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A MULTIPLE CASE STUDY EXAMINING NEUROPSYCHOLOGICAL PROPERTIES OF THE COGNITIVE ASSESSMENT SYSTEM

by

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Dedicated to the sunshine of my life, Zanna

Abstract

The purpose of this exploratory study was to arrive at a first approximation of neuropsychological properties of the Cognitive Assessment System (CAS) in a sample of adult brain-damaged patients (N =32) each with a single localized infarct in the cortex and subcortical regions. Thirty-five robust double dissociations were found between individual CAS subtests and 12 patterns were evident. Matching Numbers was doubly dissociated from Figure Memory (n=1). Number Detection was doubly dissociated from Word Series (n=3), Sentence Repetition (n=6), and Sentence Questions (n=2). Nonverbal Matrices was doubly dissociated from Word Series (n=4) and Sentence Repetition (n=4). Verbal Spatial Relations was doubly dissociated from Word Series (n=2) and Sentence Repetition (n=4). Figure Memory was doubly dissociated from Word Series (n=3), Sentence Repetition (n=3) and Sentence Questions (n=2). Finally Sentence Repetition was doubly dissociated from Sentence Questions (n=1). Each case was analyzed separately in terms of the average z-score index of impairment and in the context of previously published neuropsychological studies examining similarly constructed tasks. Group lesion analysis revealed that damage to the basal ganglia predicted impairment on Planned Codes ($p < 0.001$); right anterior cingulate damage predicted impairment on Expressive Attention ($p < 0.001$); left posterior perisylvian region damage predicted impairment on Verbal-Spatial Relations ($p = 0.02$); and left temporoparietal or right frontal lobe damage predicted impairment on Word Series ($p = 0.01$). ANOVA at the level of PASS scales with lesions divided into four quadrants of the brain (anterior-posterior vs. left-right) revealed contradiction of 5 of 7 statements defining the neural correlates of PASS theory. Right hemisphere patients were more impaired on the planning scale ($p < 0.01$) while posterior patients were more impaired on the attention ($p = 0.03$) and the simultaneous scales ($p = 0.02$). Right hemisphere patients were more impaired on the simultaneous scale ($p = 0.02$) and there was a location by hemisphere interaction such that right posterior patients performed exceedingly poor ($p = 0.04$). The data seriously challenged the assertion that code content is independent of code type as specified in the simultaneous-successive theory. In sum there was little evidence that the PASS model as currently conceived has the necessary specificity to be used in neuropsychological practice. However at the level of the CAS subtests reliable patterns of double dissociations and specificity for regional damage to distributed neural networks underlying performance were demonstrated.

Preface

Several non-traditional models of intelligence and corresponding test batteries have been developed in the last decade. Many were designed with the explicit intention of better linking advancements in cognitive psychology with that of instruction and assessment (Sternberg, 1997). Among these new batteries are the Kaufman Assessment Battery for Children (Kaufman & Kaufman, 1983); the Kaufman Adolescent and Adult Intelligence Test (Kaufman & Kaufman, 1993); the Swanson Cognitive Processing Test (Swanson, 1996); Cognitive Assessment System (Naglieri & Das, 1997); and finally, the Woodcock-Johnson III Tests of Cognitive Abilities (Woodcock, McGrew & Mather, 2001).

The Cognitive Assessment System, or CAS (Naglieri & Das, 1997), is the operationalization of the PASS theory of intelligence (Das, Naglieri & Kirby, 1994) that is itself an elaboration of Alexander Luria's neuropsychological model of intellectual functioning. PASS is an acronym for *Planning*, *Attention*, *Simultaneous*, and *Successive* cognitive processes. These four cognitive processes are described by Das and colleagues as having underlying functional neuroanatomical units or 'the blocks' -- the seed of which was originally described many years before by von Monakow at the turn of the century (Kolb & Whishaw, 1996) and substantially elaborated by Luria (1980) through his syndrome analysis of hundreds of neurological patients. Accordingly, these blocks are purported to function in synchrony in the performance of intelligent, goal-directed behaviors. Unlike traditional IQ tests, the CAS incorporates stand-alone measures of planning as well as some variants of attentionals tasks, which for neuropsychologists are sometimes subsumed under the rubric of executive functions (Lyon & Krasnegor, 1996).

In the CAS battery planning tasks have been structured so that flexibly utilized strategies optimize performance on each subtest and in this sense there is a divergent as opposed to convergent quality to them. It is the inclusion of such novel strategy-tapping tasks, in addition to the CAS's assessment of more conventional verbal and non-verbal memory, that demarcates this test as non-traditional (Naglieri & Das, 1997). Although neuropsychologists often refer to these strategic processes as executive functions (Lezak, 1995; Spreen & Strauss, 1998), educational psychologists often refer to these highest of cognitive processes as self-regulatory and metacognitive in nature (Winne, 1995).

In the context of schooling, it is known that executive function demonstrates a protracted developmental course, with evidence of non-linear task and age interactions as well as knowledge domain and context interaction effects. Thus, simple net-effect models of the impact of schooling on executive function, which often use the cumulative number of years of schooling as the independent variable, have been unable to adequately characterize the inherent complexity and domain-specific development of such cognitive processes (Ardila, Pineda & Roselli, 2000). In addition, these self-regulatory processes have considerable developmental interactions with sociocultural context factors (Friedman & Scholnick, 1997), rendering these malleable and teachable cognitive processes of considerable interest to educators since a primary constituent of many developmental disabilities is fundamentally self-regulatory in nature.

The CAS, and its related remedial programs, is the culmination of several decades of experimental pilot work by Das and colleagues. Standardization of the CAS was completed on a stratified random sample of over 3000 individuals aged 5 to 18 in the US and evidence suggests that these norms may also be useful in the Canadian context (Parrila, 1997; Alexander, 1998; Papadopoulos, 1998). Previous research using the CAS with children with learning difficulties, traumatic brain-injured children, and aging populations has revealed some promising results with regard to the identification of cognitive strengths and weaknesses indicated by their CAS profiles (Naglieri, 1999). In sum research completed to date suggests that the CAS may be uniquely poised to become a useful research instrument, perhaps more than a widely used clinical instrument.

The PASS Theory

The PASS model of intelligence is summarized by Das, Naglieri and Kirby (1994) and elaborated more fully by Das, Kar and Parrila (1996) as well as by Naglieri (1999). Das and colleagues provided one of several links between Luria (1980) who is the 'most frequently cited Soviet scholar in American, British and Canadian psychology periodicals' (Solso & Hoffman, 1991, p. 251) and the field of intelligence. The PASS model consists of four essential activities of planning, attention, simultaneous, and successive processing that employ and alter an individual's knowledge base in the service of goal-directed behavior. According to the PASS model, cognitive functioning includes four components: *Planning* processes that provide cognitive control, utilization of processes and knowledge, intentionality, self-regulation to achieve a desired goal, and *Attention* processes that provide focus and selection of cognitive activity over time. *Simultaneous* and *Successive* are hypothesized to be the two forms of operation on information. Simultaneous is a mental process by which the individual integrates separate stimuli into a single whole or group while successive is a mental process by which the individual codes items into a specific serial order that forms a chain-like progression. These two latter cognitive processes were the subject of extensive earlier studies by Das, Kirby and Jarman (1979).

The PASS theory of intelligence is purported to be constructed on the basis of Luria's model, which is more commonly associated with European, qualitative, process-based approaches to neuropsychology. In contrast, North American neuropsychology has generally emphasized using precise sequences of hypothesis testing protocols, actuarial tables, and base rate data (Kaplan, 1988). In a recent issue of *Neuropsychology Review* on Luria's legacy, guest editor, David Tupper (1999, p. 3), summarized the differences between Lurian and North American approaches to neuropsychology. Tupper notes that Luria's neuropsychology is typically theory-driven, attempts to support or confirm an overriding theory or meta-theory, is synthetic, and is derived from clinical neurology. In contrast, North American approaches typically attempt to disconfirm and successively rule out alternative hypotheses and in clinical practice only indirectly seeks to address metatheory(s), is analytical, and is derived principally from psychometrics.

Contrasts can also be made between these two approaches with respect to assessment methods. Tupper notes that Lurian neuropsychology is qualitative in nature, flexible, attempts to identify links in a functional system of interacting neural modules, is clinical-theoretical in orientation, and is single-case orientated. North American neuropsychology is psychometric, standardized, actuarial, quantitative, and uses multiple statistical tests/procedures and group studies. It may be no overstatement that the single-case and group approaches have in the past been portrayed in the literature as diametrically opposed in fundamental underlying assumptions. The well-described single-case does provide an opportunity for first approximations or evidence of contradiction of existing theories of supposed brain and behavior relationships as well as the establishment of new scientific knowledge in unique cases. However, an emerging consensus among many clinical neuroscientists is that ultimately, group studies are needed in order to parse out which cognitive processes common across individuals are instantiated by separable neural subsystems (Robertson, Knight, Rafal & Shimamura, 1993). Therefore, when it is considered that clinical neuropsychological assessment is by nature a single-case study orientated design, it becomes apparent that a combined metatheoretical perspective in conjunction with quantitative post-hoc hypothesis testing with group-derived data may be advantageous for the clinician who is seeking to arrive at diagnostic summaries in a meaningful context.

Tupper (1999) also acknowledged that two of Luria's books remain among the top ten essential readings in neuropsychology, in a recent survey of clinical neuropsychologists (e.g., see Ryan & Bohac, 1996). It appears that Luria's influence is likely more significant in understanding the neuropsychology of higher mental processes such as planning and problem solving (e.g., Smith & Jonides, 1999). In contrast, Luria's qualitative characterization of syndromes, resulting from damage to posterior cortical regions involved in sensory and perceptual functions, although still useful from a clinical vantage point, is giving way to a much more experimentally-based and formal cognitive neuroscience explanation of the neural basis of these visual, auditory, praxis and language functions (Gazzaniga, 2000). Finally, at an international, level Luria's influences on methodological approaches to neuropsychological assessment continue to be substantial, and in North American neuropsychology Luria's methods, perhaps more so than his theory, continue to substantially shape practices in pediatric neuropsychology (Tupper, 1999).

However, Luria's contributions have extended beyond neuropsychology (Languis & Miller, 1992, Das, 1995; Berninger, 1998). Tupper found several underlying themes in Luria's conceptualizations that have been of special interest to educators, assessment specialists, and rehabilitation health professionals. These include Luria's conceptualizations that higher psychological functions are nested within the sociohistorical context of the individual and society, his delineation of functional units of the brain, his syndrome analysis approach, his flexible system-level localization of brain function, and his emphasis on the verbal regulation of behavior. Tupper describes the " [PASS model] as another example of a second-generation Lurian adaptation that clarifies, operationalizes, and extends, to some degree, Luria's model. Of course, an updated, contemporary model incorporating subcortical interactions, recent cerebellar research, and emotional understanding is sorely needed... (p. 2)."

Although previous batteries have been constructed on the basis of Luria's theory, such as Golden, Purisch and Hammeke's (1985) *Luria-Nebraska Neuropsychological Battery* (LNNB) and Kaufman and Kaufman's (1983) *Kaufman Assessment Battery for Children* (K-ABC), these tests have met with mixed reviews. The LNNB is still popular among child neuropsychologists and is qualitatively orientated, while the K-ABC was Kaufman's attempt to psychometrically operationalize part of Luria's theory. Lezak (1995, p. 720) described a number of problems with the LNNB, the chief one among these being the "considerable verbal demands made by many of the items biases this test against persons whose language skills are deficient" as in aphasia, which is common after almost any left hemispheric or significant subcortical damage. Spreen and Strauss (1998, p. 144) note that "little evidence has been supplied so far that actually validates the neuropsychological implications of the sequential-simultaneous (left-right hemisphere) dimension for the K-ABC and that the dichotomy has little if any foundation in Luria's theories about brain function, which [Luria] speculated...may also be related to the anterior-posterior dimensions of the brain".

The PASS theory of intelligence includes two additional scales of planning and attention in contrast to the K-ABC's sole emphasis of the sequential-simultaneous distinction. Like the simultaneous and successive subtests, the planning and attention subtests were chosen on the basis of their "correspondence to the theoretical framework and functional architecture of the PASS theory" (Naglieri & Das, 1997a, p. 14). Much of this previous work is summarized by Das, Kirby and Jarman (1979) and Das, Naglieri and Kirby (1994) and more recently by Naglieri (1999) and it is based upon prior factor analysis studies, judgments of face validity of extracted factors, and previous findings pertaining to the neuropsychological correlates of tasks similar to those included on the CAS.

In a recent reply to CAS critics, Naglieri (1999b) noted evidence suggesting that the planning tasks on the CAS do involve strategy use and that performance patterns on these tasks are unlikely to be attributable to speed, since these planning tasks do not correlate with achievement in the same way that speed tests do. Moreover, Naglieri notes that the CAS is highly predictive of school achievement for children, yields differential cognitive profiles for children with attention and learning problems, and that the PASS scores have direct relevance to methods of intervention. However, an actual assessment of the neuropsychological basis of the PASS theory, as an operationalization of Luria's theory, has yet to be undertaken aside from one preliminary study.

Gutentag, Naglieri and Yeates (1998) studied the performance patterns of children with traumatic brain injury (TBI) on the Cognitive Assessment System. These investigators found that 22 children aged 9 to 17 with moderate to severe closed head injury had significantly lower scores on planning and attention compared to a matched control group. Subsequently within-group comparisons revealed that the TBI group's planning and attention scores were significantly below their simultaneous and successive scores consistent with previous findings suggesting that such children have poor performance on executive and attention functions (Kaufman et al., 1993). Although Gutentag and colleagues advised that there was need for caution in interpreting these findings, given the small and selected sample, there were also some notable trends at the subtest level. Number detection was the only subtest among the attention subtests that was significantly lower in the TBI group while sentence repetition was unexpectedly significantly lower in the TBI group among the successive tasks. The authors attributed the latter abnormally low scores to neuroimaging findings that have documented an antero-posterior gradient in the lesions that result from TBI, with relatively larger lesions within anterior brain regions (Levin et al., 1989). Although these studies are provocative, such studies cannot provide localization information needed to evaluate the neuropsychological properties of the CAS and hence PASS theory in its entirety. Sudden deceleration or blunt trauma injuries associated with TBI often result in diffuse axonal shearing injury to multiple white matter fiber tracts that is not possible to localize to one specific region of the brain (Lezak, 1995).

This exploratory study was designed with the intent of better understanding the neural correlates of performance on the Cognitive Assessment System composite scales and subtests. It has been previously noted that head-injured patients often sustain diffuse injury throughout the brain as a consequence of shearing and contre coup injury, and patients with neurodegenerative disorders often suffer similar types of diffuse patterns of lesions (Lezak, 1995). In contrast stroke patients were selected as the focus population for this study since lesions caused by stroke are often rather circumscribed and focal nature.

From a practical vantage point stroke occurs with relatively high frequency within the general hospital admissions population and thus happens to be a common enough occurrence (Bornstein & Brown, 1991).

Incidentally, several new stroke patients are admitted each day to the Neurology wards of 4G3 and 4G4 at the University of Alberta Hospital, and so there was sufficient numbers of patients to draw from so that only those persons with focalized brain injury were included in the study. Other factors that played a favorable role in the implementation of this study included that the principal investigator had collaborated on previous research projects with members of the Division of Neurology at the University of Alberta and had some experience in both psychological assessment of humans as well as training in conducting research in experimental models of stroke. For these practical and theoretical reasons stroke was judged to be the best available model with which to better understand the neural correlates of performance on the CAS subtests within the time and resource constraints.

A Brief Review of the Logic of Lesion Analysis and Localization

Before we begin with Chapter 1's more descriptive and summative goals a review of the main theoretical issues involved in lesion analysis and functional localization critical to understanding the logic of this study are discussed.

Functional Reorganization?

As Robertson, Knight, Rafal and Shimamura (1993, p. 710) note the possibility of neural reorganization in patients should be tested through converging evidence from various populations using different methods. Unfortunately these neural reorganizational changes after recovery from brain injury can obscure original patterns of functional localization in the intact human brain. This potential confound [of degree] is present in virtually all neuropsychological studies conducted in patients tested several months after injury. However in this study patients were tested on average only two weeks post-injury so functional reorganization may be less a concern as a potential confound than in most other neuropsychological studies where patients are often assessed several months after brain injury.

Localization?

Robertson et al (1993, p. 711) state that..."group studies in cognitive neuropsychology are if anything, better at articulating functionally distinct components or modules than the single-case design...each approach [single versus group study] has its own usefulness, and each should complement the other; however, for issues of discovering cognitive modularity, group designs that demonstrate behavioral separability and converging evidence of biological separability are preferred..." These authors take the position that characterization of functional neural networks underlying cognitive functions is one of the essential goals of neuropsychology. Robertson et al contrast their position with that of the radical cognitive neuropsychologist camp who advocate the single case as the only legitimate focus of study in neuropsychology (e.g., McCloskey and Caramazza, 1988). Radical cognitive neuropsychology attempts to solve the ubiquitous problem of between-subjects variability present in neuropsychological studies at the expense of generalizability, predictability and the possibility of refutation.

This radical position that has fallen into disfavour, especially since the rise of the quantitative and experimental rigor of cognitive neuroscience, does not address the issue of the centrality of brain-behavior relationships. This point is all the more salient nested within the framework of the "neo-Lurian" orientation of the PASS model as operationalized in the CAS (Das, 1999). Considering Luria's strong form of localizationism (Tupper, 1999) contrasted for example with Karl Lashley's extreme view of the equipotentiality of brain function one might reasonably expect that localization of function would figure prominently in evaluating any Lurian battery. Therefore the demonstration of localization of function would be essential in determining the construct validity of a 'neo-Lurian' theory such as PASS.

Single versus Group Design?

Every effort was made to give a fair and balanced representation of the data that was collected in this study by including both single case and group means analysis. Since Luria's fundamental unit of analysis was single case syndrome analysis this provided more impetus to include both methods. However single case analysis is not without its inherent difficulties. Robertson et al (1993) argued that it is virtually certain that advocates of the single case methodology will find evidence in favour of a specific hypothesis if they test a large number of patients and then report 2 or 3 patients only from these cases as independent samples. *In brief the data in the literature are guaranteed to support the hypothesis.* When each case's explanation is limited to inferences based on previously empirically established findings then this problem can be significantly attenuated. In contrast genuine patterns of neuropsychological impairments across cases may only be properly understood with the explanation-building paradigm of the single case study (Yin, 1994).

Other difficulties with the extreme '*data reduction*' view associated with a strong form of the "group mean analysis only position" is that group means obscure potentially useful patterns of reversed associations between subtests at the single case level. Such reversed associations or crossover interactions have direct causal implications for further developing construct validity of a neuropsychological instrument. Adopting such a theoretically grounded method of data analysis as opposed to atheoretical data reduction (e.g., factor analysis) is all the more important during the exploratory stage of data analysis.

Still other questions that cognitive neuropsychological research should aim to answer in addition to localization of function according to Robertson et al are: (i) What do the modules do? (ii) How and when do they interact with one another? As Lloyd (2000) demonstrates evidence for modularity is strong only within the auditory and visual domains associated with the temporal and occipital lobes. Also modularity is often stronger at more perceptual levels of information processing than at more conceptual-based tasks. Robertson and colleagues note that single case studies are useful in the exploratory stages of a study when one is first formulating hypothesis about cognitive and brain processes. An essential part of this initial hypothesis generation stage is task decomposition and analysis in order to determine what exactly is modular about a task, and what is not, and the conditions under which a task is modular. In Chapter 1 an exhaustive review of the literature formulated a set of relatively well-specified hypothesis about potential patterns of localization of the CAS subtests.

Ideally the single and group studies offer the most compelling evidence for modularity when there is convergence in the findings from both in-depth studies of single individuals can lead to illuminating hypothesis on brain-behavior relationships that have the potential to add to the scientific literature. Screening is crucial in establishing the sphere of generalizability of the findings and in the context of this study a specific group of adult brain injury patients with the least potential for associated confounding variables was selected. Toward this end screening was based on neuropsychological and biological criteria and was not based on clinically diagnosed syndromes. This is an important distinction as Robertson and colleagues have noted since such practices enable the establishment of independent variables (e.g., lesion locus and side) which would be expected to be predictive *a priori* of outcomes on a particular dependent measure (e.g., CAS subtest). In Chapter 1 an exhaustive review of each case is included since there was no previously published evidence establishing patterns of double dissociations or functional localizations at the level of the CAS subtests (Chapters 3 and 4). Finally the study concludes with a quantitative group analysis at the level of the CAS scales for which testable *a priori* predictions had already been made (Chapters 5 and 6).

In conclusion some of the strengths of the group design are that subjects are grouped into an objective criteria (e.g., lesion locus) and thus there are bonafide independent variables. The dependent variables consist of composite scale scores, subtest scores, and demographic variables. In judging the merits of single and group designs Robertson and colleagues conclude "...for the (development) and testing of models of normal cognition, a single patient's deficits are generally most useful as a first approximation that should be followed by group studies, if possible..." Furthermore these authors noted that "...for purposes of demonstrating cognitive modularity, the location of lesion is not as important as the fact that the lesions are distinct...(p. 713)" Thus efforts were directed towards including patients with focal lesions who did not have secondary diffuse collateral neural damage as a result of some pre-existing or co-morbid neurological condition. Group studies can be advantageous since this method affords the demonstration of significant differences despite variable functional deficits in processes outside the ones of concern -- thereby increasing the generalizability of the findings. Finally group studies rely on objective subject inclusion criteria for experimenters who wish to replicate, extend or refute the results of other studies.

Functional Neuroimaging and Traditional Lesion Studies?

With the development of functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) there have been attempts to link the findings from these newer methods with the classic neuropsychological literature that relied on almost exclusively the lesion analysis technique. However as Lloyd (2000) adds the link between neuropsychology and functional neuroimaging is not entirely straightforward since the mainstay of neuropsychology, the lesion study, builds towards its general conclusions through complex inferences, whose stages rest on several assumptions. Four related series of inferences are required in lesion analysis: i) the lesion must be characterized in objective anatomical terms; ii) data on how the injured person's behavior differs from the norm must be established; iii) from behavioral deficit the neuropsychologist must infer an account of the missing function; and finally iv) that inferred missing function is attributed to the missing brain. As Lloyd explains this multiple inferential process is limited by small sample sizes, personality factors, age, individual brain variations and functional plasticity common in neuropsychological lesion studies.

The principle strength of the functional neuroimaging study in contrast is that it can examine the same set of neuropsychological assessment tasks -- provided that they have been operationalized within a functional neuroimaging environment -- in more subjects, and with randomization controlling for the spurious influence of these extraneous factors.

As Lloyd (2000) notes:

> "...functional neuroimaging reveals regions of the brain that are particularly active when normal subjects perform tasks dependent on a particular hypothesized underlying brain function. Lesion studies reveal the incapacity to perform tasks depending on the same underlying functions, conjoined with the lesion of the corresponding brain region. If the two regions identified by these two methods overlap, the general conclusion that the region's job to compute the hypothesized function is supported. The logic of both methods reflects a prior commitment to modularity of function in the brain. If brain modules are dedicated to execute particular functions, then the overall goal of both neuropsychology and functional neuroimaging is the localization of functions, the search for the anatomical boundaries of the functional modules...(p. 628)"

However it is known that many structures contribute to diverse tasks and that most functions are correlated with activation in many regions rather than a single structure. Furthermore neuroimaging is illustrating that functions is not uniformly distributed, with every structure participating in every task; rather, structures range in their contribution to functions, some showing near-modular specialization as in the temporal and occipital cortex (Lloyd, 2000) and others such as prefrontal cortex showing wider diversity of functions. In this context Lloyd classifies modularity as being either traditional, that associated with occipital and temporal cortex, or *quasi-modular* as typified by frontal and parietal cortex. Quasimodular cortex then would not be easily characterized as a cognitive transform of some discrete function a to function b, but rather the function would be best characterized disjunctively such that: region x has a degree of participation in a specified set of related tasks sharing similar properties. Together functional neuroimaging and lesion studies can help to characterize the complexity of these *disjunctive functions*, where each disjunctive function is associated with a combination of brain areas. Both methods can unpack cognitive functions disjunct by disjunct and thus can offer convergent means of predicting the behavioral manifestations of particular lesions – in effect undertaking *virtual lesion analysis*.

This was precisely the goal of the exhaustive review of the cognitive components and neural substrates of tasks similar to those included in the CAS within Chapter 1. All lesion and functional neuroimaging studies using a task judged to be most similar to the historical antecedent of each of the tasks included in the CAS were analyzed for the involvement of specific brain regions across studies. Where there was convergence across studies on the particular combination of brain region(s) involved in the archetypal task – these were labeled the critical lesion loci. Thus every effort was made to understand the relationship between brain function and performance on the CAS subtests and composite scales in terms of interconnected multiple brain regions or neural networks involved to various degrees in performance on each of the CAS subtests. Secondly it should be explicitly stated that Chapter 3 and 4 are organized around left and right hemisphere lesions for sake of convenience and this format is not meant to imply an adherence to a niave "left versus right brain function hypothesis" prominent within the educational popular press a decade ago (Byrnes, 2001). Finally it was not intended by the author that the focus on precise determinations of the extent of each lesion in patients should be misinterpreted by readers as an implicit or explicit acceptance of an extreme localizationist and dated account of brain function. Such an extreme localizationist account of brain function is rapidly being replaced by dynamic neurocomputational modeling approaches for understanding the complexity of brain-behavior relationships (Horwitz, Tagamets & McIntosh, 1999).

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Chapter 1: Neuropsychological Properties of Tasks Similar to CAS Subtests

The Cognitive Assessment System is an individually administered test of cognitive abilities for ages 5 up to 18 years old (Naglieri & Das, 1997). This test was standardized on a stratified random sample of 2200 individuals who were selected to approximate US census data. The Cognitive Assessment System (CAS) consists of four composite batteries: Planning, Attention, Simultaneous, and Successive. Its composite scales are designed to be theoretically congruent with Luria's (1966) description of functional systems instantiating cognitive processes.

Naglieri (1999, p. 11) described planning as providing cognitive control, utilization of knowledge, intentionality, and self-regulation to achieve a desired goal(s). Attention in turn provides focused, selective cognitive activity and resistance to distraction. The two forms of operation or coding of information, (tasks which are usually associated with memory tasks in conventional tests of intelligence), are simultaneous and successive (Luria, 1966). Simultaneous is a mental process by which the individual integrates separate stimuli into a single whole, gestalt or group whereas successive is required when one must arrange items in memory in a strictly defined order (Das, Kirby & Jarman, 1979).

Classical planning or executive function tasks such as the *Tower of Hanoi, Tower of London, Wisconsin Card Sort Test, Visual Search, Verbal Fluency, Matching Familiar Figures Test* are increasingly being used to study planning abilities in children and adults (Ardila, Pineda & Rosselli, 1999). These authors noted that the Wisconsin Card Sort Test (WCST), letter and category verbal fluency tasks, and Trail-Making Test (TMT) generally correlated poorly with conventional psychometrically measured intelligence as measured by the WISC-R. Among the few correlations with WISC-R subtests that were significant, letter or phonological fluency correlated 0.40 with vocabulary, category fluency correlated 0.51 with information, and WCST perseverative errors correlated – 0.37 with block design. There were no significant correlations with either TMT A or B. These results suggest that conventional intelligence tests do not appropriately evaluate executive functions, the most important element of purposeful or *intelligent* behavior. The planning tasks incorporated on the CAS are an attempt to rectify these inadequacies of conventionally operationalized models of intelligence. Other recently released psychoeducational tests such as the Woodcock Johnson Test of Cognitive Ability have also included such metacognitive measures as such as concept formation tasks.

In this paper the author will show that there do exist neuropsychological tasks that are sensitive to brain injury and that are similar to those tasks included on the CAS. One of the key strengths of the CAS is its extensive standardization, and some of the CAS's subtests may provide useful information beyond that offered by existing neuropsychological tests. Planning and attention are sometimes grouped together under the umbrella term, executive function, and owing to the extensive reciprocal connectivity between frontal and subcortical regions, the strict dichotomization between these two processes may be problematic (Lyon & Krasnegor, 1996). Using a hierarchical multi-sample confirmatory factor analysis (HMSCFA) of the CAS's standardization data across its 12-year age-span Kranzler and Keith (1999) similarly voiced these criticisms about the psychometric soundness of discriminating between the planning and attention tasks, and argued that these should not be viewed as distinct.

Furthermore, the conceptualization of planning as characterized by Das and colleagues is perhaps too limited in that perspective-taking (e.g., theory of mind) and affective regulatory aspects central to understanding metacognitive processes are not well characterized (see also Tupper, 1999). Still, with the CAS incorporation of executive function and attention along with traditional verbal and nonverbal memory tasks in an integrated model are a substantial improvement over previous approaches lacking a theoretical focus. In short the CAS is a well-standardized psychometric instrument with yet undetermined neuropsychological properties.

The reliabilities for the PASS scales are: Planning = 0.88, Attention = 0.88, Simultaneous = 0.93, Successive = 0.93, and the Full-Scale = 0.96. The average reliability of the twelve subtests across age cohorts ranges from a low of .75 (Matching Numbers) to a high of .89 (Nonverbal Matrices and Figure Memory) while the average reliability collapsed across ages and subtests is .81. Speech Rate, the optional subtest on the Successive scale, will not be included in this review since it is only administered in lieu of Sentence Questions between the ages of five and seven, rather than through the entire age range. The manual accompanying the CAS contains a review of empirical studies supporting this test's content, construct and criterion-related validities and potential contexts of use beyond education (Naglieri, 1999).

In one study, Gutentag, Naglieri and Yeates (1998) found that the Planning and Attention composite scales as well as select subtests included within the CAS reliably discriminated between children and adolescents with traumatic brain injury and demographically matched controls. These authors did note the preliminary nature of these findings and despite the small sample size, the results suggest that some of the CAS's subtests may provide useful information on cognitive functions for assessing children with traumatic brain injuries and by extension perhaps in cases of focalized brain injuries.

Although the authors of the CAS allude to the historical antecedents of the development of the CAS tasks, no contemporary information is provided on the degree to which these tasks might exhibit neuropsychological sensitivity, specificity, or lateralizing properties based on prior empirical information. In Chapter 1 a profile of the neuropsychological characteristics of twelve individual subtests included within the CAS is developed based on prior empirical studies of similarly constructed tasks. These analogous tasks have been previously shown to be sensitive and specific to patterns of focal and distributed brain damage within the existing neuropsychological literature.

Planning Scale Tasks

Matching Numbers

Matching Numbers is completed manually on four pages, each of which contains eight rows of numbers with six numbers per row. Examinees are instructed to underline the two numbers in each row that are the same. Numbers increase in length across the four pages from one digit to seven digits. Items were constructed so that there was a balance of targets across the columns, and this feature might render this task suitable for the detection of visual neglect. The time limit for items 1 through 3 is 150 seconds and for item 4 it is 180 seconds. Ages 7 to adult start at item 2. The subtest score is based on the combination of time (speed) and number correct (accuracy) for each page completed. The summed raw scores are then converted into a cumulative ratio score where a combination of high speed and accuracy boosts the score. This subtest has an average internal reliability of 0.75 across ages. An analysis of the cognitive, motor, and perceptual requirements of this task would include as components: cognitive strategies, visual scanning, fine motor skills, motor speed, eye-hand coordination, and visual recognition of previously learned numbers.

The Matching Numbers task was created to require the adoption of a strategy for optimal efficiency of completion (Naglieri & Das, 1988). During standardization of the CAS, verbal protocol analysis data was collected to determine the relationship between strategy use and performance at the subtest level (Ericsson & Simon, 1984). Between the ages of 5 and 17 strategy use continually climbed from 71 to 97%, and older examinees generally used more complex strategies than their younger counterparts -- such as looking at the last whole number and then the first in a methodical process of elimination (Naglieri & Das, 1997). Examinees used up to eight different strategies in the 15 to 17 year old group and strategy users had consistently higher performance scores than strategy non-users on this subtest. As yet, there are no comprehensive studies examining the neuropsychological properties of the Matching Numbers test aside from Gutentag et al.'s (1998) preliminary study of a small sample of TBI children with non-localized brain damage. In this study, Matching Numbers successfully discriminated between demographically matched control and TBI children with presumed greater level of neuropathology along the anterior rather than posterior gradient based on structural magnetic resonance imaging studies (Levin et al. 1989).

Both Matching Numbers and the 'field of search' task (Teuber, Battersby & Bender, 1951) involve searching for a target. Teuber and colleagues' version involved presentation of an array of 48 patterns distributed irregularly over a screen within the patient's field of view. Immediately after the appearance of the duplicate test pattern, the patients searched with eye movements for the target that matched the one in the center and the person was timed for each search period. These early studies demonstrated reduced speed in searching, and reduced efficiency of searching, implying a strategic implementation deficiency which was especially pronounced after frontal lobe injury.

Although Matching Numbers shares the visual search component with Teuber's task, there are a number of important differences between these two tasks. In Matching Numbers, especially with the longer number series, we might expect working memory to begin to play a more important role than in the perceptually based 'field of search' task. Lengthy spans of numbers on the final trials of this subtest will almost certainly require working memory resources, a contention which is supported by subject verbal reports of rehearsal of numbers during searching for matches within a row (Das & Naglieri, 1997, p. 84). Both Matching Numbers and Teuber's task have visual distractors. A main difference however, is that in Teuber's task the working memory requirements are minimal while these requirements are substantial in the more difficult items of Matching Numbers (e.g., 7-digit numbers among four other distractors of similar length).

Lesions within the right inferior frontal gyrus have been shown to be especially deleterious to performance on visual search tasks (Binder, Marshall, Lazar, Benjamin & Mohr, 1992) perhaps owing to the propensity for cases of lesions deep to the white matter of the frontal eye fields that are in close proximity. Recently Husain and Kennard (1997) found that as the number of distractors increased, so did impairment in visual search selectively for a patient with a right frontal lesion as compared with a right fronto-parietal infarction. These results suggest that parietal lesions degrade the representation of ipsilateral space thereby fundamentally impairing automatic search processes whereas frontally lesioned patients only manifest such 'neglect' phenomenon when the processing burden induced by distracters is too great. Thus the representation remains unimpaired in frontal neglect -- only the controlled direction of attention is impaired when too many distracters are present.

Aside from the visual search element of Matching Numbers there is the mental tracking component. Mental tracking typically involves elements of perceptual tracking, complex mental operations (e.g., remembering the first and last digit of number among other numbers) as well as scanning (Lezak, 1995, p. 366). These are all salient aspects of Matching Numbers and these covert mental processes are sometimes referred to as divided or shifting attention tasks. The classic example of such tasks is the reversed span task of the Wechsler's Digit Span Backward (DSB). Black (1986) found that left hemisphere patients performed a full point behind right hemisphere patients in a large sample of brain-damaged patients on DSB. Injury severity was the critical determinant of deficits in reversed span as measured by WAIS-R DSB in Uzzell, Dolinskas and Langfitt's (1988) large study of head-injured patients. Leskelae et al. (1999) also found significantly poorer performance on DSB in frontal patients compared to non-frontal patients.

In gerontological studies, a cued visual search task paradigm was used to study search efficiency in elderly demented Alzheimer's (DAT) patients and demographically matched controls (Parasuraman, Greenwood & Alexander, 2000). Although non-demented adults demonstrated a modulation of search efficiency over the entire range of precision of target localization, the dynamic range of spatial attention was restricted over the most precise cue in the DAT group suggesting an underlying perceptual and memory impairment in the early stages of DAT. On the basis of these studies, the CAS's hybrid visual search and mental tracking task (Matching Numbers) might be expected to be highly sensitive to dementing processes stemming from frontal dysfunction.

Planned Codes

Planned Codes is a paper and pencil subtest requiring manual written responses. Each page has a distinct array of X's and O's within a larger arrangement of rows and columns. A legend at the top of each page shows how letters correspond to simple codes (e.g., A, B, C, D matched to OX, XX, OO, XO; respectively). Examinees are provided with an abbreviated practice sample A before completing item 1, or a similar sample B before completing item 2. Each page contains seven rows and eight columns of letters without codes. Examinees are required fill in the appropriate code in empty boxes beneath each letter. On the first page, all the A's appear in the first column, all the B's in the second column, and all the C's in the third column, and so on. On the second page, letters are configured in a diagonal pattern. The time limit for each item is 60 seconds for ages 8-17. All ages complete both items 1 and 2. Examinees are instructed to complete each page how ever they would choose to do so -- which allows for flexibility in choosing an appropriate strategy. As with Matching Numbers, the subtest score is based on the combination of time (speed) and number correct (accuracy) for each page completed. The summed raw scores are then converted into a cumulative ratio score where a combination of high speed and accuracy boosts the score. This subtest has an average internal reliability of 0.82 across ages 5–17. An analysis of the cognitive, motor, and perceptual demands of this task would include as components: cognitive strategies, visuomotor scanning, fine motor skills, motor speed, eye-hand coordination and visual form recognition.

Planned Codes like the Symbol Digit Modalities Test (Smith, 1991) could potentially allow for an oral in addition to a written response that could be advantageous if a patient's fine motor skills were impaired because of brain injury. However, as yet, this subtest is not normed for an oral response format. Planned Codes is similar to many coding tests that were originally devised by Yoakum and Yerkes* (1920) and later elaborated on and refined in Wechsler's (1955, 1974, 1981) Digit Symbol subtests. Smith (1991) altered the Digit Symbol subtest by preserving the essential substitution format of Wechsler's Digit Symbol subtest but reversed the presentation of the material, as well as the name of the test, so that the symbols are printed and the numbers are written in. This could enable a comparison between written and oral response formats. It is also notable that the Digit Symbol and Symbol Digit Modalities Test (SDMT) differ in cues to spatial location contained in the key because in the Digit Symbol the keyed items are numerically arranged whereas in the SDMT the sequence of stimulus symbols is random (e.g., Glosser, Butters & Kaplan, 1977). For these reasons the SDMT may require greater spatial attention allocation requirements than the Digit Symbol subtest. Planned Codes is similar to the Digit Symbol since in Planned Codes the stimulus symbols are also sequentially organized thereby downgrading the spatial attention allocation requirements of the task.

SDMT has been extensively normed for both of these response formats (Smith, 1991). In the SDMT examinees are allowed 90 seconds to complete the codes for a maximum score of 110 on each of the oral and written forms (110 items). This compares with a time limit of 60 seconds for the CAS's Planned Codes with a maximum score of 56 for each item. SDMT is likely the most closely related task to that of the CAS's Planned Codes and additional analysis of the essential differences between these two tasks may illuminate the latter's neuropsychological properties. In addition to the scanning, tracking, and motor speed requirements that are common to both of these tasks, there is a prominent strategy component in the CAS's Planned Codes in item 2 that is not as central in the well-structured SDMT. Hence item 1 of Planned Codes may be much more similar to SDMT than item 2 since in item 1 there is essentially a symbol substitution task with extra credit awarded for speed of completion.

* For an excellent historical example of some of the glaring prejudices and biases of psychometrists of early twentieth century psychology readers are referred to this text.

In the CAS standardization sample, verbal protocol analysis revealed that an examinee's adoption of more complex strategies increased rapidly from a low of 69% at age 5 to a high of 95% at age 17 on the Planned Codes subtest (Naglieri & Das, 1997, p. 86). The rate of utilization of more complex strategies across these ages was similar to that of Matching Numbers. In general, older children used complex strategies such as coding A's then B's on the diagonal for item 2. These were strategies that children aged 5 to 7 used very infrequently (e.g., < 2%). There are other notable differences between the SDMT and Planned Codes. Among these differences are that whereas in the SDMT the key contain non-verbal symbols, in the Planned Codes the key contains letters only, suggesting that Planned Codes could be slightly more amenable to verbalization. The strategy component associated with Planned Codes may similarly confer on it a greater sensitivity to anterior as opposed to posterior damage (Shallice & Burgess, 1991) or diffuse damage since such strategy-tapping tasks are known to be highly sensitive to diffuse damage (Lezak, 1995).

Both the Digit Symbol and the SDMT are highly similar in construction which explains the high correlations between these two instruments: r = .62 in brain damaged children (Lewandowski, 1984); r = .78 between WAIS-R Digit Symbol and written form of the SDMT in solvent exposed workers; r = .73 in nonsolvent exposed subjects (Bowler, Sudia, Mergler, Harrison & Cone, 1992); and r = .91 between the written form of SDMT and Digit Symbol in adult neuropsychological referrals (Morgan & Wheelock, 1992). Although Planned Codes has not yet been subjected to extensive neuropsychological investigation in Gutentag et al.'s study, this subtest reliably discriminated between TBI children and demographically-matched controls (p < 0.001). Only one other subtest was discriminating of these two groups of children at this level of significance (e.g., Number Detection). Incidentally Digit Symbol is commonly administered as part of neuropsychological assessments since it is a subtest of the Wechsler batteries. However, the SDMT is the test of choice for assessing differences in cognitive function after brain injury by virtue of its dual response format.

SDMT has been extensively used with neuropsychological patients. According to Shum, McFarland and Bain (1990) the SDMT is a test of attention. These investigators used a factor analysis approach with eight other common tests of attention with three groups: high ability controls, normal adult controls, and closed head injury patients. A three-factor solution emerged for both the control and patient groups that these authors labeled as visuo-motor scanning, sustained attention, and visual/auditory span. In the control group, the first factor of visuo-motor scanning explained 0.67, 0.58, and 0.53 of the variance in WAIS-R Digit Symbol, SDMT written, and SDMT oral respectively. The proportion of variance explained by scanning in the closed head injury group increased by 6%, 33%, and 40% on the WAIS-R Digit Symbol, SDMT written, and SDMT oral tests respectively. Interestingly, in both groups, the Trail-Making Test and Letter Cancellation were also highly correlated with visuo-motor tracking. Trail-Making and Letter Cancellation will be discussed further under the heading of Planned Connections and Number Detection; respectively in subsequent sections of this chapter.

Schear and Sato (1989) found that although visual acuity was significantly correlated with performance on the WAIS Digit Symbol ($p < 0.001$) it did not contribute significantly in a regression model. However, performance on the Finger Tapping Test (dominant hand) or the Grooved Pegboard Test did predict unique amounts of variance to the regression, and these measures are conceptualized as primarily measuring motor speed. These data suggest that *motor speed or dexterity* rather than visual acuity *per se* is a significant component explaining the variance in performance on the SDMT, and hence, in all likelihood, this is true of the CAS's Planned Codes. Schear and Sato's data do imply that where visual acuity is compromised such as in occipital lesioned patients, Planned Codes vis-à-vis SDMT may be rendered invalid and unsuitable for use.

Another significant individual difference variable associated with symbol substitution tasks is that women consistently outperform men (see Lezak, 1995, p. 380 for a review). Polubinski and Melamed (1986) demonstrated that the main effect of sex on performance on the verbal response format of the SDMT was highly significant ($p > 0.001$) and that the interaction of sex and handedness was also significant ($p < 0.01$). Recall that Shum et al. (1990) previously demonstrated that close relatives of these tasks (e.g., Trail Making Test, SDMT, and Letter Cancellation tasks respectively) all loaded significantly on visuomotor tracking in which motor agility figured prominently. These data are consistent with the alternative interpretation that the Planning and Attention tests that involve visual tracking and target detection, such as Planned Codes, are disproportionately measuring motor speed (e.g., see Kranzler & Keith, 1999) for which there appears to be significant sex difference in favor of women (Lezak, 1995).

Ponsford and Kinsella (1992) studied a sample of brain-injured patients on an extensive battery of focused attention, sustained attention, and supervisory attention tasks (Tower tasks) to establish which neuropsychological measures best-reflected core deficits. These authors found that the oral format of the SDMT was the best measure of reduced mental speed and that focused attention, sustained attention, and supervisory attention tasks did not predict unique amounts of variance in this factor. The SDMT has also been found to be exceptional at detecting dementia, a disease in which there are a prominent global cognitive declines and pervasive memory impairments (Pfeffer et al., 1981; Knopman & Ryberg, 1989). In particular, loss of functional synapses within the midfrontal and inferior parietal lobes surrounding the temporal lobes correlated with objective measures of dementia in Alzheimer's patients (Terry et al., 1991). These changes appear to disconnect the temporal lobes, frontal lobes and the parietal lobes (Lezak, 1995, p. 207) perhaps accounting for other notable selective impairments in tasks requiring rapid attention shifting (Parasuraman & Haxby, 1993) such as in the SDMT. Smith (1991) reports in his manual that no systematic lateralizing properties have been found with the SDMT. Other studies found performance on the SDMT to correlate well with neurodegeneration of the caudate in Huntington's disease patients (Starkstein et al., 1988; Sanchez-Pernaute et al., 2000) as well as with the prominent changes within the substantia nigra in Parkinson's disease (Starkstein et al., 1989).

Planned Connections

Planned Connections of the CAS contains eight items. Items 1-6 involve a sequence of numbers only and items 7 and 8 involve a sequence of numbers and letters (e.g., 1-A-2-B-3-C, etc.). These last two items require the subject to connect, in an alternating fashion, a series of numbers and letters in their proper sequence when arranged on the page in a quasi-random fashion. If an examinee makes a mistake, the examiner directs the examinee's attention to the correct position while continuing timing. The items are constructed so that the examinee never completes a sequence by crossing one line over the other. This provides spatial cues that can be used to reduce the search space when looking for the next number or letter in a sequence. Ages 8 to adult start at item 4. The score is the summed time to completion for items

1 to 5 for ages 5 to 7 while the score is the summed time to completion for items 4 to 8 for ages 8-17. Unlike Matching Numbers and Planned Codes, bonus marks are not given for accuracy on Planned Connections; however, time taken to correct errors via prompting from the examiner is incorporated into the timed score. The average internal reliability for Planned Connections across ages is 0.77.

Planned Connections originates from a task included in the Army Individual Test Battery (1944) that was incorporated by Reiten (1955) into the Halstead-Reitan Neuropsychological Battery (HRNB). Planned Connections' prototype currently is the Trail Making Test within the HRNB (Reitan, 1992). The main differences between these two tests is that the graduated level of difficulty of the items within Planned Connections that makes it well-suited to younger children and older brain-damaged children (Gutentag et al., 1998). Another major difference between these two tests would be that in Reitan's version both an intermediate and an adult form are constructed. The intermediate form is used for children aged 9 to 14 years of age and consists of 15 stimuli rather than the 25 in each form in the adult version. Item 8 of Planned Connections consists of 26 stimuli arranged in an alternating number and letter format. In the CAS standardization sample, verbal protocol analysis revealed that adoption of more complex strategies increased from a low of 76% at age 5 to 96% at age 17 (Naglieri & Das, 1997, p. 86). Older children tended to use more complex strategies such as repeating the alphabet/number series to themselves and these were strategies that were infrequently used by younger children (< 17% at age 5).

In Gutentag et al.'s (1998) study Planned Connections was moderately discriminating between traumatic brain injury children and controls. Given the similar nature of the Trail Making Test (TMT) with the CAS's Planned Connections, a detailed summary of the neuropsychological properties of the TMT will follow. Crowe (1998) has recently parsed the essential elements of the TMT and derived a series of 11 component measures in a large neurologically healthy sample of college students using factor analysis for which Part A and B were predicted variables. Part A was uniquely predicted by *visual search* and *motor speed* measures while Part B was predicted by the visual search and *cognitive set shifting*. Crowe's study points to TMT A and B as measuring different cognitive functions. Although TMT is among the most commonly used test in neuropsychological practice, owing to it high sensitivity in diagnosing brain damage (Lezak, 1995; Spreen & Strauss, 1998) it is ineffective in lateralizing lesions (Heilbronner, Henry, Buck, Adams & Fogle, 1991).

In another context TMT was found by Lafleche and Albert (1995) to be discriminating of mild Alzheimer's disease compared to matched healthy controls along with three other executive function tasks. An analysis revealed that patients were most impaired on tasks relying upon concurrent manipulation of information. Another dementia study in which the TMT was used found that 67% of Alzheimer's patients' errors were related to an inhibitory deficit whereas normal elderly adults had only 24% errors of an inhibitory nature -- a performance pattern that was more obvious on Part B (Amieva et al., 1998). This inhibitory deficit is hypothesized to be indicative of deterioration of a frontal-mediated performance component on the TMT although it has been noted that the TMT is also highly sensitive to diffuse brain damage (Lezak, 1995). The TMT has also been found to be discriminating of patients with cerebrovascular and Alzheimer's dementia compared to controls although this task could not discriminate between these two patient groups (Barr, Benedict, Tune & Brandt, 1992). Finally, Rasmusson, Zonderman, Kawas and Resnick (1998) found that completion times on Part B accounted for a significant proportion of the variance in dementia scores in a large unselected sample of elderly people after statistical correction for age, education and gender.

Starkstein et al.'s (1988) account suggested that caudate lesions, as is often found in Huntington's disease, result in selective impairments on the TMT (e.g., Planned Connections) and Symbol substitution tasks (e.g., Planned Codes). In another study illustrating the sensitivity of the TMT to subcortical lesions, Alegret et al. (2000) examined the effects of surgical removal of the posteroventral aspect of the globus pallidus in advanced stage Parkinson's disease, before and after surgery, while 'on' or 'off' dopaminergic medication. Before pallidotomy patients performed better while on medication on TMT B and a reversed pattern was found after surgery. The authors hypothesized that the improvement in sequencing ability as measured by TMT B before surgery was interpretable in terms of a general improvement in motor function. Patients were also administered a verbal fluency task before and after surgery and performance was impaired for both 'on' or 'off' medication conditions. These results imply a more complex and dynamic interplay between pallidal integrity, dopaminergic tone and executive function than was previously believed to be the case.

Recall that Shum, McFarland and Bain (1990) established that Digit Symbol, SDMT (e.g., Planned Codes), Letter Cancellation (e.g., Number Detection) and the TMT all loaded on the first factor of visuomotor scanning or tracking in a battery of eight tests of attention. Furthermore, Starkstein et al. found that when the variance accounted for by TMT A was partialled out statistically (thus controlling for visual search and motor speed) the correlation between caudate atrophy and TMT B still remained highly significant. In view of the results of Crowe (1998) this implies that caudate atrophy is strongly related to impairments in mental tracking and cognitive set-shifting. By extension Planned Connections is likely sensitive to dysfunctions of subcortical dopaminergic tone in neurodegenerative disorders as well as to integrity of structures within the basal ganglia, especially the caudate nucleus and globus pallidus.

Clearly the TMT is sensitive to subcortical damage, however there is an unresolved and continuing controversy as to whether Part B of TMT is an 'executive function' marker task and hence sensitive to frontal lobe lesions additionally. Arbuthnott and Janis (2000) found that the TMT B/A performance ratio, an index of executive function, correlated well with other executive tasks measuring set-switching where the motor and perceptual demands were minimized. Reitan and Wolfson (1995) found no significant differences on Part A or B of TMT between frontal and non-frontal lesioned patients nor were differences between left versus right frontal lesions significant. Similarly, Anderson, Bigler and Blatter (1995) found no significant differences between a frontal and non-frontal TBI group of patients on the TMT although there was a marginally significant trend in this direction on TMT A. However TBI is a marker for more generalized diffuse axonal injury (DAI) that is not apparent on conventional magnetic resonance imaging, therefore the non-frontal group may have had non-specific neural damage that was not represented in imaged cortical atrophy. A similar study by Johnstone, Leach, Hickey, Frank and Rupright (1995) contradicted these findings and demonstrated that frontal lobe TBI patients tested several years after injury manifested a specific impairment on TMT B compared to demographically-matched controls. Non-frontal TBI patients in contrast were impaired on both TMT A and B compared to controls.

These results again suggest a specific frontal contribution to the set-shifting or mental flexibility aspect of TMT B.

Others including Crockett, Hurwitz and Vernon-Wilkinson (1990) compared the performance of psychiatric, anterior and posterior lesioned patients on the TMT. There were no significant differences between anterior and posterior lesioned patients on the TMT although psychiatric patients performed significantly better than anterior and posterior lesioned patients on TMT A ($p < 0.01$) and TMT B ($p < 0.05$). D'Esposito et al (1996) studied recovery of executive function following anterior communicating artery rupture. Patients were divided into two groups: those with bilateral medial frontal lesions including the anterior cingulate (group 1: $n = 5$) and patients with basal forebrain lesions (group 2: $n = 5$). Only on the verbal fluency and Trails B task was the extent of recovery on 4 executive measures significant when measured at 3 and 4 months ($p < 0.05$). Group 1 was impaired on 3 out of 4 executive measures while group 2 was unaffected on 3 of 4. Finally, from a practical standpoint, the TMT is largely invulnerable to the effects of aphasia (Ehrenstein et al's study as cited in Spreen & Strauss, 1998, p. 538) making it suitable for use with left hemisphere patients.

Attention Scale Tasks

Expressive Attention

Expressive Attention uses two different sets of items depending on the age of the examinees. For children ages 5 to 7, the child's task is to judge whether the stimulus picture is either a large or small animal, regardless of the relative size of the pictures on the page (item 1). The tests interference items are usually opposite the actual size (item 3) and only item 3 is used for scoring purposes. Although the young children's version of Expressive Attention captures the essential interference effect of the Stroop test it has some dissimilarities from the latter in that it emphasizes visuospatial analytical processes unlike the classic Stroop test. For this reason, performance on the iconic version of Expressive Attention may recruit different neural subsystems than its counterpart and discussions will therefore be restricted to the version of Expressive Attention used with older examinees.

In contrast, examinees older than 8 years of age are presented with three pages. On the first page, examinees read color words (e.g., Blue, Yellow, Green, and Red) presented in quasi-random order.

Examinees then name the color of a series of rectangles (printed in blue, yellow, green and red). Finally, the words Blue, Yellow, Green, and Red are printed in a different color ink than the colors the words name. The examinee is instructed to name the ink color that the word is printed in, rather than read the word aloud, as fast possible without any errors. Performance on the last page is used as the measure of attention. Examinees have three minutes to name the color of the ink that the 40 words are printed in. The subtest score is based on the combination of time (speed) and number correct (accuracy) for each page completed. The summed scores are then converted into a cumulative ratio score where a combination of high speed and accuracy boosts the score. Although only item 6 is used for scoring purposes, item 4 (Word Reading Time) and item 5 (Color Naming Time) provide potentially useful neuropsychological information to the examiner and careful timing and observation of errors on these tasks should be made. Spreen and Strauss (1998, p. 214) note that the two initial neutral conditions (e.g., word reading and color naming time) administered before the interference condition can be used to tease apart motor slowing from cognitive dysfunction in brain-damaged patients. Unfortunately, the norms provided in the CAS manual do not allow for this comparison. Expressive Attention has an average internal reliability of .80 across ages 8-17.

Expressive Attention is virtually identical to Stroop's (1935) original version that is routinely employed in clinical neuropsychological practice. McLeod (1991, p. 203) summarized a number of key findings common across studies examining the Stroop. These include: (1) that it is the orthographic and particularly the acoustic/articulatory relations between the irrelevant word and the to-be-named ink color that make the most contribution to interference effects; (2) as the word's semantic relatedness to the concept of color increases, so does its power to interfere; (3) greater interference can be elicited if an unrelated word's meaning is primed shortly before the color-naming trial; (4) and that there is generally greater interference for orthographic languages like English when the Stroop is presented to the left hemisphere. Initially, the cause of the Stroop effect in normal subjects was attributed to the faster reading time as opposed to color naming that set in motion multiple responses competing for output or the so-called response competition model.

Das and Naglieri (1997, p. 18) note that "the conflict between the two choices occurs at the point of output or expression" hence their derived name Expressive Attention. Posner and Snyder (1975) originally discussed this distinction between controlled and automatic or highly practiced tasks although currently, it is known that interference occurs at all levels of processing from encoding to the time of response (Cohen, Dunbar & McClelland, 1990). Moreover, Wingfield, Goodglass and Lindfield (1997) note the case of a primary progressive aphasia patient with localized posterior cortical atrophy whose speed of reading was no faster than his speed of naming but who still demonstrated the Stroop effect. Wingfield et al note that this data critically challenges the identification of automaticity with processing speed and instead is congruent with an account based on slowing of this patient's phonological access via the written word (encoding) without weakening the connection strength between semantic associations -- so that the interference effect is still shown. In contrast to the multitude of cognitive studies with the Stroop test, there have been far fewer published neuropsychological studies with this task.

Perret's (1974) widely cited initial finding of performance sensitivity on the Stroop to left frontal lesions has recently been disputed. Vendrell et al (1995) found that patients with lesions in the right anterior cingulate (n=13) performed significantly poorer than patients without these lesions (n=19) in naming time and in the interference Stroop condition. Patients with right lateral lesions (n=12) similarly made more errors than patients without such lesions (n=20) but who still sustained frontal lesions. Patients with left frontal lobectomies (n=5) performed normally on naming time, the interference Stroop condition, and number of errors compared with controls. These analyses were conducted using a multiple regression approach with high-resolution lesion localization that could account for the discrepancy between the findings of Vendrell et al. and Perret's earlier study. Interestingly in Vendrell et al's study only 71% of patients with frontal lobe lesions performed normally on the Stroop implying that it cannot be considered a globally 'frontal lobe marker' test.

Stuss's (1991) study of five patients with large bilateral orbitofrontal lesions who made good recovery from neurosurgery as 'treatment' for schizophrenia, is illuminating on the non-specificity of the Stroop to exclusively frontal lobes lesions. In Stuss's study, orbital patients (n=5) performed normally compared to matched controls on word reading, color naming and the interference condition suggesting that it is the integrity of dorsal rather than the inferior aspects of the prefrontal cortex that are necessary for performance on the Stroop. Ahola, Vilkkii and Servo (1996) came to the same conclusion in a sample of anterior communicating artery rupture patients in which the damage was localized to mainly the inferior medial aspects of the frontal lobes but who had unimpaired Stroop test performance.

Recently event-related fMRI which has advantage of invulnerability to habituation confounds and changes in behavioral strategies typical of block-design fMRI was used to parse the neural circuits involved in performance on the Stroop test. Leung et al (2000) found that performance on the Stroop specifically activated the anterior cingulate, insula, premotor and inferior frontal regions and that the right frontal regions had an earlier time-course of activation than the left hemisphere. In agreement with earlier lesion studies, orbital regions were not activated by the Stroop task. Khateb et al. (2000) corroborated this pattern of a dominancy of the right anterior cingulate for performance on the Stroop using a combination of EEG source localization and event-related potential mapping.

In addition to its utility as a neuropsychological task sensitive to anterior cingulate and right dorsolateral prefrontal cortex damage, the Stroop has also been found to be useful in studies of dementia. In a longitudinal repeated measures design spanning 3.5 years, initially, non-demented Parkinson's patients were administered a comprehensive neuropsychological battery. Only picture completion of the WAIS, the interference section of the Stroop, and a verbal fluency task were predictive of later dementia diagnosis (Mahieux et al., 1998). Others have replicated this finding of the sensitivity of the Stroop to both Parkinson's and Huntington's disease (Starkstein et al., 1988; Hanes, Andrewes, Smith & Pantelis, 1996). In addition Koss, Ober, Delis and Friedland (1984) noted a sensitivity of the Stroop to early Alzheimer's disease although in severe cases the interference effect was completely attenuated. These findings were attributed to disinhibition and breakdown in the semantic network because of gross cortical atrophy.

Number Detection

Number Detection is a two page paper and pencil subtest. Examinees are required to underline in pencil 45 target numbers among 135 distracters arranged in 15 rows and 12 columns for a total of 180 targets and distracters. Children aged 5 to 7 complete items 1 and 2 while ages 8 to 17 complete items 3 and 4. On item 3 examinees are presented in the upper right hand corner of the page with the numbers 1, 2, and 3 printed in stenciled open font. Examinees must then search and underline matching target numbers among regular number and stenciled font distracters within a 150 second time limit. On item 4, examinees are presented with the letters 1, 2, 3 printed in regular font and 4, 5, and 6 printed in stenciled font. Again, examinees must search and underline the corresponding numbers among regular number and stenciled font number distracters within a 150 second time limit. The number of false detections is subtracted from the number of correct detections to give an accuracy score. The subtest score is based on the combination of time (speed) and number correct (accuracy) for each page completed. The summed scores for items 3 and 4 are then converted into ratio score where a combination of high speed and accuracy boosts the score. Subjects are given several practice items before starting items 3 and 4 so that the examiner can infer that the subject has understood the task. Subjects are then instructed to complete items 3 and 4 in the same manner. The average internal reliability across ages is 0.77.

Number Detection's most similar neuropsychological analog would be any of the cancellation tests devised by Diller et al (1974) to measure sustained attention, visual scanning, activation and inhibition of rapid responses. The essential vigilance task consists of rows of letters or numbers interspersed with targets and the difficulty of such tasks can be increased by (1) decreasing the physical space between characters; (2) increasing the number of distracters; (3) using spatial gaps between targets; or, by (4) varying the number of targets (Lezak, 1995). Diller and colleagues' standard administration consisted of six 52-character rows in which distracters were randomly interspersed with approximately 18 targets in each row. Diller et al's task yielded a target frequency of 35% as opposed to Number Detection's 25% target rate. Another important difference between the two tasks is the field of view. In Diller et al.'s original version, a wide-angle horizontal field of view is emphasized while in Number Detection examinees are presented with a more restricted horizontal field of view and an elongated vertical field of view. Scoring can be based on speed, errors or false detections, and omissions for the whole page or segregated by hemifields. The latter format can be used to quantify visual neglect by calculating the relative proportions of omissions in each hemifield by drawing an imaginary line down the center of the page.

Generally, randomly distributed targets and nonverbal shapes rather than verbalizable shapes, (e.g., letters) elicit greater inattention. Moreover, patients with lesions on the left side rarely exhibit right neglect except in the acute phase while right posterior parietal and to a lesser extent frontal lesions are particularly apt to result in left visual field attention deficits (Lezak, 1995). Binder, Marshall, Lazar, Benjamin and Mohr (1992) noted a peculiar pattern of letter cancellation task deficits with unimpaired line bisection (Diller et al, 1974) associated with right frontal or basal ganglia lesions. Posterior lesions were associated with impaired line bisection several cases of whom had no cancellation deficit. More recently an fMRI study of horizontal line bisection found increased neural activity in the: parietal lobes bilaterally (though predominately on the right), early visual processing areas bilaterally, the left cerebellar hemisphere, anterior cingulate and bilateral prefrontal cortex (Fink, Marshall, Weiss & Zilles, 2001).

Interestingly line bisection and letter cancellation scores were not correlated with each other in Binder et al's unselected sample of right hemisphere stroke patients. These findings imply dissociable right anterior and posterior neglect syndromes, the former corresponding to an inability to expect and detect changes in a sequential cognitive representation while the more common posterior neglect syndrome may be described as a distorted perceptual representation of external space. In the context of the CAS the greater potential working memory load of item 4 of Number Detection (e.g., 6 distinctive characters) as opposed to conventional line cancellation task's two characters suggests that Number Detection might display a relatively greater sensitivity to right anterior as opposed to right posterior lesions.

Recently, digit cancellation tests have been used in the clinical assessment of dementing disorders, in particular, Alzheimer's disease. Della Sala, Laiacona, Spinnler and Ubezio (1992) deconstructed the digit cancellation task into its cognitive processing components via task analysis yielding three sequentially arranged sets of actions: (1) assigning a special salience to the two target digits leading to a privileged representation in a working memory buffer, (2) scanning the sequence of digits line by line from top to bottom, and (3) penciling out a target. These authors note that this divided attention task's step 2 would more likely involve a feature or serial rather than automatic or parallel search such as occurring during the pop-out effect. Thus whenever the search is for three or more spatially independent digits acting as targets in the same matrix, a featured conjunctive search or controlled processing is required. Number Detection item 3's three targets and item 4's six targets might be expected then to elicit relatively greater control, working memory capacity, sequencing, attention, and effort on a continuum from low to high.

Additionally, Della Sala et al. analyzed the error patterns made by Alzheimer's patients to infer at which steps the patients were failing their digit cancellation task. There was little impairment in the first step since false detections were relatively rare in this group of patients. An impairment of the second step in Alzheimer's patients -- namely the perceptual decision while scanning -- seemed to be the hallmark of Alzheimer's behavior. Three distinct patterns were noted: (i) unsystematic within-line scanning in spite of the left-right reading procedure suggested by the examiner in practice trials, (ii) another was 'looking without seeing' in which patients passively scanned such that perception did not trigger and pace cancellation or gaze shifting (omissions), and (iii) Alzheimer's patients were slow at making the discriminating decision. Defective performance on the motor step three was only a factor for 2 of 74 Alzheimer's patients with severe parietal lobe dysfunction attributable to Balint's syndrome.

Collectively these results are consistent with the hypothesis that poor cancellation test performance (or more generally poor performance on divided attention tasks where rapid shifts in attentional resources are required) is mainly due to passively scanning and slowness in the perceptual decision. The failure to deploy attentional resources effectively between scanning and perception suggests that processing resources are actually insufficient. This hypothesis is corroborated by the similar error pattern of healthy controls when performance is speeded or frontal lobe patients performing the regular scanning task -- mainly a greater proportion of omission in all three populations. The poor performance of Alzheimer's patients on the digit cancellation test is congruent with prominent deficits on divided attention tasks found by previous investigators (Baddeley, Logie, Bressi, Della Sala & Spinnler, 1986). These results imply that the similarly constructed Number Detection subtest may be a suitable dementia-screening test when used in conjunction with the other CAS subtests since 24% of Della Sala et al's Alzheimer patients demonstrated little or no performance deficit on the digit cancellation test when used alone.

Receptive Attention

Receptive Attention is a two page paper and pencil test. On the first page, letters that are physically the same (e.g., BB but not Bb) are targets. This is a physical similarity classification task with a time limit of 120 seconds. On the second page, letters that have the same name (e.g., Aa not Ba) are targets. The latter task is a more difficult lexical similarity classification task with a time limit of 180 seconds. Page one consists of 200 pairs of letters arranged in 20 rows and 10 columns with 50 targets (25% targets). Page two consists of 200 pairs of letters with 51 targets and the same set of distracters (n~150). The number of false detections is subtracted from the number of correct detections to give an accuracy score. The subtest score is based on the combination of time (speed) and number correct (accuracy) for each page completed. The summed scores are then converted into ratio score where a combination of high speed and accuracy boosts the score. Both the physical match and lexical match ratio scores are added together to give a Receptive Attention raw score. For each page, subjects are instructed to either underline the letter pairs that are exactly the same (physical match) or alternatively have the same name (lexical match). Subjects are given several practice items before starting either the physical or lexical match page so that the examiner can ensure that the subject understands the task. The average internal reliability across ages is 0.77.

Receptive Attention is modeled on two tasks developed by Posner and Mitchell (1967, p. 394), a paradigm in which subjects were required to classify pairs of stimuli [letters] either as same or different by pressing the key of a tachistoscope apparatus. Using this protocol, Posner and Mitchell found a consistent average difference in reaction time of 71 milliseconds in favor of physical match for these two tasks. The magnitude of this difference would translate into a minimum cumulative 4-second difference in favor of physical match if the subject were to complete the entire set of 200 items. Incidentally physical match ratio scores are consistently greater than those of lexical match across ages with mean scores on each subtask increasing incrementally from ages 5 to 17. Error analysis (false detections) for both physical and lexical match as well as separate total time and number correct scores for each of these tasks would provide potentially useful neuropsychological information although separate tables for this type of analysis is not provided in the CAS *Administration and Scoring Manual*.

The lexical/physical identity task paradigm was popularized in studies of hemispheric asymmetries using divided visual field presentation formats. Kok, van de Vijver and Bouma (1985) presented physical and name identity letter pairs to either the left or right hemispheres. Reaction time measures demonstrated a right visual field superiority for lexical matches and a left visual field superiority for physical matches. Banich and Belger (1990) also used a divided visual field presentation of physical/lexical identity letter pairs of increasing difficulty. These investigators established that while coordination between hemispheres during a simple physical identity task is detrimental to performance, parallel processing of the hemispheres becomes advantageous in more complex tasks such as lexical identity. In the context of understanding hemispheric lateralization patterns underlying reading skills Cormier and Tomlinson-Keasey (1991) examined the specialization for letter-matching in children aged 6 to 8 using a tachistoscopic presentation paradigm. These investigators found a constant left hemisphere advantage in reaction time for verbal stimuli in grades 1 and 2 and a small right hemisphere advantage in kindergartners' accuracy of letter matching. These findings provide some support for a developmental progression in changes in visual field advantages. Such changes could relate to neuropsychological patterns of differential hemispheric advantages underlying reading subskills perhaps through mechanisms of maturation of commissural fibers in children within these age ranges thereby enabling efficient cross-hemispheric coordination of processing resources.

In the context of adult neuropsychology research Eviatar and Zaidel (1994) studied three commissurotomy patients performing these dual-matching tasks presented either to the right or left visual fields. Pairs of letters were presented either unilaterally to each hemisphere or bilaterally -- with each hemisphere receiving one of the letters to be compared. All patients could perform letter matches when using nominal and physical decision criteria when presented unilaterally even when visual field and response hand were crossed. However cross hemisphere comparisons of letter identities was not possible for any patients while only one of three patients could cross hemisphere compare physical identities. These studies suggest that the Receptive Attention task could be useful in identifying neurodevelopmental disorders where there is presumed to be abnormalities of the corpus callosum (e.g., Fischer, Ryan & Dobyns, 1992) by using a task decomposition method in conjunction with other CAS subtest profiles.

In a variation of Posner's physical/lexical match task, subjects were presented with two conditions (Hines, Poon, Cerella & Fozard, 1982). In the first condition, two digits were to be judged 'same' only if they were identical [physical match] whereas in the second condition, a rule level match was required in which only pairs of digits that were both odd (i.e., 7 and 3) or both even (i.e., 6 and 4) were judged as same [lexical-semantic match]. Mixed odd-even pairs were judged as 'different'. Subjects consisted of two groups: undergraduates (mean age = 21) and older subjects (mean age = 71). Older subjects had longer reaction times than younger subjects and subjects in both age groups took longer to make rule-based judgments. In both the physical and rule-match conditions the effects of age were highly significant which these authors attributed to deterioration of encoding mechanisms in the aged. In a better controlled study using three age groups with mean ages of 20, 60, and 69, Gutentag and Madden (1987) similarly found that there was a larger increase in reaction time with age in the attention demands of the encoding or comparison of lexical identity as opposed to physical identity. The authors note that this finding is congruent with Craik and Byrd's (1982) premise that one should find a dramatic increase with age in the attention demands of 'deeper' processes involving memory retrieval than in the demands of 'shallower' perceptual analysis procedures associated with physical identity tasks.

Simultaneous Scale Tasks

Nonverbal Matrices

Nonverbal Matrices is a 33-item non-timed subtest that utilizes shapes and geometric designs that are interrelated through spatial or logical organization. Examinees are required to decode the relationships among the parts of the item and choose the best of the six options to occupy a missing space in the grid. Each matrix is scored as correct or incorrect and the subtest score is based on the total number of items answered correctly. For the purposes of neuropsychological investigations, examiners should start all examinees at the sample item followed by item 1. Nonverbal Matrices included in the CAS was originally developed by Naglieri (1985) in the Matrix Analogies Test and this in turn is similar to Raven's Standard Progressive Matrices (Raven, 1958). Nonverbal Matrices average internal reliability across ages is 0.89.

Nonverbal Matrices consists of items involving completion of geometric patterns, spatial visualization and reasoning by analogy in order of increasing difficulty. Pattern completion items require the individual to examine the direction and shapes in a diagram to determine which of six options accurately completes the pattern. Spatial visualization items are solved by combining the diagrams within a row and a column to obtain the solution or by imagining how a shape will look when it is manipulated spatially. Reasoning by analogy items requires the individual to analyze the matrix diagram conceptually on the basis of the specific variable(s) (i.e., shape, size, shading) that change and determine how these changes converge to result in a new figure. These latter sets of problems are the most difficult and are conceptual as opposed to perceptual in nature. A classification of the individual items in terms of processing dimensions would include items 1 to 9 as involving almost exclusively pattern completion. Items 10 to 20 involve predominately spatial visualization whereas increasingly difficult items from 21 to 32 involve mostly conceptually based analogical reasoning skills. Healthy 17 year olds can be expected to successfully complete 21 items. Therefore if one is interested in comparing performance on visuoperceptual versus analogical reasoning type items, items 1 through 9 should be grouped into set 1, and 10 and above should be grouped into set 2.

The Raven's Standard Progressive Matrices (RSPM) was originally developed to be used as a 'culture-free' measure of intelligence and since then it has been used extensively as a measure of nonverbal or fluid intelligence and reasoning (Spreen & Strauss, 1998). The Raven Colored Progressive Matrices (RCPM) (Raven's, 1965) consisting of 36 items (as opposed to the RSPM's 60 items), grouped into three sets of 12 items. It was developed for children ages five and a half to adult. The lower floor level of difficulty of the RCPM items renders it suitable for neuropsychological studies and it is perhaps most similar to Naglieri's Matrix Analogies Test. Early work demonstrated that the Raven's Matrices are highly sensitive to visual neglect in early stages of recovery after right hemisphere stroke and that this deficit significantly resolves itself within six months (Campbell & Oxbury, 1976). Berker and Smith (1988) also demonstrated that the Raven's Matrices were especially sensitive to right posterior lesions, and that anterior lesions were less deleterious to performance on this task.

In an effort to reduce the problem of erratic responses associated with unilateral spatial neglect and to understand the relative contributions of the two hemispheres to this task without the confound of visual neglect, Caltagirone, Gainotti and Micelli (1977) devised a simple yet ingenious method of administration. This procedure involved the presentation of the complex figure containing the missing piece on the same side of bisected space as the lesion within the patient's hemisphere (e.g., a left hemisphere lesioned patient would have been presented the complex figure in their left visual field and vice-versa). Furthermore, presenting the six alternatives in a column along the midline minimizes the confounding effects of visual neglect. In subsequent neuropsychological studies, this modified RCPM task has been the most extensively studied using the three sets of RCPM items to examine presumed differential hemispheric contributions to performance on these tasks.

The CAS's Nonverbal Matrices, with its presentation of the complex stimulus figure similar to the Raven's Matrices does not allow for the restricted hemifield presentation of Caltagirone et al. Therefore, like the RSPM and the RCPM, the Nonverbal Matrices is vulnerable to the potential confound of visual inattention independent of brain-damage induced decrements in cognitive performance -- especially as a result of right posterior lesions. However it is possible that cutting and pasting the Nonverbal Matrices items within the CAS's Stimulus Book on to a white backdrop could easily adopt Caltagirone et al.'s format. This would of course require norming of Nonverbal Matrices with an appropriate reference group.

In other studies using the modified RCPM format of Caltagirone et al Denes, Semenza, Stoppa and Gradenigo (1978) compared the improvement of left and right stroke patients. Patients were tested within a week of admission and two months later. The greatest improvement was observed in the right hemisphere patients in set B while for the left hemisphere group, greater improvement was found in set A. The authors concluded that the RCPM is a non-homogenous test and that improvement after stroke is chiefly due to residual perceptual and cognitive capacities of the intact hemisphere.

As with the Nonverbal Matrices the RCPM consists of individual items that Villardita (1985) classed as involving principles of sameness, symmetry, or analogy. Items involving sameness presumably depend on perceptual abilities while those involving symmetry imply internal verbalization for the analysis of item characteristics, and those involving analogies depend on conceptual thinking. Using the modified RCPM, Villardita divided subjects into 4 groups: right hemisphere stroke patients, left hemisphere stroke patients without aphasia, stroke patients with aphasia, and demographically-matched controls. Group performance patterns were compared on sets I (completion or sameness), set II (symmetry or visualization), and set III (analogical reasoning). Interestingly, left hemisphere patients with aphasia performed the poorest in terms of total RCPM score (sets I, II, III combined).

Right hemisphere lesioned patients performed significantly poorer than left hemisphere non-aphasic patients on set I, while left hemisphere aphasic patients scored significantly poorer than left hemisphere non-aphasic and right hemisphere patients on set II. On set III, which emphasizes analogical reasoning, right hemisphere patients scored significantly better than both left hemisphere groups. These results suggest that set I is dependent on the integrity of perceptual organization modules localized within right hemisphere. Subjects appear to rely on linguistic mediation to solve items from set II since aphasics selectively performed poorest on this set. Set III was only sensitive to left hemisphere damage suggesting a left hemisphere dominance in solving the most complex problems. This hypothesis is congruent with Zaidel, Zaidel and Sperry's (1981) assertion that only the left hemisphere is capable of benefiting from the opportunity of error correction via verbal mediation as witnessed in the performance of commissurotomy and hemispherectomy patients on the modified RCPM.

Similarly, Gainotti, D'Erme, Villa and Caltagirone (1986) studied the effect of focal brain lesions with the modified RCPM in a larger sample of patients than Villardita's study. When the effects of lesion size, education, and age were statistically controlled, there was no effect of laterality of lesion although subjects with aphasia scored significantly poorer than left hemisphere patients without aphasia. Also, impairment was greater in (receptive) posterior lesioned aphasics than anterior lesioned aphasics (fluent). These findings are also consistent with the importance of bilateral posterior temporoparietal regions co-extensive with receptive language areas in optimal performance on the RCPM.

In a recent fMRI study normal subject's performance on problems adapted from the three sets of the RCPM were compared to the activation pattern associated with simple visuospatial pattern matching control tasks (Prabhakaran et al, 1997). This group found evidence in support of distributed neural networks being involved in performance on the RCPM. Analogical reasoning (e.g., set III) problems activated bilateral frontal, left parietal, occipital, and temporal regions to a greater extent than figural reasoning problems (e.g., set II). Right frontal and bilateral parietal regions were activated more by figural reasoning than pattern matching while figural reasoning problems selectively activated areas involved in spatial and object working memory. Analogical reasoning problems activated other areas involved in verbal working memory and executive function suggesting that fluid intelligence involves a network of memory systems working in a distributed but concerted manner.

The RCPM has also recently demonstrated its utility in the detection of visuospatial impairments in patients in the early stages of Parkinson's disease without dementia (Cronin-Golomb & Braun, 1997). Compared to controls, early stage Parkinson's patients made significantly more errors on the RCPM. Defective performance on set I of RCPM by the Parkinson's patients was also significantly correlated with their performance patterns on other tests of visuospatial function including mental rotation, reading of road maps, and copying geometric figures. In contrast, correlations between Parkinson's patients' performance on the RCPM set I and executive function and verbal memory measures were not significant suggesting that set I is uniquely predictive of visuospatial dysfunction early in the course of the disease before the onset of dementia. The authors attributed this impairment to involvement of a disconnection of the thalamocortical circuit that includes the dorsolateral prefrontal cortex and the posterior parietal lobes common to both human and other primates (Selemon & Goldman-Rakic, 1988).

Verbal-Spatial Relations

Verbal-Spatial Relations is composed of 27 items that require the comprehension of grammatical descriptions of spatial relationships depicted in accompanying sets of pictures and stimulus sentences. Examinees are shown items containing six drawings and a printed question at the bottom of each page. The items involve pictures of people, objects and shapes that are arranged in a specific logical and spatial manner. For example, the item, "Which picture shows a circle to the left of cross under a triangle above a square?" includes six drawings with various arrangements of geometric figures, with only one exactly matching the description. The use of content items such as pictures of children with toys on items 1 through 10 makes this test suitable for use with young children. Norms are provided for individuals aged

5 to 17 years, although children younger than 5 years of age may successfully answer many of the easier items 1 through 10. The examiner reads the question aloud and then the examinee is required to select the option that best matches the verbal description. Examinees are required to indicate their answer within thirty-seconds to receive a correct response. The subtest score reflects the total number of items answered correctly. The average internal reliability across ages is 0.83.

Verbal-Spatial Relations earliest predecessor would be the Token Test, originally devised by De Renzi and Vignolo in 1962. Poeck and Hartje (1979) described a variation of this test which was administered in both the standard auditory presentation format as well as separately using the visual presentation of the sentences. Assessment in the auditory and written formats of the Token Test is a useful clinical tool in isolating performance dissociations between these two modalities. Auditory comprehension problems often result from lesions confined to Wernicke's area and visual comprehension deficits (alexia), often result from lesions within the association areas of the visual cortex. The CAS could be readily adapted for these purposes for both experimental and clinical purposes by simply covering the stimulus sentence at the bottom of the stimulus book for the auditory presentation or having the examinee read the sentences in the visual presentation format without the examiner's verbal prompt.

Neuroanatomical studies of performance on the Token's Test have been conducted in stroke lesion patients these results have been correlated with sensitive modern psycholinguistic tests of syntactic comprehension yielding significant relationships (Naesser et al, 1987). In one such study, patients with nine different forms of aphasia and heterogeneous lesions were tested on the Boston Diagnostic Aphasia Examination or BDAE (Goodglass & Kaplan, 1972), the Token test, and the Palo Alto Syntax Test or PAST (Peraino, 1976), involving ten common types of syntactic classes of contrasts. Using the PAST, subjects were instructed to point to the appropriate picture after the experimenter read a logical grammatical sentence that matched one picture among three foils in a manner similar to the CAS's Verbal-Spatial Relations. The mean total number of errors on the PAST for each aphasia group closely paralleled the overall comprehension levels as tested by the BDAE (r = .91), Token Test (r = .88) and BDAE and Token Test (r = .90). In an earlier study by Naessar and colleagues (1981) correlations between lesion size and PAST were found to be significant (r = -.75), BDAE (r = -.61), and Token Test (r

= - .67). A rank order of difficulty of the PAST items revealed that gender, on/under, negative/affirmative, object number and subject number were the five easiest pairs whereas past/present, subject/object reversible, is/are, relative clauses, and future/present were the five most difficult pairs.

The rank order of difficulty of these items was similar between Wernicke's aphasics and anterior aphasics (e.g., transcortical motor aphasia, Broca's, subcortical aphasia) although the mean number of errors made on each PAST contrast pair was always greater for the Wernicke's group than the anterior lesion groups. Naesser et al (1987) subsequently undertook a detailed error analysis between aphasia groups on the PAST items for which there were four choices (pictures) for the examinee to choose from. The types of pictures available for response to each PAST sentence included the correct picture, the opposite of the syntactic contrast picture, and two semantically related foils. Verbal-Spatial Relations is similarly constructed although more psychometrically sound in that it provides for six alternatives: a picture for the correct response, the opposite of the syntactic contrast picture (foil), and four semantically-related pictures ranging in proximity from close to far in meaning (foils).

In Naessar et al's (1987) study young children were also assessed and compared with the aphasic patients for the purposes of understanding the development of syntax. For mildly aphasic and 6-year old children, 90% to 100% of the incorrect pictures chosen were pictures for the opposite contrast sentence. In severe cases of aphasia, global aphasics choose only 52% of their incorrect responses as the opposite syntactic contrast, and even choose 7% of their reponses as remote semantically related pictures. Three-year-old children were most similar compared to severe Wernicke's aphasics. Three-year old children's' incorrect choice of the opposite contrast picture was 72% compared with 83% of severe Wernicke's patients. When number of errors on each of the ten separate syntactic contrast pairs of the PAST was considered in a discriminant function analysis, 12 of 12 anterior aphasics and 13 of 14 posterior aphasics were correctly classified.

Subject-object reversible and relative clauses were the most impaired in severe aphasia. Subject-object reversible sentences involve items such as "The boy is hitting the ball" vs. "The ball is hitting the boy" whereas relative clauses consist of sentences such as, "The guard who has the rifle stops the robber" vs. "The guard stops the robber who has the rifle". The Verbal-Spatial Relations subtest would be similarly amenable to this type of error classificatory analysis and might prove useful in studies of dementia where recent studies have successfully examined response biases at the item level in these populations (Amieva et al, 1998). Error types on the Verbal Spatial Relations could likewise be classed into opposite contrast, semantically close or remote responses yielding potentially useful information in terms of diagnostic efficacy or early detection of dementia changes.

The results of Naessar et al's (1981; 1987) studies indicate that severe syntactic comprehension deficits are often associated with extensive temporal lobe lesions witnessed in cases of Wernicke's and global aphasia. In contrast lesions outside Wernicke's area are often associated with milder syntactic comprehension deficits. The left perisylvian region within the left hemisphere and especially the posterior superior temporal gyrus, appeared to be particularly sensitive to syntactic comprehension difficulties. The surrounding perisylvian areas including parts of the inferior frontal and parietal lobes also exhibited localization characteristics for these syntactic processes.

A recent fMRI study of syntax in neurologically normal healthy adults provides an additional perspective on syntactic processing underlying performance on tasks such as the Token Test, Palo Alto Syntax Test and the Verbal-Spatial Relations subtest of the CAS. Dapretto and Bookheimer (1999) demonstrated that at least in normal brains it is the pars operculis of Broca's area (BA 44) that is critically implicated in processing syntactic information whereas the lower portion of the left inferior frontal gyrus (BA 47, pars orbitalis) is selectively involved in processing the semantic aspects of a sentence. In this functional neuroimaging study the subject's attention was implicitly directed towards deciding whether two sentences were the same or different, and the choice involved either syntactic or semantic processing. Sentences were matched for level of difficulty and content as closely as possible. In addition to these two selective and unambiguous peak activations associated with each type of task, language-processing regions more typically implicated by lesion studies also demonstrated foci of activation. These regions included the superior and middle temporal gyrus, supramarginal and angular gyrus. Furthermore, there was relatively greater activation in the syntactic condition only within portions of the middle temporal gyrus, the temporal pole, and the angular and supramarginal gyrus. Overall greater activation was found within the left hemisphere in terms of both magnitude and extent compared with right hemisphere homologous regions.

It appears that frontal and temporoparietal regions implicated in language processing by lesion studies are also activated in Dapretto and Bookheimer's functional neuroimaging study. However, this functionally distributed perisylvian language system is modulated by the particular linguistic function maximally engaged by a given item's processing characteristics. Syntactic processing was associated with a greater volume of activation within the posterior temporoparietal cortices despite identical difficulty across conditions. This finding is in agreement with previous studies suggesting that language processing varies as a function of the computational demands imposed by the cognitive task (e.g., semantic versus syntactic processing) even when qualitative differences in processing do not involve quantitative differences in processing time (Just, Carpenter, Keller, Eddy & Thulborn, 1996). This group found larger volumes of activation in both Broca's and Wernicke's areas as a function of syntactic complexity (e.g., processing difficult object relative clauses versus subject relative clauses versus active conjoint clauses) that points to the functionally distributed and computational resource limited nature of syntactical processing. Processing of syntactically complex items with multiply-embedded relative clauses as is found on the most difficult items of the Verbal-Spatial Relations might be expected to involve a widely distributed functional language network including frontal, temporal, and parietal cortices.

Another promising test of syntactic comprehension that has been developed and normed in the UK is the Test for the Reception of Grammar or TROG (Bishop, 1989). This test is similar to both the PAST and the Verbal-Spatial Relations subtest of the CAS. The TROG is a four-choice sentence-matching task containing 80 items, divided into 20 blocks testing different lexical, morphosyntactic, or syntactic constructions. As with the PAST and the CAS, the choices consist of semantic and syntactic pictographic foils and the author provides detailed item-by-item information using error analysis. The TROG has recently demonstrated its sensitivity in detecting the early stages of dementia of the Alzheimer's type (DAT) dementia. Croot, Hodges and Patterson (1999) demonstrated that early stage DAT patients demonstrated sentence comprehension deficits that conventional instruments such as the Mattis Dementia Rating Scales or the Mini-Mental Status Examination were unable to detect. Performance on the TROG was highly related to DAT severity independent of memory impairments highlighting the need for continual development of sensitive syntactic comprehension instruments. Also of interest was that like Naessar and colleagues' studies of aphasic stroke patients, embedded clause sentences of the TROG items elicited significantly more errors and successfully classified even minimally demented patients.

Figure Memory

Figure Memory* is a 27-item subtest in which examinees are shown two- or three-dimensional geometric figures for five seconds. The figure is then removed and the examinee is presented with a response page that contains the original design embedded in a larger, more complex geometric matrix of fine lines. Examinees are asked to identify the original design embedded within the more complex figure by outlining it with a red pencil. To be scored correct, all lines of the design have to be reproduced without any additions or omissions. The score reflects the total number of items correctly completed without any errors. The drawn responses make this subtest particularly suited to qualitative analysis of constructional praxis error patterns. The average internal reliability across ages is 0.89.

Figure Memory is modeled on a number of copying tests used in neuropsychology. Among the most commonly used is the Benton Visual Retention Test or BVRT (Sivan, 1992) in use by Benton and colleagues since 1946. Such copying tests derive from Poppelreuter's overlapping figures test developed in the 1920s (see Spreen and Strauss, 1998, pp. 500-501). The BVRT consists of three alternate forms consisting of ten items each. Under separate administration conditions, the examinee is required to copy the geometric figure on a blank sheet of paper after either a 5 or 10-second delay. The score is the total number of correct items as well as the number of errors. The BVRT utilizes a standard error classification procedure that facilitates clinical interpretation of results. Errors can include: omissions, distortions, perseverations from previous items, rotations, misplacements, and relative size errors.

Figure Memory does not presently use such an error analysis schema although Spreen and Strauss's classification could be readily adopted in neuropsychological studies with the CAS. The chief difference between the Figure Memory task and the BVRT is that in the latter the geometric figure must

*The author should point out that the term *Figure Memory* should not be taken as an affront on the conventions of political correctness!

be redrawn entirely from memory therefore emphasizing visual memory, in addition to the visual recognition and visuoconstructive aspects of the task. In Figure Memory the geometric figure is embedded within a complex design on a response item therefore emphasizing visual perceptual disembedding.

The Embedded Figures Test or EFT of Witkin, Oltham, Raskin and Karp (1971) consists of 16 straight line drawings that are used as stimulus figures on the left side of the page while the right half of each page contains the stimulus figure in which the stimulus figure is embedded. Spreen and Benton have used this task at the University of Victoria Neuropsychology Laboratory since 1969. As with the CAS Figure Memory, examinees are required to search for and trace the stimulus figure in the complex design although in EFT there is no delay between presentation of the stimulus figure and complex geometric response figure. Unlike the BVRT, the EFT has a distinctive visual search component in addition to its visuoconstructive properties. Items of both the BVRT and Figure Memory have a delay between presentation of the stimulus and response -- emphasizing short-term visual memory. Moreover, some of the items of each of these tasks can be readily verbalized, therefore one might expect that, depending on item characteristics different items might have differential propensities for hemispheric lateralization.

Early studies suggested a right hemisphere processing bias for the EFT based on lesion studies (De Renzi & Spinnler, 1966) and a greater sensitivity to anterior as opposed to posterior lesions (Egelko et al, 1988). Other studies of brain-lesioned patients note that patients with both left hemisphere damage with aphasia or anterior damage performed poorly on this test (Teuber, Battersby & Bender, 1951). In a study by Russo and Vignolo (1967), left hemisphere lesioned patients without aphasia performed similarly to normal controls while aphasics performed the worst. In a summative evaluation, Corkin (1979) suggested that the degree of impairment on the EFT was more closely associated with the size of the lesion than to the laterality of it. Finally, in an on-line version of the EFT administered within a functional magnetic resonance imaging experiment, an even clearer illustration of the neural networks critically involved in performance on this task have been demonstrated (Ring et al, 1999). Neurologically normal individuals demonstrated characteristic activation of bilateral parietal regions, right dorsolateral prefrontal cortex, and bilateral occipital cortex consistent with preferential activation of the dorsal visual stream during performance on the EFT (Ungerleider, Courtney & Haxby, 1998).

The cousin design copying test, the BVRT, has also been studied extensively in neuropsychological studies and appears to be particularly adept at detecting subtle visual memory deficits early in the dementing process. Netherton et al (1989) found that figural reproduction errors increased when Parkinson's patients were tested 6 months apart while no apparent increase in errors were found for elderly age-matched control subjects. The BVRT has also demonstrated its potential utility in the early detection of visual memory disturbances and was predictive of later diagnosis of Alzheimer's disease as early as six years prior to onset even after adjusting for age, general ability, and immediate memory (Zonderman et al, 1995). In the context of neurodegenerative diseases lesions within the corpus callosum of multiple sclerosis patients were found to be particularly detrimental to performance on the BVRT perhaps highlighting the inter-hemispheric coordination of processing that is necessary for optimal performance on this task (Ryan et al, 1996). Collectively, the results with the BVRT indicate that the Figure Memory task would be sensitive to the early effects of dementing processes and its wide range of item difficulties (27 for Figure Memory versus the BVRT's 10) may provide for the assessment of even more subtle early changes in visual memory functions.

Another test that is most similar to Figure Memory is the Visual Patterns Test or VPT (Wilson, Wiedmann, Hadley & Brooks, 1989; Della Sala, Gray, Baddeley & Wilson, 1997). This test is essentially a visual working memory task minus the spatio-sequential component. The main difference is that gross cubes in VPT must be disembedded and drawn in by the examinee in the response form's matrix template. VPT's cube disembedding nature may render it less sensitive to confound due to occipital lesions. Another advantage of VPT is that it contains two parallel forms although there are only 15 items per form. VPT was normed on neurologically normal adults with a mean age of 42 (range 13 to 92). A significant correlation was found between VPT and age ($r = -.55$) as well as VPT and years of education ($r = +.42$). Moreover, males demonstrated a small performance advantage on the VPT compared with females. As yet, no group data has been published on this task's neuropsychological specificity and sensitivity.

Successive Scale Tasks

Word Series

Word Series requires the examinee to repeat words in the same order as stated by the examiner. The task consists of the following nine single-syllable, high frequency words: Book, Car, Cow, Dog, Girl, Key, Man, Shoe, Wall. The task consists of 27 items in total. Each series ranges in length from 2 to 9 words, presented at the rate of one word per second. Items are scored as correct if the examinee reproduces the entire word series in the correct sequence. The score is based on the total number of items correctly repeated. The average internal reliability across ages is 0.85.

Word Series is modeled on the Wechsler scale's digit span forward using words of series ranging in length from two to nine items. Recall that WAIS-R digit span forward consists of two trials each of digit sequences. In Word Series, these two trials consist of words rather than digits. Among the earliest empirical studies examining word span in this manner were those by Talland (1965). In a systematic estimate of the immediate word span for unrelated monosyllabic items examined in individuals between the ages 20 and 69, it was found that there was an average free recall score of five that was remarkably stable across these five decades of life. Miller (1973) was the first to use this innovative span task in the manner most similar to that of digit span forward -- that is, requiring recall of words in the correct sequence. Comparing two age matched (mean age = 58) groups of Alzheimer's and control subjects, Miller found that in controls the mean span was five words while in demented patients it was four.

Traditional digit span measures have been criticized because this procedure is insensitive to the normal of effects of aging. Such verbal span measures have given rise to tests with increased sensitivity to immediate memory span by employing techniques with more than eight items (Trahan, Goethe & Larrabe, 1989, p. 82). Such supraspan tests do have greater developmental sensitivity and predictive utility (Benton, Hamsher, Varney & Spreen, 1983). In practice the neuropsychological properties of digit span forward have been studied more often than word span in brain-damaged patients. Trahan et al found that 46% of left hemisphere unilaterally lesioned stroke patients scored below the suggested cutoff score compared with 33% of right hemisphere unilaterally lesioned stroke patients and 25% of severe closed head injury patients with diffuse damage. These figures contrast with the impairment rates of 13%, 24%, and 16% impairment rates as detected by the WAIS-R digit span. These data suggest that word span is more sensitive to the effects of brain damage and perhaps left hemispheric injury than traditional digit span measures. A moderate correlation between these two tasks (r = 0.35) in these subjects suggests that these two tasks are measuring similar processes.

Digit span forward is a test of immediate auditory memory and it is also sensitive to the examinee's capacity to focus and sustain attention (Kaplan, Fein, Morris & Delis, 1991, p. 23). The Word Series and digit span tasks are similar in terms of the cross-correlation profile of these two tasks, however word series is different from digit span forward in that all of the nine words that comprise Word Series are concrete, familiar, and high in imagery. It is conceivable then that retention of these words might be optimized by dually coding items using visual and verbal coding strategies (Paivio, 1995). Incidentally, there is an unexpected double plateau within the CAS standardization sample data for Word Series rather than a smooth increment in performance with increasing age. The first starts at approximately age eight and the second starts at about the age of 12. A dual coding account might argue for a greater right hemispheric role in the processing of this verbal span task than that of digit span forward on par with that of the spatial visualization account of dissociations in performance between digit span forward and backward (Kaplan et al, 1991).

Digit span has clearly been more widely studied than word span measures in so far as group neuropsychological data is concerned. Black and Strub (1978) found that on digit span forward, left posterior lesioned patients scored lowest (mean = 4.9) while right posterior patients (mean = 6.2) were not significantly different from controls (mean = 7.0). In the left hemisphere there was a 0.9 spread between anterior (mean = 5.8) and posterior lesions (mean = 4.9), while in the right hemisphere this pattern was reversed such that anterior patients (mean = 5.5) scored 0.7 points lower than posterior patients (mean = 6.2). Although these anterior-posterior differences were non-significant perhaps owing to the small sample sizes, the trends are congruent with Kaplan et al's (1991) statements that performance on digit span forward is reliant on immediate auditory memory and sustained attention. Immediate auditory recall has been shown previously to be especially sensitive to left posterior lesions involving parts of Heschyl's gyrus, middle temporal and superior temporal gyrus and inferior parietal lobule; moreover, these lesion foci correlated well with characteristic error patterns (Gordon, 1983). In contrast, sustained attention has been found to be especially impaired as measured by several different tests of this construct after right anterior lesions (Rueckert & Grafman, 1996).

Sentence Repetition

Sentence Repetition requires the examinee to repeat 20 sentences that are read aloud. Each sentence is composed of color words (e.g., "The blue is yellowing"). The examinees are required to repeat each sentence exactly as the examiner read it. Color content words are utilized, so that the sentences contain no meaning, to help reduce the influence of semantic cues and accentuate the demands placed upon syntactic processing of the sentence. Each item is scored correct if the sentence is repeated exactly as stated by the subject to the examiner. The subtest score reflects the total number of sentences correctly repeated. The average internal reliability of Sentence Repetitions across ages is 0.84.

Lezak (1995, p. 364) notes that length, meaningfulness, familiarity, and speed at which the examiner speaks sentences are all important factors determining the repeatability of them. McCarthy and Warrington's (1987) study of memory for word lists and sentences demonstrated evidence of a double dissociation between neural networks supporting these two processes. Sentence Repetition was facilitated in conduction aphasics with poor repetition but good comprehension by increasing the meaningfulness of stimuli. In contrast increasing the meaningfulness of stimuli had no effect on performance for a transcortical sensory aphasic with good repetition but poor comprehension. The patient's ability to repeat sentences was also compared with their ability to repeat three words contained within the sentences. The conduction aphasics were better at repeating sentences than in repeating three-word lists whereas the transcortical sensory aphasics were better at repeating three-word lists than at repeating sentences. Transcortical sensory aphasics were also tested using sentences with familiar and unfamiliar words with the finding that repetition was better with familiar words. The authors suggested that these results are consistent with two systems: the first, a relatively passive phonological store supporting word list memory and the second, an integrative memory system underpinning sentence repetition.

Since Sentence Repetition in the CAS is constructed so that the sentences are semantically meaningless it is conceptually similar to Botwinick and Storandt's (1974) *Silly Paragraphs* task. These tasks involved recall of nonsensical information which subjects are then asked to repeat verbatim as soon as the examiner has finished reading the sentence. In Silly Paragraphs*, the sentences are lengthened and repetition, but not verbal comprehension, is emphasized. An analysis of subjects between the ages of 20 and 70 revealed that age accounted for more variance in performance on silly paragraphs than comparison meaningful sentences. Also, education had a differential positive effect on recall of silly paragraphs ($p < 0.0001$) as opposed to meaningful information ($p < 0.01$). In the CAS version of the task, we can see that access to semantic representations will not provide any additional information. For these reasons one might expect the CAS version of Sentence Repetition to be a more difficult task than other sentence repetition tasks and it may be especially useful with elderly populations, given evidence of such tasks' sensitivity to aging effects.

In part Tarbuck and Paykel (1995) tested just this scenario by administering silly sentences/paragraphs to young and elderly groups of people recovering from depression. Among a battery of tasks, silly sentences was the only one for which there was a significant age by depression interaction such that the older group did not exhibit the same degree of recovery as the younger group. This discrepancy could not be explained by reduced motor speed in the elderly but was attributed to slow information processing of a cognitive nature. Few, if any other neuropsychological studies have been conducted with the silly sentences test.

Selnes, Knopman, Niccum and Rubens's (1985) large study of an unselected sample of aphasic stroke patients with neuropsychological and neuroradiological correlation underscored the importance of Wernicke's area in sentence repetition tasks. These investigators assessed patients at one month and six months post-stroke on sentence repetition and other tasks of the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983). Wernicke's area was defined as including the posterior superior temporal lobe and the infrasylvian supramarginal gyrus. A strong correlation between lesion size within Wernicke's area and the severity of the repetition deficit was found ($r = -.63$) but lesions within the infrasylvian supramarginal gyrus without extension into the posterior superior temporal lobe did not result in a persistent deficit of the ability to repeat sentences at six months. Without exception, all patients who did

*An example of such a Silly Paragraphs phrase is: "I eat pink mice. They are delicious but their green fur gives me heartburn" – adapted from Botwinick and Storandt's (1974, p. 114).

not recover the ability to repeat sentences by six months after onset had damage to Wernicke's area. Conversely, none of the patients with repetition performance in the normal range had substantial involvement of the posterior superior temporal lobe. Lesions elsewhere within the left hemisphere, especially within the perisylvian territory, including the posterior insula, suprasylvian supramarginal gyrus, and the parietal operculum were associated with transient repetition deficits in the immediate months following stroke. Anterior lesions extending past the central sulcus and including Broca's area were not associated with any impairment in repetition.

Sentence Questions

Sentence Questions is a 21-item subtest. Examinees are read a cue sentence and then asked a question. For example, the examiner states, "The blue is yellowing" and then asks the following question: "Who is yellowing?" The correct answer is of course: "blue". Responses are scored correct if the examinee successfully answers the question and the subtest score reflects the total number of questions answered correctly. The average internal reliability across ages is 0.84. Sentence Questions is constructed like Collins and Quillan's (1969) original False Sentences task. False Sentences is a reaction time memory task although Sentence Questions is untimed. In this earlier task, subjects were presented with a series of statements that are obviously true (e.g., "A bird has wings?") or false (e.g., "Hockey is a race?"), and were asked to answer accordingly in a yes/no format.

The CAS's Sentence Questions has the decision component of Collins and Quillan's (1969) False Sentences task although the decision is not based on a choice reaction time paradigm, -- rather, it is based on syntactic as opposed to semantic analysis of the stimulus sentence. False Sentences involved decisions about the properties of semantic categories implied by sentences, half of which were true and half of which were false. In contrast, Sentence Questions involves recall of key elements of the semantically meaningless sentence based on the order in which the words are presented. As a result, examinees must rely on their knowledge of syntax in order to answer the questions correctly. In future experimental studies of Sentence Questions it might be useful to measure reaction time and errors (e.g., word substitutions, paraphasias) in the overall analysis of a subject's performance on this unique task. There is no published data available on the utility of the False Sentences task in neuropsychological populations and therefore we will refer to more general syntactic comprehension tasks.

Caplan, Hildebrandt and Makris (1996) conducted a large study that included detailed neuroradiological examinations on patients with left hemisphere lesions, right hemisphere lesions and compared these individual's performance with that of normal control subjects. Subjects were tested with sentences that had previously been used with stroke patients to test for comprehension (Caplan, Baker & Dehaut, 1985). In a manner similar to CAS's Sentence Questions these authors required that "subjects structure the sentences syntactically and not simply rely on real-world knowledge to determine the correct meaning of these sentences" (Caplan et al 1996, p. 935). Subjects were tested on a wide range of sentences with varying syntactic arrangements. Lesions in the left rather than the right hemisphere affected syntactic comprehension the most although right hemisphere lesioned patients also performed significantly poorer than controls on these tasks. Lesions within the left perisylvian association cortex consisting of superior temporal gyrus, the inferior frontal gyrus, angular gyrus, supramarginal gyrus and parietal operculum were all sensitive to deficits in syntax comprehension. The authors speculated that the results were consistent with a broadly based left perisylvian region as being most important for syntactic processing but that the right hemisphere has a role to play perhaps in less specialized working memory processes in syntactically complex linguistic constructions.

Additionally, there were no differences in syntactic comprehension scores between anterior and posterior left-perisylvian lesioned patients consistent with the hypothesis that syntactic processing involves a widely distributed neural network. A well-designed PET study of normal subjects found a localized increase in regional cerebral blood flow within the pars operculis of Broca's area when subjects made acceptability judgments for syntactically more complex than syntactically less complex sentences (Stromswold, Caplan, Alpert & Rauch, 1996). It appears that assignment of syntactic structures in sentence comprehension requires the coordination of multiple distributed sites within the perisylvian region, a network with both distributed and localized processing characteristics (Caplan et al, 1996).

Summary: Predicted Patterns of Impairment

Planning: Mini-Review

Matching Number's prominent features of visual search amongst distracters (Binder, Marshall, Lazar, Benjamin & Mohr, 1992; Husain & Kennard, 1997), mental tracking, and working memory requirements (Black, 1986; Leskelae et al, 1999) suggest that it should be sensitive to frontal and perhaps maximally right frontal lesions. Smith (1991) reports that no systematic evidence has been found that the Symbol Digit Modalities Test has any lateralizing properties although other studies found performance on this closest analogue of the Planned Codes test to correlate well with basal ganglia damage (Starkstein et al., 1988; 1989; Sanchez-Pernaute et al., 2000). Damage to the anterior cingulate (D'Esposito et al., 1996; Rousseaux et al., 1996), dorsolateral prefrontal (Stuss et al., 2001) or basal ganglia (Starkstein et al., 1988; Alegret et al., 2000) all should significantly disproportionately affect performance on the sequencing task of Planned Connections.

Attention: Mini-Review

Expressive Attention is identical to Stroop's (1935) classic task. Stuss et al. (2001) found that patients with focal lesions of bilateral superior medial frontal cortex performed poorest on the interference condition while patients with posterior lesions were not significantly deficient in any condition. The Leung et al. (2000) event-related fMRI study of the Stroop found that the task specifically activated anterior cingulate, insula, premotor and inferior frontal regions while Khateb et al.'s (2000) EEG source localization study implicated the right anterior cingulate. Vendrell et al. (1995) similarly found that the integrity of the right anterior cingulate was the crucial neuroanatomical structure involved in performance on the Stroop task. Number Detection is similar to many cancellation tasks (Diller et al., 1974) and Binder et al. (1992) noted that such tasks are maximally sensitive to right frontal or basal ganglia lesions. Additionally Weinberg and Harper (1993) implicated the right parietal lobe as being especially involved in vigilance tasks.

Finally, the Receptive Attention task modeled on Posner and Mitchell's (1967) physical and identity match tasks have been demonstrated to be sensitive to callosal injury (Eviatar & Zaidel, 1994; Marangolo et al., 1998; Banich et al., 2000) by impairing cross-hemisphere comparisons of verbal identity information. Kok et al. (1985) found a right visual field superiority for lexical matches and a left visual field superiority for physical matches. Using a similar technique but with three-letter word or non-word strings Brand et al. (1983) found evidence for a serial, letter-by-letter means of analysis by the right hemisphere and a whole word approach for the left. Using a dual-hemispheric presentation of physical and identity matches in normal subjects, Banich and Belger (1990) demonstrated that coordination across hemispheres for physical match impedes efficiency of processing whereas cooperative parallel hemispheric processing enhances performance on lexical identity tasks. These results imply that interhemispheric transfer (IHT) facilitates performance by allowing for division of processing between hemispheres so that task-relevant information can be efficiently managed by a hemisphere that has a smaller processing load (Weissman, Banich & Puente, 2000).

On the basis of these findings, it would be predicted that individuals with abnormalities of the corpus callosum as in callosal agenesis would be expected to have difficulties on visual and tactile IHT tasks (Fischer, Ryan & Dobyns, 1992). In the context of qualitative aspects of performance on the Receptive Attention subtest of the CAS this could manifest itself as a proportional decrease in the number of correct responses within the left side of hemispace on item six compared with the right half of hemispace. Few published studies have examined the neuroanatomical correlates of these tasks. Gevins, Cutillo and Smith (1995) found that nonverbal patterns (physical match) elicited a P475 peak that was larger than for letter strings (identity match) over the right frontal and temporal regions. In contrast, a P620 potential in the left temporal regions was elicited during the lexical (identity) match.

Simultaneous: Mini-Review

On the Simultaneous scale, Nonverbal Matrices is closest in construction to Raven's (1965) Coloured Progressive Matrices (RCPM) and this test has been extensively used in neuropsychological studies. The potential for visual neglect to confound visuoattentional difficulties with genuine cognitive difficulties is a problem with the use of Nonverbal Matrices as currently constructed in the CAS. Nonetheless, standard administrations of the RCPM have been highly sensitive to the right hemisphere damage (Campbell & Oxbury, 1976). Berker and Smith (1988) found that the RCPM was especially sensitive to right posterior lesions and that anterior lesions were less deleterious to performance on this task. Villardita (1985) found that on set I (perceptual completion or sameness) RCPM patients with right hemisphere lesions performed poorest while on set II (symmetry or visualization) patients with aphasia performed the poorest suggestive of linguistic mediation of these items. Finally, set III (reasoning by analogy) were only sensitive to left hemisphere damage suggesting a left hemisphere dominance for complex problem solving. This is congruent with Zaidel, Zaidel and Sperry's (1981) demonstration that only the left hemisphere is capable of benefiting from error correction via verbal mediation as witnessed in the performance of commissurotomy patients when items were presented to the right visual field[*].

Finally, Prabahakran et al.'s (1997) fMRI study of modified RCPM items yielded the following results: analogical reasoning items activated bilateral frontal, left parietal, occipital and temporal regions whereas figural reasoning items activated bilateral parietal and right frontal structures. Collectively, these studies suggest that parietal regions figure prominently in performance on this relatively pure measure of fluid intelligence consistent with previous reports of lesions to the right posterior cortices resulting in the largest decrements in full-scale intelligence test scores (Warrington, James & Maciejewski, 1986).

Verbal-Spatial Relations is a task of complex syntax comprehension modeled on Peraino's (1976) Palo Alto Syntax Test. Naessar et al's (1987) study demonstrated that severe syntactic comprehension deficits were associated with extensive left temporal lobe lesions with Wernicke's aphasia while lesions outside of Wernicke's area (e.g., anterior perisylvian lesions) were often associated with mild syntax comprehension deficits. The posterior superior temporal gyrus, left inferior parietal, and the inferior frontal regions also appear specialized for syntactical comprehension. A recent fMRI study of syntactical comprehension similar in format of the Verbal-Spatial Relations revealed that the pars operculum of Broca's area (BA 44) was critically involved in syntactic as opposed to semantic processing (Dapretto & Bookheimer, 1999). In addition to this focus of activation, a distributed perisylvian network of areas more

[*]Roger Sperry was awarded a Nobel Prize in physiology and medicine in 1981 for his more than 40 years of research on the brain. The prize was given specifically for his work on the "split–brain," in which he discovered that the two cerebral hemispheres of the brain had distinct functions. In one of his most important studies, Sperry asked subjects who had undergone split-brain surgery to focus on the center of a divided display screen. The word "key" was flashed on the left side of the screen, while the word "ring" was projected on the right side. When asked what they saw, the split-brain patients answered "ring", but denied that any other word was also projected onto the screen. Only the word "ring" went to the speech center in the left hemisphere. Although the right hemisphere cannot verbalize the information (the word "key") that was projected on the left side of the screen, subjects are able to identify the information nonverbally. Sperry asked subjects to pick up the object just named without looking at it. If subjects were told to use their left hand, they could easily identify a key. However, if asked what they had just touched, they would respond, "ring."

typically implicated in lesion studies was also activated -- including the superior and middle temporal gyrus, supramarginal and angular gyrus. Greater activation in the left hemisphere was found both in terms of magnitude and extent.

Others' notably Grodzinksy (2000), have argued that most of syntax is not located in Broca's area; rather, only the transformational aspect of syntax, or algorithms that implement its use is located in and around Broca's area. Based on multiple lines of evidence, Grodzinsky provided evidence that combinatorial aspects of language such as syntax are distributed broadly throughout the left hemisphere. Pickett et al. (1988) studied patients with profound bilateral damage to the putamen and caudate nucleus that had abnormally high error rates in comprehending distinctions in meaning conveyed by syntax. These authors attributed this deficit to a role for the basal ganglia in the regulation of sequencing across modalities and hence syntax. Finally Moro et al. (2001) isolated the functional correlates of morphological and syntactical processing using a paradigm in which the neutralization of the lexical-semantic component of written sentences was achieved by using pseudowords from which the detection of syntactic anomalies was required. Contrary to previous fMRI studies this one found that the left caudate nucleus and insula were activated only during syntactic processing indicating a prominent role for these structures in syntactic comprehension.

The neuropsychological tasks most similar to Figure Memory are Embedded Figures Test (EFT) of Witkin et al. (1971) and the Benton Visual Retention Test or BVRT (Sivan, 1992). Teuber et al. (1951) initially noted that left-hemisphere anterior aphasics performed poorly on the BVRT. Russo and Vignolo (1967) found that left hemisphere patients without aphasia performed similarly to normal controls while aphasics performed the worst on BVRT. These results do suggest some verbal mediation of such figural tasks. In a well-designed study, Grafman et al. (1982) found that performance on the BVRT could be dissociated from anarithmetia (or difficulties in performing mental computations), fluid intelligence, as measured by the Ravens's Matrices (1958), and receptive aphasia as measured by the Token's Test (De Renzi & Vignolo, 1962) in left posterior lesioned patients.

Earlier studies by De Renzi and Spinnler (1966) found a right hemisphere processing bias for the EFT as well as corroborating the finding of a greater sensitivity to anterior lesions for this task (Egelko et al, 1988). Despite subtle differences between these two tasks, EFT emphasizes figural disembedding from a template while BVRT emphasizes manual copying of the figure, thus the tasks are quite similar. Finally, in a recent fMRI study of autistic and normal controls using an on-line version of the EFT, activation was noted bilaterally in the parietal and occipital regions and within the right dorsolateral prefrontal cortex (Ring et al, 1999) implying dual hemispheric processing via the dorsal visual streams (Ungerleider, Courtney & Haxby, 1998) with perhaps a right hemisphere processing bias.

Successive: Mini-Review

The Word Series subtest of the CAS is closest in construction to the Miller's (1973) word span test that in turn is modeled on the digit span forward of the Wechsler Intelligence scales. The latter have been more often studied in focal brain lesion patients yielding sensitivities to left posterior lesions (Black & Strub, 1978). Kaplan (1991) suggested that performance on digit span forward was largely a function of immediate auditory memory and sustained attention, and Gordon (1983) earlier demonstrated that the former was highly sensitive to left posterior lesions involving Heschyl's gyrus, middle and superior temporal gyrus as well as the inferior parietal lobule. In contrast, sustained attention is more a function of the integrity of the right frontal lobe (Rueckert & Grafman, 1996).

Sentence Repetition of the CAS is similar to previous sentence repetition tasks with the chief difference being that the tasks are nonsensical. This mitigates the effects of lexicosemantic processing and it is modeled on Botwinick and Storandt's (1974) original Silly Paragraphs task. Selnes et al.'s (1985) large lesion study of patients performing sentence repetition tasks found evidence for sensitivity of this task to posterior superior temporal and infrasylvian supramarginal gyrus lesions. Lesions restricted to the supramarginal gyrus did not result in lasting sentence repetition deficits at 6-months post-stroke whereas posterior superior temporal gyrus lesions did. Muller et al.'s (1997) positron emission tomography study of expressive language function found that the strongest activation for overt sentence generation minus (sentence repetition) was seen in the left middle and inferior frontal gyri with additional activation of the left inferior temporal lobe. In contrast, covert (mental) sentence repetition activated bilateral superior temporal gyrus and the inferior parietal area in all epilepsy patients studied with fMRI (Lehericy et al., 2000).

Sentence Question's earliest predecessor would likely be Collins and Quillian's (1969) false sentences which require verification as to whether a sentence was plausible or not. The Sentence Questions subtest in contrast requires recall of syntactic information to correctly answer the questions since the cue sentences do not convey any semantic meaning. Similar types of syntactically structured prompt sentences requiring a response were used by Caplan, Hildebrandt and Makris (1996). These investigators found that lesions within both the left and right hemispheres resulted in deficits in performance compared to controls implying some syntactic functions within the right hemisphere, although left hemisphere lesions were much more debilitating than right hemisphere lesions. More specifically lesions within the left perisylvian cortex consisting of superior temporal gyrus, the inferior frontal gyrus, angular gyrus, supramarginal gyrus and parietal operculum were all sensitive to syntactic deficits as measured by this task. No differences were found between anterior and posterior persisylvian regions implying that the integrity of a distributed perisylvian network is essential in optimal syntax comprehension.

Functional MRI studies have also recently been used to parse the specific networks associated with syntax comprehension. Frederici, Meyer and von Cramon (2000) found an increase of activation in the left planum temporale bilaterally and in the deep portion of the left frontal operculum during syntactic processing in an fMRI study. Kuperberg et al (2000) demonstrated robust activation of the left inferior temporal and fusiform gyrus common to pragmatic, semantic and syntactic sentences suggesting that these areas construct a higher representation of the meaning of sentences. Another fMRI study of syntactic processing of sentences similarly described activation in the middle temporal gyrus, the temporal pole and the angular and supramarginal gyrus (Dapretto & Bookheimer, 1999) and there was greater activation within the left hemisphere in terms of magnitude and extent. Collectively the lesion and functional neuroimaging studies allude to the critical importance of left temporal, left inferior parietal and the left inferior frontal gyrus in syntax processing and together comprises a distributed perisylvian neural network.

Table 1: Neuropsychological properties of CAS predicted based on similar tasks

CAS Subtests	Cognitive, Perceptual, Motor Requirements	Most Similar Task to CAS Subtest	Major Differences Between CAS Task and Predecessor	Functional Neuroanatomical Substrates of Peformance on Analog Task	Utility in the Assessment of Dementia
Matching Numbers	visual search, working memory, motor speed	*Visual Search*, Teuber, Battersby & Bender (1949); Digit Span Backwards, Wecshler (1955)	field of view, duration, working memory and strategy requirements, written response	diffuse damage, right inferior frontal gyrus, anterior > posterior	visual search
Planned Codes	scanning, motor speed, strategy deployment	*Symbol Digit Modalities Test*, Smith (1991)	additional strategy requirements	diffuse damage, basal ganglia	motor slowing
Planned Connections	set-shifting, conceptual tracking, motor speed	*Trail-Making Test*, Reitan (1992)	None	anterior cingulate, dorsolateral prefrontal cortex, basal ganglia, unaffected by aphasia	set-shifting
Nonverbal Matrices	perceptual matching, analogical reasoning, fluid intelligence	*Raven's Coloured Progressive Matrices*, Raven (1965)	None	bilateral parietal lobes, right prefrontal cortex, figural reasoning items (object and spatial working memory systems), analogical reasoning items (left hemisphere co-extensive with language networks)	general intelligence
Verbal-Spatial Relations	syntax, verbal comprehension	*Palo Alto Syntax Test*, *Peraino (1976)*: *Test for the Reception of Grammar*, *Bishop (1989)*	Little Difference	left insula, basal ganglia, left inferior parietal lobule, left superior temporal gyrus, Broca's area	highly sensitive to early stage dementia?
Figure Memory	short-term visuospatial memory	*Visual Patterns Test*, Della Sala, Gray, Baddeley & Wilson (1997)	Little Difference	bilateral superior parietal lobes, right dorsolateral frontal lobe, occipital lobes	sensitive to early stage visuospatial disturbances in dementia?
Expressive Attention	response inhibition	*Stroop Test*, Stroop (1935)	None	anterior cingulate	-
Number Detection	vigilance	*Letter/Digit Cancellation Test*, Diller et al (1974)	None	diffuse damage, right frontal lobe > right parietal lobe, right basal ganglia	-
Receptive Attention	lexical categorization, perceptual identification	*Physical/Lexical Identity Match*, Posner & Mitchell (1967)	None	corpus callosum, left temporal, right frontotemporal	effects of aging on lexical encoding
Word Series	immediate auditory memory, sustained attention	*Word Span*, Miller (1973)	None	left temporoparietal region, right frontal lobe	-
Sentence Repetition	verbal working memory, repetition	*Silly Paragraphs*, Botwinick & Storandt (1974)	Non-sense sentences minimize semantic facilitation of processing	left posterior superior temporal, left inferior parietal lobule	-
Sentence Questions	verbal comprehension, syntactical processing	*False Sentences*, Collins & Quillian(1969)	Non-sense sentences minimize semantic facilitation of processing, non-timed, emphasis is on accuracy rather than speed	left temporal, left inferior parietal, left inferior frontal gyrus	-

Chapter 2: Methodological and Statistical Description and Analysis

Statement of the Problem

In their *Interpretive Handbook*, Naglieri and Das (1997a, p. 49) note "...test validation is an ongoing process based upon multiple investigations and methodologies. The findings presented in this section [p. 49-90] should be considered an initial examination of the [CAS's] validity". It is contended that further evaluations of the neuropsychological properties of the CAS are worth studying since models of cognitive ability have demonstrated significant educational advantages over conventional IQ tests, and the CAS is one of several models of cognitive ability designed with the biological metaphor in mind (e.g., Sternberg, 1997). In this context, Luria's theory, the PASS theory as operationalized in the CAS may prove to be a valuable research tool within experimental education. These orientations have the potential to conceptually and practically address assessment issues at the interface of child development, education, and cognitive neuropsychology; especially issues pertaining to: planning, executive function, self-regulation, and metacognition.

However, a rigorous scientific evaluation of the construct validity of the CAS requires more than factor analytic work and qualitative judgments of face validity. Determining the extent to which the CAS operationalizes the neural basis of PASS theory requires essentially a three-stage analysis: (1) A comprehensive and critical review of the neuropsychological specificity and sensitivity of the CAS tasks as inferred on the basis of similar tasks used with neuropsychological populations in prior published empirical studies; (2) limitations about the brain-damaged population to be sampled (e.g., establishment of inclusion and exclusion criteria); (3) collection of the data according to the protocol and analysis of the data using a pattern matching strategy whereby theoretical propositions empirically established in step 1 are systematically and recursively tested (Yin, 1995). Such a study can in theory be readily undertaken with stroke patients since brain lesions sustained as a consequence of stroke are often readily localizable to specific regions of brain and are often circumscribed with borders distinguishing normal from abnormal brain tissue (Bornstein & Brown, 1991).

Ethical Approval

An extensive multiple-stage independent ethical review process was completed before the study commenced. A protocol outlining the characteristics of the population to be studied, any inherent risks, and ethical safeguards to patient confidentiality was submitted on a standard form to the Chair of the Ethics Committee of the Department of Educational Psychology under the auspices of the Dean's Office, Faculty of Education at the University of Alberta. Written consent to proceed with the second stage of ethical review pending minor changes to the protocol was granted by the Chair of the Ethics Committee of the Department of Educational Psychology on February 23rd, 1998 after both internal (Departmental) and external (Faculty) review (see Appendix 6a).

A written ethical submission detailing the title, investigators, authorizing signatures, description of the project, description of the sample, inclusion/exclusion criteria, description of research procedures, informed consent, risks, benefits, privacy and confidentiality issues was submitted to the HREB. The requisite Health Research Ethics Board form is available online: http://www.hreb.ualberta.ca/applying.htm. This form was completed by Simon McCrea and Dr. Robert Short and submitted to HREB: B two weeks before the scheduled meeting time. The format of the proposal review, which took place in the Faculty Conference Room of Corbett Hall, is discussed under Appendix 6b.

The panel consisted of psychologists, physicians, and representatives of Capital Health. The half-hour meeting was a formal opportunity for the investigators to plead the scientific merits of undertaking the study and for the committee to determine if there were any serious risks posed to patients by the study. Dr Robert Short (Supervisor) and Simon McCrea (Principal Investigator) attended this meeting on April 3rd, 1998. HREB: B recommended minor changes be made to the written protocol and the finalized protocol was signed by the principal investigator, Simon McCrea and a co-investigator at the time of the commencement of the study (Dr. JP Das). Dr. Robert Short and Dr. Ashfaq Shuaib were also listed as co-investigators on this study. This protocol was also reviewed and granted approval by the Chair of the Department of Educational Psychology, Dr. Len Stewin (Appendix 6c).

A written tentative approval was granted pending minor changes to the wording of consent forms by HREB:B. Verbal recommendations were made at the April 3rd, 1998 meeting that investigators not be too restrictive in their inclusion criteria to avoid sample bias and perhaps use other instruments in addition to the CAS (Appendix 6d). The final changes were made in consultation with the rest of the investigators and the final letter of permission from the Chair of HREB: B was granted in May 1998 for one year (Appendix 6e). At this time, Dr. Ashfaq Shuaib gave a tour of the neurology wards to the Principal Investigator, introduced him to the neurology ward physicians, nurses, and residents, and reviewed protocols regarding patient safety in depth with the Principal Investigator. On May 29th, 1998 the Principal Investigator received picture identification detailing his affiliation as a researcher under the auspices of the Division of Neurology and the Department of Educational Psychology (Appendix 6f).

In April 1999, a progress report was submitted to HREB: B by the principal investigator. In May, 1999 the HREB: B granted an extension of the protocol for 1999-2000 (Appendix 6g). In the fall of 1999, approval was formally granted by the HREB: B for a modification of the protocol to be undertaken such that initially, recruited patients could be reassessed at 3 months with the CAS and the WAIS-R (Wechsler, 1981) as well as notification that Dr. J.P. Das was no longer a co-investigator on the study. The study was completed in December of 1999 and the HREB: B was submitted a précis of the written report that included the main findings and notification of completion (Appendix 6h).

Protocol Summary

The initial approved HREB: B research protocol called for the collection of neuropsychological, neuroradiological, neurological, history and qualitative test performance data from a minimum of 24 participants who had each sustained a brain injury – (Appendix 5 for inclusion/exclusion criteria). A partly crossed 2 factor design was used similar to Grafman et al's (1982) study of cognitive difficulties in persons with focal lesions in one of the four quadrants of the brain. The factor of side of lesion, left or right, was crossed with the localization of the lesion, anterior or posterior. This yielded a target of 6 left anterior, 6 left posterior, 6 right anterior and 6 right posterior lesions within the initial protocol.

Efforts were made to recruit patients at equal frequencies within the four cells at approximately equal time intervals during the duration of the study. However due to the differential debilitating effects of lesions within these regions of brain some participants, especially those from within the two posterior quadrants could not as easily meet inclusion/exclusion criteria. These and other difficulties limited the achievement of a balanced fully crossed factorial design. The description of the sample that was actually recruited will be discussed after delineating the inherent limitations associated with sampling within the constraints of a naturalistic setting.

Caveats Associated with Patient Recruitment

A legitimate concern regarding the recruitment of patients was the necessity for the assessment of patients in the sub-acute phase. The mean duration post-stroke that patients were actually assessed at was two weeks. Since a comprehensive neuropsychological examination of the subjects was not the aim of the assessment (e.g., assessments required on average one hour to complete with ample rest periods) an abbreviated assessment did not produce extreme fatigue in patients judging by observational and patients' own verbal reports. Moreover assessments were undertaken in the morning after breakfast. Lezak (1995, p. 116) notes that ...'within the first few weeks or months following an event of sudden onset [such as stroke or focal brain injury], a brief examination will be necessary.' Additionally this author notes that '...during the first six to twelve weeks following the event, changes in the patient's neuropsychological status can occur so rapidly that information gained one day maybe obsolete the next...'.

In sum lengthy formal neuropsychological assessments which often may require up to 8 hours in total time are to be avoided in the immediate post-stroke phase, although this does not exclude substantially abbreviated assessments, provided that the assessments are performed at approximately the same time from each other. Meier and Strauman (1991, p. 271) have noted that a striking feature of the effects of acute stroke are the wide range of individual differences in the recovery course over the weeks and months following the episode. Several determinants of stroke outcome include the localization and extent of the lesion, age, time since stroke, premorbid functioning, cerebral dominance or laterality of language and demographic factors. Previous studies have used research protocols that have successfully assessed cerebrovascular patients within the first few weeks after stroke. Meirer and Strauman (1991) note that covariance procedures for lesion volumes are recommended with large samples, and some assessment of language function is essential since late recovering functions post-injury occur frequently in higher order cognitive functions such as language.

From a methodological standpoint it is noted that Levine, Warach, Benowitz and Calvino (1986) assessed stroke patients initially as early as 2 weeks after stroke using constructional, attentional, reading comprehension and writing to dictation tasks. These investigators found that the severity of visual neglect, if present, was a direct function of lesion size and the integrity of the unaffected hemisphere. Others including Meier, Ettinger and Arthur (1982) demonstrated the utility of a higher order executive task, the Porteus mazes, as early as 1 week after a stroke in predicting later recovery of function on measures of verbal comprehension, language processing and visuoconstructional functioning. David and Skilbeck (1984) used the RCPM and various language measures and found a significant negative correlation between nonverbal IQ and severity of aphasia at only one-month post-stroke. Basso, Capitani, Della Sala, Laiconi and Spinnler (1987) examined patients between 2 weeks and 1 month post-stroke on measures of apraxia. These investigators stressed the importance of using a multifactorial approach when determining the relationship between apraxia and other neuropsychological measures in the prediction of future recovery.

Other laboratories have also conducted neuropsychological assessments of stroke patients in the immediate weeks after stroke. Knopman, Selnes, Niccum and Rubens (1983) conducted a stroke recovery study using an aphasia battery, a verbal comprehension test, a long-term memory test and a measure of speech fluency at one-month post-stroke. Stone, Patel, Greenwood and Halligan (1992) assessed stroke patients as early as *2 to 3 days* after stroke and found that recovery was maximal in the first 10 days in terms of the efficacy of predicting future recovery. Hanley, Pettit, Todd-Pokropek and Tupper (1985) assessed a large number of in-patients 2 weeks post-stroke on a battery of occupational, neuropsychological and psychiatric measures with few methodological difficulties. In conclusion there appears to be little reason to warrant concern over the assessment of stroke patients approximately 2 weeks post-stroke; although evidence clearly implies that patients should be tested as closely together as possible post-injury if at all possible.

Another significant factor that limited the recruitment of some patients was visual neglect as a consequence of extensive subcortical or right posterior lesions. Efforts were directed towards avoiding this situation by testing patients as close to their date of discharge as possible thus allowing for a significant amount of time to pass so that the neglect could resolve on its own. Other left posterior lesioned patients although not burdened with the effects of visual neglect often had significant receptive language difficulties to the extent that completion of the CAS was difficult. For these reasons only patients with rather small lesions of the posterior cortices with restricted perceptual and language impairments were included in the study.

Cognitive Assessment

After neurology patients were admitted to the University of Alberta Hospital (UAH), patients who met inclusion and exclusion criteria were asked in-person if they would like to participate in a study of cognitive functions following stroke. The director of the Department of Neurology was the coordinating and supervising physician. If patients agreed, an appointment was made at UAH between the principal investigator and the stroke patient immediately before their discharge. The median delay between stroke onset and assessment with the CAS post-stroke was approximately 14 days or two weeks. After this brief in-person introduction by the principal investigator detailing the purposes of the study, a 'Letter of Information' and a 'Letter of Consent' were verbally explained to the stroke patient item by item or alternatively with the primary caregiver and patient together.

Provided that the stroke patient agreed to participate and the consent forms were voluntarily signed by the stroke patient, a convenient time in the day was subsequently arranged to the undertake the assessment. Administration of the CAS usually took place in the patient's own neurology ward rooms within 4G3 or 4G4 just before the patient was discharged. In some cases, an additional assessment at 3 months post-stroke with the CAS and the WAIS-R was undertaken, although this was limited to a few instances and the data from these participants is not reported here. The initial assessments were scheduled in the morning and required approximately 1 hour to complete. In those few cases, where a 3-month assessment was performed, it was scheduled to coincide with neurological follow-up appointments. Ample rest breaks were provided during assessment in order to minimize fatigue and any discomfort to the patient.

Qualitative Aspects of Task Completion

Included in the interpretation of the results of this study was process-orientated data about how individual participants completed the CAS tasks (e.g., see Kaplan, 1988). By means of detailed notes kept on the observable performance patterns of patients, in combination with probe questions included in the CAS manual, inferences as to how individuals completed subtests and items was obtained. Factors such as accuracy, speed, and analysis of error patterns were collected within the CAS score sheet. Analysis of verbal reports collected according the CAS standardized instructions was undertaken after the assessment so this did not compromise the integrity of the standardized administration format. Patient's comments were transcribed in the margins of the CAS score sheet. Prompts included the following: "How did you complete this item?" Prompts were administered after completion of the last item or the final failed item in order to understand what aspects of each subtest or item individuals had difficulty with. More detailed reflective observations about the performance of participants were kept in a confidential, bound notebook as summative performance evaluations. Efforts were made to correlate patient verbal reports with observable patterns of behavior to infer what particular cognitive mechanisms may have been used to solve a task.

Neuroimaging Procedures

Computed axial tomography (CT) or in several instances magnetic resonance imaging (MRI) scans were available for all participants for subsequent analysis in consultation with neuroradiologists. Scans were obtained as part of routine clinical care with efforts made to match the time of the nearest scan with that of the cognitive assessment. The median delay between the nearest scan and the behavioral assessment was several days. An inclusion criteria was that neuroimaging demonstrated a single cortical or subcortical lesion. It should be noted that in some cases access to CT scan files was restricted in the interim period between admission and definitive diagnosis. Thus in a few cases patients were inadvertently included in the cognitive assessments who had either no lesion or more than one lesion despite clinical neurological evidence of a single infarct. Nonetheless these patients were included within the analysis for the purposes of testing the full range of performance on the CAS subtests.

Approximately half of the neuroimages were stored in digitized dicom format and were translated into computer-generated images using the software program Medisplay® available and downloadable online for free at: http://www.medisplay.com. The other half of the CT and MRI neuroimages were visualized by first making negatives of CT/MRI films from the radiology film library and then making high-quality 5" by 8" black and white reproductions. Lesions were visualized in the horizontal axis and the slice located at the maximal diameter of the lesion was used in each case. The photographs were then copied using a regular digital scanner while Medisplay images were directed inserted into the text of the case-by-case analysis in Chapters 3 and 4. In addition to these illustrative figures of the lesions' maximal diameter, location, and extent of damage within regions of the brain, a transcribed and abbreviated summary of the lesion was done for these individual case summaries using the neuroradiologist's original transcribed report.

Materials

Participants were assessed with the CAS (Naglieri & Das, 1997) and were questioned as to their handedness, educational attainment, occupation, and previous learning history. Alternatively, clinical neurological exam data included in each patient's chart as part of routine intake clinical exams by neurologists was reviewed for suitability for use in gauging the extent of aphasic symptoms.

Design and Sample

Stroke patients were recruited from wards 4G3 and 4G4 at University of Alberta Hospital. Patients meeting the inclusion and exclusion criteria were first screened by the clinical neurosciences coordinating nurse under the auspices of the Director of the Division of Neurology. Patients initially meeting criteria were then referred to the Principal Investigator. All prospective patients meeting the inclusion and exclusion criteria were contacted.

A multiple-case study embedded design was used to explore, describe, and explain the neuropsychological characteristics of the CAS. This initial single case analysis was conducted prior to a secondary between-subjects group analysis in which each participant was given 12 levels of a single treatment (e.g., CAS administration) only once. The data from participants who eventually completed both the initial and the three-month assessment was used primarily for pilot evaluation of the test-retest properties of the CAS in brain-injured patients. However due to the small sample size (n = 6) and therefore restricted sphere of generalizability these data were not included here. It should be qualified that for each individual the effects produced by each independent variable (e.g., 12 CAS subtests) are potentially problematic to interpret because the levels of the independent variables are confounded with the ordinal positions in which those levels are administered. Effects of independent variables could conceivably be due to genuine experimental effects or to practice effects. However there is evidence that differential transfer effects within test sessions, or ordering effects are minimal in neuropsychological practice. Lezak (1995, p. 127) has noted that the order of presentation of tests in neuropsychological batteries does not have appreciable effects on performance (Cassel, 1962) with the exception being that tasks requiring manual agility often demonstrate performance decreases towards the end of the day (Neuger, O'Leary, Fishburne et al., 1981). The authors of the CAS similarly used an identical format of administration of the CAS without apparent adverse differential transfer effects within individual tests sessions. In summary, scheduling patient appointments early in the morning after breakfast and only after a proper amount of sleep should dispel these concerns.

Statistical Procedures

Efforts were directed to preserve a balance between rich qualitative description and established quantitative methodologies essential in quality case study analysis (Yin, 1994). The author therefore reports each case individually in Chapters 3 and 4 followed by cross-case analysis of double dissociation patterns across tasks and individuals in Chapter 5.

The sample consists of data from 32 in-patients at the University of Alberta Hospital neurology wards meeting inclusion and exclusion criteria examined over an 18-month period (see Appendix B). Since this sample was relatively small the primary mode of analysis was a multiple case study embedded design (Yin, 1994). For the purposes of our discussion each subject was tested once using the CAS's 12 subtests approximately 2 weeks post-stroke. This resulted in approximately 384 data cells along with an individual detailed clinical history, neurological examination, qualitative test performance data, and neuroradiological lesion characterizations. Standard CAS administration instructions were used for this heterogeneous brain damaged sample. Since no adequate norms exist yet for the CAS for adults with a mean age of 47 (age range = 20 to 67), Russell's (1987) Average Z-Score Index (AZI) was used, which is a derivation and improvement of the widely used AIR method previously described by Russell (1984). The AIR or Average Impairment Rating has been in use since the 1970s (e.g., Russell, Neuringer & Goldstein, 1970) but lacked the more rigorous psychometric properties of the AZI approach. Among the key advantages of the AZI scale according to Russell (1987, p. 390) are it:

> ...can be used to create scale scores not only for the index tests but for any test utilized in any battery. In fact, one attribute of this method is that temporary scales can be created for a new test based on brain-damaged subjects alone. Thus, when a test is added to the battery, relatively accurate temporary scales can be created after a small number of brain-damaged subjects, 30 or more, have been collected. A large sample of normals is not needed. This is done by predicting their scores from the AZI. As a consequence new tests can be added to a test battery and scaled relatively quickly (p. # 390).

As Russell further notes, the earlier precursor of the AZI or AIR was used in development of the Wechsler Memory Scale (Russell, 1975), for studies of lateralization effects (Russell, 1984b), to extend the range of the Tactual Performance Test (Russell, 1985) as well as being employed in neuropsychological practice (Russell, 2000). The AZI method essentially involves three steps: (1) choosing a reference group of tests, (2) combining the results from those tests into a reference scale and (3) deriving scaled scores from the reference scale using multiple regression. The reference scale is to be chosen with the explicit intent of anchoring to some specific group with a known absolute level of performance on some task X. As Russell (1987) notes

> "...using only brain damaged subjects for norms would leave the scales 'floating', with no anchor to a normal population. That is, the scaled scores would tell the examiner what were the relative differences between the test scores of the brain damaged subjects but not how impaired a person was in relation to a normal population" (p. 387).

Other neuropsychological scales have avoided this problem by only using brain-damaged patients in their norm development procedure (e.g., the Boston Diagnostic Aphasia Examination, Goodglass and Kaplan, 1983) with few negative consequences aside from limitations in quantifying absolutely the level of impairment in mildly affected patients. Arguably, anchoring the performance of brain damaged patients' performance to an absolute reference point is even more important in this study since a small sample is being used and heterogeneous stroke patients -- with a single lesion scattered throughout the brain across subjects -- are being recruited in order to gain some understanding of the effects of different brain lesions on performance across the full spectrum of the CAS's 12 subtests. The anchoring population used in this study was 17 years and 8 month old US students matched according to demographic characteristics to the 1992 census who had completed the CAS. Means and standard deviations for this sample of 33 students were derived from the CAS standardization sample (Naglieri & Das, 1997, p. 176-177).

An important limitation is worth mentioning at this point. Validity studies have noted how norms derived from relatively young normative samples are apt to misclassify as impaired between 58% to 100% of normal controls subjects especially in the 60-90 age range (Bornstein, Paniak & O'Brien, 1987). As a counter-example, Lezak (1995, p. 158) notes that "...tests of mental ability that provide adult norms extending into the late teens find that the population of 18 year olds does not perform much differently than the adult population at large." Hertzog and Schear (1989) and Lezak (1987) note that general slowing with advanced age requires age norms for all timed tests and that difficulty in this respect may arise for patients over the age of 60. Thus all the timed tests of the CAS may be particularly susceptible to these aging effects.

Examination of the CAS standardization data sample reveals an age progression in raw scores that plateaus between the ages 15 to 17 without exhibiting ceiling effects. Furthermore, unlike verbally based conventional IQ tests, the CAS subtests measure cognitive processes rather than learned content (e.g., Information Subtest of the Wecshler IQ scales). Therefore one might reasonably conclude that the CAS is preferentially tapping fluid as opposed to crystallized intelligence. Additionally the CAS attainment raw scores are not predicted to substantially increase at older ages since fluid intelligence is disproportionately negatively affected by normal aging (Horn & Cattell, 1967) and brain damage (Russell, 1980).

Revealingly, in the CAS *Interpretive Handbook* in a sample of 54 regular education students given both the CAS and the WISC-III, the Planning Scale correlated significantly with performance IQ (PIQ), and Perceptual Organization and Processing Speed factors; the Attention Scale correlated with PIQ and Processing Speed factor; the Simultaneous Scale correlated significantly with all the Wechsler Scales and the Successive Scale correlated with all but the Processing Speed scale. Since the Planning and Attention Scales do not correlate with verbal IQ (VIQ), these timed tasks would be predicted to be especially sensitive to declines in fluid intelligence as a result of aging and/or brain damage.

Russell (1987) notes that a -1.5 standard deviation 'cutting point' as a determination of brain damage is conventionally used in neuropsychological practice in comparison with a demographically matched control group. For the purposes of dealing with the limitations of the norming group in this study (e.g., healthy 18-year-olds) a more conservative critical z-score of -1.64 standard deviation units was selected. In addition, the double dissociation method was employed for analytic purposes thereby increasing the magnitude of differences required for statistical significance. In *double dissociation proper* there is an independent marker as to which subjects should exhibit which performance pattern based on lesion locus (Miller, 1993).

Moreover, each subject must score in the normal range on one subtest and below the *a priori* defined cut-off on the other test and vice-versa for the other subject. Although criterion normal performance at the level of 18-year-olds is being used in this study, when used in conjunction with (1) the AZI scaling method, (2) the elevated statistically defined cut-off score, (3) double dissociation proper, and (4) considering that only 4 of 32 patients are over the age of 60, a stronger rationale for the validity of conclusions derived from this analysis has been established.

To briefly review then the brain-damaged patients' scores were normed using the z-scores of the 18-year old adult group. Since all subtest scores were attainment scores except for Planned Connections the inverse transformation of the latter was calculated. A constant of 2 was added to each score to eliminate minus scores. Finally, all the subjects' index scores were averaged to form the reference scale. That is, using the z-scores, the 12 CAS subtest scales were summed and divided by 12 for each subject. In this way, the AZI was created with a mean of 1 and each interval equivalent to a standard deviation unit.

The scaled scores for individual CAS subtests and participants were derived through a series of 12 separate multiple regression analyses, one for each subtest. AZI scores were regressed on to subtest raw scores yielding predicted raw scores with distributions that were equated across subtests. Thus a given level of impairment on one subtest was equivalent to that on another. Each raw score began at 0 and was scaled to the maximum possible ceiling raw score while the AZI scores were scaled starting from 0 to 6, representing 6 standard deviation units from the y-intercept. Twelve regression equations and scatterplots were created and are depicted in Appendix 4. From these regression equations the z = 0 or mean of the reference group of 18 year olds was extrapolated yielding a reference point z-score value. Appendix 4 is included for readers who would like to be able to hand calculate or verify the raw score transformations.

This mean z-score value was subtracted from all the subjects' raw score AZI transformations to give an equated measure of the relative magnitude of deviation in the negative direction of raw scores from the reference group mean. Scores above the raw score population mean were simply assigned a value of 0 and labeled 'normal'. Each subject's raw score is depicted along with the AZI score and the probability value of the discrepancy is normed with respect to both the normal reference group and the other brain-damaged patients.

All twelve scatter plots were relatively linear with the exception of Planned Connections. Patients with raw scores above 350 were pro-rated to a ceiling of 350 in accordance with the peculiar bimodal distributional properties of the Trail-Making Test as recommended by Russell (1987, p. 388) to more closely approximate linearity. By co-norming the CAS subtests with both the brain-damaged subjects and the normal 18-year-olds through this regression analysis, predicted values of raw scores could then be extrapolated that have the property of being directly comparable across subtests and at the same time psychometrically referenced to an absolute level of performance.

Table 2: Raw data means and standard deviations

	N	Range	Min.	Max.	Mean	Standard Deviation
Age (Years)	32	47	20	67	47.1	12.3
Matching Numbers	32	18	2	20	9.5	5.1
Planned Codes	32	97	5	102	43.5	28.7
Planned Connections	29	635	90	725	310.9	179.2
Expressive Attention	32	74	3	77	35.3	19.9
Number Detection	32	105	1	106	40.8	26.8
Receptive Attention	26	63	2	65	35.6	18.2
Nonverbal Matrices	32	27	4	31	15.9	7.6
Verbal-Spatial Relations	32	19	7	26	16.7	5.2
Figure Memory	25	20	1	21	11.9	5.7
Word Series	32	16	5	21	10.8	3.5
Sentence Repetition	32	11	2	13	8.8	2.9
Sentence Questions	28	13	4	17	10.1	3.3

Table 3: Properties of the CAS required for single-case analysis

CAS Subtest	N	Range of Scale	Mean Age 17:8	Std. Deviation Age 17:8	Reliability Coefficient 15-17:12
Matching Numbers	33	0-32	17.5	4.8	.73
Planned Codes	33	0-175	104.0	27	.82
Planned Connections	33	725-0	112.0	511	.80
Expressive Attention	33	0-114	66.0	17.3	.79
Number Detection	33	0-126	74.0	19.4	.80
Receptive Attention	33	0-99	64.5	14	.85
Nonverbal Matrices	33	0-33	21.5	4.9	.91
Verbal-Spatial Rel.	33	0-27	19.5	3.8	.87
Figure Memory	33	0-27	17.0	4.3	.93
Word Series	33	0-27	12.0	4.1	.90
Sentence Repetition	33	0-20	10.0	3.1	.84
Sentence Questions	33	0-21	13.0	3.2	.83

The data from Table 7 is adapted and redrawn from the *Administration and Scoring Manual* of Naglieri and Das (1997, pp. 176-177).

Table 4: Intercorrelations between scores based on the CAS standardization sample ages 15-17:12

CAS Subtest	MN	PC	PL	EA	ND	RA	NV	VS	FM	WS	SR	SQ
Matching Numbers (MN)	-	.42	.57	.42	.42	.51	.30	.41	.31	.21	.18	.32
Planned Codes (PC)		-	.39	.27	.30	.34	.31	.25	.27	.26	.17	.26
Planned Connections (PL)			-	.50	.48	.50	.37	.45	.44	.22	.29	.38
Expressive Attention (EA)				-	.44	.39	.22	.41	.26	.22	.29	.43
Number Detection (ND)					-	.50	.26	.40	.28	.14	.24	.33
Receptive Attention (RA)						-	.21	.37	.25	.16	.13	.30
Nonverbal Matrices (NV)							-	.45	.53	.26	.26	.34
Verbal-Spatial Relations (VS)								-	.48	.30	.40	.52
Figure Memory (FM)									-	.27	.36	.40
Word Series (WS)										-	.64	.48
Sentence Repetition (SR)											-	.65
Sentence Questions (SQ)												-

The data from Table 8 is adapted and redrawn from the Interpretive Handbook of Naglieri and Das (1997, pp. 138).

Table 5: Intercorrelations between scores in the brain-damaged sample with a mean age 47

CAS Subtest	MN	PC	PL	EA	ND	RA	NV	VS	FM	WS	SR	SQ
Matching Numbers (MN)	-	**.80**	**.82**	.66	.81	.78	.65	.76	.55	.54	.43	.37
Planned Codes (PC)		-	**.65**	.76	.85	.72	.76	.75	.63	.51	.38	.49
Planned Connections (PL)			-	.67	.80	.90	.72	.72	.59	.35	.21	.28
Expressive Attention (EA)				-	**.74**	**.69**	.62	.74	.54	.57	.47	.55
Number Detection (ND)					-	**.83**	.69	.71	.65	.52	.37	.46
Receptive Attention (RA)						-	.70	.74	.78	.44	.37	.40
Nonverbal Matrices (NV)							-	**.67**	**.69**	.34	.28	.52
Verbal-Spatial Relations (VS)								-	**.56**	.57	.48	.55
Figure Memory (FM)									-	.12	.24	.44
Word Series (WS)										-	**.74**	**.66**
Sentence Repetition (SR)											-	**.67**
Sentence Questions (SQ)												-

Table 6: Change in intercorrelations between subtests for control and injured sample

CAS Subtest	MN	PC	PL	EA	ND	RA	NV	VS	FM	WS	SR	SQ
Matching Numbers (MN)	-	*.38	*.25	*.24	*.39	*.27	*.35	*.35	*.24	*.33	*.25	*.05
Planned Codes (PC)		-	*.26	*.49	*.55	*.38	*.45	*.50	*.36	*.25	*.20	*.23
Planned Connections (PL)			-	*.17	*.32	*.40	*.35	*.27	*.15	*.13	*.08	*.10
Expressive Attention (EA)				-	*.30	*.30	*.62	*.33	*.28	*.35	*.18	*.12
Number Detection (ND)					-	*.33	*.43	*.31	*.37	*.38	*.13	*.13
Receptive Attention (RA)						-	*49	*.37	*.53	*.28	*.24	*.10
Nonverbal Matrices (NV)							-	*.22	*.16	*.08	*.02	*.18
Verbal-Spatial								-	*.08	*.27	*.08	*.03
Relations(VS)									-	*.15	*.12	*.04
Figure Memory (FM)										-	*.10	*.18
Word Series (WS)											-	*.02
Sentence Repetition (SR)												-
Sentence Questions (SQ)												

Age and Subtest Score Correlations

Age was minimally correlated with the 12 CAS subtest scores for the sample of 32 patients. The range in correlations was a minimum of ($r = .05$, $p = .80$) for Word Series to a maximum of ($r = -.45$, $p < .05$) for Receptive Attention. The mean correlation was $r = \pm .27$ across the 12 CAS subtests which was non-significant. None of the age versus subtest raw score correlations were significant at the more stringent significance level of $p = 0.01$. Only Planned Codes, Figure Memory, Expressive Attention, and Receptive Attention were significant at the $p < 0.05$ level, unadjusted for multiple comparisons. For these reasons and due to the small sample size (n=32), AZI scores were calculated for all 12 CAS subtests using the entire age range of 20 to 67. The mean age of participants was 47.

Sample Description: Chapters 3 and 4

In Chapter 3, twelve patients with left hemisphere injury are described (temporal, frontal, and parietal) along with an initial non-impaired patient for purposes of illustrating the upper ranges of potential performance assessment with the CAS. Additionally, the chapter finishes with a review of two patients with bifrontal atrophy and one patient with medial frontal atrophy for a total of 16 cases. In Chapter 4, twelve patients with right hemisphere injury are described (frontal, parietal) along with 3 cerebellar and 1 brain-stem lesioned patient. Every effort was made to find equal numbers of patients -- each group having one brain lesion -- in one of the four lobes of the brain, distributed equally across the hemispheres (e.g., 4 lobes x 2 hemispheres = 8 potential cells). However, due to the relatively short period of in-patient duration, (e.g., most patients were tested approximately just before discharge at two weeks post-injury) it was logistically difficult to recruit many patients with either left temporal or left parietal injuries -- resolving receptive language impairments made communication difficult or next to impossible. Due to the highly visually based nature of many of the CAS tasks, it was also difficult to solicit occipitally lesioned patients as visual field deficits made test interpretation difficult. However, a few of the parietal lesioned patients discussed in Chapters 3 and 4 had mild injuries to some areas of the higher-order visual cortex and single-case descriptions of the these patients may help to explain the contribution of these brain regions to performance on select CAS subtests.

Frontal lesions are disproportionately represented in the data set for two reasons. The first is likely due to the relatively large area of cortex and subcortex that is 'frontal' as well as the susceptibility of frontal structures to common middle cerebral artery infarctions. Second, frontal lesions especially on the right are more apt to demonstrate 'silent' effects on cognitive tasks (such as those included on the CAS) although there are a few notable exceptions in this data set. In contrast, posterior lesions such as in the parietal or temporoparietal regions are apt to cause either visual neglect or receptive language problems that can easily violate exclusion criteria listed in Appendix 5. Finally the relatively time-restricted nature of this study precluded finer-grained patient classification procedures. With adequate time and resources, equally counterbalanced cells of patients could have been collected allowing for more rigorous cross-group classifications and interpretations of performance patterns on the CAS. Nonetheless, heterogeneous patient lesion groupings were explicitly sought after to maximize the potential of dissociating brain systems involved in performance on the individual CAS subtests.

Chapters 3 and 4 are set out to be primarily descriptive and classificatory in nature. Chapters 3 and 4 initially provide a clinical neurological history and description of the location, severity and extent of the brain injury, and a description of both qualitative and quantitative performance patterns on the CAS for each patient. Including detailed patient information was deemed necessary to provide readers with (i) the substantive basis for the conclusions of each case as (ii) a rich source of data on the CAS's neuropsychological properties that could be used as the basis for designing future studies with this instrument. All individual identifying information was removed in order to safeguard patient confidentiality. Table 1 depicts the 32 patients' demographic and brain injury classification characteristics. Chapter 5, in which the analytic technique of double dissociation was used, in contrast, provided a substantive theoretical and empirical basis for making interpretations about the localization of functions associated with different CAS subtests. *Please refer to **Appendix 15** for an extensive glossary of terms containing the meanings of neuroanatomical, cognitive psychological, neuropsychological and neurological terms.*

Table 7: Lesion classification of patients

Case #	Patient Initials	Age	Sex	Side	Primary Injury Site in the Brain	Etiology	Handed	Education
1	AM	44	F	-	None	tumour resection	Right	16
2	JD	49	M	L	left temporal	brain contusion	Right	12
3	AO	43	M	L	l. fronto-temporal	left middle cerebral artery (MCA)	Right	11
4	KC	52	M	L	left frontal	left MCA	Left	18
5	CB	46	F	L	left frontal	left basal ganglia haemorrhage	Left	12
6	FA	53	F	L	left frontal	l. internal carotid artery dissection	Left	12
7	HB	50	M	L	left frontal	left MCA	Right	12
8	JM	54	M	L	left frontal	left MCA	Right	14
9	WF	53	M	L	left frontal	left recurrent artery of Heubner infarct	Right	12
10	AK	65	M	L	left frontal	aneurysm	Right	9
11	GM	67	M	L	left parietal	tumour resection	Right	12
12	DM	28	M	L	left parietal	arterovenous malformation	Right	4
13	SB	28	M	L	left parietal	gliosis	Right	12
14	TL	41	M	-	bifrontal atrophy	unknown	Right	12
15	DK	39	F	-	bifrontal atrophy	unknown	Right	9
16	RM	23	M	-	medial frontal contusion	fall	Right	14
17	IS	55	F	R	right frontal	right MCA	Left	12
18	SW	64	F	R	right frontal	right MCA	Left	12
19	JL	54	M	R	right frontal	r. anterior cerebral artery infarct	Left	14
20	TF	20	M	R	right frontal	contusion & haemorrhage	Left	12
21	RG	47	F	R	right frontal	right posterior frontal hemorrhage	Right	9
22	GC	47	M	R	right frontal	ischemic infarct	Right	10
23	BT	55	M	R	right frontal	right basal ganglia hematoma	Right	16
24	WM	56	M	R	right frontal	intracranial hematoma	Right	9
25	JH	34	M	R	right frontal	venous infarction	Right	14
26	RA	62	M	R	right fronto-	right MCA	Right	6
27	KH	41	F	R	parietal	right MCA	Right	12
28	CS	53	M	R	right parietal	right MCA	Left	12
29	LH	27	F	-	right parietal	brain contusion	Right	12
30	FR	62	M	-	right cerebellum right cerebellum	r. posterior inferior cerebral artery	Right	12
31	PT	41	M	-	right cerebellum	post. circulation obstruction	Right	9
32	BP	54	M	-	midbrain-pons	ischemic brain stem infarct	Right	13
	$\bar{x}_{Age}$ = 47 *SD* = 12.3, Male = 23 Female = 9				12 RT & 12 LT Hemisphere Lesions	$\bar{x}_{Educational\ Level}$ = 11.7 *SD* = 2.7, 24 Left & 8 Right Handed Subjects		

Hypothesis: Localization of CAS Subtests

Based on the previous empirical review, a number of predictions about the localizing properties of CAS subtests were made based on studies of brain-damaged patients performing similar types of tasks. As Lezak (1995) has noted virtually all cognitive tasks will be sensitive to lesions anywhere within the brain; however, some tasks should demonstrate localizing properties, or maximal specificity and sensitivity as a consequence of circumscribed lesions to specific regions of the brain. Given the small sample size (N=32) and the heterogeneous nature of the lesions that introduces a large amount of error variance, the following hypotheses were tested using both non-parametric and parametric statistical approaches.

A non-parametric analysis was undertaken to evaluate the localizing properties of subtests. Each subtest score for each patient was judged significantly impaired if its average z-score impairment rating score (AZI > 1.64, $p > 0.05$), thus the effect was judged to be dichotomously present (1) or absent (0). Similarly the extent of each patient's lesion was carefully evaluated for involvement of the critical lesion locus – (Appendix 14). If any area was damaged within a lesion by subtest cell than that entire cell was scored as damaged, demarcated by an 'X'. All lesions were rated objectively according to the neuroradiologist's written CT or MRI report thereby minimizing the introduction of rating bias. Moreover the extent of each lesion as outlined in the written summary was verified with the original CT or MRI film and checked with a standard neuroradiological atlas (Moeller & Reif, 2000). Both the lesion and the subtest performance data were objectively transformed into dichotomous data for non-parametric evaluation of statistical hypothesis. All 32 patients were included in this analysis.

In addition a parametric 1 by 4 way analysis of variance (ANOVA) was also undertaken on a subset of 24 patients who could easily be classed as being included in one of four lesion groups: left anterior, left posterior, right anterior and right posterior. Eight patients with lesions not classifiable as involving these regions were excluded from this analysis of the localization potential of the PASS scales. These excluded patients included 1 patient with no indentifable lesion, 2 bifrontal atrophy patients, 1 medial frontal contusion patient, 3 right cerebellum patients and 1 mid-brain pons patient. The PASS scale means were derived from averages across each of the 3 subtests included within each of the 4 composite scales. This substantially increased the sample sizes within the four cells so that parametric ANOVA comparisons were made possible using AZI scores. The final cell sizes were thus 21 left anterior, 27 right anterior, 15 left posterior and 9 right posterior patients for a total of 72 observations. Although these samples sizes are unequal they are large enough to test predictions regarding PASS scale lesion localization quantitatively. The nonparametric analysis of the lesion specificity of the individual CAS subtests and the parametric analysis of the lesion specificity of the PASS scales are discussed in Chapter 5.

Parametric PASS Scale Predictions

With respect to the parametric PASS scale predictions Das et al (1996, p. 50) note that... *'simultaneous processing is associated with the occipital-parietal areas of the brain.successive processing is associated with the frontotemporal areas of the brain...'*. These statements imply a relatively greater posterior gradient for simultaneous processing and a relatively more anterior gradient for successive processing.

H_1: On the successive scale anterior patients will score significantly poorer than posterior patients.

H_2: On the simultaneous scale posterior patients will score significantly poorer than anterior patients.

Das et al. (1994, p. 33) also note that ... *'although it is not easy to separate arousal from attention, it is safe to say that arousal is subcortical whereas attention is also partly controlled by the cortex, especially by the frontal lobe...'*. These statements imply a greater potential for damage to attention mechanisms after anterior lesions. This group also notes that the third functional unit was associated with goal-directed behavior such that... *'injury to the frontal lobes, disturbs impulse control, regulation of voluntary action, and perception as in visual search, It has adverse effect on memory that requires the adoption of a strategy'* (p. 77).

H_3: On the attention scale anterior patients will score significantly poorer than posterior patients.

H_4:On the planning scale anterior patients will score significantly poorer than posterior patients.

Das et al. (1994, p. 57-58) also note that.... *'code content [e.g., verbal/nonverbal] is not the same as the type of coding. Among the many confusions surrounding brain laterality work is one that sees verbal coding as essentially linear or successive, while spatial coding as holistic or simultaneous. This* *confounds two dimensions that in our view should be kept distinct; verbal codes may be simultaneous... and spatial codes can be successive... Kaufman and Kaufman (1983) have fostered this confusion by suggesting that their K-ABC simultaneous and sequential tests refer either to Luria's processes or to the left brain-right brain distinction...* (p. 57-58). Regarding Luria's laws Das et al. (196, p. 62) further note that... *'the tertiary areas (or the zones of overlapping), which are responsible for the concerted working of various analyzers and the production of supramodal (i.e., symbolic) schemes. These schemes form the basis of complex forms of intellectual activity... '*. These statements imply that higher order cognitive processes should not demonstrate modality-specific influences of processing and hence should not demonstrate modality-specific lateralizing influences.

H_5: On the simultaneous scale left sided lesioned patients will score nonsignificantly differently from right-sided lesioned patients.

H_6: On the successive scale left sided lesioned patients will score nonsignificantly different from right-sided lesioned patients.

H_7: On the planning scale left anterior lesioned patients will score nonsignificantly different from right anterior lesioned patients.

Chapter 3: Left Hemisphere Lesioned Patients

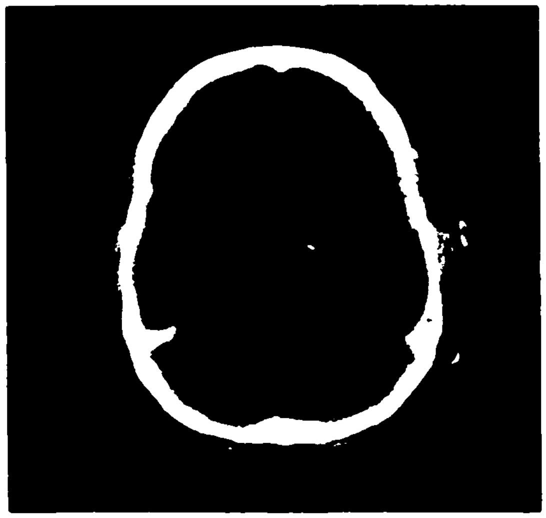
Patient 1: AM

AM was assessed with the basic battery of the CAS approximately 2 months post-surgery. During a clinical CT scan a small aneurysm on the left side of the chiasmatic cistern was identified after complaints of progressively worsening headaches and disturbed vision. Surgery involved a left fronto-temporal lobe approach in which these lobes were retracted for surgical clipping of the chiasmatic aneurysm. Although AM demonstrated no residual findings on CT after surgery, her results were included for the purposes of illustration of the potential range of utility of the CAS in the above average IQ range. AM was estimated to be in the high IQ range on the basis of past occupational, linguistic, and educational attainments. AM reported that she had been accepted to graduate school in the fall following her spring surgery.

Skin staples were still present after a left frontotemporal craniotomy and these are visible as hyperintensities around the skull surrounding the left hemisphere. Some extra-axial air was still present, predominately deep to the craniotomy although a small amount of extra-axial air was noted in the right frontal region as well. This is shown as the dark black oblong spot on the top of the right frontal lobe. Artifacts from the surgical clip resulted in less than optimal images at the basal level and were present left-sided in this image adjacent to the third ventricle. No obvious complications were detected and the ventricular system was within normal limits. The left-sided aneurysm of 6 mm diameter, immediately anterior to and contiguous with the distal left internal carotid artery had been clipped without any evidence of ischemic or hemorrhagic complications. A recent positron emission tomography study noted that frontotemporal craniotomy results in a significantly reduced regional cerebral metabolic rate at the site of retraction on par with that produced after minor ischemic stroke or traumatic brain injury (Yundt, Grubb, Diringer & Powers, 1997). Ventrolateral frontal and anterior temporal regions have been found to be particularly susceptible to these effects at the site retractor blade placement. This CT scan was performed two days prior to behavioural assessment with the CAS*.

**In accordance with radiological convention, left denotes the right hemisphere and right depicts the left hemisphere. Similarly, the top depicts the frontal poles and the bottom depicts the posterior regions. This orientation is standard throughout the remainder of Chapters 3 and 4.*

Figure 1: Axial CT Scan of AM



Except for Planned Codes all of AM's CAS subtest scores were above the arbitrarily set cut-off 'normal' score for 18-year olds. Moreover, the Nonverbal Matrices and Verbal-Spatial Relations raw scores of 27/33 and 26/27 respectively illustrate that despite her surgery her analogical reasoning and verbal comprehension remained well above average. Although non-significant in magnitude, the relatively decreased Planned Codes subtest AZI score was out of keeping with the rest of her scores and is suggestive of residual subtle motor slowing (Schear & Sato, 1989). In addition, AM's scores on the Planning and Attention scales were approximately 1 standard deviation below that of her scores on subtests included on the Simultaneous and Successive scales. AM's demeanor was not suggestive of depression although clinical ratings were not used to rule out this possibility. AM's sutures were well hidden by her hairline and had healed well although she did express concerns about her physical appearance.

The results could indicate that the CAS subtests are useful in the high ability range and that the scales are unlikely to demonstrate ceiling effects at least in brain-damaged patients. AM reported some eye fatigue on the Number Detection subtest of the CAS perhaps indicative of some residual effects of the chiasmatic aneurysm removal. Interestingly, AM reported that she used the unusual and highly complex strategy of visualizing the colours of the Sentence Repetition test while trying to remember the cue sentences. This suggests that her strategy deployment mechanisms are intact and that the moderately decreased score on the Planned Codes may be due to motor slowing.

Table 8: CAS Subtest Performance

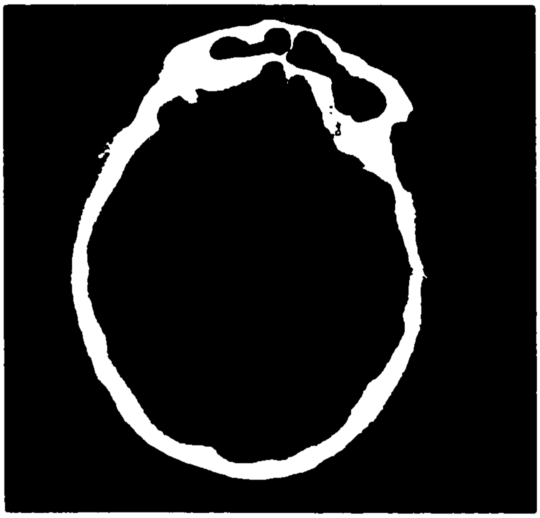
CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	20	Normal	-
Planned Codes	98	0.28	-
Planned Connections	-	-	-
PLANNING	-	0.09	-
Expressive Attention	74	Normal	-
Number Detection	80	Normal	-
Receptive Attention	-	-	-
ATTENTION	-	Normal	-
Nonverbal Matrices	27	Normal	-
Verbal-Spatial Relations	26	Normal	-
Figure Memory	-	-	-
SIMULTANEOUS	-	Normal	-
Word Series	21	Normal	-
Sentence Repetition	13	Normal	-
Sentence Questions	-	-	-
SUCCESSIVE	-	Normal	-
FULL-SCALE	-	Normal	-

Patient 2: JD

JD was involved in a motorcycle accident while travelling in excess of 100 kph when he swerved to miss a pedestrian and flipped the bike after hitting the curb. Fortunately he was wearing a helmet. JD experienced an immediate loss of consciousness for two minutes after the accident although he experienced no retrograde or anterograde amnesia. JD had been employed full-time up until the time of the accident and had made significant recovery in the months following the injury after which time he planned to return to work. Neurologists initially thought that his left orbital bone might be broken and the left side of his face was extremely swollen at the point of impact. There was no identified contre coup injury although caution in interpreting this interpretation is warranted as this type of deceleration/impact accident is a marker for diffuse axonal injury (Lezak, 1995). JD did note a "slight weakening" in his left eye following the injury.

Moderate soft tissue swelling was identified around the left temporal region. No fracture was identified. The visualized sinuses and mastoid air cells were well aerated and unremarkable in appearance. There was no evidence of intra- or extra-axial hemorrhage or mass effects. Gray-white differentiation was preserved. The ventricles were normal in size and position. Incidental note was made of some parafalcine calcification. This image was slanted in the anterior-inferior plane towards the left to provide visualization of the anterior aspect of the left temporal lobe. This CT scan was performed 28 days prior to behavioral assessment with the CAS.

Figure 2: Axial CT Scan of JD



In terms of qualitative aspects of CAS performance, JD did not use the more efficient strategy of coding on the diagonal on Planned Codes Item 2, while on Planned Connections, JD repeated the alphabet/number series out loud rather than repeating them silently to himself. On Matching Numbers, the CAS's *Strategy Assessment Checklist* revealed that he used advanced strategies. All of the Successive subtests were in the impaired range with the largest decrement beyond expected values occurring on the Sentence Questions subtest consistent with some residual impairment in verbal comprehension. The finding that four of the twelve CAS subtest scale scores are above normal provides evidence that the deficiencies on the successive subtests are genuine and are not an artifact of floor effects. There was evidence of a mild impairment on the Expressive Attention subtest perhaps indicating damage to neural substrates of selective attention common after traumatic brain injury (Lezak, 1995). Finally, the pattern of injury within the left temporal region was consistent with previous reports of the potential for such injury to produce linguistic impairments on word span (Trahan, Goethe & Larrabe, 1989), repetition (Selnes, Knopman, Niccum & Rubens, 1985) and verbal comprehension tasks (Caplan, Hildebrandt & Makris, 1996).

Table 9: Axial CT Scan of JD

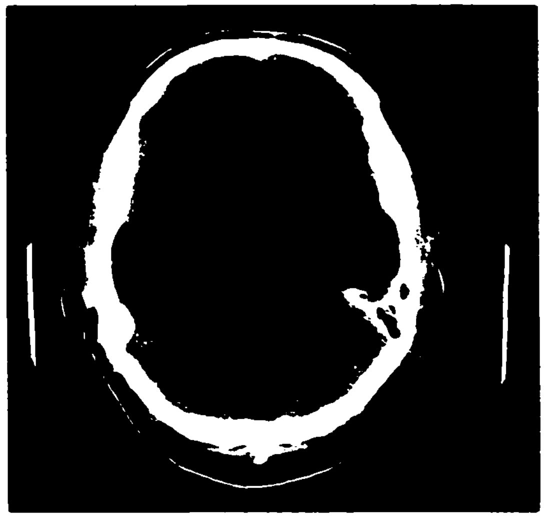
CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	17	0.12	-
Planned Codes	102	0.12	-
Planned Connections	142	0.37	-
PLANNING	-	0.20	-
Expressive Attention	46	1.21	-
Number Detection	73	Normal	-
Receptive Attention	56	0.49	-
ATTENTION	-	0.57	-
Nonverbal Matrices	29	Normal	-
Verbal-Spatial Relations	20	Normal	-
Figure Memory	19	Normal	-
SIMULTANEOUS	-	Normal	-
Word Series	7	2.10	$p = 0.02$
Sentence Repetition	7	1.82	$p = 0.03$
Sentence Questions	6	3.12	$p < 0.001$
SUCCESSIVE	-	2.35	$p < 0.01$
FULL-SCALE	-	0.78	-

Patient 3: AO

AO was successfully employed up until the time of his stroke. He was initially diagnosed with conduction aphasia. Despite his fluency and word finding difficulties, which caused him considerable frustration, he was able to successfully complete the CAS and he displayed good motivation.

There was an ill-defined hypodensity visualized via CT that was apparent within the insular and opercular regions on the left side. But, it was also seen to extend to the inferior aspect of the left temporal lobe as well as more superiorly involving the frontal lobe. Additionally, the hypodense region extended medially to involve most of the lentiform nucleus, lateral aspect of the caudate nucleus, and corona radiata anteriorly and medially. There was an associated mass effect with effacement of adjacent cortical sulci, compression of the left lateral ventricles and mild midline shift to the right. No significant hemorrhage was apparent as a consequence of this left middle cerebral infarct. This CT scan was performed seven days before behavioural assessment with the CAS.

Figure 3: Axial CT Scan of AO



AO's performance on all the Planning and Attention tasks was uniformly poor with an island of performance capability in the more perceptually based nonverbal matching items of Nonverbal Matrices. The only subtest which remained within normal performance limits was Sentence Repetition. This intact functioning on repetition is consistent with previous studies reporting the adverse effects of posterior temporal gyrus lesions on repetition whereas more anterior lesions usually spare repetition (Selnes, Knopman, Niccum and Rubens, 1985). Word Series was below normal although non-significantly impaired consistent with the anterior as opposed to posterior perisylvian focus of the lesion. Sentence comprehension was impaired consistent with studies suggesting that damage within the vicinity of Broca's area carries with it the potential for significant impairments in syntactic aspects of speech comprehension (Caplan, Hildebrandt & Makris, 1996).

On the Verbal-Spatial Relations subtest, AO was able to read the sentences printed at the bottom of the cue page implying intact orthographic mechanisms underlying reading. Nonetheless, AO's performance was significantly impaired on the Verbal-Spatial Relations subtest in congruence with reports that the inferior frontal gyrus is specifically activated when subjects engage in syntactic processing (Dapretto & Bookheimer, 1999). AO's performance on Verbal-Spatial Relations was compatible with clinical reports of his accompanying difficulties in understanding grammatical aspects of speech (e.g., prepositions) while Nonverbal Matrices was non-significantly impaired. AO's performance quickly began to taper off after item 9 on Nonverbal Matrices and his first mistake was on item 11 followed by four successive errors starting on item 15. This pattern of impairment is dependably associated with intact perceptual matching and moderately impaired reasoning. Others have demonstrated that the bilateral frontal regions are directly involved in reasoning while perceptual matching is more right posterior-localized (Prahakaran, Smith, Desmond, Glover & Gabrieli, 1997).

Table 10: AO's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	7	2.41	p = 0.008
Planned Codes	20	3.52	p < 0.001
Planned Connections	350	2.93	p = 0.002
PLANNING	-	2.95	p = 0.002
Expressive Attention	10	3.39	p < 0.001
Number Detection	22	2.25	p = 0.01
Receptive Attention	16	2.84	p = 0.002
ATTENTION	-	2.83	p = 0.002
Nonverbal Matrices	13	1.49	-
Verbal-Spatial Relations	8	2.62	p = 0.004
Figure Memory	-	-	-
SIMULTANEOUS	-	2.06	p = 0.02
Word Series	9	1.26	-
Sentence Repetition	10	Normal	-
Sentence Questions	9	1.78	p = 0.04
SUCCESSIVE	-	1.01	-
FULL-SCALE	-	2.23	p = 0.01

Patient 4: KC

KC was a successful independent businessman with an estimated premorbid ability in the high range. KC's early stroke detection made him a good candidate for intravenous anti-coagulation therapy. Subsequent CT revealed substantial resolution of the cytotoxic edema and therefore it was difficult to determine if the scattered performance pattern was due to genuine neuropsychological impairment or merely reflected premorbid intra-individual difference variables. The cognitive profile did reveal evidence of mild impairment on all the Attention subtests, with Expressive Attention exhibiting the greatest level of relative impairment (> 0.5 σ), consistent with some neuropsychological studies (Perret, 1974). Only Planned Codes displayed a greater level of impairment consistent with ubiquitous motor slowing effects associated with any brain lesion (Schear & Sato, 1989).

CT depicted some very subtle low density involving the posterior aspect of the left frontal lobe extending across the gray-white matter junction in keeping with mild cytotoxic edema after a left middle cerebral artery infarct. There were no focal changes or hemorrhage and no other lesion was identified. The ventricular systems and cortical markings appeared unremarkable. This CT scan was performed 14 days prior to behavioural assessment with the CAS.

Figure 4: Axial CT Scan of KC

Table 11: KC's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	18	Normal	-
Planned Codes	82	0.95	-
Planned Connections	90	Normal	-
PLANNING	-	-	-
Expressive Attention	54	0.72	-
Number Detection	71	0.13	-
Receptive Attention	60	0.26	-
ATTENTION	-	0.37	-
Nonverbal Matrices	31	Normal	-
Verbal-Spatial Relations	25	Normal	-
Figure Memory	21	Normal	-
SIMULTANEOUS	-	Normal	-
Word Series	14	Normal	-
Sentence Repetition	10	Normal	-
Sentence Questions	17	Normal	-
SUCCESSIVE	-	Normal	-
FULL-SCALE	-	0.17	-

Patient 5: CB

CB had great difficulty completing many of the CAS subtests despite extensive explanations and rest periods. All scores were severely impaired with the exception of more moderate impairment (e.g., ~ 2σ) on two of the four verbal subtests. CB scored 11 out of 27 on Verbal-Spatial Relations and 7 out of 27 on Word Series. She was able to comprehend some of the more complex syntax items of Verbal-Spatial Relations with the cue sentence was presented alongside a visual depiction suggesting some preservation of right hemisphere language functions (e.g., Which picture shows a cross above a triangle that is above a circle?) This compared with a raw score of 4 out of 21 on the verbally mediated Sentence Questions. The hypothesis of greater bilateral representation of language in this left hemisphere injured left-handed woman would be consistent with previous reports of greater propensity for bilateral language representation in women (Bryden, Hécaen & DeAgostini, 1983)) and in left-handers (Rasmussen & Milner, 1977) generally. Sentence Repetition was also impaired which could be interpreted in terms of general difficulties in articulation in the subacute phase after stroke.

No strategy was used on any of the Planning subtests and the Attention scores were uniformly low. There was a 3.5 cm diameter hyperdense hemorrhage present within the left basal ganglia and some associated vasogenic edema surrounding the hematoma. There was also mass effect with compression of the frontal horn of the left ventricle and mild subfalcial herniation from left to right. The midline shifted to the right by approximately 3 mm. There was some mild compression of the third ventricle and the patient had mild ventriculomegaly involving the temporal horn of the right lateral ventricle. This was associated with an isolated hemorrhage secondary to hypertension. This CT scan was performed 7 days before behavioural assessment with the CAS.

Figure 5: Axial CT Scan of CB

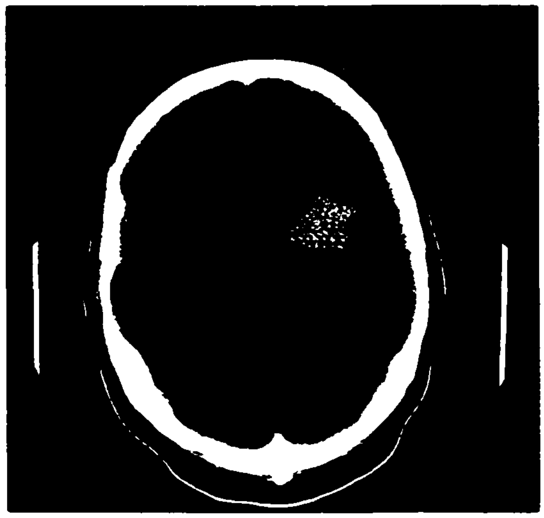


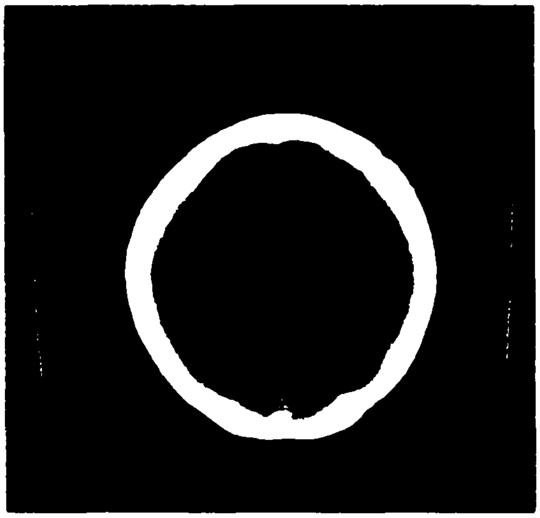
Table 12: CB's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	3	3.33	$p < 0.001$
Planned Codes	6	4.10	$p < 0.001$
Planned Connections	-	-	-
PLANNING	-	3.72	$p < 0.001$
Expressive Attention	6	3.63	$p < 0.001$
Number Detection	8	2.86	$p = 0.002$
Receptive Attention	-	-	-
ATTENTION	-	3.25	$p < 0.001$
Nonverbal Matrices	4	3.06	$p = 0.001$
Verbal-Spatial Relations	11	1.93	$p = 0.03$
Figure Memory	-	-	-
SIMULTANEOUS	-	2.50	$p = 0.006$
Word Series	7	2.10	$p = 0.02$
Sentence Repetition	5	3.02	$p = 0.001$
Sentence Questions	4	4.02	$p < 0.001$
SUCCESSIVE	-	3.05	$p = 0.001$
FULL-SCALE	-	3.12	$p < 0.001$

Patient 6: FA

FA was admitted with right-sided weakness. She had previously been healthy and was recently retired. FA was very methodical and persistent in completing all the CAS tasks. She did not use a strategy for Planned Codes item 2 although she did use an effective strategy for Matching Numbers and Planned Connections. On neuroradiological examination there was an ill-defined area of decreased attenuation involving the white matter of the anterior aspect of the left frontal lobe. This was not associated with any mass effect and was compatible with an area of ischemic damage. There were no abnormal masses identified nor was there any evidence of intracranial bleed. This CT scan was performed nine days before behavioural assessment with the CAS. This axial CT scan is depicted through the superior frontal gyrus and the lesion is localized within the middle frontal gyrus.

Figure 6: Axial CT Image of FA



FA exhibited normal performance on only one subtest, that being Word Series -- a measure of immediate auditory memory. Significantly impaired performances were found on the Planned Codes subtest perhaps indicative of subtle motor slowing (Schear & Sato, 1989) and Sentence Repetition. The use of non-sense sentences might be expected to increase the verbal working memory requirements of the task. Alternatively, Haut, Kuwabara, Leach and Callahan (2000) have demonstrated that older participants aged 60-69 used the left dorsolateral prefrontal cortex significantly more than younger participants in a PET study using a similar type of sentence repetition task. Moreover, these older subjects maintained expected material-specific lateralization in their patterns of activation consistent with previous reports of left frontal activation during performance of verbal working memory tasks. It is possible then that lesions of the left dorsolateral prefrontal cortex might be expected to disproportionately negatively effect cognitive processes using verbal working memory in older adults. The anterior and superior nature of FA's frontal lesion placed it strategically within the left dorsolateral prefrontal cortex. In contrast, performance on all other verbal tasks (e.g., Word Series, Sentence Questions and Verbal-Spatial Relations) was non-significantly impaired.

Table 13: FA's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	12	1.26	-
Planned Codes	56	2.03	p = 0.02
Planned Connections	145	0.41	-
PLANNING	-	1.23	-
Expressive Attention	48	1.09	-
Number Detection	47	1.17	-
Receptive Attention	43	1.26	-
ATTENTION	-	1.17	-
Nonverbal Matrices	20	0.27	-
Verbal-Spatial Relations	16	0.80	-
Figure Memory	11	1.38	-
SIMULTANEOUS	-	0.82	-
Word Series	12	Normal	-
Sentence Repetition	6	2.42	p = 0.008
Sentence Questions	12	0.44	-
SUCCESSIVE	-	0.95	-
FULL-SCALE	-	1.04	-

Patient 7: HB

HB was admitted for a follow-up after a stroke that occurred several years previously. HB's performance was significantly impaired on the Planned Codes subtest consistent with general motor slowing effects of lesions on coding tasks (Schear & Sato, 1989). HB was also significantly impaired on the Matching Numbers subtest.

HB's performance on Receptive Attention was significantly defective compared to the stroke comparative sample. All of HB's verbal subtests (e.g., Word Series, Sentence Repetition and Sentence Questions) were in the normal range while Verbal-Spatial Relations was one standard deviation unit below expected values although non-significantly impaired. Syntactic comprehension assessed by the Verbal-Spatial Relations subtest appears to be particularly sensitive to damage within the left opercular region of Broca's area (Dapretto & Bookheimer, 1999).

A neuroradiological examination revealed an old infarct involving the left frontal lobe, in the distribution of the anterior branch of the left middle cerebral artery. This was associated with mild sulcal widening as well as dilatation of the frontal horn of the left lateral ventricle. No acute intracranial pathology was identified. This CT scan was performed 4 days prior to behavioural assessment with the CAS.

Figure 7: Axial CT Image of HB

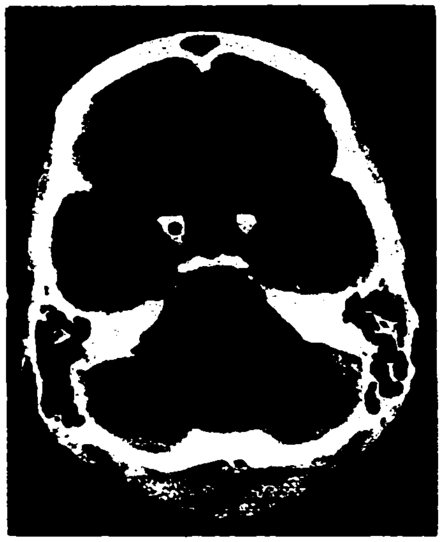


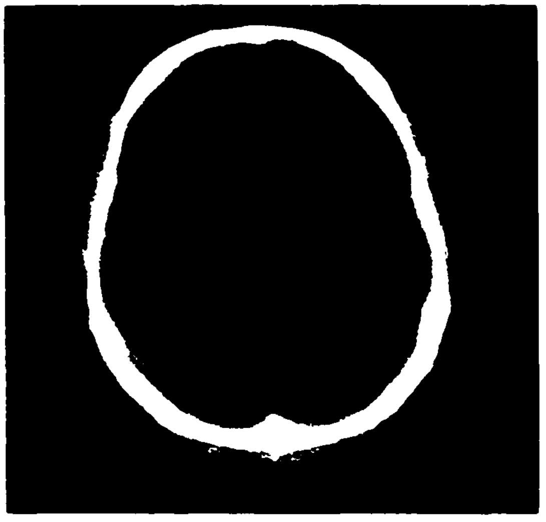
Table 14: HB's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	9	1.95	p = 0.03
Planned Codes	44	2.53	p = 0.006
Planned Connections	236	1.53	-
PLANNING	-	2.00	p = 0.02
Expressive Attention	48	1.09	-
Number Detection	52	0.95	-
Receptive Attention	33	1.84	p = 0.03
ATTENTION	-	1.29	-
Nonverbal Matrices	18	0.62	-
Verbal-Spatial Relations	15	1.02	-
Figure Memory	15	0.46	-
SIMULTANEOUS	-	0.70	-
Word Series	12	Normal	-
Sentence Repetition	13	Normal	-
Sentence Questions	15	Normal	-
SUCCESSIVE	-	Normal	-
FULL-SCALE	-	1.00	-

Patient 8: JM

JM was previously healthy until he experienced a middle cerebral artery occlusion resulting in immediate ischemic and subsequent hemorrhagic transformations. There was an increased density in the cortex within the temporal and parietal regions with an intracerebral hemorrhage and surrounding gliosis in the external capsule and insular cortex. The hemorrhage extended into the corona radiata and centrum semi-ovale on the parietal region on the left side. There was also an increased density in the inferior portion of the Sylvian fissure and the posterior aspect of the interhemispheric fissure. There was also an increased density in the posterior parietal region involving the cortex. This axial CT scan is depicted through the lesion's region of maximal diameter in the external capsule of the left side, and was performed three days after behavioural assessment with the CAS.

Figure 8: Axial CT Image of JM



JM's performance on Matching Numbers was significantly impaired as was his Sentence Repetition score. The proximity of the lesion location to that of FA's and the similar impairment on Sentence Repetition raises the possibility of disruption of the dorsolateral frontal-subcortical circuit underlying performance on tasks requiring the learning of new information (Chow & Cummings, 1999). Alternatively, JM's prominent articulatory disturbances could have resulted in his poor performance on Sentence Repetition. Expressive Attention was non-significantly impaired although below-expected values consistent with and early study demonstrating some role for the left frontal lobe in performance on response inhibition tasks such as the Stroop task (Perret, 1974). Vigilance, perceptual matching, reasoning, syntax, immediate auditory memory, and verbal comprehension were all normal in JM.

Table 15: JM's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	10	1.72	p = 0.04
Planned Codes	84	0.87	-
Planned Connections	158	0.57	-
PLANNING	-	1.05	-
Expressive Attention	44	1.33	-
Number Detection	106	Normal	-
Receptive Attention	52	0.73	-
ATTENTION	-	0.69	-
Nonverbal Matrices	25	Normal	-
Verbal-Spatial Relations	20	Normal	-
Figure Memory	14	0.69	-
SIMULTANEOUS	-	0.23	-
Word Series	14	Normal	-
Sentence Repetition	7	1.82	p = 0.03
Sentence Questions	13	Normal	-
SUCCESSIVE	-	0.61	-
FULL-SCALE	-	0.64	-

Patient 9: WF

WF was included in the analysis despite these smaller infarcts since his behavioral assessment took place before the principal investigator had a chance to review the neuroradiological summary for this patient. WF reported some memory problems such as forgetting his pets' names after his stroke and he had some right lip drooping suggestive of left hemisphere damage. In addition, WF reported severe difficulties in reading suggestive of acquired dyslexia. WF also reported some residual right visual field disturbances to the extent that he was no longer licensed to drive -- likely a consequence of a small left occipital lobe infarct. This perceptual deficit was a marker for potential difficulties in making definitive interpretations of performance on the visual tasks such as in the Planning Tasks, Number Detection, Receptive Attention, and Figure Memory. In contrast, tasks purportedly emphasizing more visuospatial processing characteristics such as the Nonverbal Matrices, although visuospatially-based, were near normal levels consistent with WF's intact right hemisphere.

A CT eight months prior revealed a hypodensity involving the inferior aspect of the left occipital lobe involving both gray and white matter. The findings were in keeping with a left occipital lobe infarct. No intracranial hemorrhages were identified and the extra-axial spaces were clear. There was dilatation of both lateral ventricles such that the left was greater than the right. The major focus of damage involved an infarct at the head of the left caudate nucleus and the anterior aspect of the left putamen. This was in keeping with a hemorrhage in the recurrent artery of Heubner. There was a second subcortical white matter infarct within the region of the left middle frontal gyrus. The occipital horn on the left was slightly more prominent than the right. These findings were consistent with multiple embolic vascular distribution infarcts on the left. This CT scan was performed 254 days prior to behavioural assessment with the CAS.

Figure 9: Axial CT Image of WF

Table 16: WF's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	4	3.10	$p < 0.001$
Planned Codes	22	3.44	$p < 0.001$
Planned Connections	350	2.93	$p = 0.001$
PLANNING	-	3.16	$p < 0.001$
Expressive Attention	39	1.63	-
Number Detection	24	2.16	$p = 0.02$
Receptive Attention	17	2.78	$p = 0.003$
ATTENTION	-	2.19	$p = 0.01$
Nonverbal Matrices	18	0.62	-
Verbal-Spatial Relations	18	0.34	-
Figure Memory	4	2.99	$p = 0.001$
SIMULTANEOUS	-	1.32	-
Word Series	12	Normal	-
Sentence Repetition	13	Normal	-
Sentence Questions	13	Normal	-
SUCCESSIVE	-	Normal	-
FULL-SCALE	-	1.67	$p < 0.05$

All the Planning subtest scores were well below normal with the largest on the speed-dependent Planned Codes subtest. Expressive Attention was the only subtest of the Attention scale for which there was no significant impairment, although it was substantially below expected values -- perhaps due to the lengthy recovery period and propensity for right rather than left frontal lesions to result in the most severe impairments on this task (Vendrell et al, 1995). Although Nonverbal Matrices and Verbal-Spatial Relations were near normal Figure Memory was severely impaired. However the poor Figure Memory performance could not be attributed to a strictly visual impairment. Support for Sergent's (1992) hypothesis of a possible potential "local processing" deficit is found in analyses of error patterns on the last four items failed. In each item it can be seen that WF traced the outline of the pattern perfectly, however for items 5 through 8, the details of the middle sections were entirely omitted despite adequate instruction and demonstration of the correct procedure (see Figure 10 below). A caveat is of course that WF's multiple infarcts suggest caution against over-interpretation.

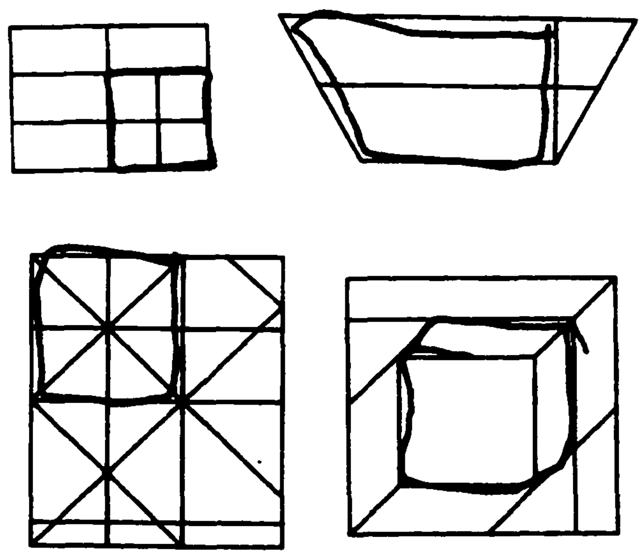


***Figure 10**. Items 5,6,7,8 of Figure Memory completed by WF (top left, top right, bottom left and bottom right, respectively). Note the missing details on the inside of the outlines suggesting impaired local processing.*

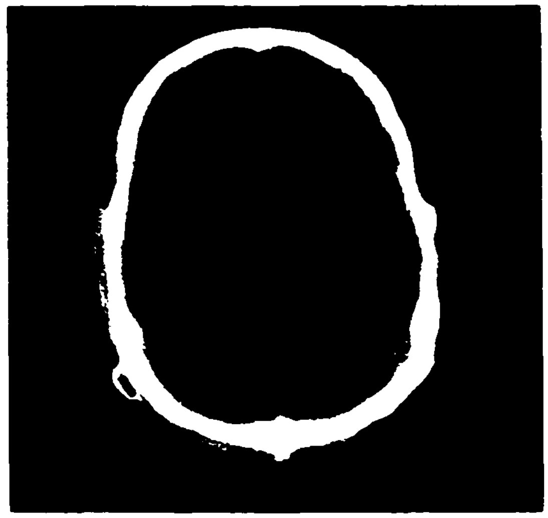
Patient 10: AK*

AK had a severe hemorrhagic stroke in the left frontal lobe 6 years prior to his assessment. He had been previously independent and gainfully employed as a skilled technical worker. His family reported that his behavior was regressive after his stroke. On assessment he was found to be disorientated to time, date and year and his Mini-Mental Status Examination (Folstein et al, 1979) score of 20 out of 30 was in the severely impaired range.

CT revealed a large region of cystic encephalomalacia involving the inferior left frontal lobe extending to involve the anterior aspect of the cingulate gyrus on the left side. There was some associated gliotic change involving the frontal pole of the left temporal lobe and in the periventricular region around the right frontal lobe. There were two surgical clips just off the midline anteriorly as there had been a prior left frontal craniotomy. The features indicated a prior aneurysm with secondary changes related to hemorrhage. Both frontal horns of the lateral ventricles were dilated, more so on the left, related to the noted gliotic changes. The ventricles were otherwise unremarkable. There was a small curvilinear hyperintensity adjacent to the calvarium of the left frontal lobe that most likely represented some thickened and calcified dura. The visualized brain stem and cerebellum appeared unremarkable. This axial scan is depicted at the region of lesion's maximal diameter within the inferior aspect of the left frontal lobe. This CT scan was performed the day before behavioural assessment on the CAS.

*A version of the following two reports (e.g., Patients #10 & #11) was accepted for publication as a case study in the neuropsychology journal *Brain and Cognition* in December of 2000.

Figure 11: Axial CT Image of AK



AK was suspected of having strategic infarct dementia on the basis of the lesion locus and the clinical findings. Therefore a comparative patient who was closely matched to him in terms of age, sex, education, ethnic grouping, occupational background, and lesion locus was found within this study's' case study database. This comparison with non-demented patient GM is discussed under patient 11. Both AK and GM's level of premorbid ability (VIQ) were estimated at between 87 and 111 at 15% confidence intervals. AK and GM were each assessed on the Mini-Mental Status Exam (MMSE) within days of the CAS assessment.

A non-parametric Wilcoxon signed-rank test demonstrated that GM's performance on the 12 CAS subtests was significantly better on the whole compared to AK's ($z = 2.981$, $p < 0.003$ for a two-tailed test). Although assumptions regarding normality of distributions of scores within subtests were violated there are a number of trends worthy of comment between these two patients. GM's performance on the verbal scale of Word Series appeared to be significantly better than that of AK. Also of note was the consistently lower performances on the Successive scale in AK compared to GM. Matching Numbers also appeared to discriminate between these two subjects. The MMSE, observational, history, and neuroradiological findings are consistent with strategic infarct dementia as a sequalae of left caudate and globus pallidus infarction in AK (McPherson & Cummings, 1996). These results suggest that the CAS may be useful in the context of neuropsychological assessment of dementia of a vascular etiology. All subtest scores were in the significantly impaired range.

Table 17: AK's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	5	2.87	p = 0.002
Planned Codes	5	4.15	p < 0.001
Planned Connections	350	2.93	p = 0.002
PLANNING		3.32	p < 0.001
Expressive Attention	5	3.69	p < 0.001
Number Detection	28	1.99	p = 0.02
Receptive Attention	10	3.19	p < 0.001
ATTENTION	-	2.96	p = 0.002
Nonverbal Matrices	6	2.71	P = 0.003
Verbal-Spatial Relations	11	1.93	p = 0.03
Figure Memory	4	2.99	p = 0.001
SIMULTANEOUS	-	2.54	p = 0.006
Word Series	5	2.94	p = 0.002
Sentence Repetition	4	3.62	p < 0.001
Sentence Questions	6	3.12	p < 0.001
SUCCESSIVE	-	3.23	p < 0.001
FULL-SCALE	-	3.01	P = 0.001

Patient 11: GM

GM had surgery for the removal of a left superior parietal-occipital oligodendroglioma 6 years previously. He was followed up with a routine scan for the detection of tumour recurrence and fortunately there was none. GM was administered the MMSE near this time and scored in the normal range of 28 out of 30. He lived independently and was a high functioning individual. An EEG administered in close proximity to the CAS behavioural assessment was consistent with an underlying lesion in the left parietal-occipital region.

An MRI scan revealed that the previous left parietal craniotomy site had remained unchanged. The ventricles were slightly enlarged but not displaced, and widening of the sulci over both hemispheres was again apparent, with localized sulcal widening again noted in the right parietal region perhaps due to Wallerian degeneration. At the site of surgery, increased signal in the white matter was noted under the bone flap and extending somewhat anteriorly, with no evidence of mass effect and no further extension from the previous study. The basal ganglia and subarachnoid cisterns appeared normal. After augmentation the small irregular areas of augmentation in the white matter of the left parietal lobe at the site of surgery were again noted, but did not increase in size and was possibly related to scarring. No other areas of abnormal augmentation were identified. This MRI scan was performed four days prior to behavioural assessment with the CAS.

Figure 12: Axial CT Image of GM

Table 18: GM's CAS Performance*

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	12	1.26	-
Planned Codes	14	3.77	$p < 0.001$
Planned Connections	296	2.26	$p = 0.01$
PLANNING	-	2.43	$p = 0.008$
Expressive Attention	15	3.09	$p < 0.001$
Number Detection	24	2.16	$p = 0.02$
Receptive Attention	25	2.31	$p = 0.01$
ATTENTION	-	2.52	$p = 0.006$
Nonverbal Matrices	11	1.84	$p = 0.03$
Verbal-Spatial Relations	14	1.25	-
Figure Memory	9	1.84	$p = 0.03$
SIMULTANEOUS	-	1.64	$p = 0.05$
Word Series	10	0.84	-
Sentence Repetition	7	1.82	$p = 0.03$
Sentence Questions	7	2.68	$p = 0.004$
SUCCESSIVE	-	1.78	$p = 0.04$
FULL-SCALE	-	2.09	$p = 0.02$

* The practice of using first and last initials to designate patients throughout this study has been done to protect the anonymity of the patients who graciously participated in this study. Moreover this is common practice in case study and particularly neuropsychological research. In some cases initials have been changed if two or more patients had the same initials. Any resemblance of the patient's initials to other individuals is coincidental.

GM was the oldest patient tested on the CAS and although most of his subtest scores fell within the impaired range, cursory examination of the raw scores revealed that the CAS subtests did not appear to be inadequate in terms of contending with floor effects. Matching Numbers, Verbal-Spatial Relations and Word Series, which are measures of visual search, syntactical comprehension with a pictographic aid, and immediate auditory memory, were not significantly impaired. Planned Codes was severely impaired consistent with the motor slowing effects of brain lesions irrespective of the lesion locus (Schear & Sato, 1989). Since Matching Numbers was not significantly impaired, this suggested that motor slowing rather than a strategy application disorder (Shallice & Burgess, 1991) was the root source of the disorder on the speeded Planning tasks. Congruent with this hypothesis on the *Strategy Assessment Checklist* it was demonstrated that GM used sophisticated strategies for task completion.

Clinical neurological testing revealed that he was unable to write a sentence perhaps indicative of agraphia. In addition he had some impairment in recalling the names of objects. The locus of GM's lesion would be consistent with a disconnection of posterior parietal regions from frontal areas that can sometimes result in speech apraxias (Heilman, Rothi & Valenstein, 1982). Both measures of vigilance (Number Detection) and lexical categorization (Receptive Attention) were impaired which is consistent with reports of general impairments in vigilance after any brain injury (Lezak, 1995) as well as activation of left parietal regions during lexical decision tasks (Heun et al, 1999). Although Verbal-Spatial Relations was non-significantly impaired Nonverbal Matrices and Figure Memory were impaired congruent with reports of left parietal regions activation during performance on matrices (Prahakaran et al, 1997) and figural disembedding tasks (Ring et al, 1999). Finally the locus of the patient's lesion in proximity to parietal association area is consistent with the sparing of immediate auditory memory (Word Series), an associated impairment in sentence repetition (Selnes et al, 1985), and impairment on verbal comprehension of the Sentence Questions subtest (Caplan et al, 1996).

On the lexical identity match item of Receptive Attention qualitative data indicated a disproportionate number of omissions in the right visual field (see next page). GM's lexical discrimination difficulties in the right visual field are consistent with Kok, van de Vijver and Bouma's (1985) findings of right visual field superiority for lexical matches and left visual field superiority for physical matches. If left hemisphere substrates of lexical encoding were damaged, as is hypothesized in this case one might reasonably expect disproportionate attenuation of the right visual field lexical matching effect. This pattern of omissions is also consistent with Gutentag and Madden's (1987) finding of greater inefficiency in older adults on lexical identity tasks. On item 1 of Receptive Attention, GM made only two omissions in the right visual field as opposed to zero omissions in the left visual field.

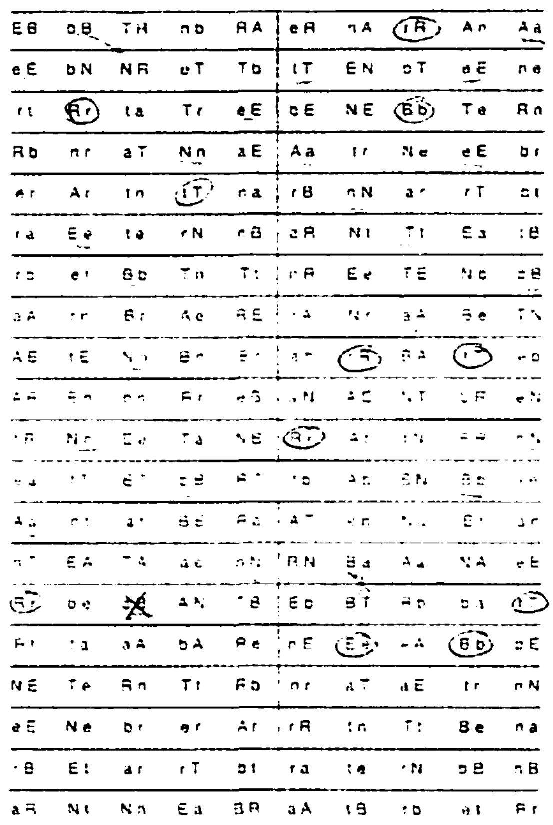


Figure 13. *Item 6 of Receptive Attention for GM. The percent of omissions was 15% in the left visual field and 36% in the right visual field. GM's marks are underlined while the examiner circled omissions. GM made one self-correction, evidence of intact strategy mechanisms, and the examiner noted one false-detection (e.g., crossed out).*

Patient 12: DM

DM was examined as an in-patient for an arteriovenous malformation. His first language was not English and his level of education was low due to cultural disadvantage. These factors suggest extreme caution in interpretation of the verbal scales since it is unclear if the deficient performance is due to an inadequate opportunity to learn or genuine neuropsychological impairment. In contrast the results of the remainder of the CAS subtests appear valid since he was able to complete the practice items in all cases with relative ease. There were extensive serpentine areas of enhancement posterior and inferior to the subacute hemorrhage in the left parietal region. The appearances were highly suggestive of an arterial venous malformation with acute intracerebral hemorrhage. There was also vasogenic edema throughout the left parietal lobe extending into the occipital lobe but there were no other abnormalities noted. This CT scan was performed three days prior to behavioural assessment with the CAS.

Figure 14: Axial CT Image of DM

Table 19: DM's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	5	2.87	p = 0.002
Planned Codes	14	3.77	p < 0.001
Planned Connections	295	2.25	p = 0.01
PLANNING	-	2.96	p = 0.002
Expressive Attention	37	1.75	p = 0.04
Number Detection	20	2.34	p < 0.01
Receptive Attention	32	1.90	p = 0.03
ATTENTION	-	2.00	p < 0.003
Nonverbal Matrices	17	0.79	-
Verbal-Spatial Relations	13	1.48	-
Figure Memory	11	1.38	-
SIMULTANEOUS	-	1.22	-
Word Series	6	2.52	p = 0.006
Sentence Repetition	5	3.02	p = 0.001
Sentence Questions	-	-	-
SUCCESSIVE	-	2.77	p = 0.003
FULL-SCALE	-	2.19	p = 0.01

DM's performance on all the Planning and Attention subtests were significantly impaired. Among these six subtests his best score was on Expressive Attention probably because his illiteracy negated the interference effects of the task (MacLeod, 1991). Each of these tasks was complicated by DM's low level of literacy and he reported that he "did not know his alphabets well" and therefore caution in the interpretation of the results is warranted. On item 1 of Number Detection there was some evidence for an asymmetric visual field bias such that DM was more likely to omit numbers in the open font in the right visual field (44% omissions) versus the left visual field (15% omissions). This greater tendency towards errors in the right visual field for DM was present on all the items of Number Detection and Receptive Attention except for item 1 of Receptive Attention – that being physical identity. Again this pattern of results is similar to Patient 11 (GM) and is congruent with Kok, van de Vijver and Bouma's (1985) finding of a right visual field superiority for lexical matches and a left visual field superiority for physical matches.

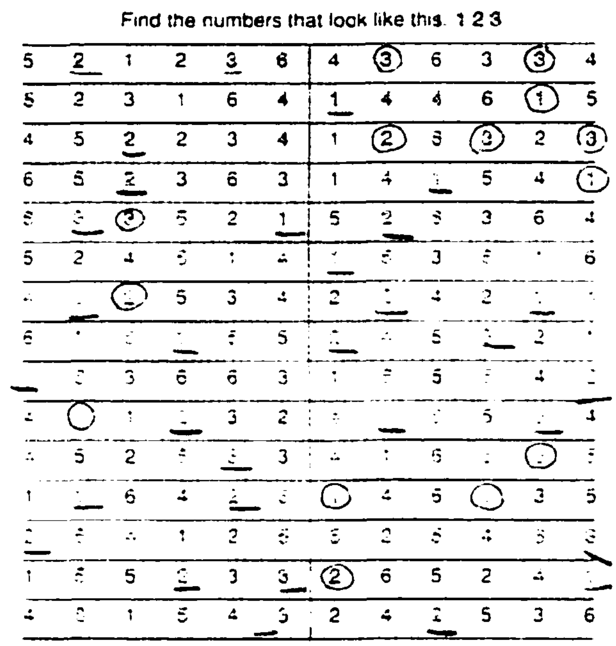


Figure 15. Item 3 of Number Detection for DM. The percentage of omissions was 44% in the right visual field and 15% in the left visual field suggestive of mild right visual neglect perhaps as a consequence of his left parietal infarct.

DM's performance was not significantly impaired on Nonverbal Matrices, Verbal-Spatial Relations and Figure Memory and his raw score for Nonverbal Matrices was on par with that of an average healthy 18-year old. Since matrices tasks are among the highest loading subtests on general intelligence (Lezak, 1995), it appears that DM's pattern of performances is a combination of poor educational opportunities and neuropsychological impairment rather than being singly attributable to low general ability.

Patient 13: SB

SB was assessed during an in-patient stay while neuroradiological investigations were done. There was a loss of gray and white matter identified predominately involving the paracentral lobule and the anterior aspect of the left postcentral gyrus. This was associated with widening of the adjacent sulci. No other supratentorial abnormality was identified. The temporal lobes are normal in appearance. This MRI scan was performed 89 days prior to behavioural assessment with the CAS. No intervening neurovascular events occurred during this time.

Figure 16: Axial MRI Image of SB

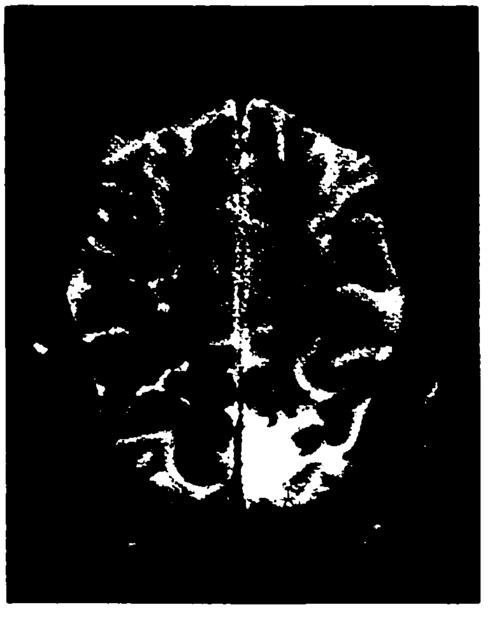


Table 20: SB's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	11	1.49	-
Planned Codes	54	2.11	p = 0.02
Planned Connections	168	0.69	-
PLANNING	-	1.43	-
Expressive Attention	34	1.94	p = 0.03
Number Detection	44	1.30	-
Receptive Attention	36	1.67	p < 0.05
ATTENTION	-	1.64	-
Nonverbal Matrices	17	0.79	-
Verbal-Spatial Relations	17	0.57	-
Figure Memory	6	2.53	p = 0.006
SIMULTANEOUS	-	1.30	-
Word Series	11	0.42	-
Sentence Repetition	8	1.21	-
Sentence Questions	6	3.12	p < 0.001
SUCCESSIVE	-	1.58	-
FULL-SCALE	-	1.49	-

Most noteworthy among SB's CAS results was a significantly impaired performance on Figure Memory. SB's poor performance could not be attributed to visual disturbances. Only 4 out of 25 subjects tested on the Figure Memory subtest had raw scores less than SB. The visualized softening in the superior parietal lobule with EEG evidence of a underlying seizure disorder suggests the possibility of epileptogenic functional perturbation and/or kindling of the homologous superior parietal regions in the right hemisphere via commissural fibers (Foldvary & Wyllie, 1999). Although patients with epilepsy were routinely excluded from the protocol SB was mistakenly included and his results have been included for comparative purposes despite the difficulties in drawing definitive parallels with stroke lesioned patients. In this context it is possible that SB's manifestly poor performance on Figure Memory is a reflection of disruption of the dorsal visual stream important in visual working memory (Ungerleider, Courtney & Haxby, 1998). Congruent with this hypothesis, Ring et al (1999) found strong bilateral activation of the superior parietal regions during performance on the closely related Embedded Figures Test in an fMRI study.

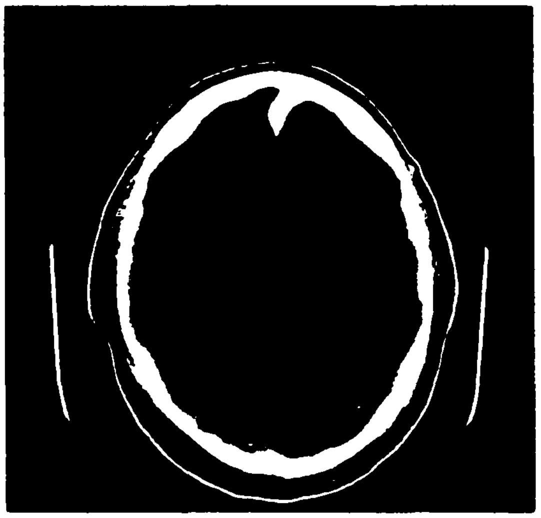
Planned Codes was significantly impaired in keeping with previous studies (Schear & Sato, 1989). Although verbal comprehension as tested with Verbal-Spatial Relations was near normal, SB's performance on Sentence Questions was significantly impaired in accord with damage to left parietal association cortex (Caplan et al, 1996). On the Attention subtests Number Detection was unaffected while Expressive

Attention and Receptive Attention were significantly impaired. An analysis of the Record Form of the CAS for Expressive Attention and Receptive Attention revealed that although SB's accuracy was high on each of these tasks his speed was relatively slow thereby penalizing each respective ratio score. This suggests that general slowing of cognitive, in addition to motor processes, may be one effect of left parietal lesions especially relevant to SB's performance on Expressive Attention. Considering that SB's performance on Sentence Repetition was nonimpaired while on Expressive Attention it was impaired may imply that a purely motor account of the deficit is untenable. Rather damage to posterior parietal association areas may account for this 'cognitive slowing' apparent in his performance.

Patient 14: TL

TL was admitted for a suspected cerebrovascular accident that ultimately proved to be negative and he had a history of a chronic drinking problem. Nonetheless, neuroradiological investigation revealed moderately severe bifrontal atrophy. The ventricles were visualized and appeared normal both in size and position, however the right temporal horn was fractionally larger than the left. Widening of the sulci bifrontally was evident and was especially prominent in the superior frontal regions. An associated widening of the subarachnoid spaces adjacent to the frontal poles extending into the anterior hemispheric fissure was noted, strongly suggestive of localized bifrontal atrophy. Anterior calcification in the falx was also noted. The gray-white matter interfaces were not optimally visualized but no obvious infarct was seen. The basal ganglia, pons, brain stem, and subarachnoid cisterns were normal. This CT scan was performed one day before behavioural assessment with the CAS.

Figure 17: Axial CT Image of TL



All the Planning tasks were impaired except for Planned Connections. On Matching Numbers, TL reported that he used the inefficient strategy of "memorizing the last four digits of each number" while on Planned Codes he did not use a strategy. TL's nonsignificantly impaired performance on Planned Connections would be congruent with previous reports that the Trail Making Test is non-specific for frontal lobe dysfunction (Anderson, Bigler & Blatter, 1995; Crockett, Hurwitz & Vernon-Wilkinson, 1990; Reitan & Wolfson, 1995). Nicolas et al (1997) demonstrated that even well nourished alcoholics were particularly prone to develop frontal lobe atrophy and impairment on frontal lobe tasks compared with demographically matched controls. Similarly, associated atrophy of the corpus callosum particularly within the genu of the corpus callosum is a reliable finding in chronic alcoholics (Estruch et al, 1997).

Since in normal subjects the pars operculis of Broca's area has been found to be highly activated during processing syntax in fMRI studies (Dapretto & Bookheimer, 1999), it is conceivable that the synergistic effect of frontal and putative genual atrophy might be expected to negatively impact syntax comprehension, as well as indirectly interfere with recruitment of homologous right hemisphere regions important for logical reasoning about the Verbal-Spatial Relation's accompanying visuospatial syntactic frames. This elaborate and admittedly speculative hypothesis requires substantiation with similar cases but is congruent with the syndrome profiles of four other neurology patients discussed (e.g., see AO, CB, HB & SB). Sentence Repetition was also impaired which might arise as a consequence of atrophy of dorsolateral prefrontal cortex involved in this task with exaggerated working memory requirements due to its nonsemantic nature. Small, Kemper and Lyons (2000) found that sentence repetition performance correlated with working memory scores on sentences of varying degrees of complexity and these authors interpreted this finding with a resource capacity theory of sentence comprehension. Finally, TL's impaired performance on Sentence Questions could be a manifestation of disrupted syntactic parsing mechanisms associated with the integrity of the inferior frontal lobe (Stromsvold, Caplan, Alpert & Rauch, 1996). It was noted that TL's speech was poorly articulated and this is not inconsistent with the neuroradiological findings.

Table 21: TL's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	8	2.18	p = 0.01
Planned Codes	38	2.78	p = 0.003
Planned Connections	200	1.08	-
PLANNING	-	2.01	p = 0.02
Expressive Attention	39	1.63	-
Number Detection	43	1.34	-
Receptive Attention	39	1.49	-
ATTENTION	-	1.49	-
Nonverbal Matrices	21	0.1	-
Verbal-Spatial Relations	12	1.71	p = 0.04
Figure Memory	14	0.69	-
SIMULTANEOUS	-	0.83	-
Word Series	10	0.84	-
Sentence Repetition	6	2.42	p = 0.008
Sentence Questions	7	2.68	p = 0.004
SUCCESSIVE	-	1.98	p = 0.02
FULL-SCALE	-	1.58	-

Patient 15: DK

DK was admitted to the neurology ward for observation after a suspected transient ischemic attack that ultimately proved to be negative. The lateral third and fourth ventricles were normal in size, shape and position. There was some widening of the subcortical subarachnoid space bifrontally over the cerebellum out of keeping with the patient's age and suggestive of a moderate degree of atrophic change. No mass effect or density alteration of significance was seen supra or infratentorially. There was some mineralization of the globus pallidus bilaterally unusual for this age group; however, there was no evidence of an ischemic infarct. This CT scan was performed eight days prior to behavioural assessment on the CAS.

Figure 18: Axial CT Image of DK

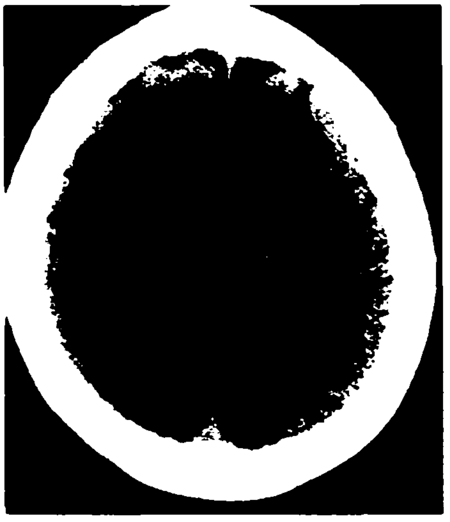


Table 22: DK's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	12	1.26	-
Planned Codes	54	2.11	p = 0.02
Planned Connections	350	2.93	p = 0.002
PLANNING	-	2.10	p = 0.02
Expressive Attention	29	2.24	p = 0.01
Number Detection	34	1.73	p = 0.04
Receptive Attention	25	2.31	p = 0.01
ATTENTION	-	2.10	p = 0.02
Nonverbal Matrices	11	1.84	p = 0.03
Verbal-Spatial Relations	15	1.02	-
Figure Memory	12	1.15	-
SIMULTANEOUS	-	1.34	-
Word Series	8	1.68	p < 0.05
Sentence Repetition	7	1.82	p = 0.03
Sentence Questions	9	1.78	p = 0.04
SUCCESSIVE	-	1.76	p = 0.04
FULL-SCALE	-	1.82	p = 0.03

DK was not living independently at the time of her admission and there were indications of a pre-existing mild mental handicap. DK was unable to progress beyond the perceptual matching items of Nonverbal Matrices and perform simple analogical reasoning items. Shulman, Yirmiya and Greenbaum (1995) demonstrated significantly greater impairment on reasoning rather than perceptual matching items of matrices items among autistic and mentally handicapped individuals compared to normal individuals matched in terms of mental age. Since there was some mild frontal atrophy but no definitive neuroradiological findings, intellectual handicap was likely the cause of the low scores on CAS subtests. None of DK's scores were in the normal range.

Inordinate motor slowing was evident on the Planned Codes subtest (Schear & Sato, 1989) and mental flexibility (Crowe, 1998) was severely impaired on the Planned Connections subtest. Apparent changes in the globus pallidus could be a marker for impaired performance on the Planned Connections subtest (Alegret et al, 2000). DK had a strong tendency to perseverate on the letter to number alternations for items 7 and 8 on Planned Connections. The Strategy Assessment Checklist revealed that DK used inefficient or no strategies on all the Planning tasks. DK's performance was significantly impaired on all the speeded Attention tasks. An analysis of error patterns revealed generally slow completion times and low accuracy which is consistent with previous reports of larger decrements in performance on Planning and Attention subtests in intellectually handicapped persons (Das et al, 1995). There was difficulty in interpreting the results of the low subtest raw scores on the Successive scale due to the non-specific nature of the neuropathology. A more likely etiology is the generally lower performance on all CAS subtests by the mentally retarded (x = -1.3σ, range = -0.93σ to -1.8σ) in the CAS standardization sample (Naglieri & Das, 1997, p. 77).

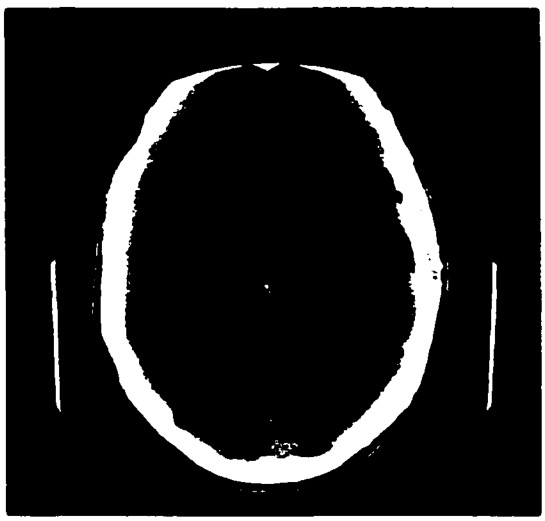
Patient 16: RM

RM was working full-time on a construction project up until the time of his accident. He was admitted to emergency after falling off a ladder backwards from a height of 15 feet. He sustained a loss of consciousness for several minutes afterwards and reported that he had a headache. It appears that a wheelbarrow cushioned his fall. He arrived at the emergency department with nausea, vomiting and back pain with a Glasgow Comas Scale (GCS) of 14/15 (Jennett & Bond, 1975). He was able to move all his limbs, was orientated to time and place although his speech was incoherent at times, and he had decreased strength in his left hand. He remained alert and conscious throughout his period of hospitalization and was subsequently discharged. He had sustained an injury 11 years prior to his left eye although previous ophthalmological testing demonstrated that he had developed adequate compensatory mechanisms.

RM was referred for a CT scan of the brain the day after his accident as well as two weeks after his injury. On the initial CT, post-traumatic changes were evident in a small right tentorial hematoma.

Hyperdensity in the anterior falx posteriorly was noted suggesting tracking of the subdural into the inferior falx. There was interhemispheric subarachnoid hemmorhage between the medial frontal lobes bilaterally. Hemorrhage was identified in the left mid-frontal lobe involving the superior frontal gyrus, middle frontal gyrus, as well as the mesial frontal structures back to the anterior aspect of the cingulate gyrus. The areas of hemorrhagic contusion in the medial left frontal lobe in the superior frontal gyrus extended back to the high frontal region within approximately 4 to 5 cm of precentral gyrus. There was some hemorrhagic contusion seen in the medial right frontal lobe superior to the hemorrhagic contusion in the medial left frontal lobe. This extended back to within approximately 5 to 6 cm of the precentral gyrus on the right side. On the subsequent CT scan the hemorrhages had diminished in density. There was still residual mild edema seen in the medial frontal cortex bilaterally while there had been significant tentorial subdural hematoma resorption. This CT scan was performed 67 days after behavioural assessment with the CAS.

Figure 19: Axial CT Image of RM



All of RM's Simultaneous and Successive subtest raw scores were above the normal range for healthy 18-year olds. In addition, Expressive Attention and Number Detection were above the normal range. Curiously, Receptive Attention, a measure of lexical categorization was marginally although non-significantly impaired. Interpretation of this finding was clouded by the visual problems with RM's left eye. The only other significant finding of note was RM's depressed Planned Connections score out of keeping with his Full-Scale IQ measured at 126 with the WAIS-R (Wechsler, 1981) 6 months after his injury. On the WAIS-R a disparity between his VIQ of 127 and his PIQ of 114 was suggestive of some minor motor slowing. RM demonstrated some perseveration on item 7 of Planned Connections suggestive of a potential loss of mental flexibility. D'Esposito et al (1996) found that medial frontally lesioned patients were disproportionately impaired on the Trail Making Test compared to basal forebrain lesioned patients.

Table 23: RM's CAS Performance

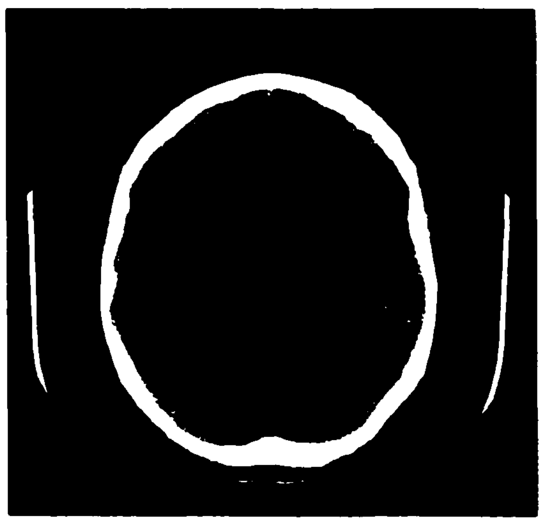
CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	16	0.35	-
Planned Codes	98	0.28	-
Planned Connections	200	1.08	-
PLANNING	-	0.57	-
Expressive Attention	77	Normal	-
Number Detection	86	Normal	-
Receptive Attention	44	1.2	-
ATTENTION	-	0.4	-
Nonverbal Matrices	22	Normal	-
Verbal-Spatial Relations	23	Normal	-
Figure Memory	21	Normal	-
SIMULTANEOUS	-	Normal	-
Word Series	12	Normal	-
Sentence Repetition	12	Normal	-
Sentence Questions	15	Normal	-
SUCCESSIVE	-	Normal	-
FULL-SCALE	-	0.24	-

Chapter 4: Right Hemisphere Lesioned Patients

Patient 17: IS

IS was admitted for left hemiplegic symptoms and slurring of speech. A neuroradiological examination revealed that the size, shape, and position of the ventricular system was normal. The cortical subarachnoid spaces were widened over the cerebellum marginally more than might be expected in this age group but these changes were still within normal limits. There was a relatively well-defined low density in the posterior frontal region including the frontal portion of the operculum on the right side. The visualized portion of the brain stem was normal. This axial image depicts the lesion in the region of greatest diameter within the right posterior inferior frontal lobe. The CT scan was performed the day before behavioural assessment with the CAS.

Figure 20: Axial CT Image of IS



The most significant finding was the poor performance on Planned Codes suggestive of motor slowing (Schear & Sato, 1989) in the presence of near normal performance on Planned Connections. This may be due to the lateral as opposed to medial nature of IS's frontal lesion (D'Esposito et al, 1996). Both the Expressive Attention and Number Detection were mildly although non-significantly impaired, perhaps a reflection of the propensity for right frontal lesions to affect performance on tasks tapping the neural correlates of sustained attention (Vendrell et al, 1995; Binder et al, 1992).

Table 24: IS's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	12	1.26	-
Planned Codes	43	2.57	p = 0.005
Planned Connections	148	0.45	-
PLANNING	-	1.43	-
Expressive Attention	48	1.09	-
Number Detection	51	1.00	-
Receptive Attention	-	-	-
ATTENTION	-	1.05	-
Nonverbal Matrices	18	0.62	-
Verbal-Spatial Relations	22	Normal	-
Figure Memory	-	-	-
SIMULTANEOUS	-	0.31	-
Word Series	18	Normal	-
Sentence Repetition	13	Normal	-
Sentence Questions	-	-	-
SUCCESSIVE	-	Normal	-
FULL-SCALE	-	0.78	-

Patient 18: SW

SW was admitted with a right middle cerebral artery infarct. She displayed excellent motivation throughout the examinations. Neuroradiological examination revealed a fairly extensive hypodense area with some loss of cortical grey and white matter differentiation that was noted in the right frontal lobe extending into the anterior aspect of the basal ganglia. There was no convincing evidence of vasogenic edema although there was a slight positive mass effect. The appearances suggested an ischemic infarct of the right middle cerebral artery without hemorrhage. This CT scan was performed nine days prior to behavioural assessment with the CAS.

Figure 21: Axial CT Image of SW

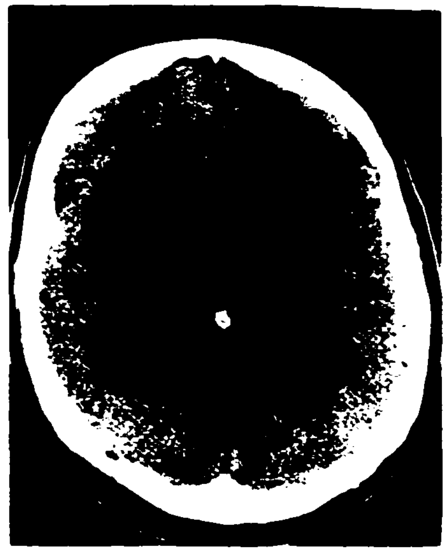


Table 25: SW's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	11	1.49	-
Planned Codes	47	2.40	p = 0.008
Planned Connections	204	1.13	-
PLANNING	-	1.67	p < 0.05
Expressive Attention	49	1.03	-
Number Detection	48	1.13	-
Receptive Attention	35	1.72	p = 0.04
ATTENTION	-	1.29	-
Nonverbal Matrices	6	2.71	p = 0.003
Verbal-Spatial Relations	16	0.80	-
Figure Memory	8	2.07	p = 0.02
SIMULTANEOUS	-	1.86	p = 0.03
Word Series	13	Normal	-
Sentence Repetition	10	Normal	-
Sentence Questions	10	1.34	-
SUCCESSIVE	-	0.45	-
FULL-SCALE	-	1.32	-

Planned Codes was the only Planning subtest which was significantly impaired which is consistent with previous studies (Schear & Sato, 1989). Among the Attention subtests Receptive Attention was the only subtest that indicated significantly impaired results. It was not readily apparent why Receptive Attention was disproportionately affected among the Attention subtests although SW at an age of 64 was the third oldest patient tested. Gutentag and Madden (1987) found a larger increase in reaction time with age in the attention demands of the encoding of lexical identity as opposed to physical identity tasks congruent with Craik and Byrd's (1982) conclusion that deeper processing requires greater attention demands. Congruent with this hypothesis omissions increased by 56% from physical identity match on item 5 compared to lexical identity on item 6 on the Receptive Attention subtest for this patient.

The other notable finding was a significantly impaired performance on Nonverbal Matrices and Figure Memory on the Simultaneous scale. The right dorsolateral cortex was prominently activated during performance on a task similar to Figure Memory, that being Embedded Figures Test in an fMRI study (Ring et al, 1999). Similarly in another fMRI study, Prabhakaran et al (1997) found bilateral frontal activation during the analogical reasoning problems and prominent right frontal and bilateral parietal activation during figural reasoning items of the Ravens Coloured Progressive Matrices. A highly atypical pattern of early errors on items 3, 5, 7, 8, and 10 of the perceptual matching items of Nonverbal Matrices fits the pattern predicted by these neuroimaging studies.

Patient 19: JL

JL was admitted the night after experiencing mild weakness on his left side. This was accompanied by abnormal behavior such as aimlessly wandering around, self-reports of visual hallucinations, as well as dressing inappropriately. When examined in the emergency room he was apathetic, disorientated but at the same time calm. He would attempt to answer questions but was mistaken with many of his answers and appeared unalarmed about his present condition or situation.

Neuroradiological examination revealed that his ventricles were essentially normal in size and position but there was a peripheral, roughly triangular, well-defined hypointensity involving the right frontal lobe, extending from the genu of the corpus callosum to the inner table of the skull. There was minimal midline shift from the right frontal lobe to the left. Some linear augmentation of structures within the lesion possibly represented vessels or compressed gyri. There was some visualization of the carotid siphons and proximal middle cerebral arteries, but not the anterior cerebral arteries and parafalcine calcification was present. The sulci were especially compressed over the right frontal region and slightly widened over the left. The posterior fossa structures appeared to be normal. The appearance was compatible with a subacute infarct in the distribution of the right anterior cerebral artery possibly including the recurrent artery of Heubner. This CT scan was performed in the morning before the behavioral assessment with the CAS.

Figure 22: Axial CT Image of JL

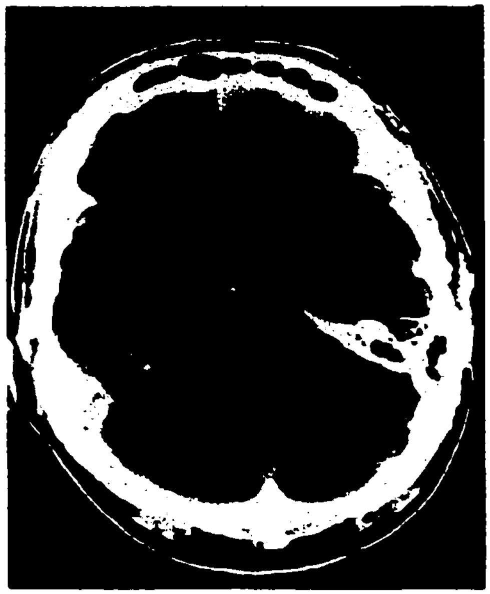


Table 26: JL's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	3	3.33	$p < 0.001$
Planned Codes	18	3.61	$p < 0.001$
Planned Connections	350	2.93	$p = 0.002$
PLANNING	-	3.29	$p < 0.001$
Expressive Attention	3	3.82	$p < 0.001$
Number Detection	3	3.08	$p = 0.001$
Receptive Attention	-	-	-
ATTENTION	-	3.45	$p < 0.001$
Nonverbal Matrices	6	2.71	$p = 0.003$
Verbal-Spatial Relations	12	1.71	$p = 0.04$
Figure Memory	-	-	-
SIMULTANEOUS	-	2.21	$p = 0.01$
Word Series	12	Normal	-
Sentence Repetition	13	Normal	-
Sentence Questions	-	-	-
SUCCESSIVE	-	Normal	-
FULL-SCALE	-	2.35	$p = 0.009$

All the Planning and Attention subtest items of JL were severely impaired consistent with his large right frontal lesion. The *Strategy Assessment Checklist* revealed that JL did not use any strategies for any of the Planning subtests implying a strategy implementation disorder (Shallice & Burgess, 1991). JL also had to be reminded several times not to turn the page when only half-way through the Planned Connections items suggestive of disinhibition of automatic behaviors (Edwards-Lee & Saul, 1999). Severe left visual neglect was apparent on Number Detection (see below) in congruence with previous studies (Husain & Kennard, 1997).

Find the numbers that look like this: 1 2 3

5	2	1	2	3	6	4	3	6	3	3	4
6	2	3	1	6	4	1	4	4	6	1	5
4	5	2	2	3	4	1	2	6	3	2	3
6	5	2	3	6	3	1	1	1	5	4	1
6	3	3	5	2	1	5	2	6	3	6	4
5	2	4	5	1	4	1	5	3	6	1	6
4	3	2	5	3	4	2	2	4	2	1	4
6	1	6	1	5	5	2	4	5	3	2	1
1	6	3	6	6	3	1	6	5	5	4	2
4	1	1	2	3	2	4	1	6	5	3	4
4	5	2	6	3	3	4	1	6	5	3	5
1	1	6	4	2	6	1	4	6	1	3	5
2	6	4	1	2	5	5	2	5	4	6	3
1	5	5	2	3	3	2	6	5	2	4	1
4	6	1	5	4	3	2	4	2	5	3	6

***Figure 23:** Item 3 from Number Detection for JL. The percent of omissions was 86% for the left visual field and 20% for the right visual field. The line down the middle is drawn in to designate the bisected fields of hemi-space. Underlines are JL's marks, circled responses are omissions and the two x's are false detections scored by the examiner.*

Nonverbal Matrices was also severely impaired consistent with previous reports of the right frontal lobe as being critically involved in performance on matrices tasks (Prabahakran et al, 1997). JL was unable to perform any of the analogical reasoning items and even failed items 1, 3, and 4 of Nonverbal Matrices suggestive of nonverbal perceptual matching impairment. Interestingly, JL's performance on Verbal-Spatial Relations was just marginally significantly impaired suggesting premorbid left language lateralization. Large magnitude single dissociations in performance were illustrated by JL's above average performance on Word Series and Sentence Repetition and suggest strongly left lateralized language function despite JL's left-handedness.

Patient 20: TF

TF was working full-time as a licensed heavy equipment operator up until the time of his accident. He presented in the emergency department after being assaulted. Witnesses report that he received a heavy blow to the forehead after a confrontation and that he slumped forward and fell to the sidewalk. He lost consciousness for a period of 20 minutes after the blow and was amnesic about the entire incident. On clinical examination, his lower jaw was found to have a simple fracture and he was discharged several hours later after being prescribed an anti-inflammatory for the swelling. The following day he returned to local hospital approximately 24 hours after the initial injury. He had been complaining of progressively worsening headaches with accompanying nausea, severe vomiting, and photophobia all throughout the day after the injury occurred.

On this second admission to the local hospital the following day, TF opened his eyes to voice commands only and he was found to have a sluggish left pupil and a GCS of 14/15 (Jennett & Bond, 1975). Some hours later, following a routine CT scan, an expanding large right frontal lobe hematoma was discovered and he was immediately rushed by air ambulance to University of Alberta Hospital for preemptive neurosurgical observation. His hematoma gradually began to resolve and there was significant resorption of blood over the next weeks as revealed by serial non-contrast enhanced CT scanning. During his stay as an in-patient in acute-care, his jaw was reset and subsequently wired for recuperative purposes under local anaesthesia but this did not appreciably interfere with TF's subsequent articulation.

TF was assessed with the CAS approximately 2 weeks post-injury. TF displayed some difficulties in understanding complex oral instructions but his intact initiative and self-monitoring was evident in requests to start tasks over again after he noticed that he had made mistakes. Family members reported that he demonstrated some residual difficulties in remembering daily tasks such as chores and planned events after his accident and that he sometimes required reminding.

TF was referred for a non-contrast enhanced CT scan immediately after his accident and repeatedly during his stay in the acute-care setting. The scan closest to the first CAS testing period at approximately 2 weeks post-injury, revealed a subacute intracerebral hemorrhage measuring approximately 5.5 x 2.3 x 3.5 cm identified within the right mid-frontal lobe. The hemorrhage was heterogeneous in density with a small amount of vasogenic edema manifest as effaced sulci in the right frontal lobe. In addition, there was some hemorrhagic and non-hemorrhagic contusion in the inferior medial left frontal lobe. The mild edema in the right frontal cortex extended up to the mid-frontal lobe under both superior and middle frontal gyri. There was a second region of non-hemorrhagic contusion seen in the left mid-frontal lobe adjacent to the falx just under the superior frontal gyrus. A subsequent CT approximately two weeks after his injury revealed that there had been substantial resorption of the hemorrhage and that some of the edema had significantly resolved. This CT scan was performed two days prior to behavioral assessment with the CAS.

Figure 24: Axial CT Image of TF

Table 27: TF's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	14	0.81	-
Planned Codes	62	1.78	P = 0.04
Planned Connections	184	0.89	-
PLANNING	-	1.16	-
Expressive Attention	26	2.42	P = 0.008
Number Detection	78	Normal	-
Receptive Attention	65	Normal	-
ATTENTION	-	0.81	-
Nonverbal Matrices	21	0.1	-
Verbal-Spatial Relations	16	0.8	-
Figure Memory	21	Normal	-
SIMULTANEOUS	-	0.45	-
Word Series	11	0.42	-
Sentence Repetition	11	Normal	-
Sentence Questions	12	0.44	-
SUCCESSIVE	-	0.43	-
FULL-SCALE	-	0.64	-

TF demonstrated a rather isolated pattern of impairment on Planned Codes (Shear & Sato, 1989) and Expressive Attention (Vendrell et al, 1995). Curiously, no other scores were significantly impaired and TF returned to work approximately 6 months after his accident. He did report after this time that his "memory lapsed at times" but other than these minor complaints his family reported that he did not appear to suffer any other ill effects. At this time he was also assessed with the WAIS-R (Wechsler, 1981). TF's scores were as follows: FSIQ = 100, VIQ = 91, and PIQ = 114. TF's scaled score of 5 on the Verbal scale was moderately discrepant from the rest of his verbal subtest mean scores (x = 8.3). Arithmetic of the WAIS-R has been traditionally conceived as involving two primary cognitive factors: these being (i) working memory (ii) and mental manipulation of information in addition to computation and number fact retrieval (Kaplan, Fein, Morris & Delis, 1991, p. 39). Langdon and Warrington's (1997) demonstration that the structural integrity of the right hemisphere was just as important for arithmetical reasoning as the left hemisphere was for arithmetical computation could contextualize TF's WAIS-R arithmetic results since these word problems initially require abstraction of the essence of the problem into an acceptable computational format.

Patient 21: RG

RG was admitted with left hemiplegia and suspected right middle cerebral artery infarct. Neuroradiological examination revealed a well-defined lesion which measured 1.8 x 2 x 3 cm and which was adjacent to a densely calcified portion of the falx. No deformity of the ventricular system was seen. The lateral, third and fourth ventricles were normal in size, shape and position. The cortical subarachnoid spaces were normal except for the area overlying the lesion in the right posterior frontal lobe where it was obliterated due to mass effect. No abnormality of the visualized portions of the brain stem or cerebellum was seen. This CT scan was performed four days prior to behavioural assessment.

Figure 25: Axial CT Image of RG

Table 28: RG's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	14	0.81	-
Planned Codes	16	3.69	$p < 0.001$
Planned Connections	137	2.06	$p = 0.02$
PLANNING	-	2.19	$p = 0.01$
Expressive Attention	32	2.06	$p = 0.02$
Number Detection	45	1.26	-
Receptive Attention	51	0.79	-
ATTENTION	-	1.37	-
Nonverbal Matrices	18	0.62	-
Verbal-Spatial Relations	17	0.57	-
Figure Memory	12	1.15	-
SIMULTANEOUS	-	0.78	-
Word Series	11	0.42	-
Sentence Repetition	11	Normal	-
Sentence Questions	10	1.34	-
SUCCESSIVE	-	0.59	-
FULL-SCALE	-	1.23	-

Planned Codes was severely impaired indicative of motor response slowing (Schear & Sato, 1989) and RG did not use a strategy for this subtest. Planned Connections was also significantly impaired, attributable to motor slowing as well as reduced mental flexibility owing to the lesion's proximity and encroachment on medial frontal structures (Crowe, 1998; D'Esposito et al, 1996). Interestingly, for such a well-demarcated and moderately-sized lesion, the only other notable finding was a significantly impaired performance on the Expressive Attention subtest highly consistent with previous studies demonstrating the sensitivity of the Stroop test to right frontal lesions (Vendrell et al, 1995). RG was a cheerful woman with an optimistic attitude who looked forward to returning to work.

Patient 22: GC

GC was admitted to hospital for a tumour in the right frontal lobe. Neuroradiological examination revealed a densely mineralized hyperdensity in the right frontal lobe as well as a hyperdense component in the frontal operculum. There were also some calcifications within the pons. Gyral atrophy was noted in the left frontal pole perhaps as a consequence of Wallerian degeneration secondary to the primary site of the lesion. This CT scan was performed 36 days prior to behavioural assessment with the CAS.

Figure 26: Axial CT Image of GC

Table 29: GC's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	4	3.10	p < 0.001
Planned Codes	21	3.48	p < 0.001
Planned Connections	350	2.93	p = 0.001
PLANNING	-	3.17	p < 0.001
Expressive Attention	6	3.63	p < 0.001
Number Detection	10	2.77	p = 0.003
Receptive Attention	22	2.49	p = 0.006
ATTENTION	-	2.96	p = 0.002
Nonverbal Matrices	15	1.14	-
Verbal-Spatial Relations	17	0.57	-
Figure Memory	12	1.15	-
SIMULTANEOUS	-	0.95	-
Word Series	5	2.94	p = 0.002
Sentence Repetition	2	4.83	p < 0.001
Sentence Questions	7	2.68	p = 0.004
SUCCESSIVE	-	3.48	p < 0.001
FULL-SCALE	-	2.64	p = 0.004

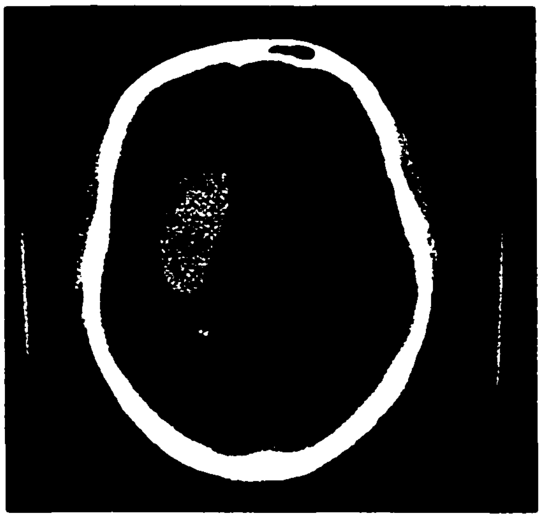
All of GC's Planning, Attention and Successive subtest performances were in the severely impaired ranges. Although GC used strategies on all three Planning subtests his times were inordinately slow as they were on all the Attention tasks consistent with the generalized slowing effects of brain lesions on planning and attention tasks (Schear & Sato, 1989). However, motor slowing cannot be the sole source of these unexpectedly low scores on the Successive scales as these are untimed tests. An alternative interpretation is that GC has severely impaired sustained attention as a result of his extensive right frontal lesion (Rueckert & Grafman, 1996). It would appear that the most severe manifestations of his attention deficit would manifest itself on those tasks that are speeded or which are presented in only one modality thus negating the potential for dual coding (Paivio, 1995). In support of this hypothesis there was no visuospatial neglect on any of the CAS subtests and dually coded Verbal-Spatial Relations was the most mildly affected subtest of the CAS.

GC's past history of seizure suggests caution in over-interpreting the results of these CAS findings. It was observed that GC's level of concentration lapsed continually throughout the examination. The marked atrophy of GC's left inferior frontal regions is itself an indicator for potential difficulties in expressive language (Lezak, 1995). Behaviorally, this was observed in GC's deliberate, slowly articulated, and barely audible speech. Yet another potential confound is mentionable. The atrophy in the lobe contralateral to the lesion along with EEG evidence of an underlying seizure disorder suggested the possibility of epileptogenic functional perturbation and/or kindling of the homologous inferior frontal region via commissural fibers (Foldvary & Wyllie, 1999). Although patients with epileptogenic focuses were routinely excluded from the protocol, SB was mistakenly included and his results have been included for comparative purposes despite the inherent difficulties in drawing definitive parallels with stroke-lesioned patients.

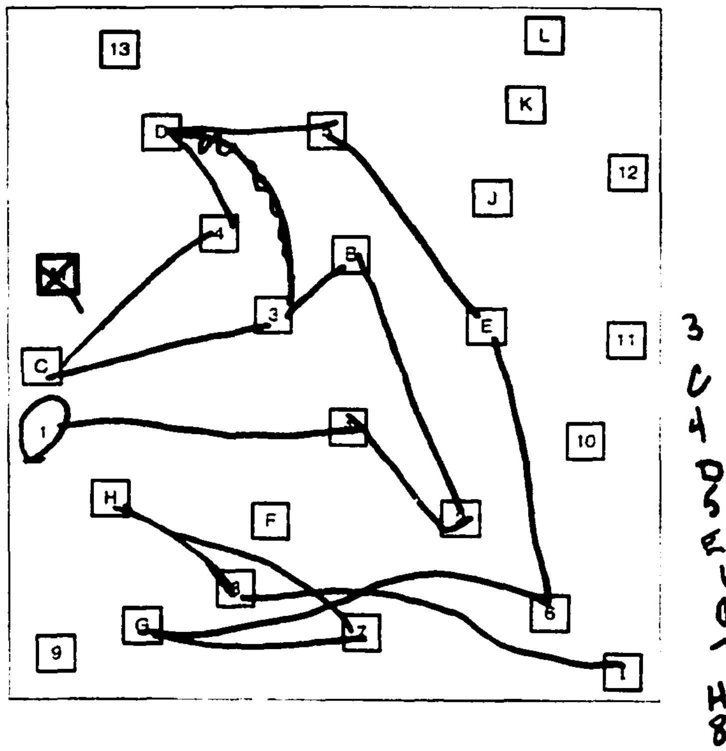
Patient 23: BT

BT's first sign of stroke was severe pain experienced underneath his right temple that progressed into complete left hemiplegia. Neuroradiological examination revealed an acute hematoma centered on the right basal ganglia. The hematoma was causing compression of the ipsilateral lateral ventricle with associated midline shift. There was intraventricular blood within the occipital horn of the right lateral ventricle and there was also a small amount of vasogenic edema surrounding the hematoma although the basal cisterns were open. The etiology was likely due to a hypertensive hemorrhage with intraventricular extension. This CT scan was performed seven days after behavioural assessment with the CAS. This axial scan depicts the maximal diameter of the acute hematoma centered in the right basal ganglia.

Figure 27: Axial CT Image of BT



BT was previously healthy and working full-time up until the time of his stroke. All BT's Planning and Attention subtest scores were in the severely impaired range. On the Planned Connections subtest he knew which letter or number was next in the series but was unable to locate them in the visual field. This is despite the fact that he even wrote the letters down on the right side of the page as a mnemonic aid (see **Figure 28** next page).



On Number Detection, BT demonstrated severe left visual field neglect. Subsequent testing of the limits after the formal administration revealed that he had to be reminded to draw his attention to the left side of space (see Figure 29 below: Number Detection item for BT).

Find the numbers that look like this: 1 2 3 4 5 6

4	3	1	5	1	4	2	2	5	1	3	4
1	4	2	6	3	6	4	5	3	5	3	6
2	4	1	6	6	2	3	6	1	2	3	5
1	5	5	4	6	3	1	4	5	6	2	2
1	4	6	3	4	5	3	2	3	4	6	X
2	5	2	1	6	4	3	6	5	3	5	6
5	6	4	5	3	2	6	1	2	4	3	1
1	4	6	2	3	4	6	5	2	3	1	5
3	1	4	3	5	2	6	2	1	3	5	6
2	5	2	1	1	6	5	6	3	4	4	2
4	1	6	4	2	5	3	4	1	2	6	5
3	3	5	6	6	4	1	2	6	4	2	2
6	1	4	2	4	3	5	1	6	3	5	4
5	4	3	2	6	5	1	4	2	5	[illegible]	6
2	1	5	1	3	4	2	5	3	1	4	4

BT's severe visual neglect would be expected to negatively impact performance on all the visuospatial subtests, although it is perhaps telling that the Nonverbal Matrices was minorly and Figure Memory was minimally impaired. Motor slowing was likely a significant factor on all the Planning and Attention subtests for BT (Shear & Sato, 1989), however motor slowing is unlikely to be the sole factor for the other CAS subtests since BT's raw score of 14 out of 33 on Nonverbal Matrices is out of keeping with the performance of the average 18-year old on this test (e.g., 21 out of 33 items). Moreover, considering that BT had four years of university education, a professional occupation, and he was in an older age cohort places his estimated premorbid Barona IQ at 120 ± 12 at 15% CI. In this context, all of BT's Simultaneous scores are below expected values (Barona, Reynolds & Chastain, 1984).

Nonverbal Matrices was more impaired (e.g., ~ 1 σ) than Figure Memory and this may indicate that Nonverbal Matrice's functional neuroanatomical substrates of performance are relatively more anterior as opposed to posteriorly localized. This would be congruent with neuroimaging and lesion studies examining the processing characteristics of figure disembedding (Ring et al, 1999) and analogical reasoning items (Prabhakran et al, 1997; Waltz et al, 1999). In the former instance a Figure Memory resembling task gave rise to strong posterior parietal activation while the latter analogical reasoning items similar to Nonverbal Matrices were especially sensitive right prefrontal lesions. The verbal successive subtests were not impaired consistent with lateralization of language functions to the dominant hemisphere in this right-handed patient. Of note, Verbal-Spatial Relations was in the borderline impaired range suggesting a significant right hemisphere computational aspect to this subtest in congruency with previous cases discussed herein.

Table 30: BT's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	2	3.56	$p < 0.001$
Planned Codes	37	2.82	$p = 0.002$
Planned Connections	350	2.93	$p = 0.002$
PLANNING	-	3.10	$p < 0.001$
Expressive Attention	27	2.36	$p = 0.009$
Number Detection	13	2.64	$p = 0.004$
Receptive Attention	-	-	-
ATTENTION	-	2.50	$p = 0.006$
Nonverbal Matrices	14	1.32	-
Verbal-Spatial Relations	14	1.25	-
Figure Memory	15	0.46	-
SIMULTANEOUS	-	1.01	-
Word Series	12	Normal	-
Sentence Repetition	9	0.61	-
Sentence Questions	14	Normal	-
SUCCESSIVE	-	0.20	-
FULL-SCALE	-	1.63	-

Patient 24: WM

WM was admitted to hospital with aphasic symptoms and left hemiplegia of acute onset. A large parenchyma hematoma measuring up to at least 4.5 cm in maximal dimension was present, its epicentre in the region of the internal capsular white matter on the right. There was some surrounding edema with mass effect that distorted the adjacent basal ganglia and thalamus. Blood dissected into the ventricles and a huge clot essentially filled the right lateral, third, and fourth ventricles. Some compression and distortion of the right lateral ventricles was seen with subfalcine herniation from right to left of at least 8-10 mm. The basal ganglia appeared to be patent. There was some relative effacing of sulci in the parietal and temporal lobes on the right and the symptoms were in keeping with an acute intracranial hypertensive bleed and associated hematoma. This CT scan was performed ten days prior to behavioural assessment with the CAS.

Figure 30: Axial Image of WM

Despite significant resorption of hemorrhage and resolution of edema at the time of behavioural testing one can see that all of WM's CAS subtest scores are in the severely impaired range -- with the exception of Figure Memory and the subtests of the Successive Scale. The obliteration of the right basal ganglia and compression and likely damage to the thalamus is a marker for potential subcortical vascular dementia (McPherson & Cummings, 1996). The prognosis for recovery for this patient was not deemed to be especially positive and whether clinically diagnosable subcortical dementia would become manifest would be dependent on an adequate observation period past the sub-acute phase of this devastating stroke. WM had significant difficulties with maintaining arousal during the visual tasks although he did express an interest in participating in the study. Severe left visual field neglect was evident on Number Detection.

In the context of such pervasive impairments it is perhaps more informing to examine what patterns of marginal sparing of cognitive functions are evident. Word Series, Figure Memory, Sentence Questions, and Sentence Repetition were the least impaired in order of increasing magnitude of impairment. Verbal-Spatial Relations was severely impaired revealing the significant visuoconstructive aspect of this task as was Nonverbal Matrices. Figure Memory's lesser impairment was perhaps explainable in terms of a performance dependency on intact bilateral parietal regions (Ring et al, 1999). Similarly, Word Series was almost unimpaired consistent with previous reports of localization to the posterior perisylvian regions of Wernicke's area (Gordon, 1983) that is in a quadrant of the brain far removed from the maximal locus of damage. Comprehension and repetition were also impaired in WM. Under the circumstances of the large lesion these effects remote from the site of the lesion could be due to any number of reasons including: secondary degenerations, compression, and altered cerebral blood flow dynamics post-stroke (Bornstein & Brown, 1991). For these reasons caution against over-interpretation of WM's findings are warranted.

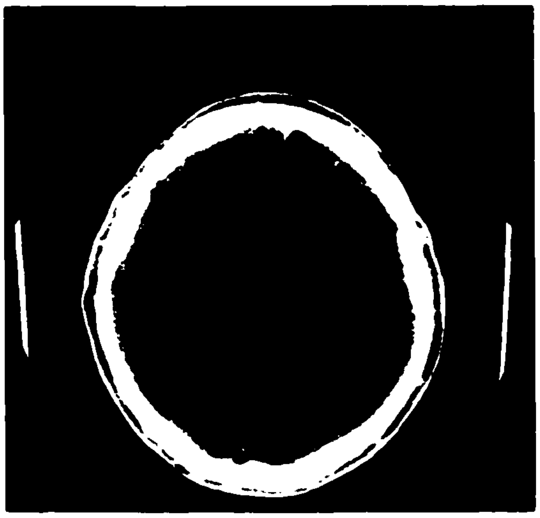
Table 31: WM's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	3	3.33	$p < 0.001$
Planned Codes	13	3.81	$p < 0.001$
Planned Connections	350	2.93	$p = 0.002$
PLANNING	-	3.36	$p < 0.001$
Expressive Attention	12	3.27	$p < 0.001$
Number Detection	1	3.16	$p < 0.001$
Receptive Attention	2	3.66	$p < 0.001$
ATTENTION	-	3.36	$p < 0.001$
Nonverbal Matrices	5	2.89	$p = 0.002$
Verbal-Spatial Relations	7	2.85	$p = 0.002$
Figure Memory	8	2.07	$p = 0.02$
SIMULTANEOUS	-	2.60	$p = 0.005$
Word Series	8	1.68	$p < 0.05$
Sentence Repetition	6	2.42	$p = 0.008$
Sentence Questions	8	2.23	$p = 0.01$
SUCCESSIVE	-	2.11	$p = 0.02$
FULL-SCALE	-	2.86	$p = 0.002$

Patient 25: JH

JH was admitted to hospital with left hemiplegia and severe headache. He was previously healthy and employed up until the time of his admission. The history indicated a sagittal sinus thrombosis with right hemispheric venous infarct. There was no indication of hydrocephalus and there was a very slight right-to-left midline shift that was evident. An irregular area of hypo-attenuation was noted in the central aspect of the right centrum semiovale that extended rostrally and laterally to involve the right frontal cortex. The pattern is of cytotoxic edema in a non-arterial distribution. No focal areas of hyperattenuation were noted to indicate interval hemorrhagic transformation. Mild mass effect was demonstrated with partial effacement of the right hemispheric cerebral sulci to the level of the convexity. The basilar cisterns were normal. This axial CT scan was performed within a day of the behavioural assessment with the CAS and it passed through the region of maximal anterior-posterior hypo-attenuation within the centrum semiovale.

Figure 31: Axial CT Image of JH



JH was found to have clinically significant impairments on three subtests of the CAS. Planned Codes was impaired indicating general response slowing (Schear & Sato, 1989) and JH did not use a strategy on this task. Matching Numbers was also impaired and this was manifest mainly as slowed scanning of the visual arrays of numbers although his accuracy level was 96%. Recall that JH's lesion was located within the lateral aspect of the right middle frontal cortex. Lesions within the right frontal lobe have been previously shown to be especially deleterious to performance on visual search tasks (Binder et al, 1992; Husain & Kennard, 1997). Nonverbal Matrices was borderline impaired which is consistent with the majority of damage within the right frontal lobe (Prabhakran et al, 1997; Waltz et al, 1999). The deficit in the comprehension of complex syntax evident in Sentence Questions could arise due to the compromise of homologous dual processing resources of the pars opercularis in the right hemisphere (Stromswold, Caplan, Alpert & Rauch, 1996). Alternatively cognitive slowing as a consequence of edematous changes have been previously shown to have the most pronounced effects on higher order cognitive functions such as language comprehension (Bornstein & Brown, 1991).

Table 32: JH's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	10	1.72	p = 0.04
Planned Codes	41	2.65	p = 0.004
Planned Connections	219	1.32	-
PLANNING	-	1.90	p = 0.03
Expressive Attention	63	0.18	-
Number Detection	64	0.44	-
Receptive Attention	62	0.14	-
ATTENTION	-	0.25	-
Nonverbal Matrices	13	1.49	-
Verbal-Spatial Relations	22	Normal	-
Figure Memory	20	Normal	-
SIMULTANEOUS	-	0.50	-
Word Series	11	0.42	-
Sentence Repetition	9	0.61	-
Sentence Questions	8	2.23	p = 0.01
SUCCESSIVE	-	1.09	-
FULL-SCALE	-	0.93	-

Patient 26: RA

RA was admitted with right hemiparesis and clinical neurological exam revealed a visual gaze deviation to the right, a left homonymous hemianopsia, and a left upper motor neuron facial droop. Although RA's speech was slightly slurred he did not have any aphasia. Neuroradiological examination revealed a large area of infarction involving the right frontal lobe extending superiorly to the level of the frontal convexity. There were slightly more mottled low-density changes involving the right parietal lobe extending inferiorly and superiorly. There was relative sparing of the brain parenchyma between these two regions but there was subtle increased attenuation within the low density involving the parietal lobe. There remained diffuse effacement of the sulci throughout the right hemisphere. The posterior fossa, brainstem and left hemisphere were unremarkable. The appearance was consistent with a large middle cerebral artery infarct. This CT scan was performed three days before behavioural assessment with the CAS.

Figure 32: Axial CT Image of RA

RA's CAS subtest scores were uniformly low due to the large and distributed nature of the infarct within the right hemisphere. However, there is one curious pattern of sparing corresponding to immediate auditory memory that was within normal limits. A normal raw score for a healthy 18-year old is 12 out of 27. Perhaps not surprisingly CT examination reveals complete sparing of the angular gyrus and supramarginal gyrus in the right hemisphere, as well as, in the undamaged left hemisphere, perhaps allowing for an island of preserved function in the face of global deficits on more complex cognitive tasks. Immediate auditory recall has been shown previously to be especially sensitive to left posterior lesions involving parts of Heschyl's gyrus, middle and superior temporal gyrus and inferior parietal lobule (Gordon, 1983). These results imply that cognitive functions of homologous sites within the undamaged hemisphere may be adversely affected by damage in the hemisphere without the cognitive function in question.

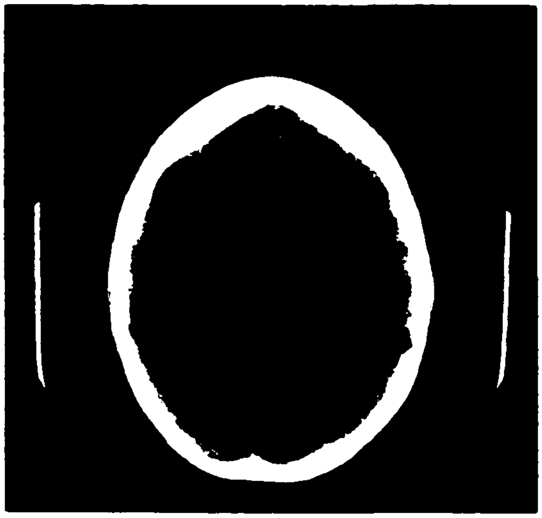
Table 33: RA's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	3	3.33	$p < 0.001$
Planned Codes	10	3.94	$p < 0.001$
Planned Connections	350	2.93	$p = 0.002$
PLANNING	-	3.40	$p < 0.001$
Expressive Attention	22	2.66	$p = 0.004$
Number Detection	11	2.73	$p = 0.003$
Receptive Attention	9	3.25	$p < 0.001$
ATTENTION	-	2.88	$p = 0.002$
Nonverbal Matrices	4	3.06	$p = 0.001$
Verbal-Spatial Relations	8	2.62	$p = 0.004$
Figure Memory	1	3.68	$p < 0.001$
SIMULTANEOUS	-	3.12	$p < 0.001$
Word Series	11	0.42	-
Sentence Repetition	7	1.82	$p = 0.03$
Sentence Questions	7	2.68	$p = 0.004$
SUCCESSIVE	-	1.64	$p = 0.05$
FULL-SCALE	-	2.76	$p = 0.003$

Patient 27: KH

KH was admitted with left hemiplegia and slurred speech. Neuroradiological examination revealed an area of infarction in the distribution of the right middle cerebral artery that involved grey and white matter. There was a small amount of edema and there were some areas of cortical sparing evident superiorly. The area of infarction included the anterolateral region of the right temporal lobe as well as the parietal lobe. There was no associated hemorrhage and the posterior fossa and left hemisphere were essentially normal. This axial CT scan was performed two days after behavioural assessment with the CAS and depicts the central part of the lateral ventricles and the supramarginal gyrus.

Figure 33: Axial CT Image of KH



All of KH's Planning and Attention subtest scores were in the severely impaired range and she exhibited severe left visual field neglect on the Number Detection subtest (see **Figure 34** below) consistent with a right parietal injury (Lezak, 1995). KH did not use any strategies on any of the Planning subtests and her completion times were inordinately slow on the Planning and Attention subtests (Schear & Sato, 1989). The severely impaired performance on all the Planning and Attention subtests, as a result of motor slowing, visual neglect, and strategy deployment disorder precludes more accurate characterizations of the specificity of these tasks in view of the large right hemisphere lesion in KH's brain.

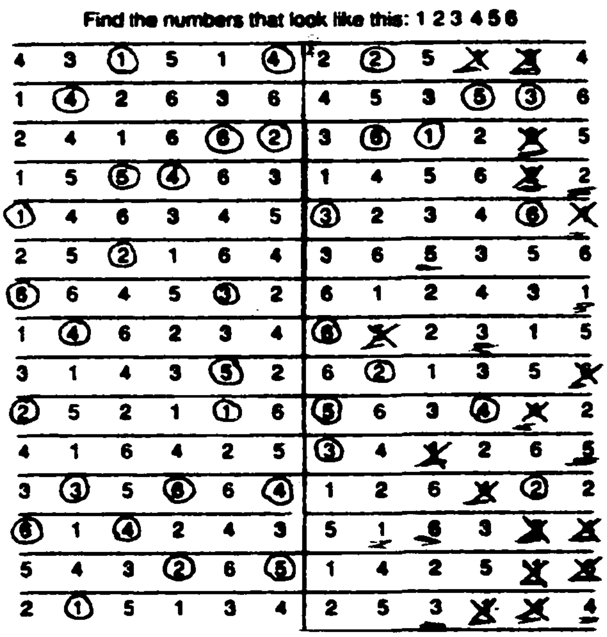


Figure Memory was more severely impaired than Nonverbal Matrices implying a greater sensitivity of Figure Memory to right posterior damage compared with Nonverbal Matrices' anterior sensitivity gradient. Sentence Questions was also significantly impaired perhaps due to transient edematous changes that are especially prone to adversely effect higher order cognitive processes such as language comprehension (Bornstein & Brown, 1991). An otherwise unimpaired performance on the Verbal-Spatial Relations subtest by KH could imply strong dominant hemisphere lateralization of this task and/or some measure of computational compensation by homologues of Broca's area.

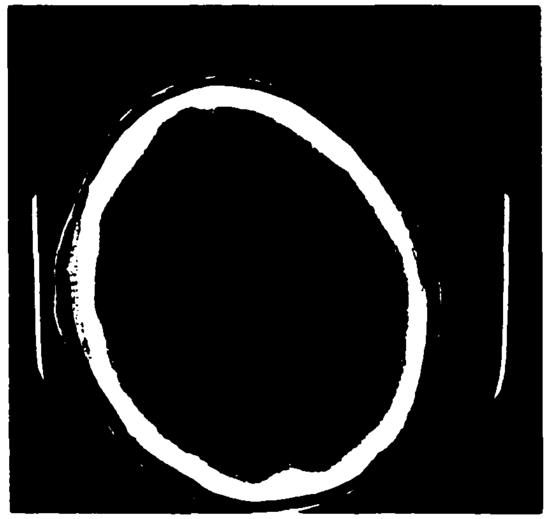
Table 34: KH's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	3	3.33	$p < 0.001$
Planned Codes	32	3.02	$p = 0.001$
Planned Connections	350	2.93	$p = 0.002$
PLANNING	-	3.10	$p < 0.001$
Expressive Attention	26	2.42	$p = 0.008$
Number Detection	8	2.86	$p = 0.002$
Receptive Attention	12	3.07	$p = 0.001$
ATTENTION	-	2.78	$p = 0.003$
Nonverbal Matrices	12	1.67	$p < 0.05$
Verbal-Spatial Relations	13	1.48	-
Figure Memory	4	2.99	$p = 0.001$
SIMULTANEOUS	-	2.60	$p = 0.005$
Word Series	10	0.84	-
Sentence Repetition	8	1.21	-
Sentence Questions	8	2.23	$p = 0.01$
SUCCESSIVE	-	1.43	-
FULL-SCALE	-	2.34	$p < 0.01$

Patient 28: CS

CS was fully employed and healthy up until the time of his stroke. He was admitted with left hemiparesis as well as slurred speech. He was immediately referred for a CT examination. A fairly well defined hypointense area in the right posterior frontal and parietal regions was visible with bridging hypointensities noted in the white matter of the right centrum semiovale. The lesion also extended to the surface of the cortex in the right parieto-occipital region. In the triangular hypointense region there were several small areas of high density, especially within the frontal regions indicating hemorrhagic transformation. The ventricles were of normal size and there was minimal shift to the left. The appearance was compatible with subacute infarction in the distribution of the ascending frontoparietal and parietal branches of the right middle cerebral artery. There was slight compression of sulci over the right hemisphere. This CT scan was performed the day before behavioural assessment with the CAS.

Figure 35: Axial CT Image of CS



CS's performance on Planned Codes was poor (Schear & Sato, 1989) consistent with the general effects of motor slowing with brain lesions. Matching Numbers was also significantly impaired with the deficit likely occurring for reasons of inaccuracy and slowness. Lesions within the right inferior frontal gyrus have been shown to be especially deleterious to performance on visual search tasks (Binder et al, 1992). Husain and Kennard (1997) also found that as the number of distractors increased, so did impairment in visual search selectively in a patient with a right frontal lesion as opposed to a right fronto-parietal lesion. Matching Numbers significant visual search component might be expected to be impaired given CS's similar frontoparietal lesion. The Attention tasks were less significantly impaired despite left visual field neglect as apparent on Number Detection (see **Figure 36** next page). The impairment on Expressive Attention coincides with reports of right frontal lesions significantly impairing performance on the Stroop test (Vendrell et al, 1995).

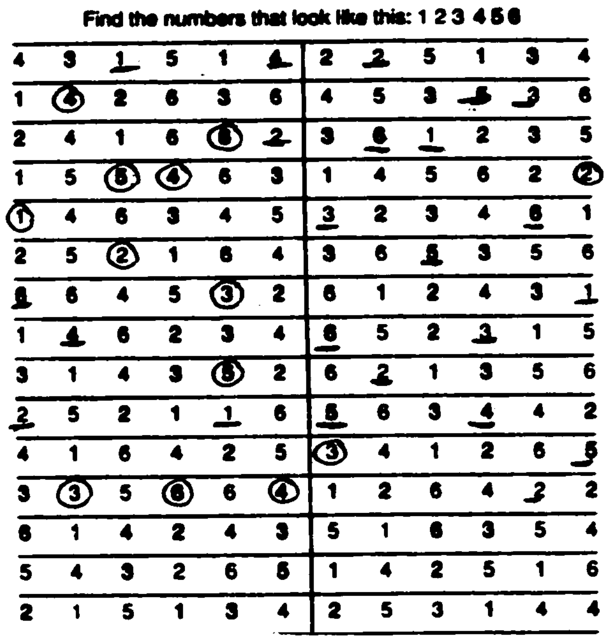


***Figure 36:** Item 4 from Number Detection for CS. The percent of omissions was 61% for the left visual field and 11% for the right visual field. The line down the middle is drawn in after scoring to designate the bisected fields of hemi-space. Underlines are CS's marks and the circled responses are omissions.*

Nonverbal Matrices was severely impaired consistent with destruction of right hemisphere frontal and parietally located neural networks underlying performance on this task (Prabhakran et al, 1997). Verbal-Spatial Relations was non-significantly impaired and almost near normal levels. More anterior right hemisphere homologs of the pars opercularis of the left hemisphere appear to be relatively undamaged in CS, and might explain in part his near normal performance on this task (Dapretto & Bookheimer, 1999).

Table 35: CS's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	7	2.41	$p = 0.008$
Planned Codes	22	3.44	$p < 0.001$
Planned Connections	-	-	-
PLANNING	-	2.93	$p = 0.002$
Expressive Attention	35	1.88	$p = 0.03$
Number Detection	32	1.82	$p = 0.03$
Receptive Attention	-	-	-
ATTENTION	-	1.85	$p = 0.03$
Nonverbal Matrices	4	3.06	$p = 0.001$
Verbal-Spatial Relations	18	0.34	-
Figure Memory	-	-	-
SIMULTANEOUS	-	1.70	$p < 0.05$
Word Series	9	1.26	-
Sentence Repetition	8	1.21	-
Sentence Questions	11	0.89	-
SUCCESSIVE	-	1.12	-
FULL-SCALE	-	1.81	$p = 0.04$

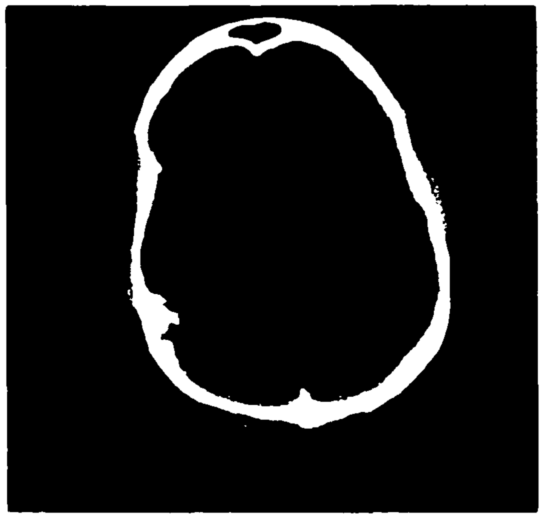
Patient 29: LH

LH was involved in an automobile collision with a moose while travelling at 100 kph and was subsequently airlifted to University Alberta Hospital by air ambulance. She was admitted to the neurosurgical intensive care unit and was found to have multiple bruises to the chest and abdomen at the site of her seat belt. LH had a large frontal scalp laceration as the result of the accident.

Neuroradiological examination revealed some residual subarachnoid hemorrhage predominately in the interhemispheric fissure. There were traces of blood within the lateral ventricles however there was no hydrocephalus. A small right cerebellar contusion was evident which was at its greatest diameter in the image depicted on the next page. No other lesions were evident and there was no significant extra-axial fluid collection. This CT scan was performed ten days before behavioural assessment on the CAS.

Shortly after her accident, LH reported, "I think I have an impairment in my thinking, since the accident. It's harder now to understand other people's perspective". LH's caregiver reported that she was able to converse well but was vague with her train of thought at times. LH exhibited some emotional lability as observed by nurses and staff and she also had some trouble articulating words. LH was ordered not to drive for three months following her discharge.

Figure 37: Axial CT Image of LH



All of LH's Planning and Attention subtest scores were impaired although non-significantly. It should be noted that sudden deceleration injuries are markers for more subtle diffuse axonal injury resulting in stretching of axons and fiber bundles (Lezak, 1995). The most significantly impaired subtest was Planned Codes, illustrating that this subtest is highly sensitive to both diffuse and localized damage throughout the brain (Schear & Sato, 1989). Matching Numbers was also mildly impaired and the contusion within the right cerebellum could be a marker for mild contre coup damage in the anterior temporal or frontal pole regions as these regions are highly susceptible to traumatic brain injury (Schnider & Gutbrod, 1999). Number Detection, a measure of vigilance, was also impaired perhaps suggesting damage to the ascending reticular activation system -- the long afferent fiber tracts which are particularly prone to damage as a consequence of closed head injuries (Schnider & Gutbrod, 1999).

Table 36: LH's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	11	1.49	-
Planned Codes	68	1.53	-
Planned Connections	215	1.27	-
PLANNING	-	1.43	-
Expressive Attention	63	0.18	-
Number Detection	43	1.34	-
Receptive Attention	54	0.61	-
ATTENTION	-	0.71	-
Nonverbal Matrices	25	Normal	-
Verbal-Spatial Relations	22	Normal	-
Figure Memory	-	-	-
SIMULTANEOUS	-	Normal	-
Word Series	10	0.84	-
Sentence Repetition	10	Normal	-
Sentence Questions	13	Normal	-
SUCCESSIVE	-	0.28	-
FULL-SCALE	-	0.66	-

Patient 30: FR

FR was admitted to hospital after exhibiting slurred speech, left hemiplegia, and his own reports of light-headedness. FR had some weakness in his right eye and he had a previous history of hypertension. Neuroradiological examination revealed a subtle focal area of low attenuation within the right posterior cerebellar hemisphere. The lesion most likely existed within a branch distribution of the posterior inferior artery. There were no focal cerebral abnormalities identified, nor was there any hemorrhage however there was some evidence of generalized cortical atrophy. This CT scan was performed two days before the CAS behavioural assessment and is sectioned through the pons, fourth ventricle and the cerebellar hemispheres.

Figure 38: Axial CT Image of FR

During FR's assessment, he was articulate with fluent speech and displayed no overt visual problems. As expected Planned Codes was impaired indicative of generalized motor slowing (Schear & Sato, 1989) as was Planned Connections. The latter finding was more difficult to explain but one possibility is impairment in the substantial subvocal verbal rehearsal requirements of the task that require the integrity of the right cerebellar hemisphere. Fiez et al (1996) noted that based on several PET studies, tasks requiring verbal rehearsal are associated with higher blood flow in the inferior prefrontal cortex and the right cerebellum. Subvocal rehearsal is a common strategy used for completion of the Planned Connections by subjects as revealed by verbal protocol analysis (Naglieri & Das, 1997, pp. 87-90). In the same way the lexically based tasks of Expressive Attention and Receptive Attention might also be expected to be impaired given the substantial subvocal articulatory aspects of these tasks. Cubelli and Nichelli (1992) demonstrated neuropsychological evidence implying the existence of a distributed network involving projections from the supplementary motor area to the striatum and via the pontine nuclei to the cerebellar cortex supporting inner speech.

Table 37: FR's CAS Performance

CAS Subtest & Composite Scale	Raw Sores	AZI	Probability
Matching Numbers	14	0.81	-
Planned Codes	49	2.32	p = 0.01
Planned Connections	250	1.70	p < 0.05
PLANNING	-	1.61	-
Expressive Attention	22	2.66	p = 0.004
Number Detection	40	1.47	-
Receptive Attention	30	2.02	p = 0.02
ATTENTION	-	2.05	p = 0.02
Nonverbal Matrices	20	0.27	-
Verbal-Spatial Relations	24	Normal	-
Figure Memory	11	1.38	-
SIMULTANEOUS	-	0.55	-
Word Series	13	Normal	-
Sentence Repetition	11	Normal	-
Sentence Questions	14	Normal	-
SUCCESSIVE	-	Normal	-
FULL-SCALE	-	1.05	-

Patient 31: PT

PT was admitted with symptoms of a brain-stem stroke. Neuroradiological examination revealed that there were several areas of low attenuation. There was a lesion within the superior aspect of the right cerebellar hemisphere. Two smaller but critical focuses of low attenuation involved the right thalamus and the left occipital lobe. The posterior aspect of the left cerebellum of PT also sustained small infarcts. There was no hemorrhage evident nor was there any midline shift. The fourth ventricle was normal in shape and position and the etiology of the infarcts was judged to result from a posterior circulation embolic event. This axial image was sectioned through the region of maximal diameter of the right thalamic lesion. This CT scan was performed four days prior to behavioural assessment with the CAS.

Figure 39: Axial CT Image of PT

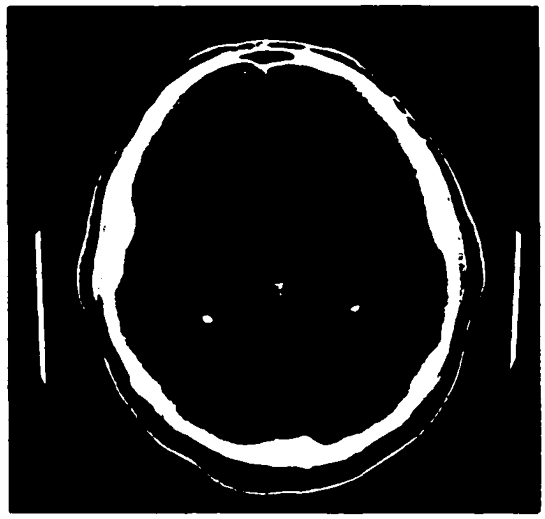


Table 38: PT's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	18	Normal	-
Planned Codes	81	0.99	-
Planned Connections	135	0.29	-
PLANNING	-	0.43	-
Expressive Attention	54	0.72	-
Number Detection	68	0.26	-
Receptive Attention	58	0.38	-
ATTENTION	-	0.45	-
Nonverbal Matrices	15	1.14	-
Verbal-Spatial Relations	25	Normal	-
Figure Memory	10	1.61	p ~ 0.05
SIMULTANEOUS	-	0.92	-
Word Series	16	Normal	-
Sentence Repetition	13	Normal	-
Sentence Questions	11	0.89	-
SUCCESSIVE	-	0.30	-
FULL-SCALE	-	0.52	-

The major finding with PT was abnormally low performance on Figure Memory. PT reported difficulties with focusing in the center of his field of vision. On the Figure Memory task, he reported that he "knows what he saw" and would even draw out what he saw but he could not find the figure during tracing. Perhaps these data imply a specific visuospatial memory deficit. Recent fMRI studies have provided some perspective on the nature of PT's impairment on the Figure Memory task. Honda et al.'s (1998) PET study of visual paired association tasks required subjects to memorize figures and after a short delay they were asked to judge whether a subsequent figure formed one of the memorized figures. This task shares many of the same features with the Figure Memory task. These investigators found right dorsolateral prefrontal cortex, left inferior frontal cortex and bilateral cerebellar activation during this neuroimaging task compared with a control choice reaction time task. The significance of these findings for PT is the implication of the involvement of a *cerebello-thalamo-cortical circuit* as critical in performance of visuospatial short-term memory tasks such as Figure Memory.

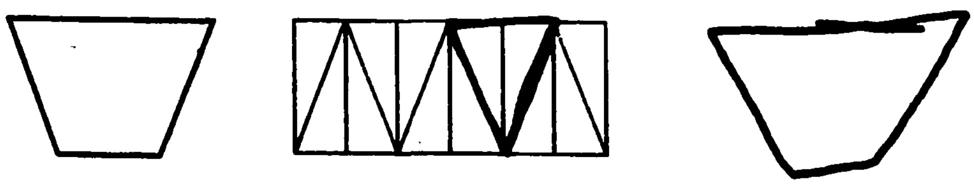


***Figure 40:** Item 15 of Figure Memory for PT. The left figure illustrates the stimulus picture. In the middle frame is depicted PT's unsuccessful attempt at disembedding the figure from the matrix. Depicted in the right figure is PT's successful free copy of the stimulus figure with the template present, completed as part of a testing of the limits after administration of the standardized assessment.*

Patient 32: BP

BP was admitted for symptoms of a brain-stem stroke. A neuroradiological exam revealed very calcified basilar arteries and it was uncertain whether there was some calcification of the left vertebral artery as well. Some low density was noted postero-centrally at the mid brain-pons junction which was compatible with a small area of infarction. No other abnormality was noted and the appearance was consistent with an ischemic infarct of the brain-stem. This axial CT scan was cut through the region of maximal diameter of the pons low density and it was performed four days prior to behavioural assessment with the CAS.

Figure 41: Axial Image of BP

The most severely impaired performance for BP was on Planned Codes consistent with previous reports of this tasks' sensitivity to motor slowing (Schear & Sato, 1989). BP complained of some difficulties with vision in his left eye and previously had sustained a detached retina in an accident. This history does suggest some caution in making interpretations about those tasks requiring fine visual discriminations. However, visuospatial tasks such as Nonverbal Matrices were in the normal range and Receptive Attention, requiring even finer visual discriminations, was not significantly impaired implying that a visual sensory loss was an unlikely explanation for the pattern of impairments.

Matching Numbers shares many features with visual search tasks (Teuber, Battersby & Bender, 1951) and the lesion locus and clinical symptoms were consistent with an oculomotor disturbance of gaze as a consequence of this midbrain-pons junction infarct (Kim, Kang, Lee & Lee, 1993). These authors noted that hand clumsiness especially during the acute post-stroke phase is a common sequalae of such pons strokes. BP did have considerable difficulties marking the score sheet form resulting in his slow speed despite his high accuracy.

On the Attention scale, Expressive Attention and Number Detection were also impaired but to digress the exceptionally low Word Series score is perhaps essential in interpreting the overall pattern of results. Similarly, to patient FR, pontine infarcts have been implicated in impairments in subvocal articulation. Cubelli and Nichelli (1992) noted that neuropsychological evidence suggests that a distributed network involving projections from the supplementary motor area to the striatum and via the pontine nuclei to the cerebellar cortex supports inner speech. The findings on Word Series, Expressive Attention, and Number Detection could all be explained by this hypothesis. This supposition could also be useful in explaining the mildy but not significantly impaired performance on Receptive Attention. On item 6 (lexical match) of Receptive Attention, BP's performance was exceptionally poor while on item 5 (physical match), BP's performance was near normal. Thus physical match may not require any verbal mediation while lexical match could perhaps explaining the differential impairment on these two subtasks of Receptive Attention.

Table 39: BP's CAS Performance

CAS Subtest & Composite Scale	Raw Scores	AZI	Probability
Matching Numbers	8	2.18	p = 0.01
Planned Codes	43	2.57	p = 0.005
Planned Connections	236	1.53	-
PLANNING	-	2.09	p = 0.02
Expressive Attention	38	1.69	p < 0.05
Number Detection	31	1.86	p = 0.03
Receptive Attention	38	1.55	-
ATTENTION	-	1.70	p = 0.04
Nonverbal Matrices	23	Normal	-
Verbal-Spatial Relations	20	Normal	-
Figure Memory	16	0.23	-
SIMULTANEOUS	-	0.08	-
Word Series	7	2.10	p = 0.02
Sentence Repetition	9	0.61	-
Sentence Questions	10	1.34	-
SUCCESSIVE	-	1.35	-
FULL-SCALE	-	1.31	-

Chapter 5: Patterns of Double Dissociations and Groups Means Analysis

The method of dissociating performance patterns between cases was first formally articulated by Teuber (1955). The double dissociation remains today among the most robust methods for identifying brain-behaviour functional relationships. It involves the situation in which one subject performs poorly on task A and well on task B, with the reverse occurring for another subject (Shallice, 1979). This can be easily understood as a crossover interaction if depicted graphically. However, as Miller (1993, p. 160) has qualified, in order for proper logical inferences regarding cause and effect relationships to be determined a number of stricter criteria also need to be met.

Among the first of these criteria is subjects need to be defined in terms of an independent criterion that usually being the locus of the lesion. This allows for *a priori* hypotheses to be generated as to which subjects should exhibit which particular performance pattern as a result of specific lesions. The integration of extant neuropsychological theory with the method of pattern matching among cases allows for ruling out alternative explanations. Furthermore replication among similar cases using an established protocol, and collection of multiple sources of evidence enable the researcher to establish a chain of evidence (Yin, 1994). It is this *chain of evidence* which when a case study is well-constructed, can actually allow for generalization beyond the individual case and directly contribute to and build upon the existing scientific literature.

A number of other factors are important in determining whether a dissociation has actual functional significance or is just a statistical artifact. The magnitude of the difference usually determined by z-scores is one way of analyzing the effect of different lesions on performance on task X for two individuals. Another important factor is the reliability of the instrument being used to test for a particular cognitive process. A final caveat on establishing what Miller (1993, p. 162) refers to as '*double dissociation proper*' is that it is necessary for each subject to score within the normal range on one subtest. This qualification rules out the alternative hypothesis that a mere ceiling or floor effect is accounting for the significant z-score discrepancy between the two patients. When these four criteria are met, Miller suggests that there is *strong evidence* that two cognitive processes are clearly fractionable even if this involves just two subjects.

Using these strict criteria, each of the 32 patients' performances on the 12 CAS subtests was classified as normal (meeting or exceeding the mean performance level of healthy 18 year olds), deficit (discrepant AZI scores of magnitude greater than z = 1.64, p < .05) or neither. Furthermore, only those patients with at least one score in the normal range among the 12 CAS subtests were included. This restriction effectively excluded half of the sample. Sixteen patients thus remained who had at least one score in the normal range and one in the impaired range enabling the potential establishment of double dissociations. A comparative analysis of the included and excluded patients is summarized in the chart below.

Table 40: Raw scores for excluded group

	N	Min.	Max.	Mean	Std. Dev.
Age (yrs)	16	23	67	45	13.8
Matching Numbers	16	3	20	8.8	5.6
Planned Codes	16	5	98	39.3	32.4
Planned Connect.	13	90	725	359.5	196.2
Nonverbal Matrices	16	4	31	14.5	8.8
Verbal-Spatial Rel.	16	7	26	15.7	5.8
Figure Memory	12	1	21	10.2	6.3
Expressive Atten.	16	5	77	33.3	23.3
Number Detection	16	1	86	33.9	26.2
Receptive Attention	13	2	60	28.4	17.8
Word Series	16	5	21	9.8	3.8
Sent. Rep.	16	2	13	7.3	2.8
Sent. Quest.	14	4	17	8.9	3.7

Table 41: Raw scores for included group

	N	Min.	Max.	Mean	Std. Dev.
Age (yrs)	16	20	64	49.2	10.7
Matching Numbers	16	2	18	10.3	4.7
Planned Codes	16	16	102	47.8	24.7
Planned Connect.	16	135	580	271.5	159.5
Nonverbal Matrices	16	6	29	17.3	6.1
Verbal-Spatial Rel.	16	8	25	17.8	4.4
Figure Memory	13	4	21	13.5	4.8
Expressive Atten.	16	3	63	37.3	16.2
Number Detection	16	3	106	47.6	26.3
Receptive Attention	13	16	65	42.7	16.1
Word Series	16	7	18	11.8	2.8
Sent. Rep.	16	6	13	10.3	2.3
Sent. Quest.	14	6	15	11.2	2.5

Table 42: Discrepancy analysis between excluded and included groups

CAS Subtests	Included Group Mean AZI Score	Excluded Group Mean AZI Score	Discrepancy	Correlations Between Included & Excluded	Paired Samples T-Test Probability
Matching Numbers	1.65	2.00	0.35	-	-
Planned Codes	1.65	2.72	1.07	-	-
Planned Connections	1.96	3.04	1.08	-	-
Nonverbal Matrices	0.74	1.23	0.49	-	-
Verbal-Spatial Relations	0.39	0.84	0.45	-	-
Figure Memory	0.81	1.54	0.73	-	-
Expressive Attention	1.74	1.97	0.23	-	$p = 0.03$
Number Detection	1.14	1.74	0.60	-	-
Receptive Attention	1.27	2.11	0.84	-	-
Word Series	0.04	0.92	0.88	$p < 0.05$	$p = 0.004$
Sentence Repetition	Normal	1.58	1.58	-	-
Sentence Questions	0.80	1.83	1.03	$p = 0.04$	$p = 0.001$
Mean	1.02	1.79	0.78	-	$p < 0.05$

In addition to the paired sample t-tests conducted between the included and excluded groups at the subtest level, comparisons were made between these two groups on a number of demographic and lesion locus variables. Comparisons were made between the two groups on levels of education, age, handedness, anterior versus posterior nature of the lesion, left or right hemispheric involvement and sex. Paired sample t-tests revealed that the included group was significantly older than the excluded group ($t = 2.67$, $df = 15$, $p = 0.02$) implying that age cannot account for the consistently poorer performance on each CAS subtest among the excluded group.

Chi-squared tests revealed that there was a significantly higher frequency of posterior lesioned patients among the excluded group ($\chi 2 = 9$, $df = 1$, $p = 0.003$). The frequency of posterior lesioned patients was 13% in the included group, 38% in the excluded group, and 25% in the sample as a whole. Meier and Strauman (1991) have noted that unlike anterior temporal and prefrontal lesioned patients, posterior temporoparietal lesioned patients are more apt to result in sizeable discrepancies between verbal and visuospatial abilities on conventional intellectual tests. This implies that a disproportionate frequency of the posterior lesioned patients, may have been too globally impaired to allow for the isolation of double dissociations.

There were also significantly more males in the included group compared to the excluded group ($\chi 2 = 4$, $df = 1$, $p < 0.05$) but this was true of the sample as a whole (e.g., 23 males vs. 9 females) and the frequencies of the sexes between the two groups was similar. There were significantly more right-handers in the excluded sample ($\chi 2 = 6.3$, $df = 1$, $p < 0.01$). Eighty-one percent of excluded patients were right handed versus 68 percent of right-handers in the included sample compared with 75 percent of right-handers in the sample as a whole. This coincides with previous reports of there being greater potential for recovery from aphasic complications of stroke in left-handed patients (Meier & Strauman, 1991).

Table 43: Characteristics of excluded cases

Case #	Patient Initials	Age	Sex	Side	Primary Injury Site in the Brain	Aetiology	Handed	Educ-ation
1	AM	44	F	-	None	tumour resection	Right	16
4	KC	52	M	L	left frontal	left MCA	Left	18
5	CB	46	F	L	left frontal	left basal ganglia hemorrhage	Left	12
10	AK	65	M	L	left frontal	aneurysm	Right	9
11	GM	67	M	L	left parietal	tumor resection	Right	12
12	DM	28	M	L	left parietal	arterovenous malformation	Right	4
13	SB	28	M	L	left parietal	gliosis	Right	12
14	TL	41	M	-	bifrontal atrophy	unknown	Right	12
15	DK	39	F	-	bifrontal atrophy	unknown	Right	9
16	RM	23	M	-	medial frontal contusion	fall	Right	14
22	GC	47	M	R	right frontal	ischemic infarct	Right	10
24	WM	56	M	R	right frontal	intracranial hematoma	Right	9
26	RA	62	M	R	right fronto-parietal	right MCA	Right	6
27	KH	41	F	R	right parietal	right MCA	Right	12
28	CS	53	M	R	right parietal	right MCA	Left	12
29	LH	27	F	-	right cerebellum	brain contusion	Right	12

Table 44: Characteristics of included cases

Case #	Patient Initials	Age	Sex	Side	Primary Injury Site in the Brain	Aetiology	Handed	Education
2	JD	49	M	L	left temporal	brain contusion	Right	12
3	AO	43	M	L	l. fronto-temporal	left middle cerebral artery (MCA)	Right	11
6	FA	53	F	L	left frontal	l. internal carotid artery dissection	Left	12
7	HB	50	M	L	left frontal	left MCA	Right	12
8	JM	54	M	L	left frontal	left MCA	Right	14
9	WF	53	M	L	left frontal	left recurrent artery of Hubner infarct	Right	12
17	IS	55	F	R	right frontal	right MCA	Left	12
18	SW	64	F	R	right frontal	right MCA	Left	12
19	JL	54	M	R	right frontal	r. anterior cerebral artery infarct	Left	14
20	TF	20	M	R	right frontal	contusion & haemorrhage	Left	12
21	RG	47	F	R	right frontal	right posterior frontal hemorrhage	Right	9
23	BT	55	M	R	right frontal	right basal ganglia hematoma	Right	16
25	JH	34	M	R	right frontal	venous infarction	Right	14
30	FR	62	M	-	right cerebellum	occlusion of the r. posterior inferior cerebral artery	Right	12
31	PT	41	M	-	right cerebellum	posterior circulation obstruction	Right	9
32	BP	54	M	-	midbrain-pons	ischemic brain stem infarct	Right	13

The chief difference between the included and excluded groups in terms of lesion locus is the complete absence of only parietal lesioned patients in the included group. In the largest and most comprehensive study of its kind, Warrington, James and Maciejewski (1986) found that WAIS VIQ was most sensitive to temporoparietal lesions in the left hemisphere and parieto-occipital lesions in the right hemisphere. PIQ was most sensitive to parieto-occipital lesions in both the left and right hemispheres. Collectively, the lack of representation of parietal lesioned patients among the included group is likely a function of the debilitating effects of parietal lesions on general intellectual functioning, perhaps mediated indirectly through disruption of neural substrates of visuospatial attentional, constructional praxis and linguistic mechanisms (Lezak, 1995).

Table 45: Classification of double dissociations

Double Dissociations	CAS Subtest Comparisons N = 35	Case Comparison	Case Numbers
1. (1)	Matching Numbers vs. Figure Memory	JH vs. PT	25 vs. 31
2. (4)	Nonverbal Matrices vs. Word Series	JD vs. JL	2 vs. 19
	Nonverbal Matrices vs. Word Series	JL vs. BP	19 vs. 32
	Nonverbal Matrices vs. Word Series	SW vs. BP	18 vs. 32
	Nonverbal Matrices vs. Word Series	JD vs. SW	2 vs. 18
3. (4)	Nonverbal Matrices vs. Sentence Repetition	JD vs. JL	2 vs. 19
	Nonverbal Matrices vs. Sentence Repetition	JM vs. JL	8 vs. 19
	Nonverbal Matrices vs. Sentence Repetition	JM vs. SW	8 vs. 18
	Nonverbal Matrices vs. Sentence Repetition	JD vs. SW	2 vs. 18
4. (2)	Verbal Spatial Relations vs. Word Series	JL vs. BP	19 vs. 32
	Verbal Spatial Relations vs. Word Series	JD vs. JL	2 vs. 19
5. (4)	Verbal Spatial-Relations vs. Sentence Repetition	JD vs. AO	2 vs. 3
	Verbal Spatial Relations vs. Sentence Repetition	AO vs. JM	3 vs. 8
	Verbal Spatial Relations vs. Sentence Repetition	JM vs. JL	8 vs. 19
	Verbal Spatial Relations vs. Sentence Repetition	JD vs. JL	2 vs. 19
6. (3)	Figure Memory vs. Word Series	JD vs. PT	2 vs. 31
	Figure Memory vs. Word Series	JD vs. WF	2 vs. 9
	Figure Memory vs. Word Series	JD vs. SW	2 vs. 18
7. (3)	Figure Memory vs. Sentence Repetition	JD vs. PT	2 vs. 31
	Figure Memory vs. Sentence Repetition	JD vs. WF	2 vs. 9
	Figure Memory vs. Sentence Repetition	JD vs. SW	2 vs. 18
8. (2)	Figure Memory vs. Sentence Questions	JD vs. WF	2 vs. 9
	Figure Memory vs. Sentence Questions	WF vs. JH	9 vs. 25
9. (3)	Number Detection vs. Word Series	JD vs. WF	2 vs. 9
	Number Detection vs. Word Series	JD vs. JL	2 vs. 19
	Number Detection vs. Word Series	JD vs. BT	2 vs. 23
10. (6)	Number Detection vs. Sentence Repetition	JD vs. AO	2 vs. 3
	Number Detection vs. Sentence Repetition	AO vs. JM	3 vs. 8
	Number Detection vs. Sentence Repetition	JD vs. WF	2 vs. 9
	Number Detection vs. Sentence Repetition	JM vs. WF	8 vs. 9
	Number Detection vs. Sentence Repetition	JM vs. JL	8 vs. 19
	Number Detection vs. Sentence Repetition	JD vs. JL	2 vs. 19
11. (2)	Number Detection vs. Sentence Questions	JD vs. WF	2 vs. 9
	Number Detection vs. Sentence Questions	JD vs. BT	2 vs. 23
12. (1)	Sentence Repetition vs. Sentence Questions	AO vs. JM	3 vs. 8

Table 46: Description of sample of patients with double dissociations among each other

Case #	Patient Initials	Age	Sex	Side	Primary Injury Site in the Brain	Etiology	Handed	Education
2	JD	49	M	L	left temporal	brain contusion	Right	12
3	AO	43	M	L	l. fronto-temporal	left middle cerebral artery (MCA)	Right	11
8	JM	54	M	L	left frontal	left MCA	Right	14
9	WF	53	M	L	left frontal	left recurrent artery of Heubner infarct	Right	12
18	SW	64	F	R	right frontal	right MCA	Left	12
19	JL	54	M	R	right frontal	r. anterior cerebral artery infarct	Left	14
23	BT	55	M	R	right frontal	right basal ganglia hematoma	Right	16
25	JH	34	M	R	right frontal	venous infarction	Right	14
31	PT	41	M	-	right cerebellum	posterior inferior cerebral artery obstruction	Right	9
32	BP	54	M	-	midbrain-pons	ischemic brain stem infarct	Right	13
	x_{Age} = 50 SD = 8.6, Male = 9 Female = 1			4 left and 4 right hemisphere lesions		$x_{Educational\ Level}$ = 12.7 SD = 1.9, 2 Left & 8 Right Handed Subjects		

Double Dissociation #1

One double dissociation was observed between Matching Numbers and Figure Memory. Matching Numbers, a measure of visual search, working memory, and motor speed, contrasts with the cognitive requirements of Figure Memory -- that being short-term visuospatial memory. Since Matching Numbers is a speeded test while Figure Memory is not, caution against overinterpretation is appropriate since the differences could be partly due to motor slowing. On the Figure Memory subtest a dissociation in performance in favour of JH was found despite the fact that JH's lesion encompassed a large section of the right frontal cortex. In PT the lesion was restricted to the right cerebellum implying that the right cerebellum has a prominent role to play in performance on Figure Memory. These results are consistent with Honda et al's (1998) PET study that implied the involvement of a cerebello-thalamo-cortical circuit involved in visuospatial short-term memory.

Table 47: Double Dissociation #1

Initials and Case Number	Lesion Locus	Matching Numbers Raw Score, AZI, P	Figure Memory Raw Score, AZI, P
JH (25)	right frontal	10, 1.72, p = 0.04	20, Normal
PT (31)	right cerebellum	18, Normal	10, 1.61, p ~ 0.05

Double Dissociation #2

Four dissociations were found between Nonverbal Matrices and Word Series implying separable neural substrates for each of these tasks. An analysis of the patterns of lesions among this group follows. Nonverbal Matrices, a measure of analogical reasoning, and Word Series, a measure of immediate auditory memory, are comprised of functionally and neuroanatomically distinct subsystems. Trahan, Goethe and Larrabe (1989) have previously found measures of word span to be especially sensitive to left temporal injury. Cubelli and Nicelli (1992) also noted that a distributed network involving projections from the supplementary motor area to the striatum and via the pontine nuclei to the cerebellar cortex supports inner speech. Indirectly, this suggests that if subjects use a subvocal rehearsal strategy on Word Series, the midbrain-pons infarct of BP could impair allocation of strategic processes. However, there is no independent verbal protocol analysis data to support this hypothesis. With respect to Nonverbal Matrices Prabhakran et al (1997) found bilateral frontal activation during the analogical reasoning problems and prominent right frontal and bilateral activation during the figural reasoning items of the RCPM. Collectively these empirical studies and four dissociations discussed above illustrate the importance of the integrity of midbrain regions in immediate auditory memory in addition to the left superior temporal gyrus, and these regions functional independence from the neural substrates supporting fluid reasoning.

Table 48: Double Dissociation #2

Initials and Case Number	Lesion Locus	Nonverbal Matrices Raw Score, AZI, P	Word Series Raw Score, AZI, P
JD (2)	left temporal	29, Normal	7, 2.10, p = 0.02
SW (18)	right frontal	6, 2.71, p = 0.003	13, Normal
JL (19)	right frontal	6, 2.71, p = 0.003	12, Normal
BP (32)	midbrain-pons	23, Normal	7, 2.10, p = C.02

Double Dissociation #3

Four double dissociations were observed between Nonverbal Matrices and Sentence Repetition. As in the previous set of dissociations a strong relationship between right frontal lesions and impaired performance on Nonverbal Matrices was observed with little evidence of the right frontal lobe being critically involved in performance on Sentence Repetition. Conversely left temporal lesions significantly impaired performance on Sentence Repetition without causing impairment on Nonverbal Matrices. The frontal-temporal association with impairments of performance on Sentence Repetition is consistent with Selnes et al's (1985) claim that posterior perisylvian lesions, especially those extending into Wernicke's area are critical substrates. JLs frontal lesions' extension into the insular cortex of the temporal lobe likely explains his poor performance on Sentence Repetition since Selnes et al found little evidence for anterior perisylvian lesions' effects of impairing performance on such tasks.

Table 49: Double Dissociation #3

Initials and Case Number	Lesion Locus	Nonverbal Matrices Raw Score, AZI, P	Sentence Repetition Raw Score, AZI, P
JD (2)	left temporal	29, Normal	7, 1.82, p = 0.03
JM (8)	left frontal	25, Normal	7, 1.82, p = 0.03
SW (18)	right frontal	6, 2.71, p = 0.003	10, Normal
JL (19)	right frontal	6, 2.71, p = 0.003	13, Normal

Double Dissociation #4

Two double dissociations were observed between Verbal-Spatial Relations and Word Series. An examination of JL's performance pattern revealed a clear impairment on Verbal-Spatial Relations in the context of normal performance on Word Series and Sentence Repetition. This finding illustrates a role for the right frontal lobe in the understanding syntax associated with Verbal-Spatial Relation's visuospatial aids. However JL's residual left visual field difficulties complicates interpretation of this finding. Error analysis of correct responses to targets arranged in either the leftward or rightward side of hemi-space did not reveal a consistent pattern. There was a small trend for there to be more errors for the response item on Verbal-Spatial Relations placed in the left visual field but this was unlikely to fully account for the generally poor performance of JL on this subtest.

Thus the results do suggest that the right frontal lobe plays some role in interpreting syntax especially when the lesion is rather large. In double dissociation #2, corroborative evidence was provided that the integrity of left temporal and midbrain-pons regions are important in immediate auditory memory and that this is dissociable from understanding of a visuospatially complemented sentence.

Table 50: Double Dissociation #4

Initials and Case Number	Lesion Locus	Verbal-Spatial Relations Raw Score, AZI, P	Word Series Raw Score, AZI, P
JD (2)	left temporal	20, Normal	7, 2.10, p = 0.02
JL (19)	right frontal	12, 1.71, p = 0.04	12, Normal
BP (32)	midbrain-pons	20, Normal	7, 2.10, p = 0.02

Double Dissociation #5

Four double dissociations were observed between Verbal-Spatial Relations and Sentence Repetition. AO's lesion included insular cortex and the inferior aspect of the left temporal lobe yielding predicted impairment in Verbal Spatial Relations based on neuroimaging studies using similar demanding syntax tasks (Moro et al., 2001). However AO's lesion did not encroach on Wernicke's area consistent with Selnes et al's (1985) study revealing that damage to this area was necessary to produce lasting impairments on repetition. JL's impairment on Verbal-Spatial Relations was discussed under double dissociation #4. JD's lesion was restricted to the left anterior temporal region. However, his closed head injury is a marker for more diffuse axonal injury and interpretation of his impaired performance pattern on Sentence Repetition is complicated by this fact. Sentence Repetition was also impaired in JM perhaps due to encroachment of the lesion upon white matter deep to the inferior parietal lesion (Selnes et al, 1985) and thus in close proximity to Wernicke's area. In contrast, JD's and JM's Verbal-Spatial Relations performances were near normal levels again illustrating the importance of the integrity of the right hemisphere in performance on this strongly visuospatially cued task.

Table 51: Double Dissociation #5

Initials and Case Number	Lesion Locus	Verbal-Spatial Relations Raw Score, AZI, P	Sentence Repetition Raw Score, AZI, P
JD (2)	left temporal	20, Normal	7, 1.82, p = 0.03
AO (3)	l. frontotemporal	8, 2.62, p = 0.004	10, Normal
JM (8)	left frontal	20, Normal	7, 1.82, p = 0.03
JL (19)	right frontal	12, 1.71, p = 0.04	13, Normal

Double Dissociation #6

In this analysis, we find three double dissociations of Figure Memory with Word Series all with the patient JD who had an isolated anterior left temporal lesion with suspected diffuse axonal injury. The finding of multiple embolic events within his left hemisphere complicates interpretation of performance on Figure Memory for WF whereas with SW and PT the infarcts are isolated. WF, with multiple left posterior infarcts was able to trace the global outline in Figure Memory but he was unable to fill in the details. The latter finding could potentially be attributed to a deficit in local processing as a result of diffuse left hemisphere damage (Sergent, 1982). SW and PT both had poor performances on Figure Memory that were still substantially better than WF's performance. SW and PT's performance was attributed to a disruption in the *cerebello-thalamo-cortical* circuit involved in short-term visuospatial memory processing (Honda et al, 1998). This pattern of results illustrates the importance of the cerebellum and the dorsal visual stream as well as the left hemisphere in performance on Figure Memory and its discriminability from immediate auditory memory.

Table 52: Double Dissociation #6

Initials and Case Number	Lesion Locus	Figure Memory Raw Score, AZI, P	Word Series Raw Score, AZI, P
JD (2)	left temporal	19, Normal	7, 2.10, p = 0.02
WF (9)	left frontal	4, 2.99, p = 0.001	12, Normal
SW (18)	right frontal	8, 2.07, p = 0.02	13, Normal
PT (31)	right cerebellum	10, 1.61, p ~ 0.05	16, Normal

Double Dissociation #7

There were a total of three double dissociations of Figure Memory from Sentence Repetition. This pattern was similar to the dissociations observed in the previous section #6. Both immediate auditory recall tasks (Gordon, 1983) and repetition tasks (Selnes et al, 1985) are sensitive to left posterior lesions and thus the explanations for double dissociation #6 are also applicable in explaining the double dissociations in set #7.

Table 53: Double Dissociation #7

Initials and Case Number	Lesion Locus	Figure Memory Raw Score, AZI, P	Sentence Repetition Raw Score, AZI, P
JD (2)	left temporal	19, Normal	7, 1.82, p = 0.03
WF (9)	left frontal	4, 2.99, p = 0.001	13, Normal
SW (18)	right frontal	8, 2.07, p = 0.02	10, Normal
PT (31)	right cerebellum	10, 1.61, p ~ 0.05	13, Normal

Double Dissociation #8

There were two double dissociations between Figure Memory and Sentence Questions -- each of which involved the patient WF. WF was unimpaired on Sentence Questions. WF's lesions involved the inferior aspect of the left occipital lobe involving both gray and white matter, left caudate and putamen as well as the white matter left middle frontal gyrus. This extensive area of multiple infarcts could be expected to disrupt left hemisphere-based distributed language networks. Although we find that the left superior temporal, inferior frontal, angular and supramarginal gyrus and parietal operculum are all preserved and previous studies have linked the integrity of these areas with deficits in understanding complex aspects of syntax (Caplan, Hildebrandt & Makris, 1996) which is tapped by Sentence Questions. Alternatively, WF's normal right hemisphere could play a compensatory role in syntactic processing associated with Sentence Questions given the lengthy recovery period after his initial stroke. WF's impairment in Figure Memory was attributed to a deficit in local processing as discussed under double dissociation #6.

In contrast Figure Memory was normal in JD and JH but Sentence Questions was significantly impaired. An analysis of JD's contusion revealed it to encompass the left anterior temporal lobe with the nature of the injury consistent with more diffuse axonal injury. In contrast, JH's lesion was restricted to the right frontal region. Collectively, these patterns suggest a right anterior and left perisylvian network as involved in Sentence Questions that is doubly dissociated from the posteriorly based dorsal visual stream underlying performance on Figure Memory.

Table 54: Double Dissociation #8

Initials and Case Number	Lesion Locus	Figure Memory Raw Score, AZI, P	Sentence Questions Raw Score, AZI, P
JD (2)	left temporal	19, Normal	6, 3.12, p < 0.01
WF (9)	left frontal	4, 2.99, p = 0.001	13, Normal
JH (25)	right frontal	20, Normal	8, 2.23, p = 0.01

Double Dissociation #9

In this series, three double dissociations, all involving patient JD were found. Trahan, Goethe and Larrabe (1989) have previously found measures of word span to be especially sensitive to left temporal injury while JD's intact right hemisphere and basal ganglia (Binder et al, 1992) is congruent with his unimpaired Number Detection. JL and BT's levels of impairment on Number Detection were more severe compared with WF's and both of these individuals had large right frontal lesions with basal ganglia involvement. WF's lesions were small but extensive throughout the left hemisphere but involved the basal ganglia as well. All three individuals WF, JL, and BT had complete sparing of Heschyl's gyrus, middle and superior temporal gyri and the inferior parietal lobule in the left hemisphere that Gordon (1983) identified as critical substrates involved in immediate auditory memory (Gordon, 1983).

Table 55: Double Dissociation #9

Initials and Case Number	Lesion Locus	Number Detection Raw Score, AZI, P	Word Series Raw Score, AZI, P
JD (2)	left temporal	73, Normal	7, 2.10, p = 0.02
WF (9)	left frontal	24, 2.16, p = 0.02	12, Normal
JL (19)	right frontal	3, 3.08, p = 0.001	12, Normal
BT (23)	right frontal	13, 2.64, p = 0.004	12, Normal

Double Dissociation #10

Six double dissociations were observed between Number Detection and Sentence Repetition. JD's Sentence Repetition score was significantly impaired consistent with a study demonstrating that repetition tasks are sensitive to left posterior lesions (Selnes et al, 1985). JM's Sentence Repetition score was also impaired which is interpretable in terms of encroachment of the lesion upon white matter deep to the inferior parietal cortex and thus in close proximity to Wernicke's area (Selnes et al., 1985). JD and JM's lesions spared the right hemisphere and basal ganglia and perhaps as to be expected their Number Detection scores are in the normal range (Binder et al., 1992).

AO was severely impaired on Number Detection presumably due to a large left middle cerebral artery lesion, however it is difficult to interpret this finding aside from speculating that left frontotemporal lesions can adversely affect Number Detection. Alternatively homologous brain regions within the right frontal lobe subserving vigilance could have been adversely affected given that previous investigators have demonstrated that secondary disruptions in function can occur in regions remote from the primary lesion but anatomically connected to it – which act as a functional lesion (Kossyln et al., 1993). Sentence Repetition was spared in AO consistent with previous reports of the adverse effects of posterior temporal gyrus lesions (Selnes et al, 1985). WF's lesion involved the basal ganglia (Binder et al, 1992) but spared Wernicke's area, essential in repetition (Selnes et al, 1985), and JL's large right frontal region obliterated the right basal ganglia but entirely spared the left hemisphere (Binder et al., 1992). These results imply that the vigilance network may involve both the left and right frontal cortex that is distinct from left posterior networks underlying repetition.

Table 56: Double Dissociation #10

Initials and Case Number	Lesion Locus	Number Detection Raw Score, AZI, P	Sentence Repetition Raw Score, AZI, P
JD (2)	left temporal	73, Normal	7, 1.82, p = 0.03
AO (3)	l. fronto-temporal	22, 2.25, p = 0.01	10, Normal
JM (8)	left frontal	106, Normal	7, 1.82, p = 0.03
WF (9)	left frontal	24, 2.16, p = 0.02	13, Normal
JL (19)	right frontal	3, 3.08, p = 0.001	13, Normal

Double Dissociation #11

Two double dissociations were observed between Number Detection and Sentence Questions. JD's impairment on Sentence Questions after an anterior left temporal lesion is equivocal in view of previous reports of left perisylvian regions (superior temporal gyrus, inferior frontal gyrus, angular gyrus, supramarginal gyrus, and parietal operculum) as being most sensitive to deficits in syntax comprehension (Caplan et al, 1996). These findings could imply broader unspecified damage to JD's brain perhaps as a consequence of his traumatic brain injury. JD's unimpaired Number Detection provides some evidence against diffuse subcortical damage. Perhaps the injury is localized, generally including the left frontotemporal regions, as these regions are particularly sensitive to traumatic brain injury (Schnider & Gutbrod, 1999) or the deficit is secondary to a primary difficulty in immediate auditory memory (e.g., JD's poor performance on Word Series discussed under double dissociation #9).

WF, in contrast, had unimpaired Sentence Questions scores consistent with sparing of perisylvian regions involved in comprehension of complex syntax discussed under double dissociation #8. Number Detection was noticeably impaired in WF likely a function of basal ganglia involvement, while BT's right basal ganglia lesion is highly consistent with previous reports of difficulties in vigilance activities among such patients (Binder et al, 1992). BT's preserved Sentence Questions would be consistent with lateralization of this verbal task to the dominant hemisphere in this right-handed man.

Table 57: Double Dissociation #11

Initials and Case Number	Lesion Locus	Number Detection Raw Score, AZI, P	Sentence Questions Raw Score, AZI, P
JD (2)	left temporal	73, Normal	6, 3.12, $p < 0.001$
WF (9)	left frontal	24, 2.16, $p = 0.02$	13, Normal
BT (23)	right frontal	13, 2.64, $p = 0.004$	14, Normal

Double Dissociation #12

One double dissociation was observed between Sentence Repetition and Sentence Questions. AO's lesion spared Wernicke's area that is the critical substrate of Sentence Repetition (Selnes et al, 1985) while there was damage to the insula, operculum, inferior temporal lobe as well as the superior aspect of the frontal lobe. All of these latter areas have been directly implicated in optimal performance on syntactic comprehension tasks (Caplan et al, 1996). In the case of JM we see that comprehension is largely preserved despite a small lesion in the vicinity of the left external capsule. JM's Sentence Repetition was severely impaired but this could have arisen in part from his articulatory difficulties rather than as a result of encroachment of the lesion into the posterior perisylvian region. Despite JM's normal Word Series score his poor performance on the Sentence Repetition task underlies the prominent articulatory demands of the latter task.

Table 58: Double Dissociation #12

Initials and Case Number	Lesion Locus	Sentence Repetition Raw Score, AZI, P	Sentence Questions Raw Score, AZI, P
AO (3)	l. fronto-temporal	10, Normal	9, 1.78, p = 0.04
JM (8)	left frontal	7, 1.82, p = 0.03	13, Normal

Parametric and Nonparametric Lesion Analysis of PASS Scales and CAS Subtests

In addition to the analysis of the patterns of double dissociations on the CAS subtests at the individual level, an analysis of the patterns of lesion specificity of the PASS scales and CAS subtests was undertaken at the group level.

Parametric Analysis of the PASS Scale's Specificity

Individual CAS subtest AZI scores were collapsed within PASS scales to arrive at group means for each of the four PASS scales of planning, attention, simultaneous and successive and the 4 lesion groupings: left anterior (n = 21 observations), left posterior (n = 15), right anterior (n = 27) and right posterior (n = 9). Four separate ANOVA's were carried out. The (1) PASS scale by (4) lesion groups with an average of 18 observations each per cell resulted in 72 observations in total. Eight subjects whose lesions did not fit into these groupings (1 undamaged, 2 bifrontal atrophy, 1 medial frontal, 3 right cerebellar and 1 midbrain lesioned patient) were excluded for a total of 24 patients.

It should be noted that lesions of cerebellar cortex often result in confounding ataxia on the same side as the lesion. Similarly the right cerebellar hemisphere projects to the left thalamus and cortex which in turn projects to the left pontine nuclei which then projects back to the right cerebellar hemisphere. Thus lesions in the pons and cerebellum below points of cortical decussation cannot be strictly dichotomized into the left or right hemisphere (e.g., see Kolb & Whishaw, 1996). A similar type of classification problem exists with the 1 non-damaged patient and the medial frontal patients. For these reasons all these patients were excluded. Thus each patient contributed on average 3 CAS subtest performances to the calculation of the 4 PASS scale ANOVAs.

An *a priori* statistical power analysis was carried out during the ethical review process for this ANOVA design and it is reviewed here for sake of clarity. Briefly since the attenuating effects of brain lesions on performance of neuropsychological tasks has been previously judged to be quite large – an effect which is moderated by lesion location and size – (Lezak, 1995), then in Cohen's (1988) characterization of effect sizes, Δ, would be greater than 0.80. Calculation of the non-centrality parameter, ϕ, for a 2 location (anterior versus posterior) by 2 side (left versus right) ANOVA with 6 observations per cell at $\alpha = 0.05$ equaled 1.96 -- at the level of subtest ANOVA comparisons. Extrapolation from Glass and Hopkins' (1996, p. 634) tables reveals that the associated probability of detecting an effect with this design would be greater than 0.86 that is classified as satisfactory to good in these authors' nomenclature.

Subtest ANOVA comparisons were not actually carried out since there were significant sample size deviations among subtest cells. Since sample sizes were substantially larger than these minimal cell sizes for the PASS scale comparisons the actual statistical power of the design would in all likelihood easily exceed .90 that is classified as excellent. Furthermore additional statistical power is added to this PASS 2 by 2 ANOVA given that it is a mixed within and between subjects design. Despite the unequal sample sizes the relatively large number of observations per cell allowed for four parametric PASS scale ANOVAs. However, for three of the four ANOVA comparisons there were marginal violations of the homogeneity of variance assumption which required specialized hypothesis testing. For each of the subsequent comparisons, means, standard deviations and cell sizes are listed below.

Table 59: ANOVA for Planning scale: lesion location by side

Location	Side	Mean AZI	Standard Deviation	N
Anterior	Left	2.03	1.31	20
	Right	2.36	1.04	27
	Total	2.22	1.16	47
Posterior	Left	2.06	1.23	15
	Right	3.17	0.45	8
	Total	2.45	1.15	23
Total	Left	2.04	1.26	35
	Right	2.54	0.99	35
	Total	2.30	1.15	70

Levene's test of the homogeneity of variance was violated ($t(3) = 3.53$, $p < 0.02$) due to the unequal sample sizes and therefore a modification of the Tamhane's T2 conservative pairwise comparisons test was used for all subsequent hypothesis tests on the planning scale (Dunnett & Tamhane, 1995). The main effect of location was nonsignificant but there was a main effect of side [$t(50) = 2.85$, $p = 0.006$] such that right-sided lesioned patients were significantly more impaired than their left lesioned counterparts on the composite planning scale. The interaction of location by side was nonsignificant. At the group level multiple comparisons tests revealed that right anterior lesioned patients performed significantly worse than left posterior ($p = 0.03$), right anterior ($p = 0.02$) and left anterior ($p = 0.01$) patients.

Table 60: ANOVA for Attention scale: lesion location by side

Location	Side	Mean AZI	Standard Deviation	N
Anterior	Left	1.62	1.12	20
	Right	1.84	1.26	24
	Total	1.74	1.19	44
Posterior	Left	1.91	0.91	15
	Right	2.59	0.52	8
	Total	2.14	0.85	23
Total	Left	1.74	1.03	35
	Right	2.02	1.16	32
	Total	1.88	1.10	67

Levene's test of the homogeneity of variance was violated ($t(3) = 3.92$, $p = 0.01$) due to the unequal sample sizes and therefore a modification of the Tamhane's T2 conservative pairwise comparisons test was used for all subsequent hypothesis tests on the attention scale (Dunnett & Tamhane, 1995). The main effect of side of lesion approached significance [$t(61) = 1.91$, $p = 0.06$] while the main effect of location of lesion was significant [$t(61) = 2.21$, $p = 0.03$] such that posterior patients scored significantly worse than anterior lesioned patients. The interaction of side by location was nonsignificant. At the level of group comparisons right posterior patients performed significantly poorer than left anterior patients ($p < 0.03$).

Table 61: ANOVA for Simultaneous scale: lesion location by side

Location	Side	Mean AZI	Standard Deviation	N
Anterior	Left	1.09	1.11	20
	Right	1.16	0.94	25
	Total	1.13	1.01	45
Posterior	Left	1.18	0.87	14
	Right	2.36	1.10	8
	Total	1.61	1.10	22
Total	Left	1.12	1.01	34
	Right	1.45	1.10	33
	Total	1.29	1.06	67

The homogeneity of variance assumption was tenable and therefore more liberalized ANOVA comparisons were made. There was a significant main effect of location such that posterior patients performed significantly worse than anterior lesioned patients [$F(1,63) = 5.84$, $p < 0.02$]. There was also a significant main effect of side such that right hemisphere lesioned patients performed poorer than left hemisphere lesioned patients [F(1,63) = 5.44, p = 0.02]. Finally there was a significant interaction of location by side such that right posterior lesioned patients performed significantly worse than would be expected on the basis of the simple additive effects of location and side of lesion [F(1,63) = 4.27, p < 0.04]. Interestingly the two anterior groups as well as left posterior patients were not significantly impaired judging by the AZI cutoff. Thus right posterior lesioned patients were the only group that was significantly impaired although there were no significant differences among the four groups at the level of Tamhane's T2 multiple comparisons.

Table 62: ANOVA for Successive scale: lesion location by side

Location	Side	Mean AZI	Standard Deviation	N
Anterior	Left	1.11	1.49	21
	Right	1.14	1.03	23
	Total	1.13	1.26	44
Posterior	Left	1.83	1.00	14
	Right	1.40	0.72	9
	Total	1.66	0.91	23
Total	Left	1.40	1.35	35
	Right	1.21	0.95	32
	Total	1.32	1.17	67

Levene's test of the homogeneity of variance was violated (t(3) = 6.37, p < 0.001) due to the unequal sample sizes and therefore a modification of the Tamhane's T2 conservative pairwise comparisons test was used for all subsequent hypothesis tests on the attention scale (Dunnett & Tamhane, 1995). There were no significant main effects nor was there any interaction for the successive scale and an examination of the mean AZI scores revealed that left posterior lesioned patients were the only group that was impaired in relation to the AZI criterion. There were no significant inter-group differences.

PASS Scale Summary

The PASS scale ANOVA comparisons of location (anterior, posterior) by side (left, right) allowed for the testing of the original predictions made by Das and colleagues. Recall that seven core hypothesis followed from this groups' stated premises. **Hypothesis 1** predicted that on the successive scale anterior patients would perform poorer than posterior patients given the implication of a frontal-temporal as opposed to an exclusively posterior neural substrate of successive processing. The results contradicted this hypothesis since posterior patients (x_{AZI} = 1.66, n = 23) scored poorer than anterior patients (x_{AZI} = 1.13, n = 44), although this main effect was not significant. Posterior patients were impaired in an 'absolute sense' judging by the average z-score index of impairments whereas anterior patients were not.

Hypothesis 2 predicted that on the simultaneous scale anterior patients would score significantly better than posterior patients since simultaneous processing was described as being dependent on occipital-parietal regions of the brain. The data supported this hypothesis since posterior patients scored significantly poorer (x_{AZI} = 1.61, n = 22) than anterior patients (x_{AZI} = 1.13, n = 45) although posterior patients were not impaired in an absolute sense compared to the AZI cutoff. Furthermore the additional main effect of location was modulated by an interaction effect such that right posterior lesioned patients were more impaired than would expected on the basis of the mere additive effects of location and side of lesion. This implies that there is an anterior-posterior gradient for simultaneous processing but than this effect is further modulated by a significant unknown factor.

Hypothesis 3 predicted that on the attention scale anterior patients would fare worse than posterior patients since attention was described as involving the integrity of frontal regions. The data did not support hypothesis 3. The main effect was in the opposite direction such that attention was more strongly influenced by the integrity of posterior regions (x_{AZI} = 2.14, n = 23) than anterior regions (x_{AZI} = 1.74, n = 44). These findings cast some light on the potential bases for the interaction effect described under the preceding discussion of hypothesis two. That is, right posterior patients may have had visual inattention of a perceptual nature that was primary to the cognitive deficit in simultaneous processing.

Hypothesis 4 predicted that on the planning scale anterior patients would score significantly poorer than posterior patients given Das et al's review implying the importance of these regions in the regulation of behavior. The data did not support hypothesis 4. The trend was in the opposite direction such that planning processes as operationalized in the CAS were more strongly adversely affected by posterior lesions (x_{AZI} = 2.45, n = 23) than anterior lesions (x_{AZI} = 2.22, n = 47); although both groups were impaired as judged by the AZI criterion.

Hypotheses 5 and 6 related to the hypothesized effects of the simultaneous and successive scales independence from the effects of laterality of the lesion on the basis of Das et al's assertion of '*the independence of code content from the type of coding*'. **Hypothesis 5** predicted that left sided lesioned patients should not score significantly differently from right-sided lesioned patients on the simultaneous scale. The data disconfirmed hypothesis 5 and suggested that right hemisphere lesioned patients (x_{AZI} = 1.45, n = 33) performed significantly poorer than left hemisphere lesioned patients (x_{AZI} = 1.12, n = 34) on the simultaneous scale.

Hypothesis 6 predicted that on the successive scale left sided patients should not score significantly differently from right-sided lesioned patients. This hypothesis was supported although the data illustrated a trend such that left sided patients (x_{AZI} = 1.40, n = 35) performed poorer than right-sided patients (x_{AZI} = 1.21, n = 32). Although there were approximately equal numbers of left and right hemisphere lesioned patients in this comparison, there were unequal frequencies of men and women in each of the two conditions: right sided (4F/6M) and left sided (2F/8M). There were proportionally more women in the right-sided lesioned group. A genuine effect of side of lesion, in opposition to that predicted by hypothesis 6 may have been obliterated due to the unequal frequencies of sexes between cells. Previous studies have noted that language subskills included under the rubric of the successive scale are more bilaterally represented in women than in men (Kolb and Whishaw, 1996). The larger proportion of women in the right hemisphere group could have mitigated such a potential effect of lateralization.

Hypothesis 7 predicted that on the planning scale left sided patients should not score significantly different from right-sided patients on the basis of Das and colleagues' notion of the amodal nature of tertiary cortex as in the example of prefrontal cortex. The data contradicted hypothesis 7 and suggested that right-sided patients (x_{AZI} = 2.54, n = 35) fared significantly worse than their left-lesioned counterparts (x_{AZI} = 2.04, n = 35). This result questions the veracity of Luria's account of the centrality of linguistic mediation in the regulation of behavior (Luria, 1966); and others have previously demonstrated difficulties with this position (Weiskrantz, 1988). The results are consistent with recent studies implicating the integrity of the right prefrontal cortex in performance on ill-structured problem solving tasks (Goel and Grafman, 2000), and thus indirectly support that the CAS planning tasks could be measuring aspects of these cognitive processes.

Additionally left anterior patients were as a group not significantly impaired on the attention tasks consistent with previous reports of the parietal regions as playing the central role in the covert orienting of attention (Posner, Walker, Friedrich & Rafal, 1984) and right frontal regions as being essential in sustained attention (Rueckert & Grafman, 1996). There was a significant interaction of location by side on the simultaneous scale such that patients with right posterior lesions performed far worse than would be expected on the basis of location or lesion side alone. This finding is probably due to the debilitating effects of visual neglect as a consequence of right parietal lesions such that visuoperceptual processes in addition to gestalt-synthesizing cognitive processes (simultaneous) are both disturbed. Evidence for this assertion comes from the finding that when visual neglect on the archetypal simultaneous task of the Raven's Matrices is controlled for by presentation of the stimuli in the midline using the method of Caltagirone, Gainotti and Micelli (1977) the usual sensitivity of this task to right hemisphere lesions was completely attenuated.

In summary the data supported hypothesis 2 and 6 but rejected hypothesis 1,3,4,5,7 suggesting that the neural networks supporting 'simultaneous' processing are posterior based and that as predicted the successive cognitive processes are not necessarily localizable to one or the other hemisphere. However the data did not support hypothesis 1 that successive processes are more anteriorly localized -- rather the reverse pattern was observed. The data also did not support hypothesis 3 that attention would be more anteriorly localized since patients with posterior lesions fared worse than anterior lesioned patients. Hypothesis 4 was also not supported since the direction of effects was in favour of posterior lesions having the poorest performance on planning tasks. This may imply that the CAS's speeded and kinaesthetically demanding planning tasks make greater motor sequencing requirements on posteriorly-based praxis mechanisms (Heilman, Rothi & Valenstein, 1982) rather than on non-speeded executive functions tasks exemplified by non-timed tests of category, semantic fluency and mental flexibility conventionally used in neuropsychology. Anecdotal evidence would suggest that this conclusion could be drawn since several left posterior patients had considerable difficulty performing these manual tasks despite verbally repeating the instructions and demonstrating understanding of the task, and who at the same time exhibited no obvious motor impairments.

Hypothesis 5 was refuted, suggesting the opposite, that simultaneous processing is inextricably linked with nonverbal visuospatial processing. This nonverbal processing could be analogous to the two visual-spatial processing streams described by Ungerleider, Courtney, and Haxby (1998) and it argues against Das et al's proposition that code content is independent of code type at least within the visuospatial domain. The argument that code content is not independent of code type is congruent with Paivio (1976, 1995) and most contemporary functional neuroimaging studies which hypothesize separate visual-spatial, auditory and semantic working memory networks co-extensive with anterior and posterior cortical regions (e.g., Baddeley, 1982; Goldman-Rakic, 1996). Hypothesis 7 relating to putative amodal processing in tertiary areas such as the prefrontal cortex was also not supported. This is consonant with emerging functional neuroimaging studies in humans which imply a superior/inferior parcellation of functioning within the prefrontal cortex such that dorsal regions support visuospatial working memory; ventral regions support object working memory and the anterior cingulate and dorsolateral prefrontal cortex support monitoring and maintenance functions, respectively (e.g., see Gazzaniga, 2000).

Nonparametric Analysis of the CAS Subtest's Specificity

A two-stage process was initiated to classify the (i) CAS subtest performance data and (ii) critical lesion localization map data for each subject into dichotomously scored data. All subjects were included in this analysis for a total of 32. Each subtest score for each patient was judged significantly impaired if his/her average z-score impairment rating (AZI > 1.64, p > 0.05), thus the effect was judged to be dichotomously present (1) or absent (0). Similarly the extent of each patient's lesion was carefully evaluated for involvement of the critical lesion locus – see Appendix 7. Each patient's brain scan films were rated for the presence or absence of a lesion in one of these seventeen critical lesion locus areas. If any area was damaged within a lesion by subtest cell then the entire cell was scored as damaged demarcated by an (1). Non-damaged critical lesion loci of patients were scored as absent (0). All lesions were rated objectively according to the neuroradiologist's written CT or MRI of the brain scan thereby minimizing the introduction of rating bias. Moreover the extent of each lesion as outlined in the written summary was verified with the original CT or MRI film and checked with a standard neuroradiological atlas (Moeller & Reif, 2000). In this way both the lesion and the subtest performance data were objectively transformed into dichotomous data for non-parametric evaluation of statistical hypothesis.

Nonparametric signed-ranks probability statistics were then computed for each of the 12 critical lesion locus (CLL) $_{CAS\ subtest\ 1}$ / impairment $_{CAS\ subtest\ 1}$ pairings. Damage to any area of the CLL in individual patients was predictive of impairment at the group level in four CAS subtests. Damage within the basal ganglia was highly predictive of performance on the Planned Codes subtest of the CAS ($z = -3.64$, $p < 0.001$). Damage specifically to the right anterior cingulate was also highly predictive of poor performance on the Expressive Attention subtest of the CAS ($z = 3.72$, $p < 0.001$). Damage within the left posterior perisylvian region (insula, superior temporal gyrus, inferior parietal lobe) or basal ganglia were predictive of poor performance on the Verbal-Spatial Relations subtest ($z = -2.31$, $p = 0.02$). Finally damage within either the left temporoparietal region or the right frontal lobe was predictive of poor performance on the Word Series subtest of the CAS ($z = -2.52$, $p = 0.01$). There were no other significant subtest specificities with the possible exception of Sentence Repetition that displayed marginal specificity for the left posterior superior temporal gyrus and/or the left inferior parietal lobe ($z = -1.73$, $p = 0.08$).

Chapter 6: Summary and Conclusions

In Chapter 1, the hypothesized neuropsychological properties of the CAS were reviewed after examining similarly designed tasks previously used in lesion and neuroimaging studies. From this empirical review the evidence suggested that some of the CAS subtests should have unique neuropsychological specificity and sensitivity to regional variations in location of brain injury. In Chapter 2, a short discussion of the methodological and statistical aspects of the study was undertaken as well as a description and classification of each of the study's 32 cases. In Chapter 3 and 4, left and right hemisphere cases were analyzed in greater depth in the context of the extant neuropsychological literatures. Finally, in Chapter 5 thirty-five double dissociations were analyzed for examples of neuropsychological impairment from which 12 patterns could be distinguished. Moreover parametric and nonparametric analyses of the PASS scale, and CAS subtests, in conjunction with lesion groupings and critical lesion loci were undertaken. The double dissociations at the level of the CAS subtests, non-parametric analysis of critical lesion loci at the level of CAS subtests provide convergent evidence for separable neural subsystems underlying performance on the CAS subtests. Description of each case in chapters 3 and 4 can thus be used to complement the more inferential aims of chapter 6.

In this concluding chapter, the hypothesized patterns of CAS subtest localizations discussed in Chapter 1 will be compared with the actual observed double dissociations. The patterns of double dissociations are illustrated on the next page. As table 63 depicts, 8 of the 12 CAS subtests demonstrated reliable double dissociations with each other. These were as follows: Matching Numbers (1), Number Detection (3), Nonverbal Matrices (2), Verbal-Spatial Relations (2), Figure Memory (4), Word Series (4), Sentence Repetition (5) and Sentence Questions (3).

Table 63: List of double dissociations

CAS Subtest	MN	PC	PL	EA	ND	RA	NV	VS	FM	WS	SR	SQ	*f*
Matching Numbers (MN)	-	-	-	-	-	-	-	-	1	-	-	-	1
Planned Codes (PC)		-	-	-	-	-	-	-	-	-	-	-	-
Planned Connections (PL)			-	-	-	-	-	-	-	-	-	-	-
Expressive Attention (EA)				-	-	-	-	-	-	-	-	-	-
Number Detection (ND)					-	-	-	-	-	3	6	2	3
Receptive Attention (RA)						-	-	-	-	-	-	-	-
Nonverbal Matrices (NV)							-	-	-	4	4	-	2
Verbal-Spatial Relations (VS)								-	-	2	4	-	2
Figure Memory (FM)									-	3	3	2	3
Word Series (WS)										-	-	-	-
Sentence Repetition (SR)											-	1	1
Sentence Questions (SQ)												-	-
Frequency Counts (*f*)	-	-	-	-	-	-	-	-	1	4	4	3	-

Matching Numbers Review

Matching Numbers was significantly impaired by JH's right frontal lesion and this was dissociable from the short-term visuospatial memory task of Figure Memory. This is congruent with Husain and Kennard's (1997) demonstration that the right frontal lobe is critically involved in visual search tasks such as Matching Numbers. In contrast, fMRI studies of tasks similar to Figure Memory (Ring et al, 1999) have revealed characteristic activation of bilateral parietal regions, right dorsolateral prefrontal cortex and bilateral occipital cortex, suggestive of preferential activation of the dorsal visual stream during such visuospatial short-term memory tasks (Ungerleider, Courtney & Haxby, 1998). These two visuospatial tasks appear to be largely functionally and neuroanatomically distinct. Matching Numbers and Figure Memory were only modestly correlated with each other in the standardization sample in congruence with this hypothesis (e.g., r = 0.31).

Planned Codes Review

Conspicuously absent from the list of subtests demonstrating reliable double dissociations from each other was Planned Codes which was significantly impaired in 78% of patients, congruent with previous reports of such tasks sensitivity to even mild brain damage (Schear & Sato, 1989). Although highly sensitive to brain damage this task's speeded and fine motor dexterity requirements made it unsuited to differentiating among more severely brain injured patients. Rather, this task could potentially be useful as a general marker of organic involvement in much the same way that the Symbol Digit Modalities Test is currently used (Smith, 1991).

Planned Connections Review

Planned Connections was also significantly impaired in 50% of patients but was not doubly dissociated from any other subtest. Although the predecessor of Planned Connections, the Trail-Making Test, has among the highest sensitivities in detecting brain damage (Lezak, 1995), it is ineffective in lateralizing lesions (Heilbronner et al, 1991). Furthermore, the conglomeration of the number sequences score with the number-letter sequence score items in Planned Connections in effect may obscure genuine differences in performance between each of these two types of tasks (Crowe, 1998). Crowe found that the Trail Making Test could be factored into two segments. Part A was uniquely predicted by visual search and motor speed while Part B was uniquely predicted by visual search and cognitive set shifting. Part A would correspond to items 4 to 6 while Part B would correspond to items 7 and 8 of Planned Connections.

This is a crucial distinction since Johnstone et al (1995) found that while frontal patients were only impaired on Part B of Trail Making, non-frontal patients were impaired on both Parts A and B. Future investigators might consider dividing the Planned Connections subtest of the CAS into these two components for neuropsychological evaluation purposes. The only patient scoring in the normal range was KC, a patient with estimated premorbid ability in the high range and with a subtle low density in the posterior lateral aspect of the left frontal lobe presenting with mild aphasic symptoms. This lesion site was consistent with previous reports of the Trail-Making Test as being largely invulnerable to the effects of aphasia (Spreen & Strauss, 1998, p. 538).

Table 64: Percentages of patients scoring normally, below average and deficit on subtests

CAS Subtest	Sample (N)	Normal %	Below Average %	Significant Deficit %
Matching Numbers	32	9.4	37.5	53.1
Planned Codes	32	0	21.9	78.1
Planned Connections	28	3.1	40.6	50.0
Expressive Attention	32	6.3	40.6	53.1
Number Detection	32	15.6	43.8	40.6
Receptive Attention	26	3.8	50.0	46.2
Nonverbal Matrices	32	21.9	46.9	31.3
Verbal-Spatial Relations	32	34.4	43.8	21.9
Figure Memory	25	20.0	48.0	32.0
Word Series	32	40.6	37.5	21.9
Sentence Repetition	32	43.8	21.9	34.4
Sentence Questions	28	28.6	25.0	46.4
Average Across Subtests	30	19.0	38.1	42.4

Expressive Attention Review

Expressive Attention was also among the list of subtests not doubly dissociated from any other subtest. This subtest had the fourth lowest rate of patients scoring in the normal range suggesting that this subtest is highly sensitive to mild brain injury (Stuss et al, 1985) but it may be insensitive in distinguishing among more severely brain-damaged patients. Ponsford and Kinsella (1992) have previously shown that in severely brain-injured patients, color naming and word reading scores on the Stroop were among the most discriminating of slowed information processing. Accuracy but not speed was relatively preserved in Ponsford and Kinsella's patients. On the Expressive Attention subtest of the CAS word reading and colour naming norms are not provided and these would be useful to provide for neuropsychological purposes.

Incidentally only two patients scored in the normal range on Expressive Attention: AM and RM. Both of these patients were estimated to be in the high range of premorbid ability. AM had no obvious complications as a result of a left frontotemporal craniotomy with the exception of the potential for mild injury at the site of retraction (Yundt et al, 1997). RM's lesion was restricted largely to the left anterior prefrontal cortex with some medial damage. High premorbid ability and intact right frontal structures could have acted interactively to preserve functioning on this measure of response inhibition for these two patients (Vendrell et al, 1995).

Number Detection Review

Number Detection was strongly doubly dissociated from Word Series, Sentence Repetition, and Sentence Questions. In 8 of 11 cases, a patient with a left temporal lesion scored significantly poorer on these verbal subtests as did one patient with a left frontotemporal lesion and one with a left frontal lesion with insular damage. These findings are consistent with these processes involving immediate auditory memory (Gordon, 1983; Trahan et al, 1989) Wernicke's area (Selnes et al, 1985) or involving a distributed perisylvian language network (Caplan et al, 1996); respectively. The patients scoring poorly on Number Detection consisted largely of patients with right frontal lesions (Binder et al, 1992). An examination of the extreme quartiles revealed that patients scoring in the top 25% on Number Detection had the following profile: 1 no lesion, 1 left temporal, 2 left frontal, 1 medial frontal, 2 right frontal, 1 right cerebellum. Those patients scoring in the bottom 25% consisted of: 1 left frontal, 1 left parietal, 4 right frontal and 2 right parietal. In sum severely impaired performance on Number Detection was associated with large right frontal lesions or posterior parietal lesions both of which would be expected on the basis of previous studies (Binder et al, 1992).

Receptive Attention Review

The fourth and final subtest that was not involved in any double dissociation was Receptive Attention. Receptive Attention had the third lowest rate of patients scoring in the normal range suggesting that this subtest is also highly sensitive to brain injury but may be insensitive in distinguishing among the more severely brain-injured patients included in this sample. Two previous studies found that older patients scored significantly poorer on tasks similar in construction to Receptive Attention (Hines et al, 1982; Gutentag & Madden, 1987), a finding that was attributed to the greater attentional demands of deeper levels of processing associated with memory retrieval (Craik & Byrd's, 1982). There was only one patient with normal performance on Receptive Attention, that being TF. At age 20, TF was the youngest patient included in the sample. His lesion was restricted almost exclusively to the right prefrontal cortex and suggests a posterior substrate of performance on this task. His performance on physical identity was excellent (ratio score = 45) while his performance on lexical identity was poor (ratio score = 10). Thus despite this large discrepancy and his focal lesion TF earned the highest raw score in the patient sample.

Further analysis revealed a 12-point difference in favour of frontal lesioned patients on Receptive Attention that may have been rendered nonsignificant due to variability and small sample sizes (n = 13: frontal, n = 7: posterior). An analysis of patients (N=6) scoring in the bottom quartile on Receptive Attention revealed that there were four posterior lesioned patients and two patients with large frontal lesions with encroachment of these frontal lesions into posterior regions, especially anterior temporal regions. Scores were uniformly low across physical and lexical identity in this low scoring group. Although tentative the results could imply an anterior-based network for retrieval demands of the lexical identity subtask, perhaps congruent with Tulving et al's (1994) Hemispheric Encoding Retrieval Assymetry (HERA) model. These authors noted a tendency for right frontal regions to be activated during retrieval of information from memory and the left frontal cortex to be activated during encoding of information from memory during functional neuroimaging studies. Posterior regions subserving optimal performance on physical identity or an object recognition system might coincide with Ungerleider and Miskin's (1982) occipitotemporal or ventral visual stream of object perception and identification. However, in the absence of stronger evidence in the form of double dissociations these statements must remain speculative.

Nonverbal Matrices Review

Nonverbal Matrices was doubly dissociated from Word Series, a measure of immediate auditory memory. In the first instance, the four patterns of dissociations revealed the importance of the integrity of the midbrain regions and the left superior temporal gyrus in immediate auditory memory and the independence of such auditory processes from the nonverbal reasoning associated with Nonverbal Matrices. Deficits on the latter were associated with large right dorsolateral lesions of the prefrontal cortex in accordance with previous studies implicating a complex bilateral frontal-parietal network as involved in reasoning about these items (Prabhakran et al, 1997). An analysis of those individuals scoring in the top 25% on Nonverbal Matrices revealed the following pattern: 1 no damage, 1 left temporal, 2 left frontal, 1 bifrontal atrophy, 1 medial frontal, 1 right frontal, 1 right cerebellar, and 1 midbrain-pons. All individuals had rather small lesions compared to the bottom quartile. Of those individuals scoring in the bottom 25% they consisted of: 1 left frontal, 2 left parietal, 1 bifrontal atrophy, 3 right frontal and two were 2 right parietal. Collectively, these data suggest that a broadly distributed bilateral parietal and right frontal neural network is important for performance on the Nonverbal Matrices which would be difficult to localize to a specific brain region per se.

Verbal-Spatial Relations Review

Verbal-Spatial Relations was strongly doubly dissociated from Sentence Repetition and to a lesser extent Word Series. Two patients, one with a left frontotemporal and the other with a large right frontal lesion were impaired on Verbal-Spatial Relations while a patient with a left temporal lesion and another with a left frontal lesion were impaired on Sentence Repetition. Selnes et al (1985) previously demonstrated that Wernicke's area was among the most critical to performance on sentence repetition tasks while Trahan, Goethe and Larrabe (1989) and Gordon (1983) found that the superior temporal gyrus was most important to performance on immediate auditory memory tasks such as Word Series. Patients scoring in the top 25% on Verbal-Spatial Relations included: 1 no damage, 1 left temporal, 2 left frontal, 1 medial frontal, 2 right frontal and 4 subcortical. Patients scoring in the bottom quartile included: 1 left frontotemporal, 1 left frontal, 2 left parietal, 1 bifrontal, 2 right frontal, and 2 right parietal. Parietal and large frontal lesions appeared to be particularly deleterious to performance on Verbal-Spatial Relations while small subcortical lesions apparently had no effect on performance. These results suggest the importance of a dual-hemispheric and frontoparietal network involved in performance on Verbal-Spatial Relations with a neuroanatomically distinct, although partially overlapping, posterior perisylvian network supporting Word Series and Sentence Repetition.

Figure Memory Review

Figure Memory was doubly dissociated from Matching Numbers and from Word Series, Sentence Repetition, and Sentence Questions. A patient with a right cerebellar lesion performed poorly on Figure Memory and this was dissociated from a patient with a right frontal lesion who performed poorly on Matching Numbers. Figure Memory was normal in a patient with a left temporal lesion whereas immediate auditory memory was impaired. Patients with left frontal, right frontal, and right cerebellar lesions were impaired on Figure Memory but performed within the normal range on Word Series and Sentence Repetition. This pattern was suggestive of a strong dissociation between a superior temporal gyrus based immediate auditory memory (Gordon, 1983) or Wernicke's based sentence repetition (Selnes et al, 1985) and a distributed network of cerebellar, frontal, and parietal regions as being involved in short-term visuospatial memory (Honda et al, 1998; Ring et al, 1999). Sentence Questions was also doubly dissociated from Figure Memory with the pattern of lesions suggesting a distributed left perisylvian and right anterior network as involved in sentence comprehension (Caplan et al, 1996) that is partially overlapping but still dissociable from the dorsal visual stream underlying performance on short-term visuospatial memory of Figure Memory (Ungerleider et al, 1998).

Patients scoring normally on Figure Memory consisted of: 1 left temporal, 1 left frontal, 1 medial frontal, and 2 right frontal. All patients were relatively young (x_{age} = 35) and previously healthy. In contrast, patients scoring in the bottom quartile on Figure Memory had lesions restricted to: 2 left frontal, 2 right frontal, 1 left parietal, and 2 right parietal. The low scoring group was relatively older (x_{age} = 53) and had larger lesions. Collectively, the results do implicate the integrity of the parietal regions as being paramount for good performance on the Figure Memory subtest. These results are also consistent with previous reports of similarly designed tasks as being especially sensitive to aging effects (Della Sala et al, 1997).

Word Series Review

Word Series was reliably dissociated from Number Detection, Nonverbal Matrices, Verbal-Spatial Relations, and Figure Memory. An examination of individuals scoring normally on Word Series revealed: 1 no damage, 5 left frontal, 1 medial frontal, 4 right frontal and 2 right cerebellum. An examination of individuals scoring in the bottom quartile on Word Series revealed: 1 left temporal, 1 left frontal, 1 left parietal, 1 bifrontal atrophy, 2 right frontal, and 1 midbrain-pons lesioned patient. Collectively, the results imply a sensitivity of Word Series to left posterior perisylvian lesions, particularly those encroaching on the superior temporal gyrus (Gordon, 1983) or midbrain lesions as well as an apparent lack of an effect of anterior lesions on immediate auditory memory span.

Sentence Repetition Review

Sentence Repetition was doubly dissociated from Sentence Questions in two patients: one with a left frontotemporal lesion and the other with a left frontal lesion. The strong articulatory demands of

Sentence Repetition as constructed in the CAS were revealed in the left frontal patients' impaired repetition but intact comprehension on Sentence Questions. Alternatively these patients's poor performance could have arisen because of poor response monitoring which is a prominent function of the left frontal lobe (Grafman, 1999). In contrast, the patient with the left frontotemporal lesion had normal repetition consistent with preservation of Wernicke's area, a critical substrate of performance on this task (Selnes et al, 1985) but who happened to have poor comprehension. An analysis of the individuals performing in the top quartile on Sentence Repetition revealed: 1 no damage, 1 left frontotemporal, 3 left frontal, 1 medial frontal, 5 right frontal, and 3 right cerebellar lesioned patients. An analysis of individuals performing in the bottom quartile on Sentence Repetition revealed: 3 left frontal patients, 1 left parietal, 1 bifrontal atrophy and 2 right frontal patients. These results underscore the importance of the posterior as opposed to anterior perisylvian region more generally in repetition performance as well as this tasks functional independence from right frontal and cerebellar networks.

Sentence Questions Review

Sentence Questions is a verbal comprehension task with significant syntactic demands. An analysis of those individuals scoring in the normal range revealed: 4 left frontal, 1 medial frontal, 1 right frontal and 2 right cerebellar lesioned patients. An analysis of those individuals scoring in the bottom quartile revealed: 1 left temporal, 2 left frontal, 2 left parietal, 1 bifrontal atrophy, 1 right frontal and 1 right parietal. These results suggest the importance of a distributed network involving the left temporoparietal regions as being especially important for performance on Sentence Questions with large frontal lesions capable of reducing performance perhaps through disruption of articulatory and monitoring of performance (Kertesz, 1999).

PASS Composite Scales Localization

At the level of the PASS scales only 2 of 7 hypotheses outlined by Das et al on the specificity of the PASS processes for specific neural substrates were supported for an accuracy rate of 29%. The directional effects of the remaining 5 hypotheses were opposite to those predicted on the basis of PASS theory. These findings seriously question whether the *PASS composite scales* have the requisite specificity to be used effectively in a neuropsychological setting. The lack of specificity of the PASS scales is unlikely to be attributable to inadequacies in the experimental design since (1) a broad cross-section of brain injured patients were recruited with heterogeneous lesions focalized to specific regions of the four cortices and subcortices of the brain; and (2) the statistical power of the design was deemed satisfactory. Rather the preponderance of effects - *in the opposite direction to those predicted of the seven hypothesis* - seriously questions whether PASS itself is substantively based in the neural correlates of the model as stipulated in detail by Das et al, (1994; 1996).

CAS Subtests Localization

In contrast, the predictions made at the level of the CAS subtests in Chapter 1 by this author revealed that 4 of 12 hypotheses were supported for an accuracy rate of 33%. A more liberal inclusion of Sentence Repetition's marginal significance would elevate this accuracy rate to 42%. Moreover 8 of 12 CAS subtests revealed double dissociations with each other indicative of specificity at the level of the CAS subtests for distinct neural substrates. Thus the CAS subtests of Expressive Attention, Verbal-Spatial Relations, Word Series and to a lesser extent Sentence Repetition demonstrated robust evidence of specificity for distinct neural subsystems. Planned Codes also demonstrated sensitivity to mild neuropsychological impairment. This latter task could be useful as a potential marker task of organic involvement and/or for screening purposes. The remaining tasks were not significantly discriminating in an absolute statistical sense to the critical lesion loci as identified in the literature review. This is not in itself problematic since on the whole these tasks tap more complex and distributed networks of cognitive processes (e.g., Nonverbal Matrices: see Prahakaran et al's, 1997 fMRI study) and do suggest that the CAS may be more useful with adults in addition to children (e.g., Das et al, 1995). As an example although Nonverbal Matrices lacks neuropsychological specificity it is derived from Naglieri's (1983) Matrix Analogies Test that provides an excellent measure of general intelligence in addition to having superior scaling properties compared to the RCPM.

Sentence Questions provides a measure of verbal comprehension that is unique in that it is heavily reliant on syntactic analysis and thus avoids the problem of cultural bias due to differential learning of verbal material within subgroups. In addition to its invulnerability to the effects of aphasia Planned Connections is a standard measure in the neuropsychologist's armentarium of set-shifting and mental flexibility tasks. However for neuropsychological purposes clinicians may consider developing separate comparative norms for the visual search (items 4 to 6) and set-shifting (item 7 to 8) components. The four other subtests: Matching Numbers, Receptive Attention, Number Detection and Figure Memory are relatively new to neuropsychology especially in paper and pencil format and so a cross-case pattern analysis may be more appropriate since little normative neuropsychological data exists on these types of tasks.

There was only one instance in which Matching Numbers was doubly dissociated from another subtest. An analysis of the dissociation of Matching Numbers from Figure Memory revealed the former to be especially sensitive to right frontal structures involved in visual search. In contrast Figure Memory was associated with the integrity of a distributed cerebello-thalamo-cortical network involved in visuospatial short-term memory. Evidence implies that Receptive Attention might have an anterior-posterior gradient for each of its two subtasks of lexical and physical match; respectively. However this would require replication in larger samples than conducted in this study. Moreover the literature review implied that this task might be especially useful in the identification of neurodevelopmental disorders, perhaps those associated with abnormalities of the corpus callosum or impairments in orthographic and phonological coding with dyslexic individuals.

Number Detection is a variant of paper and pencil vigilance tasks developed in the 1970's although the task is well standardized and appears to be generally sensitive to right hemisphere lesions. This tasks broad row of numbers across the midline also renders this test especially useful in the quantitative assessment of visual neglect. Figure Memory may also be useful in eliciting qualitative data about aspects of constructional abilities in addition to its psychometric characterization of performance on visuospatial short-term memory. This task appears to be recruit the dorsal visual stream of information processing judging by recent functional neuroimaging studies.

Delimitations

This study sought to identify and examine adult brain injury patients with single localized brain lesions in the post-acute recovery phase on the basis of an approved research protocol (see Appendix 5). In addition patients were screened for their potential history of learning disabilities and none reported any.

However since many patients were over the age of 50 and went to school at a time when learning disabilities were infrequently diagnosed verbal reports may underestimate the frequency of occurrence. The hypothesis that pre-existing learning disabilities are accounting for the findings can be ruled out since the brain reserve hypothesis (Kolb & Whishaw, 1996) would predict that those individuals with pre-existing learning disabilities would be expected to be severely impaired after stroke to the extent that testing would be rendered impossible. This hypothesis can also be ruled out since there is no evidence to suggest that learning-disabled people have an elevated risk of stroke.

The primary purpose of this study was to undertake an exploratory multiple case analyses of the neuropsychological properties of the CAS operationalized on the basis of PASS theory (Das, Naglieri and Kirby, 1994). The primary focus point of the study was the single case although group analysis of means via ANOVA was carried out after analysis of double dissociation patterns. Furthermore since no previous study has undertaken such a detailed analysis of the putative localizing properties of the CAS subtests each task was analyzed in terms of the existing literature. It was not the intent of the author to reduce the data set via a correlational technique such as factor analysis, nor was the focus of the study exclusively psychometric and so such an approach would be not only impractical but inferior in establishing cause and effect relationships between single and multiple cases in terms of double dissociations, means testing and the extant neuropsychological literature. Parametric ANOVA, non-parametric χ^2, and the average Z-score regression method of anchoring subtest scores to an absolute level of impairment, were judged by the test of parsimony to be the most effective means of 'reducing' the data set into a set of theoretically and empirically substantive hypothesis tests. It was also not the author's intent to reduce the complexity of the relationship between brain and cognitive functions in terms of either naive absolute left versus right hemisphere dichotomized characterizations of brain function, nor was the adoption of the lesion method meant to imply an adherence to an outdated notion of extreme localizationism.

Limitations

Generalizability refers to the extent to which a study's findings in one group are applicable or can be used to generate hypothesis a priori in another group. In this study the independent variable was the locus of the lesion varying in location in one of four quadrants: left anterior, right anterior, left posterior and right posterior. The grain of the resolution of the CT and MRI scans far exceeded this level of analysis into one of the four groups and was judged sufficient to differentiate damaged from undamaged regions at the neuroanatomical structure level. Patients from each of these groups meeting the inclusion and exclusion criteria were recruited at equal intervals throughout the duration of the study and at approximately equal times post-injury. Furthermore since three observations were collected for each subject for each of the four ANOVA PASS scale comparisons a mixed partly crossed 2 factor ANOVA design was used. In this retrospective cross-sectional study patients were thus primarily defined in terms of the lesion locus.

There are a host of factors which could potentially adversely affect the generalizability of these findings including: errors in demarcation of the borders of the lesion, functional lesion(s) remote from the primary lesion site confounding interpretation of structure-function relationships, age differences in the differential degradation of performance between subtests, interactions between recovery of function and age by subtest, variations in lesion etiology and lesion size, gender differences in patterns of functional localization, lack of a one-to-one relationships between neuropsychological performance patterns on tasks between children and adults, variations in functional reorganization and functional plasticity between individuals in addition to a host of person-specific and demographic factors. Nonetheless despite these myriad of potential confounds significant directional effects were witnessed between the four groups using very conservative statistical criterion. These findings imply genuine experimental effects of the lesions that could not be easily attributed to an insensitive experimental design.

The key question remains though whether the findings in this sample of adults are also applicable towards children aged 5 to 17 on whom the CAS was standardized. Bates, Vicari and Trauner (1999) in their review of focal lesion studies of children note that there appears to more equipotentiality in children's brains. These authors note that the left hemisphere linguistic bias for children appears to be restricted to the left temporal lobe, is probabilistic in nature and is not irreversible. Moreover innate limitations appear to govern the kinds of knowledge that could be learned in a given brain region and govern the computations that the region is ideally suited to. Among other findings was that either left or right frontal damage delayed the development of expressive language. However localization of function in children may not necessarily be the same in adults and children because functions can be carried out by different component processes depending on age (Korkman, 1999).

In contrast functional MRI studies conducted in normal children have demonstrated patterns of functional localization similar to adults. Casey et al (1997) demonstrated similar a dorsolateral prefrontal cortex activation between children and adults on an executive function task, while Gaillard et al (2000) demonstrated activation of Broca's area and the dorsolateral prefrontal cortex on a verbal fluency task in children and adults. In the latter study children demonstrated greater right hemisphere and inferior frontal gyrus activation than adults. Nelson et al (2000) found similar patterns of activation between their 8 to 11 year old children and archival data published on adults performing a spatial working memory task. These studies suggest that at least in children without brain damage similar patterns of functional organization compared to adults appears to the rule rather than the exception. However in brain-damaged children due to the greater capacity for functional reorganization it appears that significant deviations from expected patterns of functional organization observed in adults may be expected -- especially in those individuals injured at a young age.

In sum of those few studies examining functional localization in children with focal lesions a greater propensity for equipotentiality is the rule and there is a greater diffusivity of functional localization in children's brains that is not mirrored by the functional neuroimaging data in non-brain damaged children. The latter studies demonstrate remarkable concordance in patterns of brain activation on executive, verbal and non-verbal working memory tasks compared with adults. On the basis of these conclusions it is difficult to predict whether the present studies' patterns of localization derived from adults in equally applicable to children, although since the predictions made in Chapter 1 were based on a review of both the lesion and functional neuroimaging literatures an unspecified degree of concordance would be expected. Perhaps more tellingly the 12 patterns of double dissociations do suggest that performance on the individual CAS subtests recruit different neural networks. Since double dissociations imply some measure of functional independence of cognitive processes underlying performance on a task this in turn provides evidence for separable neural networks (Miller, 1993). Such separability of neural networks implies a modularity (Robertson et al, 1993) that is unlikely to change from children to adults --

especially on tasks recruiting occipital lobe (vision) and temporal lobe (auditory) perceptually based tasks (Lloyd, 2000).

Other limitations of the study include: that lesion volume was not more closely controlled for quantitatively and through covariance analysis techniques, variation in the time at which patients were assessed post-injury with the CAS, range in age of the subjects, variation in the etiology of the brain damage, pre-existing medical conditions which might impair cognitive processes, patients were not screened for their use of potentially cognitive enhancing or debilitating medications, the sample size was rather small and exclusively subcortical or occipital lesions were not well-represented in the recruited group. In sum simple downward extension of the results to children could result in inferential errors although for simple tasks reliant on temporal and occipital cortex this caveat is unlikely to hold. It should be noted that the results with adults were robust despite the small sample. This suggests that there should be concordance between patterns of functional organization between adults and children on CAS subtests and scales at least in normal subjects. The only way to test this hypothesis would be to adapt the tasks for use in a functional neuroimaging environment. In contrast considerably variability in the pattern of functional organization on CAS subtests and scales would be expected in brain-damaged adults and brain-damaged children largely due to differences in functional plasticity between these two age groups.

Conclusions

Psychometric criticisms have been leveled against the PASS model of Planning, Attention, Simultaneous, and Successive processing (Kranzler & Keith, 1997). Although suitable for younger age groups, the planning tasks included in this battery are perhaps too narrowly conceived for older healthy adults. Deheane and Changeux (1997) define planning as "*...the goal-directed, trial-and-error exploration of a tree of alternative moves... When no direct move is available, a move must be generated, tried out, and accepted or rejected depending on its ability to bring the problem closer to a solution...*". Moreover, these tasks are closer in design to 'total-order' rather than 'partial-order' planning tasks (Spector & Grafman, 1994) since in each of the CAS's planning tasks, intermediate tasks are completed and executed according to a fixed, previously set sequence to complete a primary goal. The CAS planning tasks do not require the same degree of representational complexity and plan generation time typical of cognitive planning tasks conventionally used in neuropsychological studies (e.g., Tower of London or Hanoi tasks). For these reasons the CAS's planning tasks may be too simplistic for older adolescents and healthy adults.

At the same time, all of the subtests included on the CAS have good psychometric properties and are elaborations and in some cases substantial improvements on existing neuropsychological tasks. In addition, these tasks have a broad range of difficulty of items, data on test/re-test stability, sensitivity in detecting cognitive decline with aging (Das, Davis, Alexander, Parrila & Naglieri, 1995), and convergence with dementia rating scales (McCrea & Scott, in press). This review sought to elaborate the neuropsychological properties of the CAS subtests with the goal of setting the groundwork for future neuropsychological investigations with this instrument. Table 1 in Chapter 1 summarizes the results of the review and points toward the specific utility of the CAS in the context of the assessment of dementia in the elderly. Future norming studies need to be done with healthy elderly people as well as on abnormally aging adults (e.g., Alzheimer's, Parkinson's and Huntington's disease) to fully develop the potential of this new instrument.

This summary has been restricted to a discussion of the adult neuropsychological literature and therefore a simple downward extension of the characteristics of the CAS tasks from healthy adults and those with brain damage is unlikely to be appropriate to child neuropsychological assessment issues. Future studies examining children with focalized brain injuries in samples of adequate sizes might help to more fully elaborate the characteristics of these tasks in such populations.

The primary goal of this exploratory study was to achieve a first approximation of the neuropsychological sensitivity and potential utility of the Cognitive Assessment System in the clinical neurological setting. Eight of twelve CAS subtests demonstrated reliable double dissociations with each other and this evidence on its own suggests that the CAS may be useful in the context of assessing adults with brain injury. Although in-depth single case and group analysis data are useful in and of themselves, future studies will need to examine the CAS's neuropsychological properties with appropriate clinical samples if it was ever to be used in pediatric neuropsychology since tasks may measure different cognitive processes at different ages. The results also imply that some of the CAS tasks such as Matching Numbers, Receptive Attention, Verbal-Spatial Relations, Figure Memory, Word Series as well as the novel and syntactically demanding tasks of Sentence Repetition and Sentence Questions may provide useful information beyond that offered by existing neuropsychological tests.

The results of this study also point towards the usefulness of the qualitative aspects of CAS task completion built into its design such as the *Strategy Assessment Checklist* associated with the planning tasks. Another advantage of the CAS is its ease of administration in a short time period at the bedside in adult patients with moderately severe strokes. Future studies ought to examine normal adult controls between the ages of 50 and 70 to establish acceptable baseline levels of performance on each of the CAS subtests. Evidence suggests that the CAS may be especially useful in the context of the assessment of neurodegenerative disorders associated with the dementias. This is all the more imperative given that performance on the CAS has been previously shown to correlate well with performance on dementia rating scales. With appropriate test-retest reliability data at appropriate intervals in adults, after brain injury the CAS could prove to be an especially useful tool in clinical trials.

References

Ahola, K., Vilkki, J. & Servo, A. (1996). Frontal tests do not detect frontal infarctions after ruptured intracranial aneurysm. Brain and Cognition. 31: 1-16.

Alexander, J. (1998). Cognitive decline and Alzheimer's disease in persons with Down syndrome. Unpublished doctoral thesis. University of Alberta, Edmonton, Canada.

Alegret, A., Vendrell, P., Junqué, C., Valldeoriola, F., Nobbe, F.A., Rumià, J. & Tolosa, E. (2000). Effects of unilateral posteroventral pallidotomy on 'on-off' cognitive fluctuations in Parkinson's disease. Neuropsychologia. 38: 628-633.

Amieva, H., Lafont, S., Auriacombe, S., Rainville, C., Orgogozo, J-M., Dartigues, J-F. & Fabrigoule, C. (1998). Analysis of error types in the Trail Making test evidences an inhibitory deficit in dementia of the Alzheimer's type. Journal of Clinical and Experimental Neuropsychology. 20: 280-285.

Anderson, C.V., Bigler, E.D. & Blatter, D.D. (1995). Frontal lobes lesions, diffuse damage, and neuropsychological functioning in traumatic brain-injured patients. Journal of Clinical and Experimental Psychology. 17: 900-908.

Arbuthnott, K. & Janis, F. (2000). Trail Making Test, Part B as a measure of executive control: Validation using a set-switching paradigm. Journal of Clinical and Experimental Neuropsychology. 22: 518-528.

Ardila, A., Pineda, D. & Roselli, M. (2000). Correlation between intelligence test scores and executive function measures. Archives of Clinical Neuropsychology. 15: 31-36.

Army Individual Test Battery (1944). Manual of directions and scoring. Washington, DC: War Department, Adjutant General's Office.

Baddeley, A. (1992). Working memory: The interface between memory and cognition. Journal of Cognitive Neuroscience. 4(3): 281-288.

Baddeley, A.D., Logie, R., Bressi, S., Della Sala, S. & Spinnler, H. (1986). Dementia and working memory. Quarterly Journal of Experimental Psychology. 38: 603-618.

Banich, M.T. & Belger, A. (1990). Interhemispheric interaction: How do the hemispheres divide and conquer a task? Cortex. 26: 77-94.

Banich, M.T., Passarotti, A.M., White, D.A., Nortz, M.J. & Steiner, R.D. (2000). Interhemispheric interaction during childhood: II. Children with early-treated phenylketonuria. Developmental Neuropsychology. 18: 53-71.

Barona, A., Reynolds, C.R. & Chastain, R. (1984). A demographically based index of premorbid intelligence for the WAIS-R. Journal of Clinical and Consulting Psychology. 52: 885-887.

Barr, A., Benedict, R., Tune, L. & Brandt, J. (1992). Neuropsychological differentiation of Alzheimer's disease from vascular dementia. International Journal of Geriatric Medicine. 7: 621-627.

Basso, A., Capitani, E., Della Sala, S., Laiconi, M. & Spinnler, H. (1987) Recovery from ideomotor apraxia: A study of acute stroke patients. Brain. 110: 747-760.

Bates, E., Vicari, S. & Trauner, D. (1999). Neural mediation of language development: Perspectives from lesion studies of infants and children. In Tager-Flusberg, H. (Ed.). Neurodevelopmental Disorders. MIT Press. Cambridge, MA.

Benton, A.L. (1946). A visual retention test for clinical use. New York: Psychological Corporation.

Benton, A.L., Hamsher, K., Varney, N.R. & Spreen, O. (1983). Contributions to neuropsychological assessment. New York: Oxford University Press.

Berker, E. & Smith, A. (1988). Diaschisis, site, time and other factors in Raven performances of adults with focal cerebral lesions. International Journal of Neuroscience. 38: 267-285.

Berninger, V. (1998). Assessment, prevention, and intervention for specific reading and writing disabilities in young children. In B. Wong (Ed.). Learning disabilities (2nd Ed.) (pp. 529-555). New York: Academic Press.

Binder, J., Marshall, R., Lazar, R., Benjamin, J. & Mohr, J.P. (1992). Distinct syndromes of hemineglect. Archives of Neurology. 49: 1187-1194.

Bishop, D.V.M. (1989). Test for the reception of grammar. Age and Cognitive Performance Center, University of Manchester: Author.

Black, F.W. (1986). Digit repetition in brain-damaged adults: Clinical and theoretical implications. Journal of Clinical Psychology, 42: 770-782.

Black, F.W. & Strub, R.L. (1978). Digit repetition performance in patients with focal brain damage. Cortex, 14: 12-21.

Bornstein, R.A. & Brown, G.G. (Eds.). (1991). Neurobehavioral aspects of cerebrovascular disease. New York: Oxford University Press.

Bornstein, R.A., Paniak, C. & O'Brien, W. (1987). Preliminary data on classification of normal and brain-damaged elderly subjects. Clinical Neuropsychologist, 1: 315-323.

Botwinick, J. & Storandt, M. (1974). Memory, related functions and age. Springfield, IL: Charles C. Thomas Publishers.

Bowler, R., Sudia, S., Mergler, D., Harrison, R. & Cone, J. (1992). Comparison of digit symbol and symbol digit modalities tests for assessing neurotoxic exposure. The Clinical Neuropsychologist, 6: 103-104.

Brand, N., van Bekkum, I., Stumpel, M. & Kroeze, J.H. (1983). Word matching and lexical decisions: A visual half-field study. Brain and Language, 18: 199-211.

Bryden, M.P., Hécaen, H. & DeAgostini, M. (1983). Patterns of cerebral organization. Brain and Language, 20: 249-262.

Byrnes, J.P. (2001). Minds, brains, and learning: Understanding the psychological and educational relevance of neuroscientific research. New York: Guilford Press.

Caltagirone, C., Gainotti, G. & Micelli, G. (1977). Una nuova versione delle matricii colorate elaborata specificatamente per i pazienti con lesioi emisferiche focali. Minerva Psychiatrica, 18: 9-16.

Campbell, D.C. & Oxbury, J.M. (1976). Recovery from unilateral visuospatial neglect? Cortex, 12: 303-312.

Canavan, A.G.M., Passingham, R.E., Marsden, C.D., Quinn, N., Wyke, M. & Polkey, C.E. (1989a). The performance on learning tasks of patients in the early stages of Parkinson's disease. Neuropsychologia, 27: 141-156.

Canavan, A.G.M., Passingham, R.E., Marsden, C.D., Quinn, N., Wyke, M. & Polkey, C.E. (1989b). Sequencing ability in Parkinsonians, patients with frontal lobe lesions and patients who have undergone unilateral temporal lobectomies. Neuropsychologia. 27: 787-798.

Caplan, D., Baker, C. & Dehaut, F. (1985). Syntactic determinants of sentence comprehension in aphasia. Cognition. 21: 117-175.

Caplan, D., Hildebrandt, N. & Makris, N. (1996). Location of lesions in stroke patients with deficits in syntactic processing in sentence comprehension. Brain. 119: 933-949.

Casey, B.J., Trainor, R.J., Orendi, J.L., Schubert, A.B., Nystrom, L.E., Giedd, J.N., Castellanos, F. X., Haxby, J.V., Noll, D.C., Cohen, J.D., Forman, S.D., Dahl, R.E. & Rapoport, J.L. (1997). A developmental functional MRI study of prefrontal activation during performance of a go-no-go task. Journal of Cognitive Neuroscience. 9: 835-847.

Cassel, R.H. (1962). The order of the tests in the battery. Journal of Clinical Psychology. 18: 464-465.

Chow, T.W. & Cummings, J.L. (1999). Frontal-subcortical circuits. In B.L. Miller & J.L. Cummings (Eds.). The Human Frontal Lobes: Functions and Disorders. New York: Guilford Press.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences – (3rd Edition). New York: Academic Press.

Cohen, J.D., Dunbar, K. & McClelland, J.L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. Psychological Review. 97: 332-361.

Collins, A.M. & Quillian, M.R. (1969). Retrieval time from semantic memory. Journal of Verbal Learning and Verbal Behavior. 8: 240-247.

Corkin, S. (1979). Hidden Figures Test performance: Lasting effects of unilateral penetrating head injury and transient effects of bilateral cingulotomy. Neuropsychologia. 17: 585-605.

Cormier, P. & Tomlinson-Keasey, C. (1991). The development of hemispheric specialization of letter matching. Developmental Neuropsychology. 7: 161-176.

Corsi, P.M. (1972). Human memory and the medial temporal region of the brain. Unpublished doctoral thesis. McGill University, Montreal, Canada.

Craik, F.I.M. & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F.I.M. Craik & S.E. Trehub (Eds.), Aging and cognitive processes (pp. 191-211). New York: Plenum.

Crockett, D.J., Hurwitz, T. & Vernon-Wilkinson, R. (1990). Differences in neuropsychological performance in psychiatric, anterior- and posterior-cerebral dysfunctioning groups. International Journal of Neuroscience. 52: 45-57.

Cronin-Golumb, A. & Braun, A.E. (1997). Visuospatial dysfunction and problem solving in Parkinson's disease. Neuropsychology. 11: 44-52.

Croot, K., Hodges, J.R. & Patterson, K. (1999). Evidence for impaired sentence comprehension in early Alzheimer's disease. Journal of the International Neuropsychological Society. 5: 393-404.

Crowe, S.F. (1998). The differential contribution of mental tracking, cognitive flexibility, visual search, and motor speed to performance on Parts A and B of the Trail Making Test. Journal of Clinical Psychology. 54: 585-591.

Cubelli, R. & Nichelli, P. (1992). Inner speech in anarthria: Neuropsychological evidence of differential effects of cerebral lesions on subvocal articulation. Journal of Clinical and Experimental Neuropsychology. 14: 499-517.

Dapretto, M. & Bookheimer, S.Y. (1999). Form and content: Dissociating syntax and semantics in sentence comprehension. Neuron. 24: 427-432.

Das, J.P. (1999). A neo-Lurian approach to assessment and remediation. Neuropsychology Review. 9: 107-116.

Das, J.P. (1995). Some thoughts on two aspects of Vygotsky's work. Educational Psychologist. 30(2): 93-97.

Das, J.P., Davis, B., Alexander, J., Parrila, R.K. & Naglieri, J.A. (1995). Cognitive decline due to aging among persons with Down syndrome. Research in Developmental Disabilities. 16: 461-478.

Das, J.P., Kar, B.C. & Parrila, R.K. (1996). Cognitive planning: The psychological basis of intelligent behavior. London: Sage Publications.

Das, J.P., Kirby, J.R. & Jarman, R.F. (1979). Simultaneous and successive cognitive processes. New York: Academic Press.

Das, J.P., Naglieri, J.A. & Kirby, J.R. (1994). Assessment of cognitive processes: The PASS theory of intelligence. Needham Heights, MA: Allyn & Bacon.

David, R.M. & Skilbeck, C.E. (1984). Raven IQ and language recovery following stroke. Journal of Clinical Neuropsychology. 6: 302-308.

Dehaene, S. & Changeux, J. (1997). A hierarchical neuronal network for planning behavior. Proceedings of the National Academy of Sciences - USA. 94: 293-298.

Della Sala, S., Gray, C., Baddeley, A., Allamano, N. & Wilson, L. (1999). Pattern span: A tool for unwelding visuo-spatial memory. Neuropsychologia. 37: 1189-1199.

Della Sala, S., Gray, C., Baddeley, A. & Wilson, L. (1997). The Visual Patterns Test: A new test of short-term visual recall. Feltham, Suffolk: Thames Valley Test Company.

Della Sala, S., Laiacona, M., Spinnler, H. & Ubezio, C. (1992). A cancellation test: its reliability in assessing attentional deficits in Alzheimer's disease. Psychological Medicine. 22: 885-901.

Della Sala, S., Gray, C., Baddeley, A. & Wilson, L. (1997). The visual patterns test: A new test of short-term visual recall. Feltham, Suffolk: Thames Valley Test Company.

Denes, F., Semeza, C., Stoppa, E. & Gradenigo, G. (1978). Selective improvement by unilateral brain-damaged patients on Raven Colored Progressive Matrices. Neuropsychologia. 16: 749-752.

D'Esposito, M., Alexander, M.P., Fischer, R., McGlichey-Berroth, R. & O'Connor, M. (1996). Recovery of memory and executive function following anterior communicating artery rupture. Journal of the International Neuropsychological Society. 2: 565-570.

De Renzi, E. & Spinnler, H. (1966). Visual recognition in patients with unilateral cerebral disease. Journal of Nervous and Mental Disease. 142: 515-525.

De Renzi, E. & Vignolo, L.A. (1962). The Token Test: A sensitive test to detect disturbances in aphasics. Brain. 85: 665-678.

Diller, L., Ben-Yishay, Y. & Gerstman, L.J. et al. (1974). Studies in cognition and rehabilitation in hemiplegia. (Rehabilitation Monograph No. 50). New York: New York University Medical Center Institute of Rehabilitation Medicine.

Dunnett, C.W. & Tamhane, A.C. (1995). Step-up multiple testing of parameters with unequally correlated estimates. Biometrics. 51: 217-227.

Edwards-Lee, T.A. & Saul, R.E. (1999). Neuropsychiatry of the right frontal lobe. In B.L. Miller & J.L. Cummings (Eds.), The human frontal lobes: functions and disorders. (pp. 304-320) New York: Guilford Press.

Egelko, S., Gordon, W., Hibbard, R., Diller, L., Lieberman, A., Holliday, R., Ragbarson, K., Shaver, M.S. & Orazem, J. (1988). Relationship among CT scans, neurological exam, and neuropsychological test performance in right-brain-damaged stroke patients. Journal of Clinical and Experimental Neuropsychology. 10: 539-564.

Ericcson, K.A. & Simon, H.A. (1984). Protocol analysis: Verbal reports as data – Revised Edition. Cambridge, MA: MIT Press.

Estruch, R., Nicolas, J.M., Salamero, M., Aragon, C., Sacanello, E., Fernandez-Sola, J. & Urbano-Marquez, A. (1997). Atrophy of the corpus callosum in chronic alcoholism. Journal of the Neurological Sciences. 146: 145-151.

Eviatar, Z. & Zaidel, E. (1994). Letter matching within and between the disconnected hemispheres. Brain and Cognition. 25: 128-137.

Feigenbaum, J., Polkey, C.E. & Morris, R.G. (1996). Deficits in spatial working memory after unilateral temporal lobectomy in man. Neuropsychologia. 34(3): 16-176.

Fiez, J.A., Raife, E.A., Balota, D.A., Schwartz, J.P., Raichle, M.E. & Petersen, S.E. (1996). A positron emission tomography study of short-term maintenance of verbal information. Journal of Neuroscience. 16: 808-822.

Fink, G.R., Marshall, J.C., Weiss, P.H. & Zilles, K. (2001). The neural basis of vertical and horizontal line bisection judgments: An fMRI study of normal volunteers. Neuroimage. 14: S59-S67.

Fischer, M., Ryan, S.B. & Dobyns, W.B. (1992). Mechanisms of interhemispheric transfer and patterns of cognitive function in acallosal patients of normal intelligence. Archives of Neurology. 49: 271-277.

Foldvary, N. & Wyllie, E. (1999). Epilepsy. In C.G. Goetz & E.J. Pappert (Eds.), Textbook of Clinical Neurology. (pp. 1059-1088). New York: W.B. Saunders & Co.

Folstein, M.F., Folstein, S.E. & McHugh, P.R. (1975). 'Mini-Mental State': A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research. 12: 189-198.

Friederici, A.D., Meyer, M. & von Cramon, D.Y. (2000). Auditory language comprehension: An event-related fMRI study on the processing of syntactic and lexical information. Brain and Language. 75: 289-300.

Friedman, S.L. & Scholnick, E.K. (Eds.). (1997). The developmental psychology of planning: Why, how and when do we plan? Mahwah, NJ. Lawrence Erlbaum Associates.

Gaillard, W.D., Hertz-Pannier, L., Mott, S.H., Barnett, A.S., LeBihan, D. & Theodore, W.H. (2000). Functional anatomy of cognitive development: fMRI of verbal fluency in children and adults. Neurology. 54: 180-185.

Gainotti, G., D'Erme, P., Villa, G. & Caltagirone, C. (1986). Focal brain lesions and intelligence: A study with a new version of Raven's Coloured Matrices. Journal of Clinical and Experimental Neuropsychology. 8: 37-50.

Gazzaniga, M.S. (Ed.). (2000). The new cognitive neurosciences (2nd ed). Cambridge, MA: The MIT Press.

Gevins, A., Cutillo, B. & Smith, M.E. (1995). Regional modulation of high resolution evoked potentials during verbal and non-verbal matching tasks. Electroencephalography and Clinical Neurophysiology. 94: 129-147.

Glass, G.V. & Hopkins, K.D. (1996). Statistical methods in education and psychology – Third Edition. Toronto: Allyn & Bacon.

Glosser, G., Butters, N. & Kaplan, E. (1977). Visuoperceptual processes in brain-damaged patients on the Digit Symbol substitution task. International Journal of Neuroscience. 7: 59-66.

Goel, V. & Grafman, J. (2000). Role of the right prefrontal cortex in ill-structured planning. Cognitive Neuropsychology. 17: 415-436.

Golden, C.J., Purisch, A.D. & Hammeke, T.A. (1985). Luria-Nebraska Neuropsychological Battery: Forms I and II. Los Angeles: Western Psychological Services.

Goldman-Rakic, P.S. (1996). The prefrontal landscape: Implications of functional architecture for understanding human mentation and the central executive. Philosophical Transactions of the Royal Society of London. 351: 1445-1453.

Goodale, M. (2000). Perception and action in the human visual system. In M.S. Gazzaniga (Ed.). The new cognitive neurosciences – (2nd ed.) (pp. 365-377). Cambridge, MA: MIT Press.

Goodglass, H. & Kaplan, E. (1972). The assessment of aphasia. Philadelphia: Lea and Febiger.

Goodglass, H. & Kaplan, E. (1983). The assessment of aphasia and related disorders (2nd ed.). Philadelphia: Lea & Febiger.

Gordon, W.P. (1983). Memory disorders in aphasia – I. Auditory immediate recall. Neuropsychologia. 21: 325-339.

Grafman, J., Passafiume, D., Faglioni, P. & Boller, F. (1982). Calculation disturbances in adults with focal hemispheric damage. Cortex. 18: 37-50.

Grafman, J. (1999). Experimental assessment of adult frontal lobe function (pp. 321-344). In B.L. Miller & Cumming, J.L. (Eds.). The human frontal lobes: Functions and disorders. New York: The Guilford Press.

Grodzinksy, Y. (2000). The neurology of syntax: Language use without Broca's area. Behavioral Brain Sciences. 23: 1-21.

Gutentag, R.E. & Madden, D.J. (1987). Adult age differences in the attentional capacity demands of letter matching. Experimental Aging Research. 13: 93-99.

Gutentag, S.S., Naglieri, J.A. & Yeates, K.O. (1998). Performance of children with traumatic brain injury on the cognitive assessment system. Assessment. 5(3): 263-272.

Hanes, K.R., Andrewes, D.G., Smith, D.J. & Pantelis, C. (1996). A brief assessment of executive control dysfunction: Discriminant validity and homogeneity of planning, set shift, and fluency measures. Archives of Clinical Neuropsychology. 11: 185-191.

Hanley, S., Pettit, S., Todd-Pokropek, A. & Tupper, A. (1985). Who goes home? Predictive factors in stroke recovery. Journal of Neurology, Neurosurgery and Psychiatry. 48: 1-6.

Haut, M.W., Kuwabara, H., Leach, S. & Callahan, T. (2000). Age-related changes in neural activation during working memory performance. Aging, Neuropsychology and Cognition. 7: 19-129.

Heilbronner, R.L., Henry, G.K., Buck, P., Adams, R.L. & Fogle, T. (1991). Lateralized brain damage and performance on Trail Making A and B, Digit Span Forward and Backward, and TPT memory and location. Archives of Clinical Neuropsychology. 6: 251-258.

Heilman, K.M., Rothi, L.J. & Valenstein, E. (1982). Two forms of ideomotor apraxia. Neurology. 32: 342-346.

Hertzog, C. & Schear, J.M. (1989). Psychometric considerations in testing the older person. In T. Hunt & C.J. Lindley (Eds.). Testing older adults: A reference guide for gerontological assessment. Austin, Texas: Pro-Ed.

Hines, T., Poon, L.W., Cerella, J. & Fozard, J.L. (1982). Age-related differences in the time course of encoding. Experimental Aging Research. 8: 175-178.

Honda, M., Barrett, G., Yoshimura, N., Sadato, N., Yonekura, Y. & Shibasaki, H. (1998). Comparative study of event-related potentials and positron emission tomography activation during a paired-associate memory paradigm. Experimental Brain Research. 119: 103-115.

Horn, J.L. & Cattell, R.B. (1967). Age differences in fluid and crystallized intelligence. Acta Psychologica. 26: 107-129.

Horwitz, B., Tagamets, M.A. & McIntosh, A.R. (1999). Neural modeling, functional brain imaging, and cognition. Trends in Cognitive Sciences. 3: 91-98.

Huen, R., Klose, U., Jessen, F., Erb, M., Papassotiropoulos, A., Lotze, M. & Grodd, W. (1999). Functional MRI of cerebral activation during encoding and retrieval of words. Human Brain Mapping. 8: 157-169.

Husain, M. & Kennard, C. (1997). Distractor-dependent frontal neglect. Neuropsychologia. 35: 829-841.

Jennett, B. & Bond, M. (1975). Assessment of outcome after severe brain damage: A practical scale. The Lancet. i. 480-484.

Johnstone, B., Leach, L.R., Hickey, M.L., Frank, R.G. & Rupright, J. (1995). Some objective measurements of frontal lobe deficits following traumatic brain injury. Applied Neuropsychology. 2: 24-28.

Just, M.A., Carpenter, P.A., Keller, T.A., Eddy, W.F. & Thulborn, K.R. (1996). Brain activation modulated by sentence comprehension. Science. 274: 114-116.

Kaplan, E. (1988). A process approach to neuropsychological assessment. In T. Boll & B. Bryant (Eds.). Clinical neuropsychology and brain function: Research, measurement and practice. (pp. 125-168). Washington, DC: American Psychological Association.

Kaplan, E., Fein, D., Morris, R. & Delis, D.C. (1991). WAIS-R as a neuropsychological instrument. San Antonio, TX: The Psychological Corporation.

Kaufman, A.S. & Kaufman, N.L. (1983). K-ABC. Kaufman Assessment Battery for Children. Circle Pines, MN: American Guidance Service.

Kaufman, A.S. & Kaufman, N.L. (1993). Kaufman Adolescent and Adult Intelligence Test. Circle Pines, MN: American Guidance Service.

Kaufmann, P.M., Fletcher, J.M., Levin, H.S., Miner, M.E. et al. (1993). Attentional disturbances after pediatric closed head injury. Journal of Child Neurology. 8(4): 348-353.

Kertesz, A. (1999). Language and the frontal lobes. In B.L. Miller & J.L. Cummings (Eds.). The human frontal lobes: Functions and disorders. (pp. 261-276). New York: The Guilford Press.

Khateb, A., Michel, C.M., Pegna, A.J., Landis, T. & Annoni, J-M. (2000). New insights into the Stroop effect: A spatiotemporal analysis of electric brain activity. NeuroReport. 11: 1849-1855.

Kim, J.S., Kang, J.K., Lee, S.A. & Lee, M.C. (1993). Isolated or predominant ocular motor nerve palsy as a manifestation of brain stem stroke. Stroke. 24: 58-586.

Knopman, D.S., Selnes, O.A., Niccum, N. & Rubens, A.B. (1983). A longitudinal study of speech fluency in aphasia: CT scan correlates of recovery and persistent nonfluency. Neurology. 33: 1170-1178.

Knopman, D.S. & Ryberg, S. (1989). A verbal memory test with high predictive accuracy for dementia of the Alzheimer's type. Archives of Neurology. 46: 141-145.

Kok, A., van de Vijver, R. & Bouma, A. (1985). Effects of visual-field and matching instruction on event-related potentials and reaction time. Brain and Cognition. 4: 377-387.

Kolb, B. & Whishaw, I.Q. (1996). Fundamentals of human neuropsychology (4th ed.). New York: W.H. Freeman and Company.

Korkman, M. (1999). Applying Luria's diagnostic principles in the neuropsychological assessment of children. Neuropsychology Review. 9: 89-105.

Koss, E., Ober, B.A., Delis, D.C. & Friedland, R.P. (1984). The Stroop color-word test: Indicator of dementia severity. International Journal of Neuroscience. 24: 53-61.

Kossyln, S.M., Daly, P.F., McPeek, R.M., Alpert, N.M., Kennedy, D.N. & Caviness, V.S.Jr. (1993). Using locations to store shapes: An indirect effect of a lesion. Cerebral Cortex. 3: 567-582.

Kranzler, J.H. & Keith, T.Z. (1999). Independent confirmatory factor analysis of the Cognitive Assessment System (CAS): What does the CAS measure? School Psychology Review. 28: 117-144.

Kuperberg, G.R., McGuire, P.K., Bullmore, E.T., Brammer, M.J., Rabe-Hesketh, S., Wright, I.C., Lythgoe, D.J., Williams, S.C. & David, A.S. (2000). Common and distinct neural substrates for pragmatic, semantic, and semantic processing of spoken sentences: An fMRI study. Journal of Cognitive Neuroscience. 12: 321-341.

Lafleche, G. & Albert, M.S. (1995). Executive function deficits in mild Alzheimer's disease. Neuropsychology. 9: 313-320.

Langdon, D.W. & Warrington, E.K. (1997). The abstraction of numerical relations: A role for the right hemisphere in arithmetic? Journal of the International Neuropsychological Society. 3: 260-268.

Languis, M.L. & Miller, D.C. (1992). Luria's theory of brain functioning: A model for research in cognitive psychophysiology. Educational Psychologist. 27: 493-511.

Lehericy, S., Cohen, L., Bazin, B., Samson, S., Giacomini, E., Rougetet, R., Hertz-Pannier, L. Le Bihan, D., Marsault, C. & Baulac, M. (2000). Functional MR evaluation of temporal and frontal language dominance compared with the Wada test. Neurology. 54: 1625-1633.

Leskelae, M., Hietanen, M., Kalska, H., Ylikoski, R., Pohjasvaara, T., Maentylae, R. & Erkinjuntti, T. (1999). Executive functions and speed of mental processing in elderly patients with frontal or nonfrontal ischemic stroke. European Journal of Neurology. 6: 653-661.

Leung, H-C., Skudlarski, P., Gatenby, J.C., Peterson, B.S. & Gore, J.C. (2000). An event-related functional MRI study of the Stroop color word interference task. Cerebral Cortex. 10: 552-560.

Levin, H.S., Amparo, E.G., Eisenberg, H.M., Miner, M.E., High, W.M., Ewing-Cobbs, L., Fletcher, J.M. & Guinto, F.C. Jr. (1989). Magnetic resonance imaging after closed head injury in children. Neurosurgery. 24: 223-227.

Levine, D.N., Warach, J.D., Benowitz, L. & Calvino, R. (1986). Left spatial neglect: Effects of lesion size and premorbid brain atrophy on severity and recovery following right cerebral infarction. Neurology. 36: 362-366.

Lewandowski, L.J. (1984). The symbol digit modalities test: A screening instrument for brain-damaged children. Perceptual and Motor Skills. 59: 615-618.

Lezak, M.D. (1987). Norms for growing older. Developmental Neuropsychology. 3: 1-12.

Lezak, M.D. (1995). Neuropsychological Assessment (3rd ed.). New York: Oxford University Press.

Lloyd, D. (2000). Virtual lesions and the not-so-modular brain. Journal of the International Neuropsychological Society. 6: 627-635.

Luria, A.R. (1966). Higher cortical functions in man. New York: Basic Books.

Luria, A.R. (1980). Higher cortical functions in man (2nd ed). New York: Basic Books.

Lyon, G.R. & Krasnegor, N.A. (1996). Attention, memory, and executive function. Baltimore, MD: Paul Brookes Publishing.

MacLeod, C.M. (1991). Half a century of research on the Stroop effect: An integrative review. Psychological Bulletin. 109: 163-203.

Marangolo, P., De Renzi, E., Di Pace, E., Ciurli, P. & Castriota-Skandenberg, A. (1998). Let not thy left hand know what thy right hand knoweth. The case of a patient with an infarct involving the callosal pathways. Brain. 121: 1459-1467.

Mathieux, F., Fenelon, G., Flahault, A., Manifacier, M.J., Michelet, D. & Boller, F. (1998). Neuropsychological prediction of dementia in Parkinson's disease. Journal of Neurology, Neurosurgery and Psychiatry. 64: 178-183.

McCarthy, R.A. & Warrington, E.K. (1987). The double dissociation of short-term memory for lists and sentences: Evidence from aphasia. Brain. 1545-1563.

McCloskey, M. & Caramazza, A. (1988). Theory and methodology in cognitive neuropsychology: A response to our critics. Cognitive Neuropsychology. 5: 583-623.

McCrea, S.M. & Scott, M. (in press). A case study of strategic infarct dementia investigated with the Cognitive Assessment System. Brain & Cognition.

McPherson, S.E. & Cummings, J.L. (1996). Neuropsychological aspects of vascular dementia. Brain and Cognition. 31: 269-282.

Meirer, M.J., Ettinger, M.C. & Arthur, L. (1982). Recovery of neuropsychological functioning after cerebrovascular infarction. In R. Malatesta & L. Hartlage (Eds.). Neuropsychology and Cognition - Vol. 2. (pp. 552-564). NATO Advanced Study Series. The Hague: Martinus Nijhoff.

Meirer, M.J. & Strauman, S.E. (1991). Neuropsychological recovery after cerebral infarction In R.A. Bornstein & G.G. Brown (Eds.). Neurobehavioral aspects of cerebrovascular disease. (pp. 271- 296). New York: Oxford University Press.

Miller, E. (1973). Short- and long-term memory in patients with presenile dementia (Alzheimer's disease). Psychological Medicine. 3: 221-224.

Miller, E. (1993). Dissociating single cases in neuropsychology. British Journal of Clinical Psychology. 32: 155-167.

Milner, B. (1971). Interhemispheric differences in the localization of psychological processes in man. British Medical Bulletin. 27: 272-277.

Moeller, T.B. & Reif, E. (2000). Pocket atlas of sectional anatomy: Computed tomography and magnetic resonance imaging: Volume 1: Head, Neck, Spine, and Joints. 2nd Edition. New York. Thieme.

Morgan, S.F. & Wheelock, J. (1992). Digit symbol and symbol digit modalities tests: Are they directly interchangeable? Neuropsychology. 6: 327-330.

Moro, A., Tettamanti, M., Perani, D., Donati, C., Cappa, S.F. & Fazio, F. (2001). Syntax and the brain: Disentangling grammar by selective anomalies. Neuroimage. 13: 110-118.

Muller, R.A., Rothermel, R.D., Behen, M.E., Muzik, O., Manger, T.J. & Chugani, H.T. (1997). Receptive and expressive language activations for sentences: A PET study. NeuroReport. 8: 3767-3770.

Naesser, M.A., Hayward, R.W., Laughlin, S.A., Becker, J.M.T., Jernigan, T.L. & Zatz, L.M. (1981). Quantitative CT scan studies of aphasia II: Comparison of the right and left hemispheres. Brain and Language. 12: 165-189.

Naessar, M.A., Mazurski, P., Goodglass, H., Peraino, M., Laughlin, S. & Leaper, W.C. (1987). Auditory syntactic comprehension in nine aphasia groups (with CT scans) and children: Differences in degree but not order of difficulty observed. Cortex. 23: 359-380.

Naglieri, J.A. (1999). Essentials of CAS assessment. Toronto: John Wiley & Sons, Inc.

Naglieri, J.A. (1985). Matrix Analogies Test – Expanded Form. San Antonio, TX: The Psychological Corporation.

Naglieri, J.A. & Das, J.P. (1988). Planning-Arousal-Simultaneous-Successive (PASS): A model for assessment. Journal of School Psychology. 26: 35-48.

Naglieri, J.A. & Das, J.P. (1997). Cognitive Assessment System. Itasca, IL: Riverside Publishing.

Nahmias, C., Garnett, E., Firnau, G. & Lang, A. (1985). Striatal dopamine distribution in Parkinsonian patients during life. Journal of Neurological Science. 59: 223-230.

Nelson, C.A., Monk, C.S., Lin, J., Carver, L.J., Thomas, K.M. & Truwit, C.L. (2000). Functional neuroanatomy of spatial working memory in children. Developmental Psychology. 36: 109-116.

Netherton, S.D., Elias, J.W., Albrecht, N.N., Acosta, C. et al. (1989). Changes in performance in the performance of Parkinsonian patients and normal aged on the Benton Visual Retention Test. Experimental Aging Research. 15: 13-18.

Nicolas, J.M., Estruch, R., Salamero, M., Orteu, N., Fernandez-Sola, J., Sacanella, E. & Urbano-Marquez, A. (1997). Brain impairment in well-nourished chronic alcoholics is related to ethanol intake. Annals of Neurology. 41: 590-598.

Paivio, A. (1976). Concerning dual-coding and simultaneous-successive processing. Canadian Psychological Review. 17(1): 69-72.

Paivio, A. (1995). Imagery and memory. In M.S. Gazzaniga (Eds.). The Cognitive Neurosciences. (pp. 977-986). Cambridge, MA: The MIT Press.

Papadopoulos, T.C. (1998). A cognitive approach to reading difficulties: Assessment and remediation. Unpublished doctoral thesis. University of Alberta, Edmonton, Canada.

Parasuraman, R., Greenwood, P.M. & Alexander, G.E. (2000). Alzheimer disease constricts the dynamic range of spatial attention in visual search. Neuropsychologia. 38: 1126-1135.

Parasuraman, R. & Haxby, J.V. (1993). Attention and brain function in Alzheimer's disease: A review. Neuropsychology. 7: 242-272.

Parrila, R.K. (1997). The development of planning skills in children. Unpublished doctoral thesis. University of Alberta, Edmonton, Canada.

Peraino, M.A. (1976). A psycholinguistic comparison of syntactic comprehension in aphasic adults and normal children acquiring language. Unpublished doctoral thesis, California State University, San Jose, CA.

Perret, E. (1974). The left frontal lobe of man and the suppression of habitual responses in verbal categorical behavior. Neuropsychologia. 12: 323-330.

Pfeffer, R.I., Kurosaki, T.T., Harrah, C.H. Jr., Chance, J.M., Bates, D., Detels, R., Filos, S. & Butzke, C. (1981). A survey diagnostic tool for senile dementia. American Journal of Epidemiology. 114: 515-527.

Pickett, E.R., Kuniholm, E., Protopapas, A., Friedman, J. & Lieberman, P. (1998). Selective speech motor, syntax and cognitive deficits associated with bilateral damage to the putamen and the head of the caudate nucleus: A case study. Neuropsychologia. 36: 173-188.

Poeck, K. & W. Hartje (1979). Performance of aphasic patients in visual versus auditory presentation of the Token Test: Demonstration of a supramodal deficit. In Boller, F. & M. Dennis (Eds.). Auditory comprehension: Clinical and experimental studies with the Token test. New York: Academic Press.

Polubinski, J.P. & Melamed, L. (1986). Examination of sex differences on a symbol digit substitution test. Perceptual and Motor Skills. 62: 975-982.

Ponsford, J. & Kinsella, G. (1992). Attentional deficits following closed head injury. Journal of Clinical and Experimental Neuropsychology. 14: 822-828.

Posner, M.I. & Mitchell, R.F. (1967). Chronometric analysis of classification. Psychological Review. 74: 392-409.

Posner, M.I. & Snyder, C.R. (1975). Attention and cognitive control. In R.L. Solso (Ed.). Information processing in cognition (pp. 55-85). Hillsdale, NJ: Erlbaum.

Posner, M.I., Walker, J.A., Friedrich, F.J. & Rafal, B.D. (1984). Effects of parietal injury on covert orienting of attention. Journal of Neuroscience. 4: 1863-1874.

Prahakaran, V., Smith, J.A.L., Desmond, J.E., Glover, G.H. & Gabrieli, J.D. (1997). Neural substrates of fluid reasoning: An fMRI study of neocortical activation during performance of the Raven's Progressive Matrices Test. Cognitive Psychology. 33: 43-63.

Rasmussen, T. & Milner, B. (1977). The role of early left brain injury in determining lateralization of cerebral speech functions. Annals of the New York Academy of Sciences. 299: 355-369.

Rasmusson, D.X., Zonderman, A.B., Kawas, C. & Resnick, S.M. (1998). Effects of age and dementia on the Trail Making Test. The Clinical Neuropsychologist. 12: 169-178.

Raven, J.C. (1958). Standard Progressive Matrices: Sets A, B, C, D and E. London, H.K. Lewis. (Originally published 1938).

Raven, J.C. (1965). Guide to using the Coloured Progressive Matrices. London: H.K. Lewis.

Reitan, R.M. (1955). The relation of the Trail Making Test to organic brain damage. Journal of Consulting Psychology. 19: 393-394.

Reitan, R.M. (1992). Trail-making test: Manual for administration and scoring. Tucson: Reitan Neuropsychology Laboratory.

Reitan, R.M. & Wolfson, D. (1993). The Halstead-Reitan Neuropsychological Test Battery: Theory and clinical interpretation. Tucson, AZ: Neuropsychology Press.

Reitan, R.M. & Wolfson, D. (1995). Category Test and Trail-Making Test as measures of frontal lobe functions. Clinical Neuropsychologist. 9: 50-56.

Ring, H.A., Baron-Cohen, S., Wheelwright, S., Williams, S.C.R., Brammer, M., Andrew, C. & Bullmore, E.T. (1999). Cerebral correlates of preserved cognitive skills in autism: A functional MRI study of Embedded Figures Task performance. Brain. 122: 1305-1315.

Robertson, L.C., Knight, R.T., Rafal, R. & Shimamura, A.P. (1993). Cognitive neuropsychology is more than single-case studies. Journal of Experimental Psychology: Learning, Memory, and Cognition. 19(3): 710-717.

Rousseaux, M., Godefroy, O., Cabaret, M. & Bernati, T. (1996). Dysexecutive syndrome and disorders of motor control in prefrontal mediobasal and cingulate lesions. Revue Neurologique. 152: 517-527.

Rueckert, L. & Grafman, J. (1996). Sustained attention deficits in patients with right frontal lesions. Neuropsychologia. 34: 953-963.

Russell, E.W. (1975). A multiple scoring method for the assessment of complex memory functions. Journal of Consulting and Clinical Psychology. 43: 800-809.

Russell, E.W. (1980). Fluid and crystallized intelligence: Effects of diffuse brain damage on the WAIS. Perceptual and Motor Skills. 51: 121-122.

Russell, E.W. (1984a). Psychometric parameters of the Average Impairment Rating Scale. Journal of Consulting and Clinical Psychology. 52: 717-718.

Russell, E.W. (1984b). Theory and development of pattern analysis methods related to the Halstead -Reitan Battery. In P.E. Logue & J.M. Scheer (Eds.). Clinical neuropsychology: A multidisciplinary approach (pp. 50-98). Springfield, IL: Charles C. Thomas.

Russell, E.W. (1985). Comparison of the TPT 10 and TPT 6 Hole Form Board. Journal of Clinical Psychology. 41: 68-81.

Russell, E.W. (1987). A reference method for constructing neuropsychological test batteries. Journal of Clinical and Experimental Neuropsychology. 9: 376-392.

Russell, E.W. (2000). The cognitive-metric, fixed battery approach to neuropsychological assessment. In R.D. Vanderploeg (Ed.), et al. Clinician's guide to neuropsychological assessment. (pp. 449-481). Mahwah, NJ, US: Lawrence Erlbaum.

Russell, E.W., Neuringer, C. & Goldstein, G. (1970). Assessment of brain damage. A neuropsychological key approach. New York: Wiley-Interscience.

Russo, M. & Vignolo, L.A. (1967). Visual figure-ground discrimination in patients with unilateral cerebral disease. Cortex. 3: 113-127.

Ryan, J.J. & Bohac, D.L. (1996). Essential books and journals in North American clinical neuropsychology. The Clinical Neuropsychologist. 10: 222-228.

Ryan, L., Clark, C.M., Klonoff, H., Li, D. & Paty, D. (1996). Patterns of cognitive impairment in relapsing-remitting multiple sclerosis and their relationship to neuropathology on magnetic resonance images. Neuropsychology. 10: 176-193.

Sanchez-Pernaute, R., Kuenig, G., Alba, A., de Yebenes, J.G., Vontobel, P. & Leenders, K. (2000). Bradykinesia in early Huntington's disease. Neurology. 54: 119-125.

Schear, J.M. & Sato, S.D. (1989). Effects of visual acuity and visual motor speed and dexterity on cognitive test performance. Archives of Clinical Neuropsychology. 4: 25-32.

Schnider, A. & Gutbrod, K. (1999). Traumatic brain injury. The human frontal lobes: Functions and disorders. (pp. 487-506). In B.L. Miller & J.L. Cummings (Eds.). New York: Guilford Press.

Selemon, L.D. & Goldman-Rakic, P.S. (1988). Common cortical and subcortical targets of the dorsolateral prefrontal and posterior parietal cortices in the rhesus monkey: Evidence for a distributed neural network subserving spatially guided behavior. Journal of Neuroscience. 8: 4049-4068.

Selnes, O.A., Knopman, D.S., Niccum, N. & Rubens, A.B. (1985). The critical role of Wernicke's area in sentence repetition. Annals of Neurology. 17: 549-557.

Sergent, J. (1982). The cerebral balance of power: Confrontation or cooperation. Journal of Experimental Psychology: Human Perception and Performance. 8: 253-272.

Shallice, T. & Burgess, P.W. (1991). Deficits in strategy application following frontal lobe damage in man. Brain. 114: 727-74.

Shulman, C., Yirmiya, N. & Greenbaum, C.W. (1995). From categorization to classification: A comparison among individuals with autism, mental retardation and normal development. Journal of Abnormal Psychology. 104: 601-609.

Shum, D.H.K., McFarland, K.A. & Bain, J.D. (1990). Construct validity of eight tests of attention: Comparison of normal and closed head injured samples. The Clinical Neuropsychologist. 4: 151-162.

Sivan, A.B. (1992). Benton Visual Retention Test (5th ed.). San Antonio, TX: Psychological Corporation.

Small, J.A., Kemper, S. & Lyons, K. (2000). Sentence repetition and processing resources in Alzheimer's disease. Brain and Language. 75: 232-258.

Smith, A. (1991). Symbol digit modalities test. Los Angeles: Western Psychological Services.

Smith, E.E. & Jonides, J. (1999). Storage and executive processes in the frontal lobes. Science. 283: 1657-1661.

Smith, E.E., Jonides, J., Koeppe, R.A., Awh, E., Schumacher, E.H. & Minoshima, S. (1995). Spatial versus object working memory: PET investigations. Journal of Cognitive Neuroscience. 7: 337-356.

Smith, M.L. & Milner, B. (1984). Differential effects of frontal lobe lesions on cognitive estimation and spatial memory. Neuropsychologia. 22: 697-705.

Solso, R.L. & Hoffman, C.A. (1991). Influence of Soviet scholars. American Psychologist. 46: 251-253.

Spector, L. & Grafman, J. (1994). Planning, Neuropsychology and Artificial Intelligence: Cross-Fertilization. pp. 379-392. Elsevier Science, Amsterdam.

Spreen, O. & Benton, A.L. (1969). Embedded Figures Test. Neuropsychology Laboratory, University of Victoria, Victoria, Canada.

Spreen, O. & Strauss, E. (1998). A compendium of neuropsychological tests: Administration, norms and commentary (2[nd] ed.). New York: Oxford University Press.

Starkstein, S.E., Bolduc, P.L., Preziosi, T.J. & Robinson, R.G. (1989). Cognitive impairments in different stages of Parkinson's disease. Journal of Neuropsychiatry and Clinical Neuroscience. 1: 243-248.

Starkstein, S.E., Brandt, J., Folstein, S., Strauss, M., Berthier, M.L., Pearlson, G.D., Wong, D., McDonnell, A. & Folstein, M. (1988). Neuropsychological and neuroradiological correlates in Huntington's disease. Journal of Neurology, Neurosurgery and Psychiatry. 51: 1259-1263.

Sternberg, R.J. (1997). Intelligence and lifelong learning: What's new and how can we use it? American Psychologist. 52: 1134-1139.

Stone, S.P., Patel, P., Greenwood, R.J. & Halligan, P.W. (1992). Measuring visual neglect in acute stroke: The visual neglect recovery index. Journal of Neurology, Neurosurgery and Psychiatry. 55: 431-436.

Stromswold, K., Caplan, D., Alpert, N. & Rauch, S. (1996). Localization of syntactic comprehension by positron emission tomography. Brain and Language. 52: 452-473.

Stroop, J.R. (1935). Studies of interference in serial verbal reaction. Journal of Experimental Psychology. 18: 643-662.

Stuss, D.T., Ely, P., Hugenholtz, H., Richard, M.T., Larochelle, S., Poirier, C.A. & Bell, I. (1985). Subtle neuropsychological deficits in patients with good recovery from after closed head injury. Neurosurgery. 17: 41-47.

Stuss, D.T. (1991). Interference effects on memory functions in post-leukotomy patients: An attentional Perspective. In H.S. Levin, N. Eisenberg & A.L. Benton (Eds.). Frontal lobe function and dysfunction. (pp. 157-172). New York: Oxford University Press.

Stuss, D.T., Bisschop, S.M., Alexander, M.P., Levine, B., Katz, D. & Izukawa, D. (2001). The trail making test: a study in focal lesion patients. Psychological Assessment. 13: 230-239.

Stuss, D.T., Floden, D., Alexander, M.P., Levine, B. & Katz, D. (2001). Stroop performance in focal lesion patients: dissociation of processes and frontal lobe lesion location. Neuropsychologia. 39: 771-786.

Swanson, H.L. (1996). Swanson Cognitive Processing Test. Austin, TX: PRO-ED.

Talland, G.A. (1965). Three estimates of the word span and their stability over the adult years. Quarterly Journal of Experimental Psychology. 17: 301-307.

Tarbuck, A.F. & Paykel, E.S. (1995). Effects of major depression on the cognitive function of younger and older subjects. Psychological Medicine. 25:285-296.

Terry, R.D., Masliah, E., Salmon, D.P., Butters, N., DeTeresa, R., Hill, R., Hansen, L.A. & Katzman, R. (1991). Physical basis of cognitive alterations in Alzheimer's disease: Synapse loss in the major correlate of cognitive impairment. Annals of Neurology. 30: 572-580.

Teuber, H.L., Battersby, W.S. & Bender, M.B. (1951) Performance of complex visual tasks after cerebral lesions. Journal of Nervous and Mental Disease. 114: 413-429.

Trahan, D.E., Goethe, K.E. & Larrabee, G.J. (1989). An examination of verbal supraspan in normal adults and patients with head trauma or unilateral cerebrovascular accident. Neuropsychology. 3: 81-90.

Tulving, E., Kapur, S., Craik, F.I.M., Moscovitch, M. & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission tomography findings. Proceedings of the National Academy of Sciences, USA. 91: 2016-2020.

Tupper, D.E. (1999). Introduction: Alexander Luria's continuing influence on worldwide neuropsychology. Neuropsychology Review. 9: 1-7.

Ungerleider, L.G., Courtney, S.M. & Haxby, J.V. (1998). A neural system for human visual working memory [Review]. Proceedings of the National Academy of Sciences – USA. 95: 883-890.

Ungerleider, L.G. & Mishkin, M. (1982). Two cortical visual systems. In D.J. Engle, M.A. Goodale & R.J. Mansfield (Eds.). Analysis of visual behavior (pp. 549-586). Cambridge, MA: MIT Press.

Uzzell, B.P., Dolinskas, C.A. & Langfitt, T.W. (1988). Visual field defects in relation to head injury severity: A neuropsychological study. Archives of Neurology. 45: 420-424.

Vendrell, P., Junqué, C., Pujol, J., Angeles Jurado, M., Molet, J. & Grafman, J. (1995). The role of prefrontal regions in the Stroop task. Neuropsychologia. 33: 341-352.

Vilkki, J. & Holst, P. (1989). Deficient programming in spatial learning after frontal lobe damage. Neuropsychologia. 27: 971-976.

Villardita, C. (1985). Raven's Coloured Progressive Matrices and intellectual impairment in patients with focal brain damage. Cortex. 21: 627-634.

Waltz, J.A., Knowlton, B.J., Holyoak, K.J., Boone, K.B., Mishkin, F.S., de Menezes Santos, M., Thomas, C.R. & Miller, B.L. (1999). A system for relational reasoning in human prefrontal cortex. Psychological Science. 10: 119-125.

Warrington, E.K., James, M. & Maciejewski, C. (1986). The WAIS as a lateralizing and localizing diagnostic instrument: A study of 656 patients with unilateral cerebral lesions. Neuropsychologia. 24: 223-239.

Wechsler, D. (1981). Wechlser Adult Intelligence Scale - Revised. New York: Psychological Corporation.

Wechsler, D. (1974). Wechsler Intelligence Scale for Children – Revised. New York: Psychological Corporation.

Wechsler, D. (1955). Wechsler Adult Intelligence Scale. New York: Psychological Corporation.

Weinberg, W.A. & Harper, C.R. (1993). Vigilance and its disorders. Neurology Clinics. 11: 59-78.

Weiskrantz, L. (1988). Thought without language. New York: Oxford University Press.

Weissman, D.H., Banich, M.T. & Puente, E.I. (2000). An unbalanced distribution of inputs across the hemispheres facilitates interhemipheric interaction. Journal of the International Neuropsychological Society. 6: 313-321.

Wilson, J.T.L., Wiedmann, K.D., Hadley, D.M. & Brooks, D.N. (1989). The relationship between visual memory function and lesions detected by magnetic resonance imaging after closed head injury. Neuropsychology. 3: 255-265.

Wingfield, A., Goodglass, H. & Lindfield, K.C. (1997). Separating speed from automaticity in a patient with focal cortical atrophy. Psychological Science. 8: 247-249.

Winne, P.H. (1995). Inherent details in self-regulated learning. Educational Psychologist. 30: 173-187.

Witkin, H.A., Oltham, P.K., Raskin, E. & Karp, S.A. (1971). A Manual for the Embedded Figures Test. Palo Alto, CA: Consulting Psychologists Press.

Woodcock, R.W., McGrew, K. & Mather, N. (2001). Woodcock-Johnson III Test of Cognitive Abilities. Itasca, IL: Riverside Publishing.

Yin, R.K. (1994). Case study research: Design and methods (2nd ed). Thousand Oaks, CA: Sage.

Yoakum, C.S. & Yerkes, R.M. (1920). Army Mental Tests. New York: Henry Holt and Company.

Yundt, K.D., Grubb, R.L.., Diringer, M.N. & Powers, W.J. (1997). Cerebral hemodynamic and metabolic changes caused by brain retraction after aneurismal subarachnoid hemorrhage. Neurosurgery. 40: 442-450.

Zaidel, E., Zaidel, D.W. & Sperry, R.W. (1981). Left and right intelligence: Case studies of Raven's Progressive Matrices following brain bisection and hemidecortication. Cortex. 17: 167-186.

Zonderman, A.B., Giambra, L.M., Arenberg, D., Resnick, S.M. et al. (1995). Changes in immediate visual memory predict cognitive impairment. Archives of Clinical Neuropsychology. 10: 111-123.

Appendix 1: Classification of Normal vs. Deficient Performance on CAS Subtests

patient's name	LESION	matching numbers	planned codes	planned connections	nonverbal matrices	verbal-spatial relations	figure memory	expressive attention	number detection	receptive attention	word series	sentence repetition	sentence questions
2 JD	l temporal	-	-	-	normal	normal	normal	-	normal	-	deficit	deficit	deficit
3 AO	l fronto-temp	deficit	deficit	deficit	-	deficit	-	deficit	deficit	deficit	-	normal	deficit
6 FA	l frontal	-	deficit	-	-	-	-	-	-	-	normal	deficit	-
7 HB	l frontal	deficit	deficit	-	-	-	-	-	-	deficit	normal	normal	normal
8 JM	l frontal	deficit	-	-	normal	normal	-	-	normal	-	normal	deficit	normal
9 WF	l frontal	deficit	deficit	deficit	-	-	deficit	deficit	deficit	deficit	normal	normal	normal
17 IS	r frontal	-	deficit	-	-	normal	-	-	-	-	normal	normal	-
18 SW	r frontal	-	deficit	-	deficit	-	deficit	-	-	deficit	normal	normal	-
19 JL	r frontal	deficit	deficit	deficit	deficit	deficit	-	deficit	deficit	-	normal	normal	-
20 TF	r frontal	-	deficit	-	-	-	normal	deficit	normal	normal	-	normal	-
21 RG	r fronta	-	deficit	deficit	-	-	-	deficit	-	-	-	normal	-
23 BT	r frontal	deficit	deficit	deficit	-	-	-	deficit	deficit	-	normal	-	normal
25 JH	r frontal	deficit	deficit	-	-	normal	normal	-	-	-	-	-	deficit
30 FR	r cerebellum	-	deficit	deficit	-	normal	-	deficit	-	deficit	normal	normal	normal
31 PT	r cerebellum	normal	-	-	-	normal	deficit	-	-	-	normal	normal	-
32 BP	mbrain-pons	deficit	deficit	-	normal	normal	-	deficit	deficit	-	deficit	-	-
16	16	9	13	6	5	9	6	8	8	6	12	13	8

Appendix 2: Letter of Information Form

Research Study Name: Cognitive Profiles of Brain Injury Patients

(To be read aloud to all prospective participants)

Simon McCrea (Principal Investigator) Educational Psychology, University of Alberta 492-5897

We are looking for stroke/brain injury patients to join our study. Our task is to measure the cognitive or thinking profiles of stroke/brain injury patients. Stroke/brain injury often leads to changes in a patient's thinking. We would like to measure these changes. Our thinking profile measure is called the CAS, which stands for the Cognitive Assessment System. The CAS is based on a theory of how the mind and brain function. This thinking profile measure may help plan your rehab program, if you need one. Well-planned rehab programs can aid a patient's recovery, after the stroke/brain injury.

Your consent will be required to complete the CAS, and for the researcher to review your medical records. Your medical records will remain with the UAH medical records department. Your records will be kept secret. Your name will not be placed on published results. Only the research person will have access to your records. Your CAS records will be kept secure with the research person for 7 years. After this time your records will be shredded.

The CAS will take 1 hour to complete. You will be given as many breaks as you need. There are no known risks to this study. You may want to release your CAS results to your family doctor later. You do not have to release your results if you do not want to. You have a right to refuse to answer any question. You also have the right not to join our study. You may quit the study and your care will not be affected in any way. The Health Research Ethics Board of the University of Alberta and the Capital Health Authority has granted ethical approval for this study. If you have any questions, contact the research person at the phone number above. If you have any concerns about this study contact the Patient's Office at 474-8892. Please keep this page.

Initials of Patient ____________

Initial of Researcher ____________

Appendix 3: Letter of Consent Form

Research Study Name: Cognitive Profiles of Brain Injury Patients

(To be read aloud to all prospective participants)

Simon McCrea (Principal Investigator) Educational Psychology, University of Alberta 492-5897

(Please circle your response)

Do you know that you have been asked to be in a research study?

Yes No

Have you read a copy of the enclosed sheet telling you about this research study?

Yes No

Do you know of the positive and negative aspects of taking part in this research?

Yes No

Have you had a chance to ask questions about this study?

Yes No

Do you know that you are free to refuse to be in this study? Do you also know that you can quit this study at any time? You do not have to give a reason.

Yes No

Has the issue of patient's private records been discussed with you? Do you also know who will have access to your records?

Yes No

Should I require a witness, I will allow them to sign on my behalf.

Yes No

Do you want the research person to send your CAS results to your family doctor?

Yes No

Initials of Patient ____________

Initial of Researcher ____________

If so, please provide your doctor's name and telephone number: (You do not have to give out your doctor's name)

____
Doctor's Name

____
Doctor's Phone Number

This study was read to me by:

____

I agree to take part in this study.

____
Signature of Patient

____
Printed Name of Patient

____
Patient's Phone Number

____
Signature of Witness (Only if a witness is required)

____
Printed Name of Witness (Only if a witness is required)

____
Date

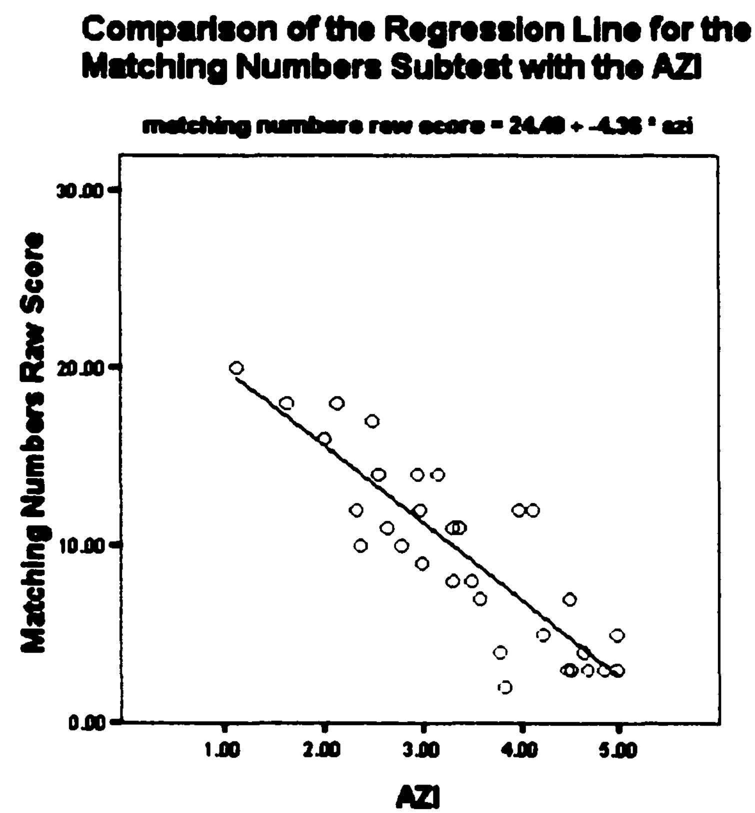
I believe that the person signing this form knows what is involved. I believe that the person signing this form consents to be involved.

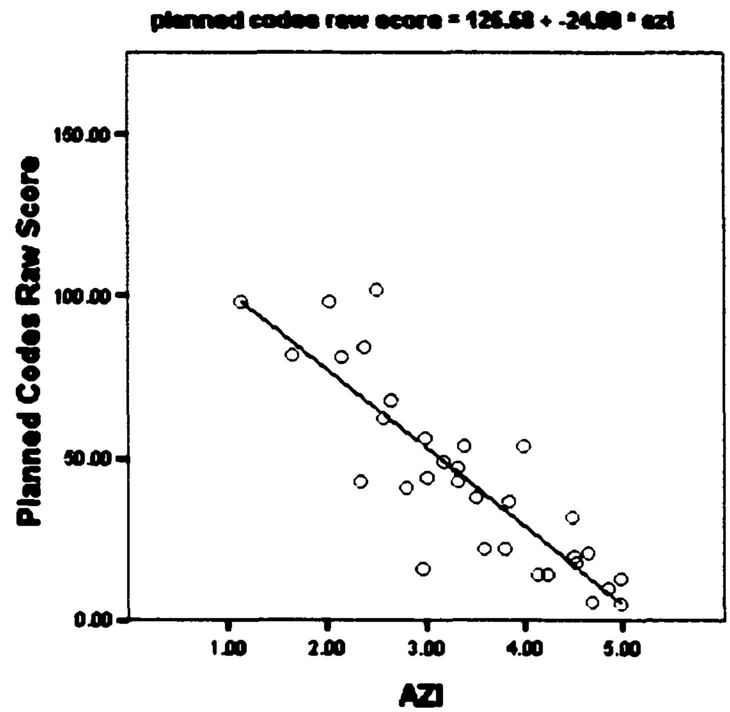
____
Name of Research Person

Initials of Patient ____________

Initial of Researcher ____________

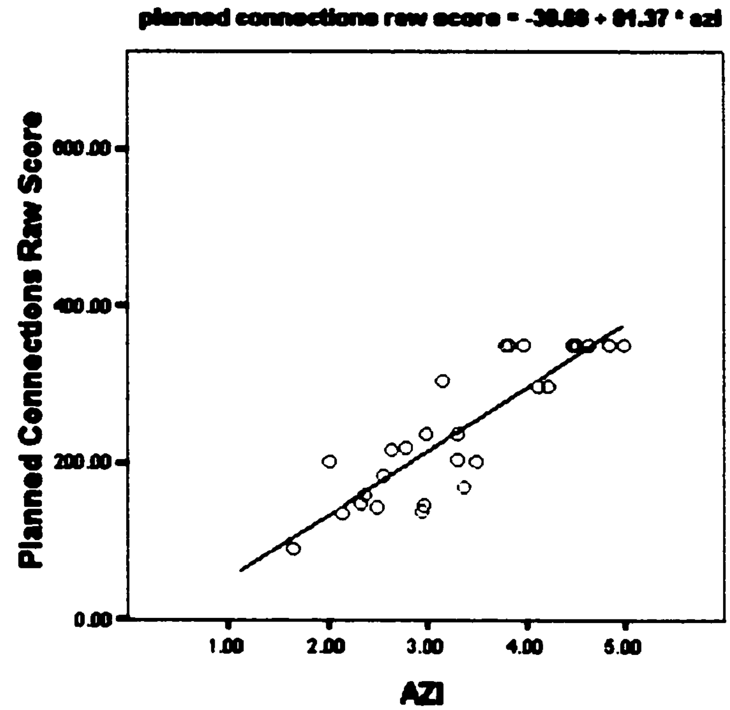
Appendix 4: Average Z-Score Impairment Index - Regression Plots and Equations



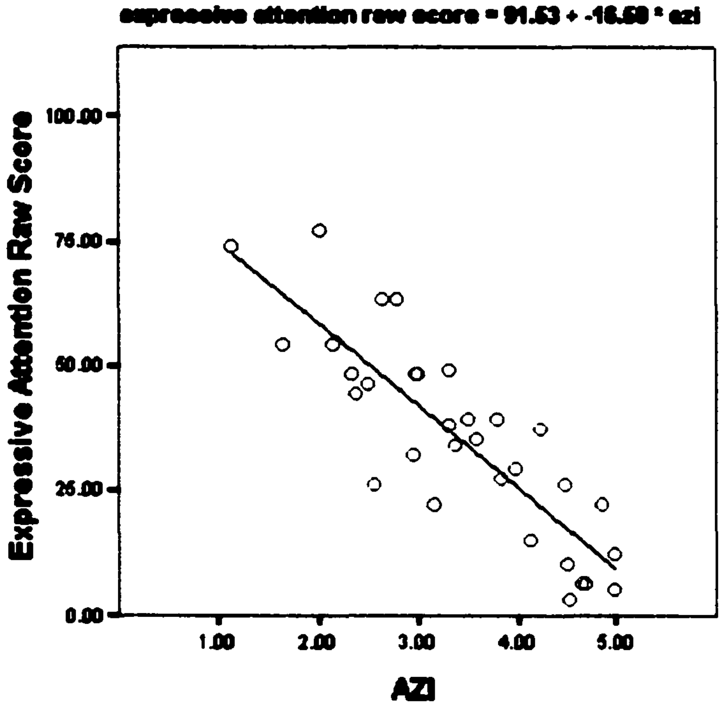


Comparison of the Regression Line for the Planned Codes Subtest with the AZI

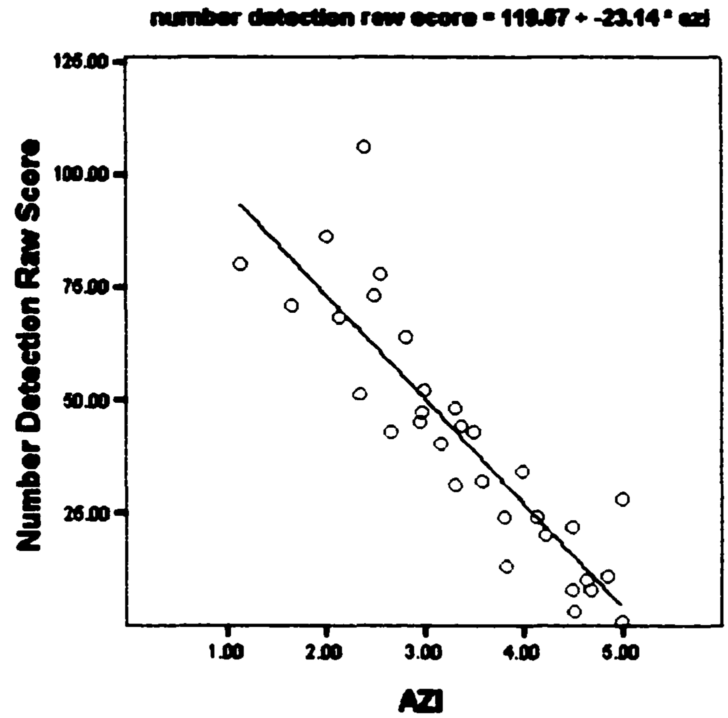
Comparison of the Regression Line for the Planned Connections Subtest with the AZI



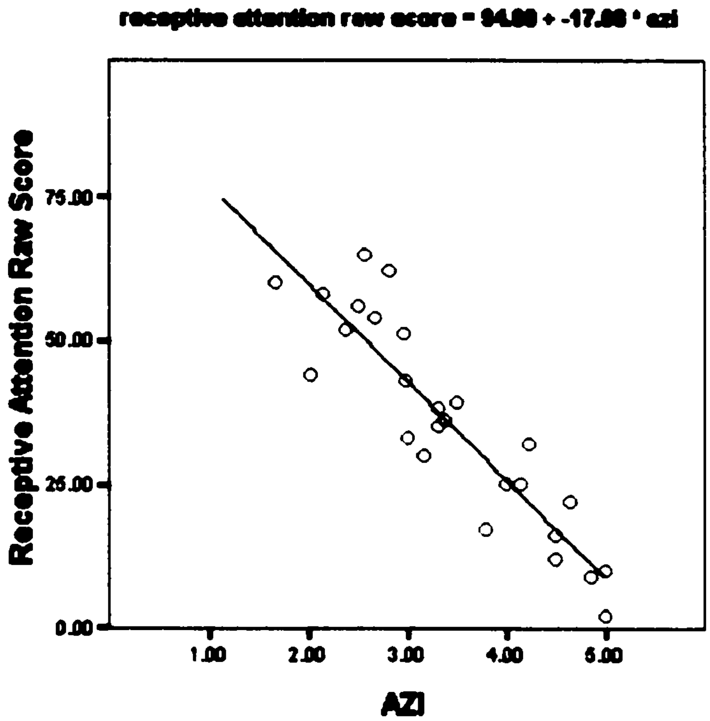
Comparison of the Regression Line for the Expressive Attention Subtest with the AZI



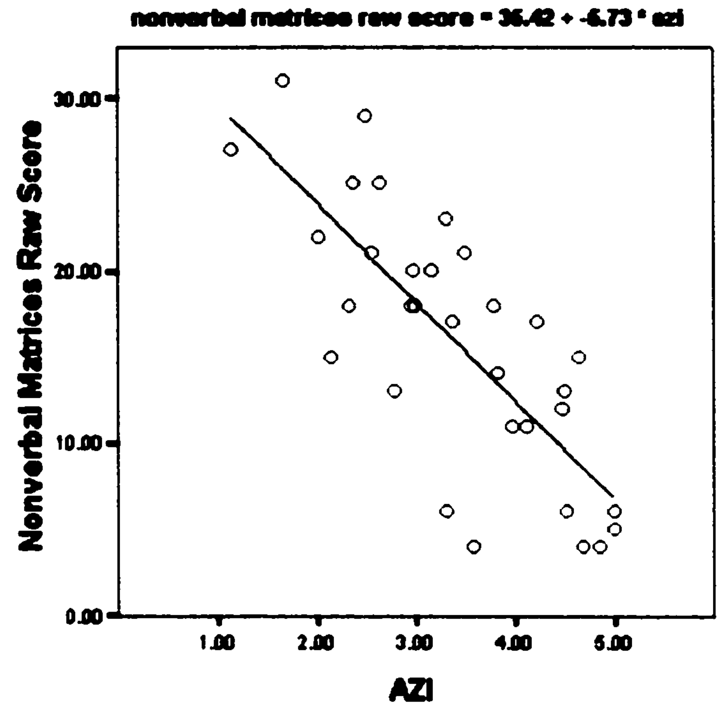
Comparison of the Regression Line for the Number Detection Subtest with the AZI



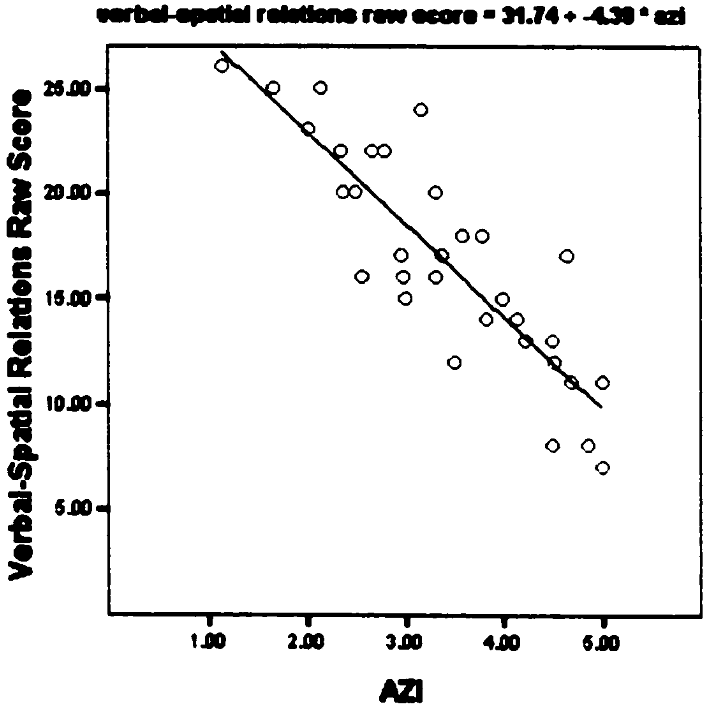
Comparison of the Regression Line for the Receptive Attention Subtest with the AZI



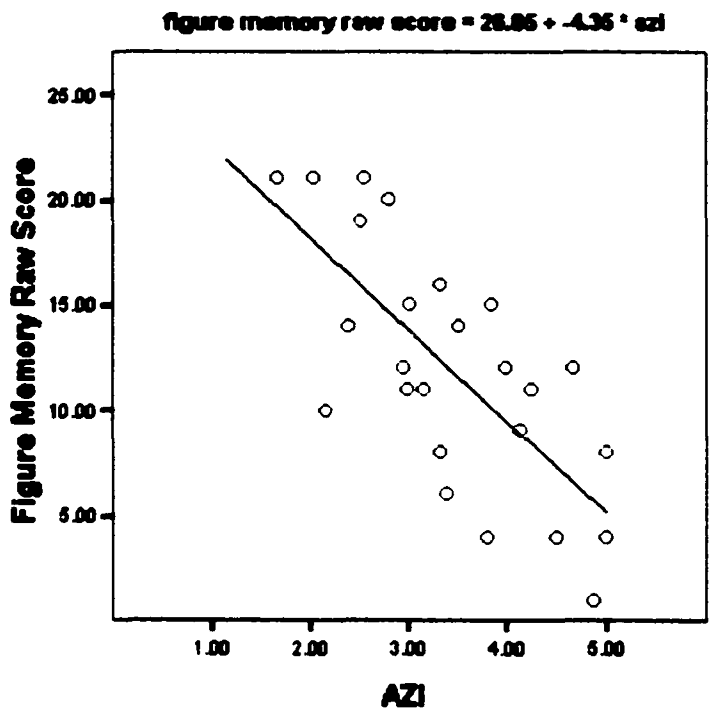
Comparison of the Regression Line for the Nonverbal Matrices Subtest with the AZI



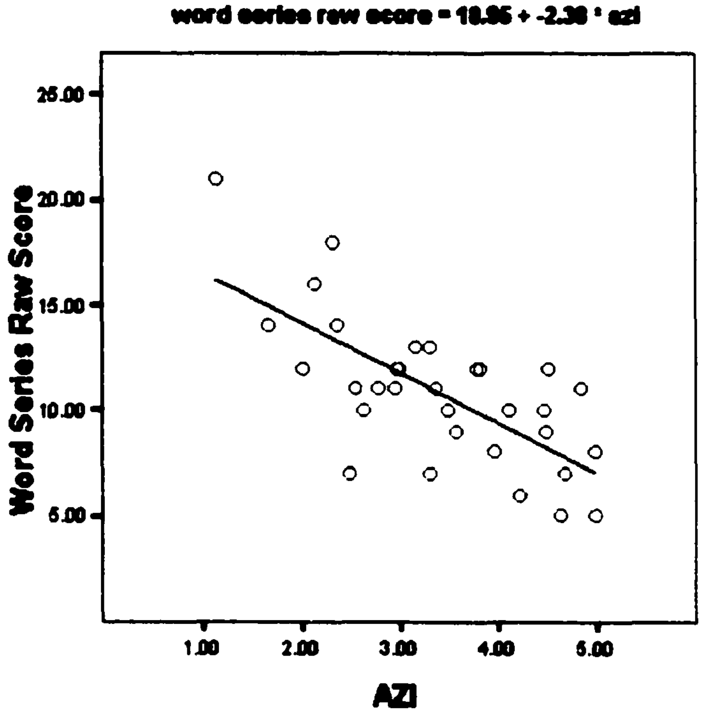
Comparison of the Regression Line for the Verbal-Spatial Relations Subtest with the AZI



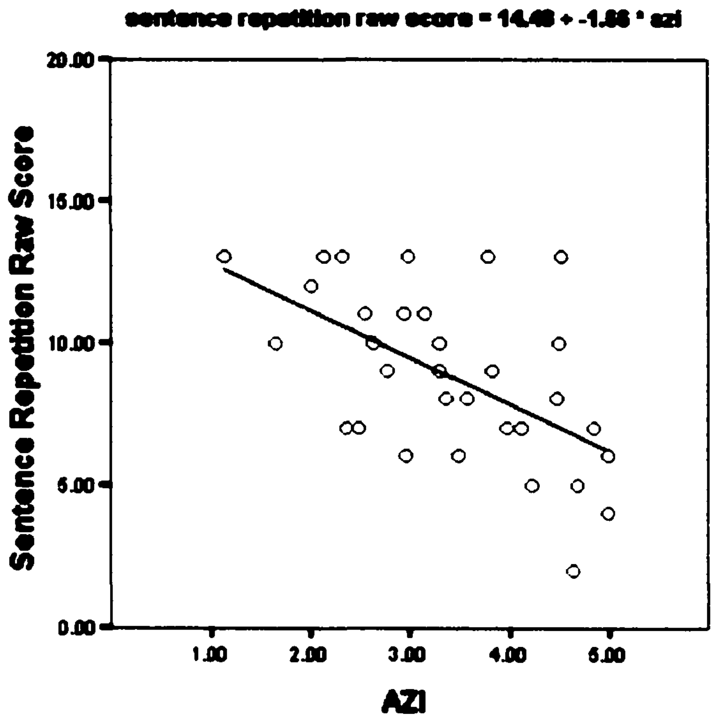
Comparison of the Regression Line for the Figure Memory Subtest with the AZI



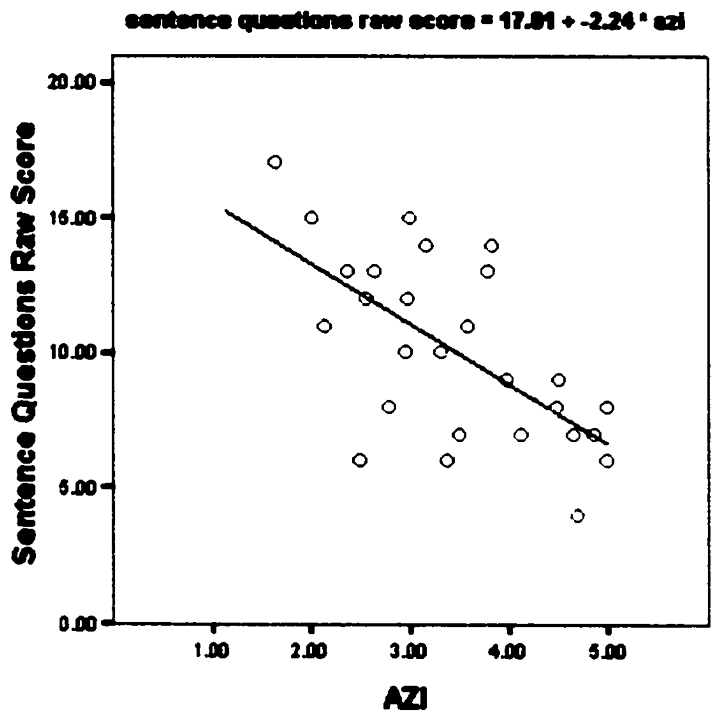
Comparison of the Regression Line for the Word Series Subtest with the AZI



Comparison of the Regression Line for the Sentence Repetition Subtest with the AZI



Comparison of the Regression Line for the Sentence Questions Subtest with the AZI



Appendix 5: Subject Inclusion and Exclusion Criteria

1) Participants were required to have provided informed consent to have their neurological charts reviewed by the principal investigator for the purposes of neurological classification. Only as much information needed to make a neurological classification was requested. Pertinent information included neuroradiological and clinical neurological exams charts. These records were reviewed in consultation with participating neurologists.

2) Participants with diffuse stroke lesions were excluded from participating in this study as were patients sustaining a severe stroke. Only patients with mild to moderate strokes were solicited. Patients classified as severe or diffuse were excluded since they would be too incapacitated to perform the tasks.

3) Persons with clinically diagnosed post-stroke depression were excluded since motor and cognitive slowing could mimic genuine organic impairments.

4) Stroke patients with severe receptive aphasia that compromises one's ability to comprehend simple instructions were excluded; although this did not preclude patients whose receptive aphasia had significantly resolved in the post-acute phase.

5) Persons under the care of a guardian were excluded if the mental disability made qualification of informed consent difficult.

6) Persons with extensive occipital infarcts were excluded since many of the CAS tasks are visually based.

7) Patients with diffuse neurodegenerative diseases (e.g.. Multiple Sclerosis) were excluded.

8) Patients over the age of 67 were excluded to avoid confounds associated with normal changes in cognition with aging in the elderly.

9) Patients with localizable single ischemic or hemorrhagic stroke infarcts were primary candidates for inclusion.

10) Some patients had CT/MRI scans that were non-definitive for a structural basis for a lesion. In some cases previous clinical neurological exams did however provide evidence for a localizing neurological syndrome and the patient was therefore tested before leaving the hospital. In several instances neuroimaging was later shown to be negative for the presence of a lesion. Nonetheless these cases were included in the analysis for comparative purposes.

11) Although the criteria of a single infarct was the inclusion criteria. In some cases secondary irregular lesions could be found as a result of embolic perturbation of a larger branch of a cerebral artery. In such cases the lesion was categorized by the locus the larger primary infarct.

Appendix 6. Departmental Ethics Approval

Feb. 23, 1998

From: Department of Educational Psychology
Research and Ethics Committee

The Research and Ethics Committee of the Department of Educational Psychology has reviewed the attached proposal and finds it acceptable with respect to ethical matters.

Applicant: Dr. Rob Short on behalf of Simon McCrea (graduate student)

Title: Cognitive Profiles of Brain-Injured Persons

Participating Agency(ies):

Richard Sr[illegible]
Chairman or Designate, Research and Ethics Committee

22 Feb 98
Date

Appendix 7. Notification of HREB:B Ethical Review

University of Alberta
Edmonton
Canada T6G 2C4

Faculty of Rehabilitation Medicine
Rehabilitation Research Centre
3-48 Corbett Hall
Director (403) 492-7856 Telephone (403) 492-2903
Fax (403) 492-1626

March 27th, 1998

Simon McCrea
6-102 Education North
Department of Educational Psychology

Dear Mr. McCrea,

Re: Cognitive Profiles of Brain-Injured Persons.

Thank you for your submission to the HREB. The meeting at which your proposal will be reviewed is on April 3, 1998, and you are asked to present at 3:20 pm. You are required to attend the meeting at the time noted above, so that any issues that arise can be addressed. If it is not at all possible for you to come, a co-investigator or a research assistant who is familiar with the project may come on your behalf.

The meeting will take place in room 2-55 Corbett Hall (Faculty Conference Room). Please wait in the adjoining room 2-35 (Alumni Lounge) until I come and invite you into the conference room. You will be asked to present a very brief (2 minutes) summary of the goals of your project. There will be two main reviewers of your proposal. They will be the first persons to ask questions of you. The rest of the committee will then be free to ask any questions of you they may have. You will then be excused from the meeting and are free to go. I will send you a letter the following week after the meeting summarizing the board's comments. There may be some items which you will need to revise before a letter of ethical approval is sent to you. Once you have submitted evidence of the required changes to me, I will send you the letter of ethical approval. If you are a grad student, please feel free to invite your supervisor to accompany you to the meeting. Refreshments will be provided in room 2-35 while you are waiting.

Enclosed are two checklists: 1) a "Project Checklist" and 2) a "Checklist for Ethical Review of Proposals". These two checklists are used by the reviewers as they go through the proposals. The checklists are enclosed for your information only. If you have any questions or concerns, please feel free to contact me. Thank you.

Sincerely,

Karen Turpin

Karen Turpin
Administrative Assistant, HREB
Health Research Ethics Board (B: Health Research)

3-08 Corbett Hall
Ph: 492-0839
karen.turpin@ualberta.ca

Appendix 8. HREB:B Form with Signatures

HREB B [X]

HEALTH RESEARCH ETHICS BOARD
REQUEST FOR ETHICS REVIEW

Section A:
General Information

A1. Title of Project:

"Cognitive Profiles of Stroke Patients"

A2. Name of Principal Investigator: Simon McCrea

Title(s): Mr.

Department: Educational Psychology / (Doctoral Student)

Mailing address for ethics information:

Department of Educational Psychology
University of Alberta
Edmonton, Alberta
Canada T6G 2G5

Telephone: 433-4322 Fax: 492-1318 Email: smccrea@gpu.srv.ualberta.ca

Signature: [signature] Date: April 24 1998

A3. Name of Co-Investigator:

Name: J.P. Das

Title(s): Dr.

Department: Educational Psychology / (Emeritus Professor)

Mailing address:

Department of Educational Psychology
University of Alberta
Edmonton, Alberta
Canada T6G 2G5

Telephone: 492-4439 Fax: 492-1318 Email: J.P.Das@ualberta.ca

Signature: [signature] Date: 22.4.98

A4. Authorising Signatures:

I support the implementation of this project.

(Signature) 27/04/1998
(Date)

L. STEWART
(Name: Please print) rint)

CHAIR.
(Title)

A5. Co-Investigator(s) / Thesis Committee:

	Name	Department	Telephone
1.	Dr. Robert Short Professor (Supervisor of PhD Committee)	Educational Psychology	492-1158
2.	Dr. Ashfaq Shuaib Professor (Neurological Consultant and Patient Referring Physician)	Director - Neurology	492-6395

A6. Expedited review:

(Not applicable)

A7. Which one of the following best describes the type of investigation proposed? Check more than one if appropriate.

[ ] clinical trial
[ ] multi-centre trial
[ ] pilot study
[ ] drug study
[X] technology assessment/development
[ ] qualitative study
[ ] epidemiological study
[ ] sequel to previously approved project
[ ] first application in humans
[X] other (specify):
Review of patient's medical records and a educational assessment.

A8. Where will the research be conducted?

[ ] Capital Health Site (specify):
[ ] Caritas Site (specify):
[X] U of A Site (specify):
Department of Neurology / University of Alberta Hospital
[ ] Other (specify):

Appendix 9. Revisions to HREB:B Protocol

University of Alberta
Edmonton
Canada T6G 2C4

Faculty of Rehabilitation Medicine
Rehabilitation Research Centre
3-48 Corbett Hall
Director (403) 492-7856 Telephone (403) 492-2903
Fax (403) 492-1626

May 15, 1998

Simon McCrea
6-102 Education North
Department of Educational Psychology

Dear Mr. McCrea,

Re: Cognitive Profiles of Brain-Injured Persons.

Thank you for submitting your revised proposal to the Health Research Ethics Board (B: Health Research) for review. The reviewers were pleased with the revised proposal. They had only a few suggestions for the information letter. The following changes may better clarify a few points: 1) in paragraph one change "thinking profile measure will help plan" to "may help plan"; 2) in paragraph two, the first sentence should be placed at the end of the letter to separate the decision of the HREB from patient consent - patients may understand HREB consent to supercede patient consent (also change ethical consent to ethical approval); 3) clarify the nature of consent requested from the patient (i.e. consent for doing the CAS and for researcher review of medical records, and distinguish research records from medical records (are UAH medical records kept in doctors' offices or UAH medical records department?); and 4) in paragraph three change "service removed" to "your care will not be affected in anyway".

Please find enclosed your letter of ethical approval for the project. On behalf of the Health Research Ethics Board, I wish you every success in your research endeavours.

Sincerely,

Karen Turpin
Administrative Assistant
Health Research Ethics Board (B: Health Research)

Appendix 10. HREB: B Ethical Approval

University of Alberta
Edmonton
Canada T6G 2G4

Faculty of Rehabilitation Medicine
Rehabilitation Research Centre
3-48 Corbett Hall
Director (403) 492-7856 Telephone (403) 492-2903
Fax (403) 492-1626

UNIVERSITY OF ALBERTA HEALTH SCIENCES FACULTIES, CAPITAL HEALTH AUTHORITY, AND CARITAS HEALTH GROUP

HEALTH RESEARCH ETHICS APPROVAL

Date: May 1998

Name(s) of Principal Investigator(s): Simon McCrea

Organization(s): University of Alberta

Department: Graduate Studies; Department of Educational Psychology

Project Title: Cognitive Profiles of Brain-Injured Persons.

The Health Research Ethics Board has reviewed the protocol for this project and found it to be acceptable within the limitations of human experimentation. The HREB has also reviewed and approved the patient information material and consent form.

The approval for the study as presented is valid for one year. It may be extended following completion of the yearly report form. Any proposed changes to the study must be submitted to the Health Research Ethics Board for approval.

Sharon Warren

Dr. Sharon Warren
Chair of the Health Research Ethics Board (B: Health Research)

File number: B-090498-EDPSY

Health Research Ethics Board

biomedical research
2J2.11 Walter Mackenzie Centre
University of Alberta, Edmonton, Alberta T6G 2R7
p.403.492.9724 f.403.492.7303
ethics@med.ualberta.ca

health research
3-48 Corbett Hall, University of Alberta
Edmonton, Alberta T6G 2G4
p.403.492.0839 f.403.492.1626
ethics@rehab.ualberta.ca

Notice to All Researchers

In carrying out this project, remember it is your responsibility to:

1) Submit any changes to the protocol / proposal for HREB approval.
2) Keep signed copies of the consent forms for 5 years and all raw data (i.e.: tape transcriptions) for at least 7 years following the completion of the study.
3) Ensure that the process of obtaining informed consent is carried out in a way that provides complete information to potential research participants and avoids coercion.
4) Monitor the safety of research procedures and equipment. The HREB must be notified about any adverse events.
5) Preserve the confidentiality of research subjects and store records in a secure area.
6) Ensure that information collected and analysed is complete and accurate.

University of Alberta

Capital Health

Appendix 11. Identification of Principal Investigator

University of Alberta
Edmonton
Canada T6G 2R7

Department of Medicine
2F1 Walter C Mackenzie Health Sciences Centre
Telephone (403) 492-6261 FAX (403) 492-3340

May 29, 1998

Neurology

Dear Simon:

As an employee in the Department of Medicine you may be required to produce identification to use the cafeteria in the Hospital, enter the Hospital during the evening or early morning or when otherwise requested by Hospital security.

This is your letter of authority to go to Human Resources, located in room 1-161 of the Clinical Sciences Building to get your picture identification. Please take this letter with you. Return the next working day to pick up your I.D.

Sincerely yours,

Marg Probst
Admin Assistant
Department of Medicine

Appendix 12. HREB:B Ethical Approval Renewal

Health Research Ethics Board

biomedical research
222.11 Walter Mackenzie Centre
University of Alberta, Edmonton, Alberta T6G 2R7
p.403.492.9724 f.403.492.7303
[illegible]

health research
3-48 Corbett Hall, University of Alberta
Edmonton, Alberta T6G 2G4
p.403.492.[illegible] f.403.492.1626
[illegible]

UNIVERSITY OF ALBERTA HEALTH SCIENCES FACULTIES, CAPITAL HEALTH AUTHORITY, AND CARITAS HEALTH GROUP

HEALTH RESEARCH ETHICS APPROVAL

Date: May 1999

Name(s) of Principal Investigator(s): Simon McCrea

Organization(s): University of Alberta

Department: Graduate Studies; Department of Educational Psychology

Project Title: Cognitive Profiles of Brain-Injured Persons.

The Health Research Ethics Board has reviewed the protocol for this project and found it to be acceptable within the limitations of human experimentation. The HREB has also reviewed and approved the patient information material and consent form.

The approval for the study as presented is valid for one year. It may be extended following completion of the yearly report form. Any proposed changes to the study must be submitted to the Health Research Ethics Board for approval.

for Dr. Sharon Warren
Chair of the Health Research Ethics Board (B: Health Research)

File number: B-090498-EDPSY

University of Alberta

Capital Health

Appendix 13. Proposed Modifications to Protocol and Approval

October 6th, 1999

Simon McCrea (Rm 6-141b)
Dept of Educational Psychology
University of Alberta
Edmonton, Alberta T6G 2G5
Email: smccrea@gpu.srv.ualberta.ca

Karen Turpin, RN, BScN
Administrative Assistant
Health Research Ethics Board (B: Health Research)
3-48 Corbett Hall
University of Alberta
Edmonton, AB T6G 2G4

Re: Cognitive profiles of brain-injured persons

Dear Karen,

I was previously notified of renewal of ethical approval for our study in a memo dated May 20th, 1999. I am presently enquiring about proposed modifications to the above protocol and any required additional review process.

Proposed changes include:

I would like to reassess recruited patients (see original protocol) with the Cognitive Assessment System or CAS (Naglieri & Das, 1997) and the Wechsler Adult Intelligence Test - Revised or WAIS-R (Wechsler, 1981) at 3 months post-stroke. This proposed change is in addition to the initial single CAS assessment as stipulated in the original protocol. Contact of patients would only be undertaken if, after initial recruitment, patients expressed an interest in a subsequent assessment session.

Reason for changes:

The WAIS-R has an extensive history of usage in a neuropsychological context (Kaplan, Fein, Morris & Delis, 1991). Comparison of the CAS results in the context of the WAIS-R results would increase the generalizability of our findings and allow for a more rigorous examination of the construct validity of the CAS (see original protocol).

Potential benefits:

WAIS-R results are routinely used in assessment recommendations of brain-injured individuals. If desired by patients, their CAS and WAIS-R results could be used by allied health professionals as adjunct information in the event that rehabilitation recommendations were required.

Potential Concerns:

A reassessment of approximately 2 hours duration would be required on the part of the patient. This reassessment could be most easily undertaken at UAH, perhaps in conjunction with a regularly scheduled check-up conducted by a UAH neurologist post-stroke. Appointments could be scheduled in the morning with ample breaks between tests. This second assessment would provide standardized WAIS-R information to allied health professionals over and above that provided by the CAS results. To reiterate the CAS results must be interpreted with caution since the CAS is being used in an experimental context. Moreover participation in the second assessment would be entirely voluntary and this would be clearly stated to the patient at the conclusion of the first assessment. Patient confidentiality could be assured by ensuring that only those patients that expressed an interest in a second assessment at after the first assessment were subsequently contacted.

References:

Kaplan, E., Fein, D., Morris, R. & Delis, D.C. (1991). WAIS-R Neuropsychological Instrument Manual. San Antonio, TX: Psychological Corporation.

Naglieri, J.A. & Das, J.P. (1997). Cognitive Assessment System. Itasca, Il: Riverside.

Wechsler, D. (1981). Manual for the WAIS-R. New York: Psychological Corporation.

Summary:

These are the proposed amendments to the protocol. Please note that these modifications will not be implemented without written confirmation from the HREB that these changes dated October 6th, 1999 are permissible. I do hope that this information is useful. Please contact me if you require more detailed information.

I look forward to your response.

Sincerely,

Simon McCrea
Principal Investigator

cc. Co-Investigators

Dr. Robert Short, Associate Chair, Educational Psychology
Dr. Ashfaq Shuaib, Chair, Neurology

UNIVERSITY OF ALBERTA

October 8th, 1999

Simon McCrea
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Carol Jaster
Regional Research Administration
University of Alberta Hospital Site
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Edmonton, Alberta T6G 2B7
Ph: 407-1372

Dear Carol,

Regarding your query about updating some information pertaining to this study:

Enclosed is the information that you requested in our phone conversations and in your fax transmittal. A copy of the complete study protocol is enclosed with requisite 1998 Departmental and 1998, 1999 HREB ethical approval notices and funding source verification items.

Study Budget

This study is indirectly funded by a *Province of Alberta Graduate Fellowship* to Simon McCrea to support my living expenses, (see enclosed materials), and not an AHFMR grant as specified in the HREB protocol item A9. I am completing this research as part of my dissertation requirements for my PhD in Educational Psychology, and no external source of funding has therefore been required for operation purposes.

Location of Study

Please note that HREB protocol item A8 stipulates that the cognitive assessments will be undertaken at the Department of Neurology, University of Alberta Hospital. More specifically, the assessments are being conducted on wards 4G3 and 4G4 in adjacent reserved examination rooms.

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Information Sheet and Consent Form

See HREB protocol item B11 on pages 9-11.

Evidence of Agreement to Provide Services in Support of the Study from Affected CHA Departments (eg. Patient Care Area)

At present no *Capital Health Authority* Sites other than University of Alberta Hospital, Department of Neurology are involved in this study. At present patients are undergoing assessments in the subacute phase post-stroke at University of Alberta Hospital. If there are changes to this status, as indicated in my prior telephone conversations with, Mr. McIsaac, Research Services, *Glenrose Rehabilitation Hospital*, then the appropriate institutional level review process would also be initiated. Additionally, as stipulated in the *Letter of Information*, *Consent Form* and *Benefits to Patient*, HREB protocol items B11 and B16, respectively, each patient completing the study will be mailed a statement of their assessment results which may/may not be useful to allied rehabilitation professionals.

Additional Changes

Please note that Dr. J.P. Das, who was initially listed as a co-investigator on this protocol, (e.g., see HREB protocol item A3) is no longer collaborating on this research study.

I do hope that this information is helpful. If you have any additional questions you can easily contact me at the above number.

Sincerely,

Simon McCrea

Principal Investigator

cc. Dr. Robert H. Short, Co-Investigator, Associate Chair, Educational Psychology
Dr. Ashfaq Shuaib, Co-Investigator, Chair, Neurology
Dr. Thomas Snyder, Dissertation Research Advisor, Department of Psychiatry

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Health Research Ethics Board

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November 19, 1999

Simon McCrea
6-102 Education North
Department of Educational Psychology

Dear Mr. McCrea,

Re: Cognitive Profiles of Brain-Injured Persons.

Thank you for your letter of November 12, 1999, addressing how the subjects will provide consent for the second assessment. Thank you also for providing copies of the revised information letter and consent form. Please proceed with the protocol change. On behalf of the Health Research Ethics Board (B: Health Research), I wish you every success in your research endeavours.

Sincerely,

Karen Turpin

Karen Turpin, RN, BScN
Administrative Assistant
Health Research Ethics Board (B: Health Research)

University of Alberta

Capital Health

Appendix 14. Critical Lesion Locus Scoresheet

	Critical Lesion Locus						
Matching Numbers	Right frontal lobe						
Planned Codes	Basal ganglia						
Planned Connections	Anterior cingulate Dorsolateral prefrontal cortex Basal ganglia						
Expressive Attention	Right anterior cingulate						
Number Detection	Right frontal Basal ganglia Right parietal						
Receptive Attention	Corpus callosum Left temporal Right fronto-temporal						
Nonverbal Matrices	Parietal lobes						
Verbal-Spatial Relations	Left insula Basal ganglia Left superior temporal gyrus Left inferior parietal lobule						
Figure Memory	Parietal lobes Right dorsolateral prefrontal cortex Occipital lobes						
Word Series	Left temporoparietal areas Right frontal lobes						
Sentence Repetition	Left posterior superior temporal gyrus Left inferior parietal lobe						
Sentence Questions	Left temporal Left inferior parietal Left inferior frontal gyrus						

Critical Lesion Locus Scoresheet

Each patient's brain was rated for the presence or absence of a lesion in one these critical lesion locus areas. If any area was damaged within a lesion by subtest cell than that entire cell was scored as damaged, demarcated by an 'X'. All lesions were rated objectively according to the neuroradiologist's written CT or MRI of the brain summary thereby minimizing the introduction of rating bias. Moreover the extent of each lesion as outlined in the written summary was verified with the original CT or MRI film and checked with a standard neuroradiological atlas (Moeller & Reif, 2000)

Appendix 15: Glossary

ACQUIRED DYSLEXIA – an inability to read that is caused by brain damage in a person who previously knew how to read
AGRAPHIA – an inability to write that is caused by brain damage in a person who previously knew how to write
ALZHEIMER'S DISEASE – a degenerative brain disorder that first appears as a progressive memory loss and later develops into a generalized dementia. Cholinergic cells in the basal forebrain and cells in the entorhinal cortex appear to degenerate first
ANARITHMETIA – an inability to perform simple mental computations caused by brain damage in a person who could previously do so
ANEURYSM – dilation of the vascular wall so that a sac filled with blood forms at the vessel wall
ANGULAR GYRUS – gyrus within the parietal lobe corresponding to Brodman's area important language functions
ANTERIOR CINGULATE – anterior strip of limbic cortex lying above the corpus callosum along the medial walls of the cerebral hemisphere
ANTERIOR COMMUNICATING ARTERY – anterior bridge of the Circle of Willis circulating blood flow between the left and right anterior cerebral arteries both originating from the carotid artery that services the orbital frontal and dorsolateral frontal regions, the anterior cingulated cortex, corpus callosum and striatum
ANTEROGRADE AMNESIA – an inability to remember events subsequent to some brain damage
APHASIA – loss of the power of expression by speech, writing or signs. Usually associated with difficulties in comprehending spoken or written language due to injury to the brain
APRAXIA – Difficulties in making voluntary movements in the absence of paralysis or other motor or sensory impairment. Often associated with difficulties making the appropriate use of an object (e.g., toothbrush)
ARTERIOVENOUS MALFORMATION – an abnormality of both arterial and venous blood flow that is often associated with tortuous blood vessels lying at the surface of the cortex
ARTICULATION – associated with speech planning and movements
ASCENDING (RAS) – ascending diffuse network of tracts located in the brainstem that functions to arouse the forebrain
ATROPHY – an area of decreased density and shrinking due to cell death
ATTENUATION (CT) – an area of darkening or lightening indicative of edematous changes or hemorrhage on a CT scan; respectively
AUTISM – a neurological condition manifest as profound deficits in language, communication and social interaction often diagnosed before the age of 3
BADDELEY'S MODEL OF WORKING MEMORY – a model of the basic architecture of cognition popularized by British neuropsychologist bearing his name who postulated a tripartite model including an articulatory loop and visuospatial sketchpad which are parts of a larger a central executive where maintenance and monitoring response functions are made
BALINT'S SYDROME – an agnosic syndrome resulting from bilateral parietal lesions. Patients display three features: i) disturbances of visual attention ii) optic ataxia (3) deficits in identifying objects in the peripheral field
BARONA IQ – a demographic index used to computed premorbid intelligence
BASAL FOREBRAIN – an area anterior to the hypothalamus that is the source of cholinergic cells which project to all cortical areas
BASAL GANGLIA – group of large nuclei in the forebrain including the caudate nucleus, putamen, globus pallidus, claustrum and the amygdala
BASILAR ARTERIES – an artery formed by the fusing of the left and right vertebral arteries and which irrigates the pons before ascending and branching into the superior cerebellar arteries and the posterior communicating arteries on the left and right
BROCA'S APHASIA – expressive difficulties or nonfluency that often occurs after lesion of the left inferior frontal gyrus

CAUDATE NUCLEUS – nucleus of the basal ganglia
CEREBELLO-THALAMO-CORTICAL CIRCUIT – a neural network important in subvocal rehearsal
CEREBELLUM – a major structure of the hindbrain involved in motor coordination, timing, conditioning, and some cognitive functions
CEREBROVASCULAR – pertaining to the arteries and veins within the brain
CHIASMATIC ANEURYSM – bleeding at the junction of the base of the brain where the two optic nerves partially cross over
CLINICAL NEUROLOGY – a specialty of medicine specializing in disorders of the central and peripheral nervous systems
COGNITIVE NEUROSCIENCE – a multidisciplinary experimental neuroscience associated with mapping cognitive functions of humans to the brain which is heavily reliant on classical lesion methods and newer functional neuroimaging and computational modeling approaches
COMMISSURAL FIBERS – bundle of fibers connecting corresponding points on the two sides of the central nervous system
COMMISSUROTOMY – surgical disconnection of the two hemispheres by cutting the corpus callosum
CONCEPT FORMATION – the establishment of regularity between events that enables some degree of prediction and the reduction of uncertainty
CONDUCTION APHASIA – a type of fluent aphasia in which words are repeatedly incorrectly but the patient has near normal comprehension
CONJUNCTIVE SEARCH – a mechanism where the sensory system searches for a particular combination of sensory information at an early stage of processing
CONSTRUCTIONAL APRAXIA – An inability to perform learned sequences of movements involved in making (e.g., drawing) something which cannot be due to move or perform the individual motor acts required in the task
CONTRALATERAL SPACE – residing on the side of the body opposite of a reference point
CONTRE COUP – a lesion or contusion opposite the side of impact to the head caused by the brain rebounding from the surface of the skull as a result of centrifugal force as is common in traumatic brain injury
CONVERGENT THINKING – a search for an answer to a problem in which there is a single answer to a question
CORPUS CALLOSUM – a fiber system of approximately 200 million axons connecting homologous sites on opposite hemispheres of the brain
COVERT ARTICULATION – silent repetition of words or phrases to oneself in their mind
CRANIOTOMY – operation in which the cranium is opened and the cortical surface is exposed
CROSS-HEMISPHERE COMPARISON TASK – a task in which the subject is required to recognize a visually presented object after handling it and thus involving two modalities
CT – computed axial tomography
CUED VISUAL SEARCH – a task in which a prompt is given to the subject to cue them to orient in a specific direction when the target appears
CUTTING POINT – a point usually 1.5 standard deviation units used by neuropsychologists to designate a potentially deficit performance on a particular task X in comparison to a group of control tasks
CYTOTOXIC – damaging to brain cells
DECUSSATION – a point at which fiber tracts cross over in the brain usually from one side to another
DEMENTIA – any of a variety of neurodegenerative disorders usually affecting the elderly in which there is are prominent memory deficits, global cognitive decline and personality disintegration
DIFFUSE AXONAL INJURY – injury to axons throughout the cortex and subcortical regions
DISINHIBITION – removal of normal tonic inhibitory influences on a system
DISTRACTORS – to be distinguished from targets in visual search paradigms
DIVERGENT THINKING – form of thinking in which there is a search for multiple solutions to a problem, sometimes associated with a generate function
DIVIDED ATTENTION – sometimes called a dual-task paradigm in which there is an attempt to perform to tasks simultaneously

DIVIDED VISUAL FIELD PRESENTATION – often performed using a projector in which objects are simultaneously presented to the left half of visual fixation (left visual field: right hemisphere) or the right half of visual fixation (right visual field: left hemisphere) and there is a corresponding faster reaction time in naming objects in the right visual field
DOMINANT HEMISPHERE – usually the left verbal hemisphere in most righted handed people
DORSAL STREAM – a neural network involved in early perceptual analysis of visual material that goes from visual cortex to parietal cortex which is primarily associated with where information is
DORSOLATERAL FRONTAL-SUBCORTICAL CIRCUIT – one of five subcortical-prefrontal cortical feedback loops implicated in working memory modulation of ongoing processing (e.g., error monitoring)
DORSOLATERAL PREFRONTAL CORTEX – prefrontal cortex anterior, superior and lateral associated with Brodman's areas 9 and 46
DOUBLE DISSOCIATION – a technique used in experimental neuropsychology whereby two areas of cortex are functionally dissociated by two behavioral tests, such that each test is affected by a lesion to one zone and not the other and vice-versa
DURA - the tough covering of the brain inside the skull
EDEMA – water accumulation within cells or in the extracellular space
EEG – electroencephalography: electrical potentials measured by placing electrodes on the skulls surface
EEG SOURCE LOCALIZATION – an advanced high-density electrode placement method in which modeling of EEG data sets with gaussian field parameters allows for the spatial resolution and localization of the major neural generators of electrical potentials
EMBOLIS – a clot
EVENT-RELATED FMRI – a high-speed functional magnetic resonance imaging technique that allows for simultaneously sequencing short duration aspects of performance of a cognitive task with the pulse-sequence acquisition such that the inherent problems associated with the low temporal resolution of regular block-design fMRI is attenuated
EVENT-RELATED POTENTIAL MAPPING (ERP) – a complex EEG waveform that is related in time to a specific sensory event which in turn is composed of a sequence of specific subunits that are related to specific aspects of neural processing
EXECUTIVE FUNCTION – those class of cognitive functions associated with goal-directed behaviors
EXTERNAL CAPSULE – a structure in close proximity with the basal ganglia important in motor programming
FACE VALIDITY – validity based on the appearance of task features
FALX OR FALCINE – referring to a sheath that separates the two hemispheres and helps to give them structural integrity
FIGURAL REASONING – determining causal relationships about objects based on an analysis of their parts visuospatial characteristics and interrelationships
FLUENT APHASIA – speech disorder where pronunciation is good and phrases appear to be sentence-like but the sentences are non-sensical
FLUID INTELLIGENCE – as opposed to Cattel's crystallized intelligence which consists of verbally learned material fluid intelligence Gf is often measured by nonverbal tasks in which learning relationships among parts of unfamiliar materials is emphasized. Gf has the highest relationship with psychometrically measured general intelligence and is epitomized in the Raven's Progressive Matrices test
FMRI – functional magnetic resonance imaging
FOCAL LESION – a restricted and circumscribed area of neural damage within the brain
FOCUSED ATTENTION – sometimes metaphorically described as akin to a 'spotlight' of conscious recollection
FOILS – distracters similar to a target
FOURTH VENTRICLE – a cerebrospinal fluid cavity at the intersection of the axis of the pons and the cerebellum between the cerebral aqueduct and the foramen of Magendie
FRONTAL CONVEXITY – the rounded cortex of the most anterior, dorsal and lateral prefrontal regions
FRONTAL HORN – the most anterior aspect of each lateral ventricle
FRONTAL NEGLECT – a search deficit syndrome which manifests itself when there are too many distracters present in a search array due to frontal lesions
FRONTAL OPERCULUM – upper region of the inferior frontal gyrus

FRONTOPARIETAL – pertaining to that region of the cortex adjacent to both the frontal and parietal lobes
FRONTOTEMPORAL – pertaining to that region of the cortex adjacent to both the frontal and temporal lobes
FUNCTIONAL COMPENSATION – a mechanism of recovery from brain injury in which behavior is modified in order to compensate for lost functions; neither the recovered behavior nor the area that mediates recovery are the same as those that are lost
FUSIFORM GYRUS – a gyrus on the ventral surface of the occipital lobe where area V4 is located
GAZE SHIFTING – the ability to move the direction of the eyes either to focus on an object
GCS
GENERAL INTELLIGENCE – the primary factor commonly found in all factor analytic data sets which is hypothesized to influence all human performance which should be distinguished from specific factors underlying specific abilities
GENU – the most anterior aspect of the corpus callosum
GESTALT – coming from the German word for shape suggesting that the sum is greater than the sum of its parts epitomized by figure and ground illusions
GLASGOW COMA SCALE – a widely used rating scheme for qualitatively gauging the extent of consciousness impairment ranging from unimpaired to coma
GLIOSIS – the migration and proliferation of glial cells in areas of neural tissue where damage has occurred; their presence warns of tissue damage
GLOBAL APHASIA – expressive and comprehension deficits in all modalities
GLOBAL PROCESSING – in Sergent's (1982) theory one of two primary means of perceptual analysis which emphasizes the gestalt synthetic nature of cognition and which is distinguishable from the feature characterization of local processing. Her work led her to the conclusion that the right hemisphere may have a relative bias towards global processing and vice versa for the left hemisphere and local processing
GLOBUS PALLIDUS – part of the basal ganglia that receives projections from the caudate nucleus and sends projections to the thalamus
GOAL-DIRECTED BEHAVIOR – volition towards action towards the achievement of a desired final state
GRAMMAR – our total linguistic knowledge, consisting of phonological, syntactical, and semantic components
GRAY MATTER – outer covering of the cortex consisting largely of cell bodies
GYRI – the protuberances originating from the surface of the brain
HANDEDNESS – one's preference of either using the left or right hand in performance on common tasks
HEMATOMA – bleeding within the brain usually on the surface between the dura and meninges
HEMIANOPSIA – loss of pattern vision in either the right or left visual field
HEMIPARESIS – paralysis on one side of the body
HEMIPLEGIA – same as above
HEMISPHERECTOMY – removal of one of the hemispheres
HEMISPHERIC-ENCODING-RETRIEVAL-ASSYMETRY (HERA) MODEL – a model developed by neuropsychologists at the Rotman Research Institute largely as a result of consistent findings across functional neuroimaging studies which implied that the left prefrontal cortex is specialized role to play in encoding of information while the right prefrontal cortex information has a specific role in memory retrieval
HEMORRHAGIC STROKE – blood vessel burst in the brain
HESCHYL'S GYRUS – gyrus of the temporal lobe of humans that is roughly equivalent to auditory area 1
HOMONYMOUS HEMIANOPSIA – visual loss due to cuts of the optic tracts, damage to the lateral geniculate or area 17 of the visual cortex
HUNTINGTON'S DISEASE – characterized by ceaseless, involuntary, jerky movements and progressive dementia
HYDROCEPHALUS – condition characterized by abnormal accumulation of fluid in the cranium, sometimes accompanied by enlargement of the head, atrophy of the brain, and mental retardation if prolonged
HYPERINTENSITY – usually an area of decreased exposure (e.g., light spot) on a CT film often indicative of bleeding into the brain
HYPERTENSION – high blood pressure which is a significant risk factor for hemorrhagic stroke
HYPOINTENSITY – localized edema within a brain regions as the consequence of ischemia an area of increased exposure (e.g., dark spot) on a CT film often indicative of ischemia

ICONIC – Neisser's name for the visual contents of sensory storage
ILL-STRUCTURED PROBLEMS – a problem is ill defined if the start or goal states are unclear, or if the operations required to change states are unspecified
IMMEDIATE AUDITORY MEMORY – short-term hearing memory usually associated with Heschyl's gyrus
INFERIOR FRONTAL GYRUS – a gyrus located ventrally and posteriorly within the frontal lobe
INFERIOR PARIETAL LOBULE – consists of the angular and supramarginal gyrus
INSULA – tissue within the Sylvian fissure that includes the gustatory cortex as well as the auditory association cortex
INTELLIGENCE – general level of intellectual functioning in the service of adaptive goal-directed behaviors
INTENTIONALITY – forming an intention or goal
INTERFERENCE – a task in which a prepotent response interferes with the execution of a subsequent response
INTERHEMISPHERIC FISSURE - the divide between the left and right hemispheres
INTERHEMISPHERIC TRANSFER – the conveyance of information from one hemisphere to the other through the corpus callosum or the subcortical commissures and sometimes across modalities
INTERNAL CAPSULE – a structure prominently involved in motor programs
INTERNAL CAROTID ARTERY – branch of the carotid artery that is a major source of blood to the brain
IPSILATERAL SPACE – located on the same side of the body as the point of reference
ISCHEMIC STROKE – reduced blood flow to a region of the brain causing reduced glucose and oxygen availability and a subsequent cascade of neurotoxic metabolic processes
KINDLING – in animal models of epilepsy a situation in which homotypic regions of the cortex demonstrate reduced seizure threshold after repeated low intensity stimulation from a primary seizure focus
LATERAL VENTRICLE – the largest area of ventricle within each hemisphere stretching from the frontal horn to the temporal horn to the occipital lobe
LATERALIZATION – process whereby functions come to be located primarily on one side of the body
PERISLYVIAN REGION – regions close to the Sylvian fissure along the borders of the parietal and temporal lobes
LEFT VISUAL FIELD – the region of hemispace processed by the right occipital cortex
LEVELS OF PROCESSING – principle whereby A semantic analysis results in a deeper code and thus a more meaningful one than a nonsemantic analysis. Second the deeper the code the more durable the memory.
LEXICAL CATEGORIZATION – determining whether two letters are the same (e.g., b B)
LEXICAL DECISION TASK – same as above
LEXICAL IDENTITY – retrieving the fact that two letters are the same, as above
LEXICOSEMANTIC – a process whereby semantic associations are retrieved from phonology
LOCAL PROCESSING – see global processing
MAINTENANCE (WORKING MEMORY) – rehearsal whose objective is simply to retain information in working memory. This rehearsal seems to be accompanied by subvocalization in the case of verbal material
MENTAL FLEXIBILITY – the capacity for change in behavior extending through perceptual, cognitive and response dimensions
MENTAL ROTATION – an ability to make a mental image of an object and imagine it in a new location relative to its original position
MENTAL TRACKING – a test of how much information a person can attend to at once and repeat it in reverse order. Involves elements of perceptual tracking as well as the performance of operations on the information
METACOGNITION – personal knowledge about the operations of the memory system
MIDBRAIN – Short segment between the forebrain and the hindbrain consisting of the tectum and tegmentum
MIDDLE CEREBRAL ARTERY – a cerebral artery that is co-extensive with the length of the Sylvian fissure and sends blood to the ventral part of the frontal lobe, the entire parietal lobe and the temporal lobe
MINI-MENTAL STATE EXAM – a brief mental exam often administered by neurologists to gauge person's orientation to person, place and time
MODALITY – vision, hearing, taste, touch, smell

MONITORING (WORKING MEMORY) – a function usually ascribed to the anterior cingulate and which examines the contents of working memory
MORPHOLOGY – the study of units of meaning within linguistics that are usually words
MRI – magnetic resonance imaging
MULTIPLE SCLEROSIS – a disease causing demyelination in the CNS which may lead to motor weakness, incoordination and speech disturbances
NEURAL NETWORK – an interconnected distributed or highly localized related organization of neurons and axons with intrinsic properties that allow it to learn and that has hierarchical, serial, and parallel processing characteristics
NEURODEGENERATIVE – an illness that causes damage to the central or peripheral nervous system
NEUROPSYCHOLOGY – study of the relationship between brain function and behavior
NEURORADIOLOGY – study of imaging technologies used in understanding and treating neurological diseases
NONVERBAL IQ – epitomized by the Raven Progressive matrices or performance IQ
NONVERBAL WORKING MEMORY – corresponds to Baddeley's visuospatial sketchpad and is coextensive with reciprocal connections between the dorsolateral prefrontal cortex and the parietal lobe in the right hemisphere
OBJECT RECOGNITION SYSTEM – the ventral visual stream instantiated by tracts from V1 to the visual temporal areas, known as the what system
OBJECT WORKING MEMORY – same as above except the pathway includes the inferior aspect of the prefrontal cortex
OCCIPITAL HORN – the posterior aspect of the lateral ventricles
OCCIPITOTEMPORAL – the region in close proximity to the occipital and temporal lobes on the ventral surface
OLIGODENDROGLIOMA – a type of brain cancer involving glial cells
ORBITAL LOBE – inferior aspect of the prefrontal cortex
ORTHOGRAPHY – a visual perceptual process underlying the recognition of letters
OVERT ARTICULATION - speech
PAIRED ASSOCIATE TASK – the learning of two initially unrelated words
PARALLEL SEARCH – a cognitive strategy in which sensory stimuli are scanned for a specific feature such as color
PARENCHYMA – the gray matter
PARKINSON'S DISEASE – a disease of the motor system that is correlated with a loss of dopamine in the substantia nigra leading to tremors, rigidity, and reduction of voluntary movement
PERIVENTRICULAR – in close proximity to the ventricles
PERSEVERATION – the tendency to emit the same verbal, motor or cognitive response to varied stimuli
PERSPECTIVE TAKING – the ability to empathize with another's point of view
PET – positron emission tomography
PHONOLOGICAL STORE – the buffer that plays an important role decoding the meaning of words
PHONOLOGY – decoding auditory phonemes or orthographic units into lexemes or units of meaning
PHOTOPHOBIA – sensitivity to light
PLAN GENERATION TIME – during planning task research usually the time from presentation of the problem to initiation of the first move which indices the complexity of the initial plans
PLANNING – a sequence of willed actions used to achieve a desired goal modeled in the form of representations of appropriate action sequences initially
PLANUM TEMPORALE – secondary cortex adjacent to Heschyl's gyrus that is larger in the left in right-handed people
PONS – a band of nerve-fibers in the brain, just above the medulla oblongata, consisting of transverse fibers connecting the two hemispheres of the cerebellum, and longitudinal fibers connecting the medulla with the cerebrum
POSTERIOR FOSSA - houses the brainstem and cerebellum
PRAGMATICS - the study or analysis of linguistic signs as they relate to the human user and his behaviour

PREFRONTAL CORTEX - the rostral part of the frontal lobe, bounded by the inferior precentral fissure in humans, which receives projection fibers from the mediodorsal nucleus of the thalamus. The prefrontal cortex receives afferent fibers from numerous structures of the diencephalon, mesencephalon, and limbic system as well as cortical afferents of visual, auditory, and somatic origin

PRIMING – treatment that does not in itself elicit a response from a system but that induces a greater capacity to respond to a second stimulus

PROBLEM-SOLVING - the action of finding solutions to puzzling questions

PSYCHOLINGUISTIC - the branch of linguistics which deals with the interrelation between the acquisition, use, and comprehension of language, and the processes of the mind

PSYCHOMETRICS - the science of measuring mental capacities and processes; the application of methods of measurement to the various branches of psychology

PURPOSIVE BEHAVIORISM - a theory and method of psychological investigation based on the study and analysis of behaviour that emphasizes the importance of intentionality and goals as modulators of stimulus-response contingencies

PUTAMEN - the outer zone or segment of the extra-ventricular portion of the grey matter of the brain

REPONSE MONITORING - an observable reaction to some specific stimulus to measure or test at intervals for the purpose of regulation or control

RESPONSE INHIBITION – an observable reaction to some specific stimulus to restrain the direct expression of an instinctive impulse

RETICULAR ACTIVITATING SYSTEM (RAS) - A region extending from the pons and medulla oblongata through the mesencephalon, characterized by a diversity of neurons of various sizes and shapes, arranged in different aggregations and enmeshed in a complicated fiber network

RETROGRADE AMNESIA - loss of memory for events before the accident

RIGHT VISUAL FIELD – the visual field on the right side of hemispace

SCANNING – visual search process

SCHIZOPHRENIA - A mental disorder occurring in various forms, all characterized by a breakdown in the relation between thoughts, feelings, and actions, usually with a withdrawal from social activity and the occurrence of delusions and hallucinations

SECONDARY DEGENERATION – atrophy of fiber tracts and neurons remote from a primary site of brain injury by the fact of their interconnectivity with the primary injured region

SELECTIVE ATTENTION - Applied to the capacity for, or process of, selection manifested by the mind or senses in reacting to certain stimuli and not to others

SELF-MONITORING – akin to response monitoring

SELF-REGULATION - control, or direction by or of oneself

SEQUENCING - The manipulation of processing of stimuli one at a time, with each idea linearly and temporally related to the preceding stimulus. Both verbal and nonverbal information may be processed sequentially when the order of the stimuli is necessary for extracting meaning or problem solving. Sequential processing is related to a variety of school-oriented tasks including memorization of number facts, applying stepwise mathematical procedures, phonics, spelling, grammatical relationships and rules, chronology of historical events, and following directions

SET-SWITCHING – the ability to change a number of things grouped together according to a system of classification or conceived as forming a whole and presumed to be a function of medial prefrontal structures

SINUS THROMBOSIS – a clot of the venous cerebrovasculature

SPAN TASKS – tasks such as digit span of the WAIS that assess immediate auditory memory but also can be visuospatial in nature

SPATIAL ATTENTION – visual selective attention show that attended stimuli have greater amplitude than unattended stimuli. The right lateral occipital area is maximally activated in the P1 component range. Similar to the dorsal stream or location based system

SPATIAL REVISUALIZATION – similar to mental manipulation or reversing of a sequence in ones mind's eye

SPATIAL VISUALIZATION – mental rotation and transposition of elements within a visuospatial array within one's minds eye

SPATIAL WORKING MEMORY – see Baddeley's visuospatial sketchpads

STRATEGY –a plan for successful action based on the rationality and interdependence of moves based on constraints
STRIATUM – caudate-putamen
STROKE – an ischemic or hemorrhagic event within the brain
stroop task
STROOP TEST – a simple color-naming task developed by Stroop (1935). A list of words is presented and the subject is asked to name the color of each stimulus as soon as possible. It is much easier to do the task when the words do not spell the names of conflicting colors due to interference
SUBARACHNOID CISTERNS – fluid-filled space situated between the arachnoid and the pia mater through cerebrospinal fluid flows
SUBARACHNOID HEMMORHAGE – clot within the region above
SUBCORTICAL – below the level of the cortex
SUBCORTICAL APHASIA – a form of aphasia often associated with lesions deep to the white matter adjacent to cortical language areas
SUBFALCIAL – below the level of the falx
SUBSTANTIA NIGRA – a part of the midbrain located at the juncture of the midbrain and the diencephalon
SUBVOCAL REHEARSAL – silent rehearsal of verbal material to oneself to aid remembering
SULCI – folds in the surface of the cortex
SUPERVISORY ATTENTION SYSTEM – Shallice's influential model of a willful central executive. SAS has access to a representation of the environment and of the organism's intention. It would be involved in the genesis of willed actions and required in situations were the routine selection of actions was unsatisfactory
SUPRAMARGINAL GYRUS - anterior part of inferior parietal lobule
SUPRASPAN – a lengthier span than that typically measured by digit span tasks
SUPRATENTORIAL – the upper part of the membranous sometimes ossified partition between the cerebrum and cerebellum
SUSTAINED ATTENTION – Nakayama and Mackeben (1989) suggested the existence of at least two types of spatially directed attention, a sustained and a transient component. Using the visual search task, they showed that both types of attention could lead to an improvement of performance; yet each is differently dependent on what are commonly described as "top-down" and "bottom-up" processing. The sustained component is under voluntary or "top-down" control because it builds up slowly, is maintained for a long time (but is weaker), and can be directed to a blank region of the visual field at will. On the other hand, the transient component is not susceptible to "top-down" influence. It builds up quickly and disappears earlier, locks time closely to the cueing event and performance is not influenced by prior knowledge or "expectancy" regarding the cue position. It seems more "primitive" or more closely tied to early visual processing, although not directly related to the earliest stages of visual processing
SYLVIAN FISSURE – the lateral sulcus running along the anterior-most aspect of the temporal lobe and bordering the most ventral aspect of the parietal lobe
Syndrome analysis
SYNTAX - the arrangement of words (in their appropriate forms) by which their connection and relation in a sentence are shown. Also, the constructional uses of a word or form or a class of words or forms
TACHISTOSCOPE - An instrument by means of which objects may be presented to the eye for a brief measured period, a fraction of a second; one of its principal applications being the measurement of 'the span of apprehension', that is, the amount of detail that can be apprehended by a single act of attention or apperception
TACTILE – pertaining to the sense of touch or somesthesis
TAMHANE'S T2 TEST – a conservative test used when the assumption of homogeneity of variances to test for the significance of multiple comparisons
TERTIARY CORTEX – multimodal cortex involved in symbolic functions
THALAMOCORTICAL – connectivity between the thalamus and the cortex
THEORY-OF-MIND – an ability to model the mental states of others and the meta-representation of one's own mental states
THIRD VENTRICLE – that portion of the central cavity of the brain that lies between the optic thalami
TRANSCORTICAL MOTOR APHASIA – symptoms include nonfluency, similar to Broca's, preserved repetition, lesion in the connection between Broca's and supplementary motor cortex

TRANSCORTICAL SENSORY APHASIA - patients can produce fluent speech but do not understand fully, cannot name, or lose semantic associations of speech
TRANSFER EFFECTS – generalization in learning
TUMOUR RESECTION – surgical removal of a malignancy
VASOGENIC EDEMA – dilatation of the blood vessel walls as a result of damage to them and consequent accumulation of fluid in the extracellular space
VENTRAL STREAM – the object recognition or what system associated with the occipitotemporal pathway
VENTRICULOMEGALY –ENLARGEMENT OF THE VENTRICULES USUALLY AS A CONSEQUENCE OF CORTICAL ATROPHY
VERBAL FLUENCY – facility in bringing forth categorical or phonological strings of related words or sounds
VERBAL MEDIATION – A means of learning through use of linguistic skills, decoding: (the word recognition aspect of reading) and encoding (spelling), written language, auditory attention and memory
VERBAL PROTOCOL ANALYSIS - one experimental method that can be used to gather intermediate state evidence concerning the procedures used by a system to compute a function. In protocol analysis, subjects are trained to think aloud as they solve a problem, and their verbal behaviour forms the basic data to be analyzed. The first step of a protocol analysis is to obtain, and then transcribe, a verbal protocol. The next step is to take the protocol and use it to infer the subject's problem space (i.e., infer the rules being used, as well as various knowledge states concerning the problem). The third step is to create a problem behaviour graph, which reflects state transitions as subjects search through the problem space in their attempt to solve the problem. Finally, the problem behavior graph is used to create a computer simulation (typically created as a production system) that will solve the problem. By comparing, in detail, the behaviour of the simulation to the verbal protocol, one can validate the assumptions that led to the program's creation. In turn, the program provides a rich description of an individual's processing steps, and transitions in knowledge, during the problem-solving process.
VERBAL WORKING MEMORY – similar to Baddeley's articulatory loop and involving the posterior perisylvian regions and connections with the inferior frontal gyrus
VIGILANCE – a tonic arousal mechanism associated with the integrity of the reticular activating system that ranges from sleep to panic
VISUAL NEGLECT - An extensive lesion of the right hemisphere including damage to the parietal lobe often results in the disorder known as left unilateral neglect (much more rarely, right unilateral neglect is seen, when it is the left hemisphere that is damaged). A person with unilateral neglect will ignore the affected half of space in many different ways. Conversations initiated by someone to the left of the patient may be ignored. Only food located on the right side of the plate will be eaten. The patient may not dress the left half of the body, and the left half of the face may not be shaved. The patient may deny ownership of the left arm or leg. There are a number of standard clinical tests for demonstrating the presence of unilateral neglect:
VISUAL SEARCH – a cognitive process involved in examining the parts of an object or array which is co-extensive with a frontoparietal network
WAIS – Wechsler Adult intelligence Scale
WALLERIAN DEGENERATION – see secondary degeneration
WERNICKE'S APHASIA – a receptive aphasia common after posterior perisylvian damage and characterized by poor comprehension with preserved fluency
WHITE MATTER – myelin tracts
WORD FINDING – retrieving the meaning of words in one's memory following a cue
WORKING MEMORY - the more contemporary term for short-term memory, is conceptualized as an active system for temporarily storing and manipulating information needed in the execution of complex cognitive tasks (e.g., learning, reasoning, and comprehension). There are two types of components: storage and central executive functions. The two storage systems within the model (the articulatory loop and the visuospatial sketchpad or scratchpad are seen as relatively passive slave systems primarily responsible for the temporary storage of verbal and visual information, respectively). The most important, and least understood, aspect of Working Memory is the central executive, which is conceptualized as very active and responsible for the selection, initiation, and termination of processing routines (e.g., encoding, storing, and retrieving).