right hemisphere subjects with long standing seizure disorders in that 7 out of 9 showed similar patterns of reversal from expected findings on the WISC-R.

The AST error of dyscalculia and the higher error rate on the right handed Finger Agnosia Test are also not consistent with the diagnosis of right hemisphere lesion.

Case four challenges the present hypothesis of hemispheric specialization. The long standing seizure history precludes a discussion of the developmental course of hemispheric specialization in this case. It could be postulated that some form of reorganization has occurred however such speculations may be fallacious. Case four portrays why there were no significant differences found between left and right lesioned subjects in the analyses of the total sample. Case four also illustrates that understanding the developmental patterns of hemispheric specialization is very complex in the case of subjects with longstanding seizure disorders.

SUMMARY OF CASE REPORTS

three out of the four representative cases and three out of the four lesioned groups support the hypothesis that left lateralized lesions lead to language deficits while right lateralized lesions lead to visuo-spatial deficits. Only the final case, a right lesioned subject with a long standing seizure disorder, is problematic to the hypothesis. By showing the reversal of expected patterns, this case, and the group to which it belongs, illustrates the clear difficulties faced when examining any subjects with longstanding seizure disorders. Such subjects confound our understanding as the dynamics of the course of specialization, pathology, and adaptation are not well known.

DISCUSSION

The present research was undertaken in order to examine brain-behaviour relationships in children with lateralized brain lesions. The principal results of the research indicate that children who have suffered lateralized lesions in absence of a premorbid neurological conditions reflect general patterns of lateralized neuropsychological test results similar to those seen in older populations.

The VIQ - PIQ Difference scores

Subjects with no known neurological history prior to the identification of lateralized lesions, showed the expected pattern of significant differences on the VIQ - PIQ difference scores; left lesioned subjects had a mean negative score while right lesioned subjects had a mean positive score. These results are in support of similar adult studies (Bornstein, 1983; Klove, 1974; McFie, 1975) and support the current interpretations employed in the practice of pediatric neuropsychology (Reynolds, 1989). But researchers caution that VIQ - PIQ difference scores are "notoriously unreliable" (Kaufman, 1979, pg 26). Kaufman (1979) feels that a difference of 12 points is "worthy of explanation" but points out that a wide range of

explanations are valid. Although 13 out of 16 subjects with negative neurological histories in the present study had VIQ - PIQ differences in the appropriate direction, only 5 had VIQ - PIQ differences greater than 12 points. If the clinician were to base a decision of laterality solely on Kaufman's criteria, 11 out of 16 cases would be false negative determinations. On the other hand, if the clinician based the laterality decision solely on the direction of VIQ - PIQ difference, 3 out of 16 cases would be false positive determinations in the wrong direction. Obviously, the number of false positive determinations would increase if patients with non lateralized lesions were examined. Fortunately, clinicians can and should base the decision regarding side of lesion on the complete battery of tests relevant to lateralization.

The present findings may be compared to the earlier results of Rudel and colleagues (1974). Firstly, Rudel and colleagues found that a VIQ of 10 points greater than PIQ indicates a lesion of the right hemisphere. Secondly, Rudel and colleagues found that a PIQ of 10 points greater than VIQ indicated a lesion of either hemisphere. In the present study one subgroup of subjects support Rudel and colleagues' first finding. The right lesioned group with negative neurological histories show deficits in PIQ relative to VIQ which approach significance. On the other hand, if results

are collapsed across history groups, the present study reflects Rudel and colleagues' second finding; both left lesioned and right lesioned groups have higher mean PIQ scores than VIQ scores. Furthermore, if we consider the positive history group only, we find that there is approximately a 10 point deficit in VIQ relative to PIQ for both lesion groups. In general, the present study suggests that VIQ scores are sensitive to damage of the left and right hemispheres while PIQ may be particularly sensitive to damage of the right hemisphere in absence of a longstanding neurological disorder. It is important to note, however, that in a large study of an unselected birth cohort, Moffit and Silva (1987) found that a depressed VIQ was also more frequent in the non-neurological population than a depressed PIQ. Therefore, the present study may reflect differences found in the general population with regards to the low VIQ scores.

Possibly the most directly comparable results are provided by Riva and Cazzaniga (1986) wherein children with lateralized damage are examined with respect to VIQ - PIQ differences. One subgroup in this study, the group with lesions after age one, is comparable to all subjects within the present study in terms of age of onset and etiology. In Rivas and Cazzaniga's study the left lesioned sample showed no significant differences between VIQ and PIQ and actually the mean VIQ was slightly larger than the PIQ. The right

lesioned group in the Rivas and Cazzaniga's study show significantly lower PIQ than VIQ. In the present study, the right lesioned group with negative histories has VIQ - PIQ differences in the same direction but the analysis in the present study did not reach significance. On the other hand, the present study offers significant results for VIQ - PIQ differences for left lesioned subjects, regardless of history, and in the same direction as seen in adult populations. In other words, the present study found more support for the present hemispheric specialization hypothesis in the left lesioned subjects while Riva and Cazzaniga found more support in their right lesioned sample. It must be noted that there was a significant lag time between lesion and testing for all subjects in the Riva and Cazzaniga study and in the Rudel and colleagues study. It is not known how this factor may have affected the potential reorganization of hemispheric specialization. It should also be noted that in the present study only the VIQ - PIQ difference score reached significance while neither the VIQ nor PIQ alone reached significance. This may suggest that the VIQ - PIQ difference is more 'sensitive' or more 'unstable' as compared to each individual IQ. To fully answer this question a more substantial study would have to be performed including premorbid IQ scores and comparable control groups.

In Dennis' (1985) multi-factorial study, VIQ is related only to left sided lesions localized in the temporal lobe while PIQ does not show a clear relation to localized damage specific to either hemisphere. Although the present study did not localize lesions intrahemispherically, the results reported herein are generally compatible with Dennis' findings. Left lesioned and right lesioned subjects with negative neurological histories showed significant differences on the VIQ - PIQ difference score. Paired t-tests calculated for left lesioned subjects showed significant differences between their VIQ and PIQ when history groups were collapsed and when only subjects with negative histories were considered. On the other hand, paired t-tests calculated on differences between VIQ and PIQ for right lesioned subjects did not reveal significant differences for the larger group or for only subjects with negative histories. Therefore, the highly significant differences between VIQ and PIQ, found only for the left lesioned sample, led to a significant result when comparing left and right lesioned subjects with negative neurological histories. Furthermore, right lesioned subjects with positive histories indicate a significant deficit of VIQ relative to PIQ that is not significantly different from any of the left lesioned subjects. Taken together, results for subjects with left lesions are similar to adult findings while the results for right lesioned subjects remain

inconclusive.

Other Components of The Neuropsychological Assessment

Other components of the neuropsychological assessment that indicated significant differences between lesion groups were the Object Assembly subtest, Tactual Performance Test, and the Finger Agnosia Right Hand test.

The Object Assembly test showed significant deficits for right lesioned subjects versus left lesioned subjects within both the larger subject group and within the group with negative neurological histories. This result suggests that the Object Assembly test may be the most sensitive subtest in distinguishing between right and left hemisphere damage. On the other hand, the consideration of any subtest or other single test outside of the context of the full assessment would not be useful in determining lateralized lesions from other clinical presentations (Bigler, 1984).

The Tactual Performance test showed two components significant in distinguishing between left and right lesioned subjects. Firstly, the right hand time score was significantly slower in right lesioned subjects when history groups were collapsed. When only the negative history group was considered, the location score was significantly lower for right lesioned subjects. These results support the idea that the TPT is one of the tests most sensitive to lateralized lesions (Jarvis & Barth, 1984; Reitan 1955b).

On the other hand, the TPT location score for right lesioned subjects with positive neurological histories was also significantly different from left lesioned subjects but in the reverse direction, with right lesioned subjects scoring higher on average than left. By distinguishing between positive history and negative history groups, the present study indicated that subjects with long standing seizure disorders do not represent the hypothesized patterns of functional deficits following unilateral brain lesions.

Possibly the most salient finding is the lack of significant results in most of the neuropsychological test components that are thought to tap laterality. Most notably, none of the scores on the AST, alone or combined, reached significance. Snow (1987) offers three explanations for negative results in a similar study using the AST with adults. Firstly, subject samples are small. In both the present study and Snow's study, the focus on lesion specificity led to decreased sample sizes. Secondly, error rates are low, even for brain damaged populations. Low error rates are useful for the 'pathognomic sign' approach to assessment but they may be insensitive to small deficits and cause statistical difficulties with a lack of homogeneity of variance. Thirdly, and this applies to many items on the neuropsychological assessment, left and right lesioned subjects may fail the same item for different

reasons. For example, a left lesioned subject may fail to read as a function of dyslexia; a right lesioned subject may err in reading because of a difficulty in perceiving items in the left visual field.

In addition to non-significant results on the AST, non-significant results were found on most of the sensorimotor tests. The finger agnosia test actually demonstrated significant results in the reverse of expected findings. When examining the case studies, it becomes evident that often the sensori-motor test results are the reverse of expected findings. It is clear that performance on these tasks may not assess lateralized cortical damage in the young brain. More comprehensive studies have more appropriately questioned the validity of these tests (Reynolds, 1989; Francis et al, 1988). The present study indicates that, even in a clearly delineated subject group, these tests do not show significance.

Age Effects

In general, the lateralized deficits seen in the subjects with negative neurological histories were similar to that seen in adult populations; A negative VIQ - PIQ difference for left lesioned subjects and a positive VIQ - PIQ difference for right lesioned subjects. Left lesioned subjects with negative neurological histories had significantly greater negative VIQ-PIQ difference scores

than their right lesioned counterparts. On the other hand, only the left lesioned subjects had a VIQ significantly different from their own PIQ in paired t-test analyses. This significant paired t-test result for left lesions held whether the negative history subjects were considered alone or in combination with positive history subjects. In other words, left lesioned subjects in the present study clearly support adult patterns of hemispheric specialization while the results for right lesioned subjects are less clear.

The ages of the subjects ranged from about 4 to 21 years of age with a mean of 13. Because the sample is so small the present study does not allow for an analysis of a wide range of age groups. The neuropsychological test battery, particularly the VIQ- PIQ differences, are not available for very young subjects. Often researchers have tested subjects with significant lag times and assumed the test results reflect previous function (Riva & Cazzaniga, 1986). In the present study, the subjects with positive neurological histories also had significant lag times between age of onset and testing. In addition, age of onset for these subjects is not clearly defined. On the other hand, the negative history subjects had age of onset at approximately the same time as testing. Unfortunately these subjects had a mean age of 12 and therefore do not adequately test the hypothesis that puberty may be a

critical developmental milestone for hemispheric specialization (Bryden, 1982; Witelson, 1987). Through examination of the individual cases it can be seen that five out of the six subjects which are under age twelve had VIQ - PIQ differences in the direction suggested by the the adult literature; negative VIQ-PIQ differences for left lesions and positive VIQ-PIQ differences for right lesions. On the other hand, the two youngest subjects (age 4 and 6) showed the smallest VIQ - PIQ difference scores. Unfortunately, due to sample size, the present study did not adequately answer the questions regarding changes across different developmental milestones. However the present results did indicate that there were no significant changes in VIQ -PIQ magnitude for this sample varying in age from 4 to 21.

Sex Differences

Sex differences were seen in the larger group of left lesioned subjects that approached significance and reflect adult findings; A higher negative VIQ - PIQ score for males than females. Male left lesioned subjects also had significant differences in their VIQ and PIQ scores, as illustrated by paired t-tests, while females did not. These results would suggest a more lateralized pattern of hemispheric specialization for males. The fact this result was nearly significant with such a small sample attests to the power of the sex effect even in this younger population.

Comparable studies have been carried out on adults in which a greater VIQ - PIQ discrepancy is seen for men with lateralized lesions (Sundet, 1986; Inglis & Lawson, 1982; McGlone, 1977, 1978). Sundet performed a linear discriminant analysis on the WAIS subtest scores for his sample of subjects with unilateral lesions. In Sundet's report, there was evidence that the laterality hypothesis may be an over-simplification. Sundet found that the hit-rate for identifying lesion side was considerably increased by disregarding the VIQ - PIQ dichotomy and focussing on patterns of subtest scores. This led the researcher to conclude that different cognitive strategies may be employed by females and males and that this could explain sex differences found on the WAIS-R following lateralized lesions.

Kimura (1987) has also indicated that the present hypothesis of sex differences in laterality may be an over-simplification in adult populations. Her work illustrates that basic speech functions in the female brain may be more focally organized within the left hemisphere than men. This focal organization would lead to spared functioning following left hemisphere damage in many cases (thus appearing as bilateral abilities). On the other hand, in some cases a strong speech deficit would be found if the lesion was located particularly in the left anterior

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region. Kimura also suggests that other language functions may be more bilateral in women than men.

Both Sunder's and Kimura's work represent large advances in understanding the intricate factors that affect sex differences in the study of lateralized lesions in adult subjects. Similar advances have not been made within pediatric populations. The present study does not have the power to examine differences intra-hemispherically. The present study does, however, offer evidence that sex differences, whatever their basis, may be evident in a young sample of left lesioned subjects. Further study is required to confirm this finding. If sex differences do exist in this younger population, then it is possible that hemispheric specialization does not vary substantially from youth to adulthood.

The History Factor

At the outset of the present study it became clear that subjects with a long standing history of seizure disorders performed differently on the neuropsychological test battery than subjects who had no known neurological history prior to the onset of the lateralized lesion. Subjects with negative histories reflected the expected pattern of results; language deficits with left hemisphere lesions and visuo-spatial deficits with right hemisphere lesions. The left lesioned group with positive histories also reflected the

expected pattern. The right lesioned group with positive histories, however, reflected a strong pattern in the reverse of expected findings. This group showed superior performance on a visuo-spatial task as compared to their left lesioned counterparts while also showing the greatest VIQ - PIQ deficits of any group. Difficulties exist for interpretation of these results in that the age of onset and lag time between onset and testing is not known in the positive history groups. If it is assumed that the positive history group had an early age of onset, then these results do reflect those found by other researchers, in that the effects of lesions of the right hemisphere in the young brain are poorly understood (Dennis, 1985).

One explanation for these results may involve the time of onset and the differential developmental course of language versus visuo-spatial functioning. Possibly the infant brain, which experiences a lesion of either hemisphere, experiences language deficits because the functions have not completely localized to the left hemisphere. In other words, non-localized but developed functions are affected by lesions of either hemisphere. Since complex visuo-spatial skills do not localize until later (Bryden, 1982), they may localize within spared brain areas. This speculation explains the VIQ scores of both positive history groups but does not explain why the

positive history right lesioned subjects actually performed better on a visuo-spatial task than their left lesioned counterparts. Additionally, it may be that left lesioned subjects undergo some form of functional reorganization that sacrifices the later developing visuo-spatial skills while right lesioned subjects undergo a reorganization that does not sacrifice later developing visuo-spatial skills. In summary, it may be that non-localized but developed language skills are sensitive to a lesion of either hemisphere while the course of developing visuo-spatial skills is dependent on the differential patterns of reorganization experienced after early left or right hemisphere damage. Negative history cases who have later lesion onset and no time for reorganization would also support this speculation. Left lesioned subjects suffer greater language deficits relative to visuo-spatial performance because the language functions develop earlier and are more lateralized at the time of lesion. The right lesioned subjects suffer less of a visuo-spatial deficit relative to language skills because visuo-spatial skills are in development and are not fully lateralized. As the brain reorganizes after these later lesions, the eventual deficits again may reflect a pattern of differential reorganization between the hemispheres.

The results also imply a significant role for the right hemisphere in the early development of language. Positive history subjects had significantly lower VIQ scores relative

to their own PIQ scores. If it is assumed that positive history subjects had early onset of the lateralized lesion coinciding with the onset of their seizure disorder, then these subjects indicate that both hemispheres are important to the early development of language.

Confirmation of such speculations is beyond the present study. however, as researchers more clearly delineate their subject groups and as the number of subjects assessed using neuropsychological, neurophysiological and neuroradiological means continues to increase, the possibility of examining these issues may become available.

SUMMARY AND CONCLUSIONS

The present study does support the general thesis that patterns of language and visuo-spatial deficits following lateralized brain damage in young subjects are similar to those seen in adults; left hemisphere lesions lead to language deficits and right hemisphere lesions lead to visuo-spatial deficits as indicated on neuropsychological test components.

Furthermore, the present study indicates that, at least for left lesioned subjects, sex differences do exist; males with left hemisphere lesions have significant VIQ-PIQ differences while females with left hemisphere lesions do not. The analysis comparing the two groups on VIQ - PIQ

differences was close to significant indicating that left lesioned males have VIQ - PIQ differences that are almost significantly higher than females.

A very important factor of history surfaced in the analysis of the results in the present study. Subjects with no long standing neurological history prior to rapid onset of the present lesion demonstrated the expected pattern of results. In addition, left lesioned subjects who had a long standing seizure disorder prior to testing and lesion identification also showed expected results. On the other hand, right lesioned subjects with long standing seizure disorders showed the reverse of expected findings; language deficits concomitant with superior visuo-spatial performance as compared to their left lesioned counterparts. This finding leads to speculations regarding the differential reorganization of the hemispheres following early long standing lesions. More directly, the present findings do indicate that the pattern of deficits following left hemisphere lesions is more clearly identifiable while right hemisphere functioning following lesions of that hemisphere remains poorly understood (Dennis, 1985).

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Appendices

Lesion Description for each subject

Subject Number	Lesion Description	VIQ-PHQ
1	left parieto-occipital, cystic lesion, removed	3
2	left posterior-temporal, low grade astrocytoma, removed	-5
3	left fronto-parietal, grade III granuloma, excised	-11
4	left temporal, arterio-venous malformation, excised	-8
5	left hemisphere, subarachnoid cyst, removed	-2
6	left posterior-parietal, tuberous sclerosis, excised	-17
7	left parieto-occipital, grade III tumour, excised	-15
8	left temporal, benign choroid plexus papilloma tumour, excised	-28
9	left fronto-temporal, benign tumour, removed	-7
10	right temporal-parietal, ganglioma, removed	19
11	right frontal, arterio-venous malformation, removed	10
12	right occipital, porencephalic cyst, removed	2
13	right frontal, grade II astrocytoma, removed	3
14	right temporal, ganglioma, removed	13
15	right posterior-temporal, ganglioma, removed	-6
16	right temporal, intracerebral hematoma, removed	-1
17	left temporal, craniotomy and partial lobectomy, partial-complex seizure history	-7
18	left anterior temporal, 1/3 of lobe resected, partial-complex seizure history	-15
19	left frontal, seizure focus, partial complex seizure history, referred to Montreal Neurological Institute for resection of focus.	9
20	Left temporal, craniotomy and lobectomy, idiopathic partial-complex seizure history	5
21	left basal frontal, tumour removed, previous posterior fossa tumour removed, seizure history	-31
22	left temporal, grade III ganglioma excised, seizure history	-21
23	right anterior, 2/3 of lobe resected, partial complex seizure history	-16
24	right temporal, lobectomy, general seizure disorder history	-24
25	right frontal, excision of epileptogenic cortical scar, complex seizure disorder history	-13
26	right frontal temporal, craniotomy and lobectomy, partial complex seizure history	-8
27	right temporal, 5 cm. tip of lobe removed with part of amygdala and hippocampus, partial complex seizure history	-15
28	right antero-temporal, 0.25*4*3 cm. of lobe removed, partial complex seizure history	1
29	right temporal, grade III tumour, removed following radiation, seizure history	-23

- - - - - O N E W A Y - - - - -

Variable VPDIFF
By Variable LESIONC lesion code All Subjects

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	248.4236	248.4236	1.6313	.2124
Within Groups	27	4111.7143	152.2857		
Total	28	4360.1379			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int for Mean
left les	15	-10.0000	11.5016	2.9697	-16.3693 To -3.6307
right le	14	-4.1429	13.1842	3.5236	-11.7552 To 3.4695
Total	29	-7.1724	12.4788	2.3172	-11.9191 To -2.4258
Fixed Effects Model			12.3404	2.2916	-11.8743 To -2.4705
Random Effects Model				2.9282	-44.3784 To 30.0336
Random Effects Model - Estimate of Between Component Variance					6.6381

Group	Minimum	Maximum
left les	-31.0000	9.0000
right le	-24.0000	19.0000
Total	-31.0000	19.0000

Tests for Homogeneity of Variances

Cochrans C = Max. Variance/Sum(Variations) = .5678, P = .616 (Approx.)
 Bartlett-Box F = .242, P = .623
 Maximum Variance / Minimum Variance 1.314

- - - - - O N E W A Y - - - - -

Variable SUBOBJA object assembly
By Variable LESIONC lesion code

All Subjects

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	56.1946	56.1946	7.0782	.0130
Within Groups	27	214.3571	7.9392		
Total	28	270.5517			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int	for Mean
left les	15	11.0000	2.9761	.7684	9.3519 To	12.6481
right le	14	8.2143	2.6364	.7046	6.6921 To	9.7365
Total	29	9.6552	3.1085	.5772	8.4728 To	10.8376
Fixed Effects Model			2.8177	.5232	8.5816 To	10.7287
Random Effects Model				1.3935	-8.0503 To	27.3606
Random Effects Model - Estimate of Between Component Variance						3.3319

Group	Minimum	Maximum
left les	7.0000	19.0000
right le	2.0000	11.0000
Total	2.0000	19.0000

Tests for Homogeneity of Variances

Cochrans C = Max. Variance/Sum(Variations) = .5603, P = .656 (Approx.)
 Bartlett-Box F = .190, P = .663
 Maximum Variance / Minimum Variance 1.274

- - - - - O N E W A Y - - - - -

Variable TPTR right hand tpt
By Variable LESIONC lesion code All Subjects

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	37.2583	37.2583	6.2100	.0207
Within Groups	22	131.9951	5.9998		
Total	23	169.2534			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int for Mean
left les	13	4.4685	1.3810	.3830	3.6339 To 5.3030
right le	11	6.9691	3.3031	.9959	4.7500 To 9.1882
Total	24	5.6146	2.7127	.5537	4.4691 To 6.7601
Fixed Effects Model			2.4494	.5000	4.5777 To 6.6515
Random Effects Model				1.2533	-10.3095 To 21.5387
Random Effects Model - Estimate of Between Component Variance					2.6231

Group	Minimum	Maximum
left les	1.9500	6.3300
right le	3.1100	15.0000
Total	1.9500	15.0000

Tests for Homogeneity of Variances

Cochrans C = Max. Variance/Sum(Variiances) = .8512, P = .007 (Approx.)
 Bartlett-Box F = 7.465, P = .006
 Maximum Variance / Minimum Variance 5.721

- - - - - O N E W A Y - - - - -

Variable FINGAR finger agnosia right
By Variable LESIONC lesion code All Subjects

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	25.8462	25.8462	5.7171	.0250
Within Groups	24	108.5000	4.5208		
Total	25	134.3462			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int for Mean
left les	14	.5000	.7596	.2030	.0614 To .9386
right le	12	2.5000	3.0302	.8747	.5747 To 4.4253
Total	26	1.4231	2.3182	.4546	.4868 To 2.3594
Fixed Effects Model			2.1262	.4170	.5625 To 2.2837
Random Effects Model				1.0019	-11.3075 To 14.1537
Random Effects Model - Estimate of Between Component Variance					1.6502

Group	Minimum	Maximum
left les	.0000	2.0000
right le	.0000	10.0000
Total	.0000	10.0000

Tests for Homogeneity of Variances

Cochrans C = Max. Variance/Sum(Variances) = .9409, P = .000 (Approx.)
 Bartlett-Box F = 18.392, P = .000
 Maximum Variance / Minimum Variance 15.915

- - - - - O N E W A Y - - - - -

Variable VPDIFF
By Variable LESIONC lesion code Negative History Subjects

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	972.3214	972.3214	12.1385	.0036
Within Groups	14	1121.4286	80.1020		
Total	15	2093.7500			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int for Mean
left les	9	-10.0000	9.1515	3.0505	-17.0345 To -2.9655
right le	7	5.7143	8.6740	3.2785	-2.3078 To 13.7363
Total	16	-3.1250	11.8145	2.9536	-9.4205 To 3.1705
Fixed Effects Model			8.9500	2.2375	-7.9239 To 1.6739
Random Effects Model				7.9082	-103.6088 To 97.3588

Random Effects Model - Estimate of Between Component Variance 113.2977

Group	Minimum	Maximum
left les	-28.0000	3.0000
right le	-6.0000	19.0000
Total	-28.0000	19.0000

Tests for Homogeneity of Variances

Cochrans C = Max. Variance/Sum(Variations) = .5268, P = .891 (Approx.)
 Bartlett-Box F = .018, P = .893
 Maximum Variance / Minimum Variance 1.113

- - - - - O N E W A Y - - - - -

Variable SUBOBJA object assembly
By Variable LESIONC lesion code

Negative History Subjects

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	75.0248	75.0248	7.5885	.0155
Within Groups	14	138.4127	9.8866		
Total	15	213.4375			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int	for Mean
left les	9	11.2222	3.2702	1.0901	8.7085 To	13.7359
right le	7	6.8571	2.9681	1.1218	4.1121 To	9.6021
Total	16	9.3125	3.7722	.9430	7.3025 To	11.3225
Fixed Effects Model			3.1443	.7861	7.6265 To	10.9985
Random Effects Model				2.1951	-18.5784 To	37.2034
Random Effects Model - Estimate of Between Component Variance						8.2715

Group	Minimum	Maximum
left les	8.0000	19.0000
right le	2.0000	10.0000
Total	2.0000	19.0000

Tests for Homogeneity of Variances

Cochrans C = Max. Variance/Sum(Variances) = .5483, P = .805 (Approx.)
 Bartlett-Box F = .059, P = .808
 Maximum Variance / Minimum Variance 1.214

- - - - - O N E W A Y - - - - -

Variable TPTLOC location test for tpt Negative History Subjects
By Variable LESIONC lesion code

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	28.6172	28.6172	5.1027	.0452
Within Groups	11	61.6905	5.6082		
Total	12	90.3077			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int for Mean
left les	7	4.1429	2.6726	1.0102	1.6711 To 6.6146
right le	6	1.1667	1.9408	.7923	-.8700 To 3.2034
Total	13	2.7692	2.7433	.7609	1.1115 To 4.4270
Fixed Effects Model			2.3682	.6568	1.3236 To 4.2149
Random Effects Model				1.4908	-16.1728 To 21.7113
Random Effects Model - Estimate of Between Component Variance					3.5609

Group	Minimum	Maximum
left les	.0000	8.0000
right le	.0000	5.0000
Total	.0000	8.0000

Tests for Homogeneity of Variances

Cochrans C = Max. Variance/Sum(Variances) = .6547, P = .456 (Approx.)
Bartlett-Box F = .493, P = .483
Maximum Variance / Minimum Variance 1.896

----- O N E W A Y -----

Variable VPDIFF All Left Lesioned Subjects
 By Variable SEX sex, m or f

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	250.0000	250.0000	2.0287	.1779
Within Groups	13	1602.0000	123.2308		
Total	14	1852.0000			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int for Mean
Female	6	-5.0000	4.9396	2.0166	-10.1838 To .1838
Male	9	-13.3333	13.6015	4.5338	-23.7883 To -2.8783
Total	15	-10.0000	11.5016	2.9697	-16.3693 To -3.6307
Fixed Effects Model			11.1009	2.8662	-16.1922 To -3.8078
Random Effects Model				4.1678	-62.9575 To 42.9575

Random Effects Model - Estimate of Between Component Variance 17.6068

Group	Minimum	Maximum
Female	-11.0000	3.0000
Male	-31.0000	9.0000
Total	-31.0000	9.0000

Tests for Homogeneity of Variances

Cochrans C = Max. Variance/Sum(Variances) = .8835, P = .016 (Approx.)
 Bartlett-Box F = 4.514, P = .034
 Maximum Variance / Minimum Variance 7.582

Paired samples t-test:		VIQ	verbal IQ		All Left lesioned Subjects		
		PIQ	performance IQ				
Variable	Number of Cases	Mean	Standard Deviation	Standard Error			
VIQ	15	89.8667	13.958	3.604			
PIQ	15	99.8667	17.578	4.539			
(Difference) Mean	Standard Deviation	Standard Error	2-Tail Corr. Prob.		t Value	Degrees of Freedom	2-Tail Prob.
-10.0000	11.502	2.970	.757	.001	-3.37	14	.005

Paired samples t-test:		VIQ	verbal IQ		Left lesioned negative history subjects		
		PIQ	performance IQ				
Variable	Number of Cases	Mean	Standard Deviation	Standard Error			
VIQ	9	91.7778	13.405	4.468			
PIQ	9	101.7778	15.547	5.182			
(Difference) Mean	Standard Deviation	Standard Error	2-Tail Corr. Prob.		t Value	Degrees of Freedom	2-Tail Prob.
-10.0000	9.152	3.051	.810	.008	-3.28	8	.011

Paired samples t-test:		VIQ	verbal IQ				
		PIQ	performance IQ				
Variable	Number of Cases	Mean	Standard Deviation	Standard Error	Left lesioned Females		
VIQ	6	90.3333	9.585	3.913			
PIQ	6	95.3333	9.993	4.080			
(Difference)	Standard	Standard	2-Tail		t	Degrees of	2-Tail
Mean	Deviation	Error	Corr.	Prob.	Value	Freedom	Prob.
-5.0000	4.940	2.017	.874	.023	-2.48	5	.056

Paired samples t-test:		VIQ	verbal IQ				
		PIQ	performance IQ				
Variable	Number of Cases	Mean	Standard Deviation	Standard Error	Left lesioned Males		
VIQ	9	89.5556	16.831	5.610			
PIQ	9	102.8889	21.275	7.092			
(Difference)	Standard	Standard	2-Tail		t	Degrees of	2-Tail
Mean	Deviation	Error	Corr.	Prob.	Value	Freedom	Prob.
-13.3333	13.601	4.534	.769	.015	-2.94	8	.019

*** CELL MEANS ***

VPDIFF		
BY LESIONC	lesion code	All Subjects
RIGID	History	

TOTAL POPULATION

-7.17
(29)

LESIONC

0 1

-10.00 -4.14
(15) (14)

RIGID

1 2

-3.13 -12.15
(16) (13)

RIGID

1 2

LESIONC

0 -10.00 -10.00
(9) (6)

1 5.71 -14.00
(7) (7)

*** ANALYSIS OF VARIANCE ***

VPDIFF
BY LESIONC lesion code
RIGID History All Subjects

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	918.987	2	459.494	4.175	.027
LESIONC	334.291	1	334.291	3.037	.094
RIGID	670.563	1	670.563	6.093	.021
2-way Interactions	689.722	1	689.722	6.267	.019
LESIONC RIGID	689.722	1	689.722	6.267	.019
Explained	1608.709	3	536.236	4.872	.008
Residual	2751.429	25	110.057		
Total	4360.138	28	155.719		

29 Cases were processed.
0 CASES (.0 PCT) were missing.

*** MULTIPLE CLASSIFICATION ANALYSIS ***

VPDIFF
By LESIONC lesion code
RIGID History

Grand Mean =		-7.172					
Variable + Category	N	Unadjusted Dev'n	Eta	Adjusted for Independents Dev'n	Beta	Adjusted for Independents + Covariates Dev'n	Beta
LESIONC							
0 left lesioned	15	-2.83		-3.30			
1 right lesioned	14	3.03		3.53			
			.24		.28		
RIGID							
1 negative history	16	4.05		4.36			
2 positive history	13	-4.98		-5.36			
			.37		.39		
Multiple R Squared					.211		
Multiple R					.459		

END

28·0|5·92

FIN