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COGNITIVE REHABILITATION AND SENSORY INTEGRATION:
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Towards A Theoretical Framework For Clinical Intervention

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ABSTRACT

COGNITIVE REHABILITATION AND SENSORY INTEGRATION:
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By

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The theory of Sensory Integration is a neurodevelopmental model which has been widely used to conceptualize the brain-behaviour relationships involved in the etiology of learning disabilities, and to guide remedial activities. The theory emphasizes the role of the brain stem in the synthesis of tactile, vestibular, proprioceptive, and kinesthetic information prior to sensory processing at higher cortical levels. This process suggests that sensory input, which may be distorted/disrupted due to subcortical damage, may impair higher sensory integrative processes and final cortical output.

As brain stem involvement is recognized in the majority of traumatic brain injuries which involve a significant loss of consciousness, the theory of Sensory Integration would appear to be relavent to such a population. The purpose of this investigation was to conduct a preliminary evaluation of the applicability of the model to this clinical group. Forty-nine brain injured individuals were assessed using the Southern

California Sensory Integration Tests, in order to evaluate six hypotheses related to the theoretical constructs. Weak but statistically significant correlation and regression analyses repeatedly supported conceptual relationships within each hypothesis and across the various stages of the theory.

The generally low predictive ability of the regression equations, and the generally low correlations, were explained by the poor reliability of some of the battery's instruments, by limited examiner experience with some instruments, and by possible secondary disabilities that may have acted as confounds. Furthermore, the lack of consistent reporting of the presence of pre-morbid learning disabilities and drug/alcohol abuse, may have introduced possible confounds. Relative to the population at large, a sampling bias may have occurred such that persons at the highest and lowest ranges of the socioeconomic spectrum may be underrepresented on the basis of both financial and educational factors.

In the final analysis it was concluded that indeed preliminary evidence exists to warrant further pure and applied research into the application of sensory integrative principles to brain impaired populations. The study encourages the development of rival theoretical models to help guide the understanding of brain functioning and recovery from a dynamic, comprehensive perspective, and recommends that such theories must have both heuristic and treatment value.

To my loving and patient wife, Madalina,

who will now have her PK and KT back!

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CHAPTER I

INTRODUCTION

Statement and Significance of the Problem

In recent years, the rehabilitation of the traumatically brain injured (TBI) adult has become a major emphasis area for clinical neuropsychology. The National Head Injury Foundation (NHIF) estimates that 400,000 individuals annually in the United States experience head trauma and require hospitalization. Further, it is estimated that serious cognitive and/or behavioural impairment occurs as a result of such accidents in about 30 to 50 thousand of these cases (NHIF, 1981). These figures however, remain quite conservative relative to the rate of head injuries projected by the National Center for Health Statistics, which estimates the number to be eight million persons annually (Wilder, 1976).

Each year greater numbers of head injury and stroke victims are surviving their trauma due to advances in acute care technology and practices (Jennett & Teasdale, 1981). As a consequence, the need for rehabilitation services has grown immensely. While physical rehabilitation interventions have expanded in response to this population's needs, cognitive remediation (CR) strategies have developed at a much slower rate (Horton & Wedding, 1984). In the United States, diverse approaches to CR have often been based upon the neuropsychological assessment instruments which were originally utilized to detect brain damage and to differentiate between neurologically-intact and brain damaged persons, and/or between pschiatrically and organically impaired individuals (Lezak,1983). Since these assessment tools were developed to enhance differential diagnosis, they were primarily derived through empirical as opposed to rational means (Luria & Majovski, 1977). Consequently, the rehabilitative approaches, which are based upon these psychometric instruments, have also tended to lack a theoretical foundation.

Satz and Fletcher (1981) argue that these assessment approaches may have been adequate during the initial stages when the differential diagnosis between TBI patients and other groups was the primary intent of testing. However, a growing literature reflects the emphasis that neuropsychologists are now placing upon the remediation of cognitive deficits (Alfano & Finlayson, 1987). This new mandate demands the neuropsychologist to go beyond the mere detection of a lesion's existence. At this juncture such evaluations must elucidate the qualitative nature and extent of the neurobehavioural deficit within the framework of the fully functional brain. Once this ideographic information is available for any given TBI subject, only then may the most expedient rehabilitative procedure be determined (Alfano & Finlayson, 1987).

Unfortunately, too often the framework of the fully functional brain is lacking in the assessment of neuropsychological integrity, resulting in the "absence of a consistent theoretical framework for conceptualizing retraining" (Satz & Fletcher, 1981). Where such theoretical models do exist to guide both research and CR however, they have often resulted in significant clinical and heuristic benefits. For example, rationally based approaches have been successfully employed in the assessment and diagnosis of aphasia using psycholinguistic models (Goodglass & Blumstein, 1973), amnestic syndromes such as Korsakoff's disease (Butters & Cermak, 1980), long-term consequences of closed head injuries (Levin, Grossman, Rose & Teasdale, 1979), and spatial neglect (Diller and Gordon, 1976, 1981).

In contrast to these examples, much less attention has been focused on: (1) the remediation of analytical reasoning and concept formation skills (Reitan, 1979; Gianutos and Grynbaum, 1983) and, (2) the impact of subcortical deficits on these higher order (cortical) cognitive skills (Kulkarni, 1987). The first issue has been addressed to some extent by several approaches including a very structured approach by Ben-Yishay (1978) and colleagues at New York University, who have developed a series of remedial modules, and by Bracy (1983) in a series of heirarchical computer-based assignments. However, these approaches have been critisized for being overly structured and nomothetic, for failing to account for individual differences in pathology and brain recovery, and for treating brain damage as a unitary, discrete entity (Alfano & Finlayson, 1987).

In addressing the problem of finding an adequate theoretical foundation for CR, Alfano and Finlayson (1987) cite the Reitan Evaluation of Hemispheric Abilities and Brain Improvement Training (REHABIT) as a potentially comprehensive and patient-oriented model. The model has three primary tracks which highlight: concrete and abstract verbal and language abilities (predominantly left hemisphere functions); concrete and abstract visuospatial and temporal-sequential abilities (predominantly right hemisphere functions); and, a "general" track supposedly accounting for logical analysis and reasoning. This model has been employed in a number of rehabilitation settings to date, however it is too early to evaluate its efficacy. One immediate criticism of this theory is that it fails to acknowledge the more recently emphasized division of the brain into anterior and posterior regions as oppossed to lateral ones, and especially, the key role played by the frontal lobes in rehabilitation (Stuss, 1986; Stuss & Benson, 1986).

From a different perspective, many of the aformentioned theoretical frameworks have failed to account for three components, two of which Satz and Fletcher (1981) identify as being integral to any theory aspiring to be clinically and heuristically relevant. From Satz and Fletcher's perspective, such models have neglected to incorporate CNS research, and research in the area of cognition and behavior. In particular, both phylogenic and ontogenic neurodevelopmental concepts are often neglected in the CR models. This gives rise to the third missing component: the direct evaluation of the integrity of subcortical areas (especially the brain stem). These brain areas play a critical role as sources of input and feedback to the cortex, and are essential to the efficient and efficacious functioning of the brain as a whole (Luria, 1973; 1980). Kulkarni (1987) has recognized the importance of the evaluation of subcortical functions, and the conceptual integration of neuro- and cognitive developmental models in cognitive remediation. Although his approach draws upon several sources (e.g., Luria, (1973; 1980), and Piaget, (1954)), its core theoretical components and clinical instrumentation is adopted from Ayres' (1973) theory of Sensory Integration (SI). This latter neurodevelopmental theory, initially established as a rational approach to understanding learning disabilities and techniques to remediate them, flourishes today, albeit not without some controversy (Weeks, 1982).

The current problem is to address the void of theoretically based CR approaches in the clinical and research literature. It is important that any CR models proposed must not strictly be empirically efficacious from a treatment perspective. They must also be based upon well constructed theoretical principles with heuristic value, to facilitate the ongoing refinement of both theory and practice.

Purpose of the Study

The purpose of this retrospective study is to examine the theory of Sensory Integration to determine whether its conceptual relationships are empirically validated when applied to a TBI population. In this manner the theory will be assessed for its practicality and efficacy as a framework for analysis with respect to TBI patients. If the underlying constructs of the theory are found to be valid for TBI patients, then the remedial strategies suggested by the theoretical framework might also be applicable to the brain injured. A finding of this nature would support the adoption of Sensory Integration as both a rational basis for treatment and as an heuristic model for CR research. The study is an outgrowth of a paper presented by Kulkarni (1987), in which the utilization of Sensory

Integration Theory and therapy was introduced. This theory formulates the basis for the Cognitive Perceptual Motor Therapy program at the Michigan State University Rehabilitation Medicine Clinic.

Sensory Integration is a neurodevelopmental model which emphasizes the paramount role of sensory input, analysis and synthesis as the primary modes for the nervous system's organization. The theory postulates a heirarchical relationship between sensory inputs and increasingly more complex and refined cognitive-perceptual activities. At the base of the heirarchy, brain integrity relies upon the efficient processing of vestibular, tactile-kinesthetic, and propriceptive information. Throughout the maturation process, the basic inputs are integrated to give rise to second level factors relating to bodily posturing, orientation, awareness, and mastery of gross motor skills. At higher levels linguistic abilities, accute visual perception and fine motor skills are established, providing a foundation for academic learning, abstract thought and reasoning, hemispheric lateralization, and psycho-social adaptation. In her presentation of the theory as it related to learning disabled children, Ayres (1973) posited that neurobehavioural impairment at higher SI levels, may be mediated by dysfunctional inputs or integrative processes at lower levels. As such, improvement in functioning or functional reorganization is pursued through remediation according to the developmental heirarchy.

The Southern California Sensory Integration Tests (SCSIT) (Ayres, 1979) is the primary assessment instrument used to determine the integrity of sensory integrative processes in learning disabled children. Adult norms are available for the majority of tests which will be used here to evaluate these functions in the TBI population in the present study. The advantage of this instrument over many others used in neuropsychological assessment is that it evaluates subcortical functioning in a more direct, precise, and standardized manner.

With respect to the application of SI theory to a TBI patient population, the following questions will be addressed:

(1) Are the major constructs, and the theoretical relationships of the constructs, expounded by SI theory empirically varifiable within a group of heterogeneous TBI patients?

(2) Do certain demographic variables (namely age, sex, education, socioeconomic status, and lesion etiology) significantly differentiate subgroups of this TBI group in terms of these constructs and their theoretical relationships?

(3) Is there empirical support to suggest that the utilization of SI theory may provide a useful conceptual framework for determining the nature of neuropsychological impairment in a TBI patient, and for neurorehabilitation planning?

The following research hypotheses address the first question posed of the investigation. It should be noted that each of the independent and dependent variables presented in the hypotheses represent individual theoretical constructs of SI theory. The linear functions expressed represent the relationship between theoretical constructs established by the theory. All hypotheses will be tested using regression analyses. The second question posed by the study will be addressed through the inclusion of the demographic variables at various stages of the regression analyses. The third question will be answered on the basis of the results of the first two questions.

Hypotheses

H1:

Attention span (DS) is a function of vestibular (SBC), proprioceptive/ kinesthetic (KIN), and tactile (TAC) integrity.

H2:

Visual scanning (VS) is a function of attention span (DS), vestibular (SBC), proprioceptive/kinesthetic (KIN), and tactile (TAC) integrity.

H3:

Position-in-space perception (PS) is a function of attention span (DS), vestibular (SBC), proprioceptive/kinesthetic (KIN), and tactile (TAC) integrity.

H4:

Figure-ground perception (FG) is a function of attention span (DS), vestibular (SBC), proprioceptive/kinesthetic (KIN), and tactile (TAC) integrity.

H5:

Motor accuracy (MAC) is a function of attention span (DS), vestibular (SBC), proprioceptive/kinesthetic (KIN), and tactile (TAC) integrity.

H6:

Arithmetic ability (AR) is a function of visuo-spatial ability (VS) and attention span (DS).

Definition of Terms

Traumatic Brain Injured - A person or persons who have sustained a head injury from which organic pathology is known or suspected.

Cognitive Remediation/Retraining - "sets of procedures designed to provide patients with the behavioural repertoire needed to solve problems, or to perform tasks...that were performed easily before the onset of brain damage." (Diller & Gordon, 1981, p. 822)

Rehabilitation - The delivery of services to TBI victims by multidisciplinary professionals with the aim of improving the person's physical cognitive, emotional and social functioning.

Clinical Neuropsychology - The specialized field of psychology which has developed a unique knowledge of brain-behaviour relationships, and its clinical application, for purposes of assessment and cognitive remediation.

Neurodiagnostics - Evaluation of nervous system integrity through objective and professionally accepted medical tests e.g. CAT scans, brain scans, x-rays, M.R.I., P.E.T., E.E.G., E.N.G., etc.

Cerebral Dysfunction - Denotes impairment in brain functioning, as evidenced by an individual's performance on a neuropsycholgical or comparable evaluative measure; whereby dysfunction is evident but specific tissue damage or other pathology is not necessarily confirmed by neurodiagnostic means.

Cortical Functions - Those behaviours for which the neocortex is generally considered to be primarily responsible.

Subcortical Functions - Those behaviours for which subcortical (brain stem, diencephalon, basal ganglia, cerebellum, etc.) areas are generally considered to be primarily responsible.

Hard Neurological Signs - Those objective pathological signs which are directly and specifically referrable to impairment of a primary cortical area, sensory organ, motor pathway, cranial nerve, or spinal cord, as confirmed by neurodiagnostic means. They include: pathological reflexes, spasticity, flacidity, organic sensory loss, paralysis, cerebellar ataxia, vertigo, pathological nystagmus, etc.

Soft Neurological Signs - Those less tangible pathological signs, the etiology of which may not directly be established through an identifiable pathological process, or through neurodiagnostic means. Those signs for which neuropsychologival measures must be used for objectification and may be cortical (secondary or tertiary area), or subcortical in nature e.g. memory loss, sensory perceptual loss, impaired judgement, concentration/attentional difficulties, impaired abstract or logical reasoning, impaired balance, reading and writing deficits, etc.

Sensory Integration (SI) Theory - A theory which espouses the paramount role of sensory input and organization in relation to normal neurological development and brain functioning.

Post concussion syndrome - A controversial and ill defined entity whose "symptoms include dizziness, headache (usually diffuse), increased irritability, insomnia, forgetfulness, mental obtuseness and loss of initiative, all of which may arise after a severe head injury with loss of consciousness or may follow what seems to have been a trivial blow to the head" (Baloh & Honrubia, 1979, p. 192).

Recovery of function - Traditionally this term and the term "function" in general are phrases which have often been poorly defined in neuro-behavioural research (Laurence & Stein, 1978). This lack of clarity has resulted in considerable confusion and misinterpretation (Luria et. al, 1969). For this reason it will be separated into the concepts of "biological recovery" and "behavioral recovery" descibed below.

Biological recovery - In biological research "the function of a given area is defined as its ability to generate action potential's in response to a specific simulus or in terms of its capacity to release certain neurotransmitters when electrically excited (Finger & Stein, 1982, p. 340). These specific neurobiological events constitute the "means" by which overt behaviour is accomplished. Such events will be denoted "biological function". They may be said to be "means oriented functions". For purposes of this study, recovery of this nature will be termed "biological recovery" of function. The term shall denote significant recuperation of the original biological sequence used to perform a specified activity, which had been disrupted due to trauma.

Behavioural recovery - Behavioural studies tend to define an area's function according to the experimental variables in question (Fingers & Stein, 1982). Such variables normally involve the organism manipulating, or acting upon, the environment in some way. When function is defined in terms of an organism's ability to accomplish a certain task, it becomes "ends" as opposed to "means" oriented. Being "ends" or "goal" oriented, responsibility for the function in question may not be directly attributable to a single, biological sequence or brain area. Rather, purposive activities such as locomotion, or manipulation of objects, communication, etc., may be accomplished through different means, each of which requires utilization of specific brain areas and interrelationships; and, the series of neurobiological interrelationships between brain regions varies according to the order of subtasks performed to accomplish the overall task. Recovery of ends-oriented or "behavioural functions" will hereafter be called "behavioural recovery".

Sparing of function - The perceived lack of behavioral impairment despite the presence of significant brain damage. Emphasis is placed on the word "perceived" because researchers are not able to test the integrity of a subjects full behavioural repertoire, and because measures of those behaviours examined may not be sufficiently sensitive to detect a change in status (Finger & Stein, 1982).

Assumptions and Limitations of the Study

This investigation is a retrospective study of a group of TBI patients who had initially been assessed using the SCSIT battery as a basis for determining behavioral brain dysfunction. After the original assessment, the test findings and theoretical principles were utilized by Kulkarni (1987) as a guide for cognitive remediation in conjuction with other concepts previously mentioned. As neither approprate control groups nor adequate post test measures are available for this sample population, the efficacy of this CR approach could not be evaluated directly at the present time. Therefore, this study will limit itself to the analysis of the SI theory itself, retrospectively.

The results of this investigation are limited to the subjects who took part in the study. All subjects had sustained a brain lesion in adulthood and, had been evaluated clinically and with the Southern California Sensory Integration Tests battery in a medical facility associated with a large mid-western university in the United States, between 1982 and 1988. The findings can be generalized to populations similar to the group of subjects studied.

Summary and Overview

The goal of this study is determine the appropriateness of SI theory as a basis for understanding brian-behavior relationships. At present there are no satisfactory comprehensive theories of cognitive remediation and no commonly applied standardized instruments to evaluate subcortical functioning. SI theory and the SCSIT battery may offer both of these advantages if the theory's tenets are supported empirically here. While this study stops short of an empirical investigation of a therapeutic regimen based on SI theory, it will examine the aggregated results of TBI patients assessed for SI dysfunction, in order to relate this theory to such a population. This inquiry will utilize retrospective patient assessment data from the SCSIT evaluation to test some of the postulates of SI theory.

CHAPTER II

REVIEW OF THE LITERATURE

The review of the literature was conducted to address several areas of the research literature which forms the empirical basis for the theory of Sensory Integration. The review will be divided into four main sections. The first section will present the major theories of bio-behavioral recovery of brain function following a TBI. Evidence of such recovery is essential for the proclamation that cognitive remediation is both possible and worthwhile. Such a review is also important from the standpoint of debunking many of the traditionally held views regarding the likelihood of recovery occurring at all, and the post onset time frame during which recovery may occur.

The second section will formally introduce the concepts and principles of SI theory. The section will include a discussion of the relationship between SI theory and Piaget's theory of cognitive development. Also to be presented will be many of the specific empirical findings which led its originator to formulate SI theory, empirical investigations of the theory itself, and investigations of the efficacy of SI based interventions in various non-TBI populations.

The next section will focus on the topic of brain stem insult as a result of TBI and the current knowledge regarding brain stem recovery. These issues are relevant to this topic because, as was stated previously, rarely is brain stem integrity thoroughly evaluated after a TBI, despite the important role of this subcortical area in overall brain functioning. Section three will present evidence suggesting that this area is commonly involved as a result of TBI. The ultimate thesis of the section is that by providing brain injured patients with an SCSIT evaluation, the post traumatic integrity of the brain stem may be determined.

The final section of this literature review will provide an analytical framework for the empirical methodology. The various concepts and theoretical relationships of SI theory will be simplified and presented in a manner condusive to empirical analysis.

Theories of Recovery

The purpose of this introductory section of the literature review is to provide a general discussion and presentation of the major theories of bio-behavioural recovery following TBI. The reasons for this discussion is twofold. First, cognitive remediation leading to improvement in functional capacity would not be possible unless the brain possessed some type of restorative mechanisms(s) (Alfano & Finlayson, 1987; Horton & Miller, 1982). While the exact nature of these restorative processes have not been elucidated consistently in the neurophysiological literature, the major issues, theories, and findings may be examined. Ample evidence exists to support the contention that indeed improvement is possible following a traumatic brain injury. Secondly, these theoretical and empirical perspectives are crucial from the standpoint that they provide the foundation upon which cognitive remediation and other forms of rehabilitation may be built (Finger & Stein, 1982). It is not always possible to determine the exact mechanism(s) responsible for recouperation through any given remedial program. However, empirical validation indicating a program's efficacy will inevitably result in a search for the underlying neural/brain process to explain it. In this way, pure research and clinical outcome studies are interdependent (Luria, 1963).

Prior to embarking on a presentation of the major rival theories of brain injury recovery, it is necessary to review some of the terms initially presented in the previous chapter. Traditionally, "recovery of function", and "function" in general are phrases which have often been poorly defined in neuro-behavioural research (Laurence & Stein, 1978). This lack of clarity has resulted in considerable confusion and misinterpretation (Luria, Naydin, Tsvetkova, & Vinarkaya, 1969). For this reason the terms "biological recovery" and "behavioural recovery" will be used for purposes of clarification. The former phrase shall denote significant recuperation of the original biological sequence used to perform a specified activity, which had been disrupted due to trauma.

Behavioural recovery is the organism's ability to perform a pre-traumatic activity, using an alternative biological function, or sequence after the biological function/sequence initially used to perform the task has been impaired. According to Laurence and Stein (1978), this means-ends distinction is important because:

> Clearly, recovery need not imply plasticity, reorganisation, or any other term intended to indicate changes in the neural topography of localized functions if the "recovered", brain-damaged organism is able to achieve goals through the employment of novel tactics or unusual behaviours... (p.p. 370-371)

This point establishes the basis for the distinction between the concepts of "recovery" and "sparing". "Recovery" refers to a return or near return to the premorbid levels of performance, either biologically or behaviourally. "Sparing", on the other hand, denotes the lack of perceived behavioural impairment despite the presence of significant brain damage. In reality, the lack of behavioural impairment may either be genuine, or more likely only perceived, due to the insufficient sensitivity of research/clinical instrumentation and their limited domains of testing.

With the relevant terminology clarified, the major theories of recovery from brain injury will now be presented. The theories will be divided into those which are predominantly biological theories of recovery and those representing the behavioural recovery camp. In conceptualizing the major theoretical positions within the field of brain injury recovery (biological and behavioural), Laurence and Stein (1978) postulated the following categories: structural explanations, physiological mechanisms, and process approaches. The structural explanations encompass those models which describe bio-behavioural recovery in terms of the physical structure of the brain. The physiological mechanism viewpoints describe various underlying physiological processes that may mediate bio-behavioural recovery. Process approaches, the final classification, are characterized by various behavioural recovery paradigms. These will each be discussed in turn.

Structural Explanations

Theoretical viewpoints which fall within the structural realm primarily describe the physical constitution of the brain. "They are static constructs in the sense that no special, particular process is alluded to; rather, recovery is seen as a necessary consequence of the way the brain is organized" (Laurence & Stein, 1978, p. 373).

As such, these interpretations may only account for sparing and not recovery. The explanation regarding this distinction is that a dynamic conceptualization of recovery is lacking. Without a dynamic construct(s) the process of recovery may not be accounted for. However, Laurence and Stein note that when the structural concepts are incorporated with more dynamic constructs, the former may become part of a description of biological recovery.

Equipotentiality and mass action theory was developed by Lashley (1929). The theory suggests that all brain tissue within a given area is of equivalent quality and characteristics. Hence, both biological and behavioural function are equally regulated by all cells in a given brain region. Given this structuralist view, the consequences of a lesion depends upon the extent of damage done to the majority of cells in the area. If some tissue (Mass Action Concept) remains spared, then sparing of function will also occur.

Redundancy or redundant representation theory is a model which closely resembles that of Lashley, and was posited by Rosner

(1970). Lashley's formulation depended upon the homogeneity between the spared and destroyed cells for maintenance of biological function (Laurence & Stein, 1978). Rosner's position, on the other hand, does not necessitate the assumption of cell homogeneity. Nevertheless, the remaining cells in an otherwise destroyed brain area, may execute the desired behaviour, unimpaired. Despite cellular specialization within a region, a certain degree of redundancy may exist between neighbouring cells.

Multiple control theory argues that any given behavioural function is mediated by more than one biological centre (Rosner, 1970). The destruction of one such regulatory area, results in loss of biological function in that area, but not a loss of behavioural functioning as other centres remain intact. Laurence and Stein (1978) criticise this theory as being "an untestable and therefore unfalsifiable hypothesis" (p. 376). Their argument is based on the fact that despite the presence of a behavioural function after each successive abalation of centres supposedly responsible for that behaviour, yet another centre may be postulated ad infinitum. However, in support of Rosner, it is not inconceivable that a constellation of abalations (hence centres) that destroys the behavioural target, may be confirmed by the destruction of all but one lesion site in subsequent experiments on a rotational basis. Hence, the necessary and sufficient conditions for behavioural functional integrity may be established and attributed to the identified multiple centres. Although, it may not be the most parsimonious and operational of theories, the multiple control theory cannot be dismissed from the realm of possibility.

Vicarious function has appeared in various forms and is closely related to redundancy theory (Goldberger, 1974). In this model a system may have dormant potential to initiate certain behavioural output, normally ascribed to a system which has been damaged. Vicarious function differs from redundancy theory and equipotentiality in that the first is based on an heirarchical formulation of the systems and substitution across systems. The other two theories view substitution within a given system.

An unpublished report by Wall (cited by Laurence & Stein, 1978) exemplifies this model well. In this presention, under normal conditions, higher and more recently evolved cortical brain areas may control lower, older structures through inhibition. Following lesion of a higher area, the inhibitory control is released, and the lower centre may be enabled to mediate the behavioural function in question.

In reviewing the structuralist positions, Horton and Miller (1984), cite several investigators (e.g. Dawson, 1973; LeVere, 1975) who consider the substitution of one brain area for a damaged one -- whether by inter-area or intra-area means -- as being highly unlikely in the human adult. The following quotation by Kalat (1981, p. 420) was presented by Horton and Miller to substantiate this point of view:

> For an area that has already established its functional specializations to take over some functions it would have to reverse some of the changes it has already undergone, cancel many of its synaptic connections, and then reorganize in some new way. There is no substantial evidence that this ever occurs, and it seems very doubtful that it does. (p. 80)

Aside from their position on multiple control theory research, Laurence and Stein (1978) criticise structuralist investigations because they derive their support from researchers' inability to detect deficits, regardless of whether or not these deficits do in fact exist. Although the failure to find deficits is the sine qua non of the concept of sparing, their caution is understandable: Measurement techniques are imperfect for detecting subtle change and behavioural change may occur in an unmeasured domain.

Physiological Mechanisms of Recovery

Physiological mechanisms of recovery may complement rather than oppose the other more theoretical (structural and process) explanations of recovery. Laurence and Stein (1978) go to great lengths to illustrate that a specific physiological mechanism may be used in support of numerous theoretical positions. In particular, the dynamically-oriented concepts, which will be discussed in the next section, may rely upon the following processes as their physiological basis.

Diaschisis is among the oldest of physiological explanations and was advocated by Von Monakow in 1914. This concept, also associated with that of "suspension of function", was used to describe transient symptoms following brain damage. According to Finger and Stein (1982), "Von Monakow coined the term... to describe the relatively short-lived effects he believed were due to inhibition of activity in brain areas close to the initial site of the damage" (p. 258). The actual mechanism of diaschisis is considered to be one of neural shock during which neural excitation is suspended in the area of the lesion. The lesion may have destroyed the neurons in the immediate vicinity, temporarily suspended their firing, or interrupted their axons projecting to other cell groups. In any of these cases, other neurons normally receiving input from the damaged area would become less active for a period of time immediately following the insult. Eventually, the secondary neurons involved, having other sources of afferent communication, would regain their ability to function independently of the lost source of input (Finger & Stein, 1982).

The concept of diaschisis has recently been used to describe recovery from non-neural changes such as the alterations in non-injured hemispheric blood flow (Meyer et al., 1970), changes in the biochemical milieu (Faugier-Grimaud, Frenois, & Stein 1978), and edema (Luria et al., 1969). However, proponents of Von Monakow argue that such processes, although perhaps valid, are fundamentally different from diaschisis (Finger & Stein, 1982). Such controversy has resulted in confusion over the definition of the original term.

At the time of the writing of their book, Finger and Stein, indicated that the empirical evidence for diaschisis was equivocal. It is noteworthy that this concept describes the processes of sparing and/or spontaneous recovery. No true biological or behavioural recovery would have taken place upon termination of the neural suppression.

Axonal regeneration involves biological recovery through regrowth or regeneration of axons in the damaged region. Moore (1974) describes the regenerative process as it occurs following the destruction of a central adrenergic (adrenalin producing) neuron in the rat:

> Within two or three days after the injury the proximal stumps of severed axons are seen as coarse, beaded and distorted fibres. By a week after transection of the axon regenerative sprouts appear from the proximal stump as groups of small, densely packed, delicate, varicose fibres. Between the first and third weeks following an injury the fibres develop into an abundant system which substantially fills the proximal border of the lesion... (p. 113)

As was cautioned by Moore, the above description merely demonstrates axonal regrowth capacity and not necessarily biological or behavioural recovery. In fact the state of the research seems to suggest that even when bio-behavioural recovery is confirmed (e.g. Bjorklund & Stenevi, 1971; Svengaardt, Bjorklund, & Stenevi, 1976), such confirmation rarely occurs and may be limited to specific types of neurons. For example, while adrenergic and dopaminergic fibres have been found to regenerate significantly, cholinergic neurons have been less successfully studied (Finger & Stein, 1982). Likewise, thin unmyelinated axons seem amenable to regrowth, whereas long myelinated fibres tend to abort regeneration (Svenguardt et al., 1976).

Most salient to this theory is whether the exact point-to-point axonal connections must be reestablished in order for behavioural recovery to occur. Neuronal regeneration has been viewed by some as a chance occurance as opposed to a teleological process (Finger & Stein, 1982). Axons are viewed as filling the synaptic voids caused by the lesion. As such, they may survive on the basis of physiological or biochemical properties, rather than on behavioural grounds. Even if some original axons were to reestablish their initial connections, these connections would have to be numerous enough and biologically efficient (i.e. biochemically and electrophysiologically sound) enough in order to promote behavioural recovery. Finally, biological recovery may be aborted if targets do not exist for the newly formed terminals to grow toward (Finger & Stein, 1982). Furthermore, the post-traumatic development of scar tissue may preclude functional connections from being made (Rosner, 1974). On the brighter side, Laurence and Stein (1978) postulate that once the necessary and sufficient conditions to promote point-to-point CNS connections are known, it may be possible to guide the process of axonal sprouting artificially.

Collateral sprouting mechanisms are of two types (Moore, 1974). The first mechanism involves the development of new branches from undamaged axons in the area surrounding the lesion. The branches then make synaptic contact (reactive synaptogenisis) with denervated cells in the vacated area. The second process involves the sprouting of branches from a damaged, as opposed to intact axon. The collateral contacts--which the neuron maintains despite some degree of axonal damage--are reinforced by sprouting within an intact area (see Figure 1). As the axon regenerates a few weeks later and the original neuronal organization is reestablished, the sprouted branch degenerates. The explanation of the figure is as follows:

> (A) Normal neuron with axon with a collateral and two separate terminal fields. (B) Axon is severed and distal portion degenerates. (C) Collateral sprouting with increase in terminal field occurs from axon, while severed portion shows early regenerative sprouting with a restrictive terminal field. (D) Regenerative sprouting produces a full size terminal field and collateral terminal field returns to normal. (Moore, 1974, p.122)

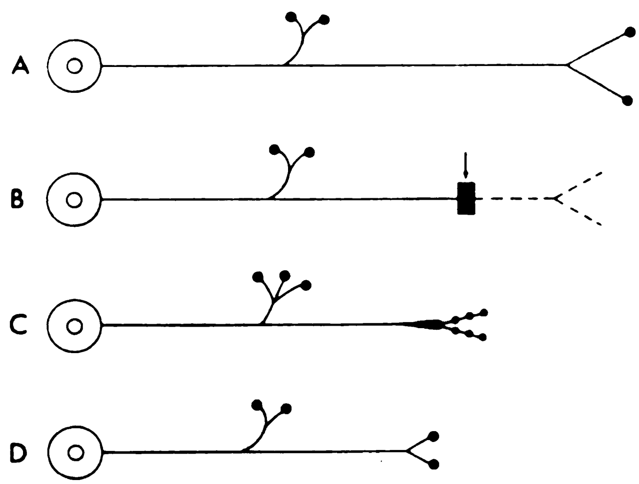

Figure 1. Collateral sprouting from collaterals of transected axons, a proposed model.

Note. From "Central regeneration and recovery of function: The problem of collateral reinnervation" by R.Y. Moore, 1974, in D. G. Stein, J. Rosen, & N. Butters (Eds.) Plasticity and recovery of function in the central nervous system (p.122), New York: Academic Press Inc. by Academic Press Copyright 1974. Reprinted by permission.

Citing research by Raisman and Field (1973), Laurence and Stein (1978) state that collateral sprouting may be site- or neuron-specific. The extent of this process is contingent upon "the rate at which axonal debris resulting from a lesion is removed from the damaged area" (p.388). Although Moore (1974) presents evidence from several studies that collateral sprouting occurs, he questions the functional significance of this mechanism from a bio-behavioural recovery standpoint. Rosner (1974) disagreed that collateral sprouting would always result in positive synaptic contacts thereby improving bio-behavioural functioning. Conversely, he ackowledged that many of the new synaptic contacts can be disruptive of the neurons receiving them. In a later review, Finger and Stein (1982) echoed Rosner's remarks with greater specificity. Their summary of the literature is presented below:

> ...The question of whether collateral sprouting can enhance recovery after brain damage, prevent it, or have no measurable behavioural affects is still not completely resloved. Although the findings of Goldberger and Murray (1978) and Lynch and his colleagues strongly suggest that anomalous growth after injury can have beneficial consequences for the organism, Teuber (1975) points out that sprouting may play a role in the development of spasticity after central nervous system damage (Liu and Chambers, 1958, McCough, Austin, Liu and Liu, 1958), as well as in epileptogenisis (Bowen, Demirjian, Karpiak, and Katzman, 1973). Devor and Schneider (1975) hypothesize that adaptive changes could reflect the degree to which collateral sprouts resemble the normal projections to a region, and they stress that these new connections could be maladaptive under some circumstances. One reason for this is that the collateral sprouts may prevent fibres that normally would grow into an area from reestablishing their synaptic contracts. It can also be argued that the new projection could introduce noise in the system. (p.100)

Denervation supersentivity may be described as increased sensitivity to synaptic input by a postsynaptic neuron which has been deprived of such input for some time. Normally, such deprivation of synaptic transmission is caused by the destruction of pre-synaptic neurons. The matter to which the neuron becomes hypersensitized is either the original neurotransmitter (neurochemical) or an alternative (endogenous) neurotransmitter. One may also conceive of supersensitivity in a generic sense, regardless of whether it pertains to the susceptability of neurons to endogenous neurotransmitters or, to exogenous drugs, which may block synaptic transmission. When this is the case, the term "dissuse supersensitivity" is often applied (Glick, 1974).Horton and Miller summarize the denervation supsensitivity concept as follows:

> ...a muscle cell becomes more sensitive to the synaptic transmitter acetylecholine, if the axon attached to it is removed (Diamond and Miledi, 1962). Any spared fibres in a given region which release the same transmitters could have a larger effect than usual, i.e., a super effect, and then a fraction of the system could compensate for a loss of axons that innervated some structure. This mechanism may partially compensate for loss of axons that innervate some structure. (p. 81)

As was described with the collateral sprouting model, this mechanism may also have deliterious effects under certain circumstances. For example, if a neuron which normally receives antagonistic input from two sources loses one, then the loss of that agonist may result in supersensitivity towards the remaining one. However, such a process may be detrimental and may produce deficits because of the new agonistic relationship between the components (Finger & Stein, 1982). A number of investigators (Glick, 1974; Laurence & Stein, 1982) cite several studies that support the existence of denervation supersensitivity. In fact, studies involving the inner eyelid membrane have found an 125 fold increase in sensitivity to epinephrine following chronic denervation, and a 40 percent increase in sensitivity in the nigrostriatal dopamine pathway in the brains of rats (Finger & Stein, 1982). Currently, research has focused more extensively on this phenomenon in the peripheral, as opposed to central, nervous system.

However, Glick (1974) emphasizes that in some investigations, it is unclear whether this model of collateral sprouting had been responsible for bio-behavioural recovery. The model itself falls short of providing a comprehensive explanation of biological restoration. As Laurence and Stein (1978) note, in the event that a large number of inputs are destroyed, resulting in inadequate neurotransmitter supplies, no degree of supersensitivity could mediate synaptic transmission. For this reason, denervation supersensitivity may best be conceived as a mechanism complementing others such as vicarious functioning, multiple control, or behavioral compensation (Finger & Stein, 1982).

Process Approaches to Recovery

Process approaches to recovery emphasize behavioural restoration as opposed to biological restoration. By their dynamic nature, these hypotheses are most suitable for describing true "recovery" unlike the static structural models.

Functional or behavioural substitution is synonomous with learning. The brain is perceived as utilizing intact areas to achieve an alternative method for accomplishing a behavioural objective (function) once mediated by a now defunct biological function (Golderberger, 1974). It is important to recognize that this theory neither accounts for nor emphasizes biological recovery in any way. The complete emphasis is on recouperation of purposive functioning.

Perhaps the strongest and most widely researched proponent of this approach is Gazzaniga (1974, 1978). From a physiological perspective this investigator has argued in favour of the principle of diaschisis to explain biological recovery phenomena, as opposed to the less aluring structuralist positions. However, he presents two laboratory scenerios, one of which suggests behavioural recovery had taken place before biological restoration through diaschisis could have occurred; and a second example illustrating behavioural restoration beyond the point where physiological recovery may reasonably be expected to account for such change (Gazzaniga, 1974). The behavioural substitution position postulates that:

> recovery in the adult, arising from non-physiological improvement, is the result of pre-existing behavioural mechanisms not necessarily previously routinely involved in a particular act now covering for the mental activity under question.... We believe that the behavioural dysfunction supposedly resulting from discrete lesions in the brain can frequently be quickly circumvented by changing environmental or behavioural contingencies. (Gazzaniga, 1974, p. 205)

In both papers (1974, 1978), Gazzaniga is able to present several investigations using adult humans which argue convincingly for his position. These studies showed that using behavioural strategies right-handed split-brain (commissurotomy) patients were able to verbalize (left-hemisphere function) the name of objects perceived stereognostically with the left hand (right-hemisphere function), when choices for object selection were limited (Gazzaniga, 1970). Similar procedures and results were found for visual-verbal tasks (Gazzaniga and Hillyard, 1971). In a later case study of a right parietal lobe stroke patient verbalize (left-hemisphere function) the name of objects perceived stereognostically with the left hand (right-hemisphere function), when choices for object selection were limited (Gazzaniga, 1970). Similar procedures and results were found for visual-verbal tasks (Gazzaniga and Hillyard, 1971). In a later case study of a right parietal lobe stroke patient with a 139 verbal I.Q., the patient was eventually able to use a verbal strategy to improve his extremely poor post-infarct block-design (traditionally right-hemisphere function) scores (Gazzaniga, 1978).

Similar behavioural strategies were found to be effective with split-brain patients experiencing word finding (dysnomia) difficulty upon visual word presentation to the right hemisphere (Gazzaniga, 1978). In these investigations, when one particular (right handed) patient was presented visually with various nouns, he was unable to recognized the words. However, when a verb such as "point" or "rub" was presented, then the subject would carry out the corresponding motion of pointing or rubbing using his left arm. He gave the correct reponse verbally. When this phenomenon was further analysed, it was found that the patient's left hemisphere was able to identify the motion of his left arm (which became a cue), and label it. Thus, the word "point" was identified correctly, but more ambiguous motions were often misidentified e.g. "itch" was given as the response instead of the correct word "rub".

The process of behavioural recovery is well illustrated by the above examples. In each case a specific strategy or cue-producing response enabled the subjects to give correct responses under certain conditions despite the significant and permanent loss of the original biological apparatus which had previously mediated the behaviour.

Laurence and Stein (1978) caution that "a substitution theory would have to explain how the "substituted " area can mediate its own functions and "take over " new responsibilities without some change in its capacity or efficiency" (p. 380). However, as Gazzaniga has demonstrated, the issue is not one of "taking over responsibility". Rather, the proposed mechanism employs altogether different behavioural sequences within the present behavioural repertoire to accomplish the task at hand. Furthermore, new behavioural sequences may be learned. The point is that the intact brain areas continue to produce the same behavioural output and continue to have the same learning potential, as they did pretraumatically. Hence, unimpaired brain areas are not truly substituting or taking over for destroyed regions as Laurence and Stein suggest. It would follow that there also need not be a corresponding decrease in "capacity of efficiency".

Radical reorganization or retraining is summarized by Luria in the following quotation:

> A pathological focus arising as the result of a wound, of haemorrhage, or of a tumor disturbs the normal working of a given brain area, abolishes the conditions necessary for the normal working of the particular functional system, and thus leads to reorganization of the working of the intact parts of the brain, so that the disturbed function can be performed in new ways. (Luria, 1973, p.p. 103-104)

This hypothesis is best understood when some of the basic tenets of Luria's position are explained. The concept of the "functional system" lies at the heart of Luria's thinking (Luria, 1980, 1973). A functional system describes that individualized pattern in various areas of the brain that act in unison to give rise to any given overt or covert behaviour. The concept emphasizes the interdependence of motor and sensory zones which work in concert--simultaneously or in sequential order. Each of these zones is integral to the successful completion of the overall task. The areas involved in a functional system are often located in completely different parts of the brain (Luria, 1973). Luria believed that a given cognitive or behavioural activity may be achieved through a variety or functional systems. Further, the organization of the social environment is thought to be the most significant determinant of neural functional systems in humans. Hence, skills such as abstraction, computation and speech are viewed as being learned behaviours rather than innate ones (Horton & Miller, 1981).

A good example of a functional system was illustrated in the last section. The reader may recall Gazzaniga's (1978) study employing the split-brain subject. The subject was asked to verbally respond to visual word presentations to the right hemisphere. Roughly, the functional system involved in a non-commissurated person, in gross anatomy terms, would be as follows: (a) reception and synthesis of the image in the right occipital lobe; (b) commissural communication between right occipital lobe and posterior area of the left temporal lobe; (c) left postero-temperal area analysis and identification of object by name; (d) neural communication (via the superior longitudinal fasciculus) between the object-naming area and Broca's area; (e) execution of motor pattern for verbalization of object name. The most strict Lurian position would recognize the necessity of all three major brain roles to be incorporated into each and every functional system. Golden (1978) summarizes these three roles as follows: "The first is the regulation of the arousal level of the brain and the maintainance of proper tone. The second is the reception, integration, and analysis of sensory information from the internal and external environments. The third involves planning, executing, and verifying behaviour" (p. 10). In the case of the split-brain patient, this functional system is interrupted at point 'b'. He was able to utilize an effective behavioural strategy by introducing (partly consciously) the following new steps to complete the process: (b-1) although unable to nominally recognize the word, the word's meaning (for self-oriented verbs only) was communicated to the right frontal lobe; (b-2) the right frontal lobe executed a motor pattern for the corresponding action word (i.e., the action of "pointing", or "rubbing") to be carried out by left upper extremity; (b-3) visual input of extremity movement to left occipital lobe; (b-4) communication between left occipital lobe and left posterior temporal area. The remainder of the functional system would be synonomous with the original formulation with the original formulation.

One can now imagine the consequences of lesions in different parts of the brain in the case above, and the diverse consequences each would have. The example illustrates Luria's (1973) point that a "functional system as a whole can be disturbed by a lesion of a very large number of zones, and also that it can be disturbed differently by lesions in different localizations" (p.p. 38-39). Contingent upon the extent of the lesion and its location within the functional system, the impact of insult may range from subtle to profound. With these underlying concepts explained, one may now come to understand the rationale for the radical reorganization hypothesis. Luria suggested that lesioned components of old functional systems may be replaced by others (as in the previous example), or new functional systems could be established (Luria, 1963). Either process would be founded upon intact neurological and physical structures. Horton and Miller (1981), site three mechanisms which Luria postulated to explain radical reorganization. First, a non-functional hemisphere may be replaced by the other hemisphere. Secondly, a subcortical area may replace an impaired cortical one. And thirdly, a cortical region may fulfill the role of a lesioned subcortical site. For each of these cases favourable research support is presented in Golden (1981) and Horton and Miller (1981). As was demonstrated by the earlier example of a functional system, other mechanisms of radical reorganization include replacement of behavioural function intracortically.

This model differs from hemispheric replacement as, in the case illustration the communicative link between hemispheres was severed, as opposed to damage within the hemispheres themselves. The right and left hemispheres were forced to communcate using alternate cortical means. Presumably subcortical-subcortical replacement may also occur although a specific example of such is not readily available.

The primary distinction between Gazzaniga's behavioural substitution and Luria's radical reorganization appears to be one more of form, than of substance. Each believes in new learning capacity, and adaptive functioning through the employment of a different behavioural strategy from the one in use prior to the lesion.

Summary of Recovery Theories Literature

The aforementioned theories and mechanisms of recovery were reviewed in order to provide a credible foundation upon which cognitive remediation strategies may be based. Theoretical models were presented from three perspectives: the structuralist approaches with their emphasis on static brain relationships and composition; mechanisms involving physiological processes; and, strictly behavioural mechanisms under the guise of process approaches to (behavioural) recovery of function. Although no particular theoretical victor has emerged, the research evidence surveyed here has supported the contention that biological and behavioural recovery exist under various circumstances. In summarizing the literature and research evidence upto to 1974, Goldberger (1974) made the following comment which holds true today:

> ...the evidence suggests that there is no one mechanism common to all lesions nor is there one which accounts for all the recovery following any one lesion. Rather it would appear that the behavioural changes which we interpret as recovery result from the collective contributions made by several mechanisms acting together upon an altered nervous system. (p.p. 314-315)

This review has addressed two important issues. First, the general hypothesis that recovery from brain damage is possible, appears to be a valid one. This notion is substantiated to various degrees depending upon the recovery mechanism in question. Secondly, this review recognizes the concern that many cognitive remediation programs do not draw upon specific mechanisms of recovery to explain their success (Alfano & Finlayson, 1987; Diller & Gordon, 1981). These programs tend to rely upon empirical measures of success and on the general assumption that biological and/or behavioural recovery occurs. Rather, than emphasizing a specific mechanism, often programs will state whether they focus generally on behavioural, or biological recovery, or both. Whenever possible, it is important for program developers to indicate the specific recovery mechanism which they perceive as being operative and paramount to their approach (Finger & Stein, 1982). This clarification should enhance the link between research and clinical work, and promote the development of recovery-oriented hypotheses, and measures for program evaluation.

Sensory Integration Theory

This section of the literature review will present a full description of the theory of Sensory Integration. It will address the major background issues pertaining to the theory's development and implementation, the theoretical concepts and stages, and the relationship between this theory and the Piagetian theory of cognitive/intellectual development. The model being reviewed and developed in this section is particularly well suited to address the criticisms towards atheoretical treatment and assessment programs (Kulkarni, 1987).

Background Issues

The Southern California Sensory Integration Tests (SCSIT) are based upon the theory of sensory integration as presented by Jane Ayres (1973). At Michigan State University (MSU) Rehabilitation Clinic, the SCSIT is accompanied, Minnesota Spatial Relations Test, Purdue Pegboard, and by certain subtests of the WAIS-R. As a comprehensive assessment, the administration of the above tests yields an overall evaluation of the patient's cognitive-perceptual-motor (CPM) functions, eye-hand coordination and cognitive behaviour (eg. attention, concentration, calculations etc.) More specifically, the collective use of the instruments can be categorized into the following areas of assessment and cognitive rehabilitation:

1. Visual perceptual functioning - visual memory, visual-motor coordination, figure-ground perception, size, shape, and depth perceptions, directionality, visual sequencing, visual scanning, visual field neglect.

2. Somatosensory perceptual functioning - laterality, motor planning (input), tacto-kinesthetic sense (especially haptic sense), tacto-kinesthetive memory.

3. Motor performance - motor planning (output), eye-hand co-ordination, left-right discrimination, discontinuous vs. smooth motor movement, grip strength, fine finger dexterity.

4. Vestibular functioning - postrotatory nystagmus, balance integrity.

5. Auditory perception - sound discrimination, figure-ground auditory perception.

6. Memory functioning - determination of strongest channel of functioning and impaired channels; assessment of visual, auditory, tacto-kinesthetic memory over immediate, short and long terms.

7. Independent living skills assessment.

Once the evaluation is completed, the individual's functioning may be assessed within a framework of sensory integration. The sensory integration model as presented by Ayres (1973, 1979) views the major role of the brain as being the control over the muscles based on sensory processing and feedback. The process of sensory integration is believed to be the primary mode for the nervous system's organization. Sensory input becomes organized for perception, adaptive response, and neural functional development. According to Ayres, neurodevelopment is the process of systematic organizations of the brain based initially on motor planning (praxis), or the sequencing of unfamiliar actions. With repetition, these actions become automatic, integrated, and triggered according to a cognitive-perceptual cue. In other words, the nervous system must first establish reflex integration and motor control over finer movements before a response repertoire can exist. Once actions are under cortical control, the receipt of sensory input is compared to past cognitions (within the sensory-relevant association area of the cortex). If the desired response is within the response repertoire, then an automatic response is emitted. On the other hand, the lack of an appropriate response (or partially available one) in the repertoire, will mean that motor planning must occur prior to the response being carried out. Hence, when an individual is first learning to drive fot example, the person is acutely aware of all the necessary information: feedback from the feet as one is learning about the sensitivity of the brake, accelerator and clutch; visual information for the perception of spatial relations, distance, and relative velocities of oncoming vehicles; and information regarding the timing of gear changes. Initially, this learning process is one of constant motor planning, but it eventually gives away to automatic response patterns which allows the individual to concentrate on a conversation, shopping list or radio broadcast as opposed to the task of driving.

With respect to the development of skilled movement, Waterland (cited by Weeks, 1982) proposed the following essential components:

> (1) sensory input from within and outside the body, (2) reflexes elicited in association with purposeful acts, and (3) voluntary movements that may be cortically controlled. Poor or unskilled movement is said to be dominated by cortical control, while skilled movement is the result of integration and balance of willed and [subcortically controlled] reflexive actions (Weeks, 1982, p.189).

The relevance of this sensory integrative and motor-planning/automatic response system is critical to brain injury. By the same token, signs of sensory integrative dysfunction may not be easily identifiable, as they tend to be more mild forms of neurological impairment i.e. soft, as opposed to hard neurological signs. In applying the model to learning disabled children, Ayres (1973, 1979) classifies these impairments as "minimal brain dysfunction" to represent their mild and potentially rectifiable nature. (It is important to acknowlege that this diagnostic entity is not fully accepted in the literature because the relevant empirical evidence remains equivocal (Satz & Fletcher, 1981)). However, the mild nature of the etiology is not to be confused with the severely disabling condition which may occur as a result of the dysfunction.

> Even though sensory integrative dysfunction is caused by irregular activity in the brain, most neurologists .... will not find anything wrong in the [person] with sensory integrative dysfunction... Minimal brain dysfunction can cause many different problems: poor sensory integration is just one of these. It can and often does, result in aphasia...severe behaviour problems, and other psychological problems. (Ayres, 1979, p. 51-52)[1]

Ayres goes on to emphasize that, at least in the case of children, individuals with sensory integrative problems may be of normal or above normal intelligence. However, the individual may have difficulty abstracting and generalizing, may be easily distracted, and hypersensitive to sound and light. Furthermore, visual perception may be effected, disturbing the individual's ability to read, perceive oncoming traffic, or find a specific object in a crowded space. In all of these situations, the sensory organs and tracts themselves may be asymptomatic. It is the integrative process itself which is dysfunctional. Ten symptoms which are most prevelant in children with learning disabilities were sited by Clements (1973): (1) hyperactivity, (2) perceptual-motor impairment, (3) emotional lability, (4) general coordination deficits, (5) disorder of attention (short attention span, distractibility perseveration), (6) impulsivity, (7) disorders of memory and thinking, (8) specific learning disabilities (reading, writing, spelling), (9) disorders of speech and hearing, 10) equivocal neurological signs and electroencephalographic irregularities. Certainly all of this symptomatology has been commonly observed in cases of mild to severe head injury (Luria, 1980; 1973) Likewise in the TBI population objective evidence of these symptoms is often lacking (Lezak, 1983). It is upon this basis SI theory may be applied to the assessment and treatment of the head injured. The following presentation of sensory integration theory will provide supportive evidence for most of its primary principles. For a full review of the theory's empirical support from the pure science literature, the reader is referrred to Ayres (1973; 1979).

The Levels of Sensory Integration

Ayres emphasizes that the most often neglected, yet most critical, sensory systems are the vestibular system, the proprioceptive system, and the tactile system. The reticular core of the brain stem plays an integratory role with respect to these basic functions (Barr & Kiernan, 1983). The vestibular nuclei act as important centers for the processing of

> vestibular input along with information from the muscles, joints, skin, and visual and auditory receptors. In addition, they organize impulses from many other parts of the brain, including the rest of the brain stem, the cerebellum, and many parts of the cerebral cortex..... The brain senses and responds to vestibular input long before we process visual and auditory inputs and this vestibular activity provides some of the building blocks for the later development of seeing and hearing. (Ayres, 1979, p. 70).[2]

Evidence supporting this view is presented in Baloh and Honrubia (1979), and Felten and Felten (1982).

The vestibular system also acts as an internal frame of reference for the individual (Ayres, 1973). The interaction of gravity with the vestibular receptors provides the individual with a sense of directionality and basic orientation to self and the external world (Baloh & Honrubia, 1979). More accurately, the vestibular system detects information about the position of the head relative to the vertical (gravitational) and horizontal planes. "For the brain to know the relationship of object, head, and body, the gravity and movement sensations must interact with muscle and joint sensations, especially from the eyes and neck" (Ayres, 1973, p. 71). It is through this regulatory process that the vestibular system adjusts the eye and neck muscles to maintain a stable visual field while the individual is in motion. Likewise, the uninterrupted flow of vestibular information to the muscles and joints, and proprioceptive feedback to the vestibular nuclei allows for the balance integration to be maintained automatically, without conscious effort. A disorganized vestibular system, alone or coupled with low muscle tone, may result in a person tiring quickly (Ayres, 1979). This phenomenon of fatigue is often observed in post-concussive patients (Rutherford, Merrett, & McDonald, 1977).

Other functions of the vestibular system include: the exchange of information with the cerebellum which refines sensory input for finer motor control; and, linking visual and auditory information (Felten & Felten, 1982). The central place accorded to the vestibular system is expressed in Ayres' (1979) statement that:

> All types of sensory input come together in the vestibular nuclei and reticular core of the brain stem. Then some of them flow up to the thalmus at the top of the brain stem for further integration. Sensory integration is completed in the cerebral hemispheres, where the information from the distance receptors--eyes and ears--is processed into precise perceptions and associations.... The visual areas of the cerebral cortex receive so much input from the vestibular system that proper development of vision would be impossible without adequate vestibular functioning throughout the years of childhood. Less is known about how vestibular activity influences the auditory process in the cerebral cortex, but it is known that vestibular activity is important for auditory processing in the brain stem. (p. 75)[3]

In support of her thesis, from a neurophysiological viewpoint Ayres (1973) sites Jung's research (Jung, 1961; Jung, Kornhuber & DaFonseca, 1963). Working with cats, Jung (1961) demonstrated the convergence of visual, vestibular and ascending reticular activating system (RAS) afferents on single neurons. This finding was interpretted as evidence that the vestibular projections provide stability of the visual image by offsetting the effects of head and body movement; simultaneously, the RAS provides cortical stimulation to enable sustained attention towards the visual field. A second study by Jung, indicated that vestibular stimulation of the labyrinthine in the cat, produced impulses throughout the cortex, and activated 90 percent of the visual cortex neurons in particular. Coupled with the first finding, the researchers postulated that the brain stem precoordinates the cortical visual-vestibular convergence.

The primary level of sensory integration

Ayres (1979, 1973) considers the integration of vestibular and proprioceptive information to be the primary level of sensory integration. She argues that such integrity is the foundation for the establishment of sound visual and tactile processing and balance functioning, all of which if impaired, may disturb the person's emotional functioning. Balance problems, poor muscle tone and auditory/visual perceptual distortions may be indicative of sensory integrative dysfunction at this level. In the case of head injury, balance difficulties may best be observed when the patient's eyes are closed standing on either foot. It seems that the head injured patient may compensate for the balance dysfunction by relying upon visual as opposed to proprioceptive sensory input (Baloh & Honrubia, 1979). When vision is occluded, the vestibular impairment is manifest to a greater degree.

The remediation of deficits at this level primarily revolves around specific activities to improve the individual's balance, haptic sense, and proprioceptive functioning.

The second level of sensory integration

The second level of sensory integration involves the development of the body percept (Ayres, 1979):

> A body percept consists of body "maps" that are stored in the brain. These maps contain information about every part of the body, the relationships among all the parts, and all the movements each part can make.... If the [body] percept does not contain a lot of good, clear information about the relationships between the left and right sides of the body, the [person] will have difficulty doing things that will require both hands or both feet together.... If the brain does not have accurate "maps" of the body, then it cannot "navigate" or plan body movements. Most adults can use a fork or put on a shirt automatically, but a young child must "motor plan" these actions. Motor planning is the sensory sensory process that enables us to adapt to an unfamiliar task and then learn how to do the task automatically. The key to motor planning is a body percept with accurate tactile, proprioceptive and vestibular information. (p. 63)[4]

Similar to the young child, the body percept of a head injured person may be distorted due to direct organic insult to the parieto-temporal association areas (Luria, 1980, 1973), and (hypothetically) indirectly, through poor tactile, vestibular and proprioceptive integration.

Several implications of dysfunction at this second level become pertinent to the sequalae of head injury. First, a poor body percept results in more time and energy being alloted for motor planning. This may explain the phenomenon of rapid fatigue among brain injured patients (Rutherford et. al, 1977). Secondly, motor planning may not occur at all if the body percept becomes destroyed due to insult, resulting in sensory disorganization. Luria (1980) has discussed the relationship between apraxia and an impaired body percept.

Thirdly, the individual is likely to experience emotional instability and poor attentional faculties as "auditory and visual stimuli may distract or overexcite [the individual] and usually do so when sensations from the body and from gravity are not well organized" (Ayres, 1979, p. 63). In the case of children with sensory integration dysfunction, Ayres has found that both hyperactivity and emotional withdrawal and isolation (i.e. psychomotor aggitation and retardation) can be consequent to such conditions. Much has been documented regarding these characteristics even in those with minor head injury (Rutherford, et. al., 1977; Rimel et al., 1984; Levin et al., 1987). Finally, problems involving left-right discrimination and directionality can also be viewed within this framework (Ayres, 1973).

Rehabilitation of the sensory integrative dysfunction at this level should focus on kinesthetic activities which promote motor planning and automatization of critical body movements.

The third and fourth levels of sensory integration

Figure 2 on the following page best depicts the dynamic integration process of the senses. At the third level, visual and auditory perception become integrated with the vestibular system (the body's frame of reference). Depth perception, spatial relations, figure-ground perception and objects in relation to one another will only be accurately perceived if the underlying sensory systems are well integrated. Further, sound eye-hand coordination and engagement in purposeful activity in general are contingent upon vestibular and proprioceptive information for direction. According to the Ranchos Los Amigos Scale (Hagen, et. al., 1979) the achievement of

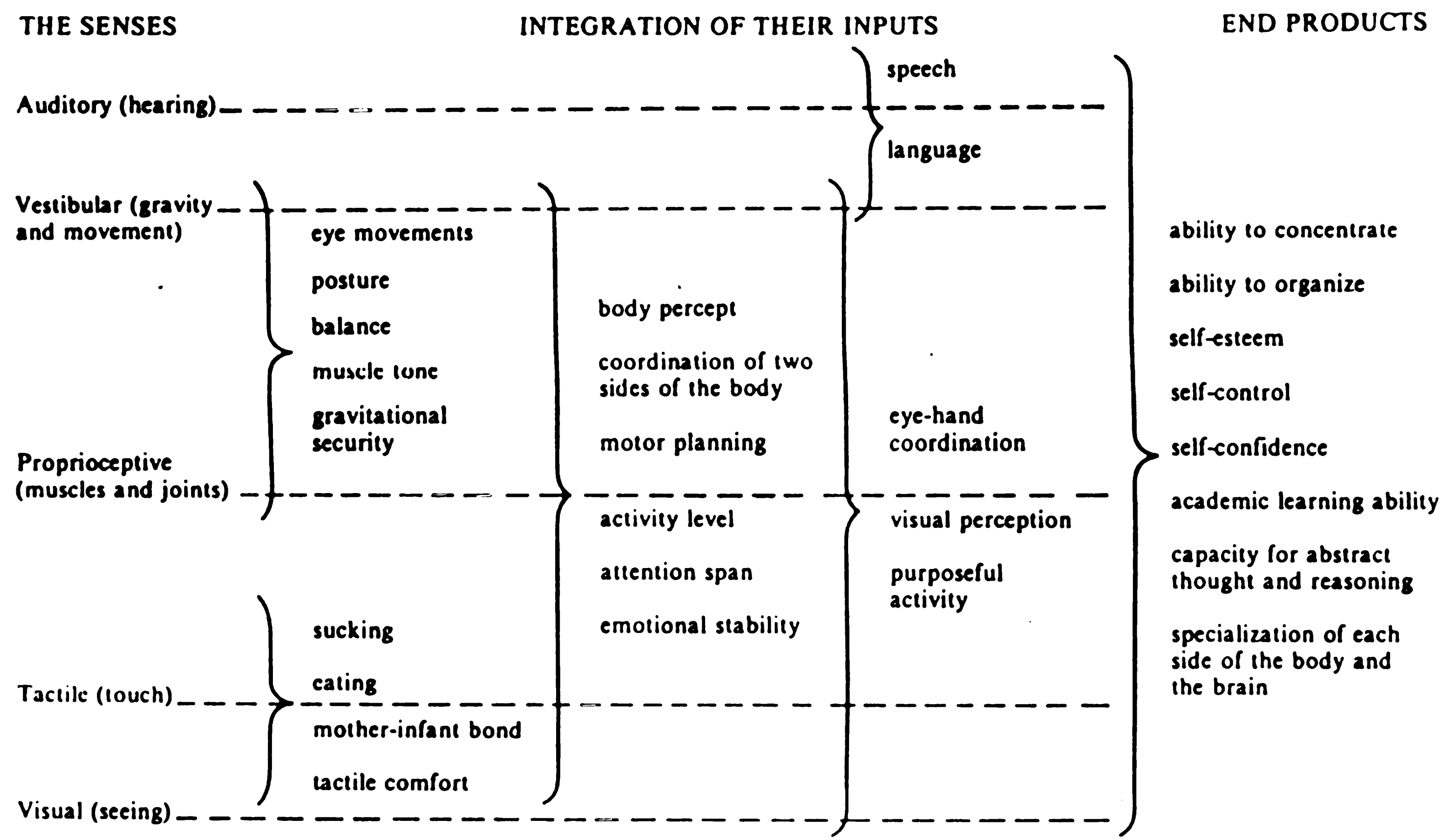

Figure 2. The senses, integration of their inputs, and their end products.

purposeful activity is one of the final indicators of head-trauma recovery.

> It is not merely enough to integrate the information from the eyes with messages to the hands; the brain also needs relevant information from gravity and movement receptors and the muscles, joints, skin of the entire body. Thus [people] with vestibular, tactile, or proprioceptive disorders often have trouble with eye-hand coordination. They cannot tell where or how to draw lines or colour between the lines. (Ayres, 1979, pp. 64-65)[5]

The fourth SI level yields one's ability to concentrate, to organize and to develop self-esteem, self-control and self-confidence. At this stage the individual has laid the foundation for academic learning ability (hence, short term memory capacity), and the capacity for abstract thought and reasoning.

Piaget's theory of cognitive-intellectual development

Jean Piaget's well recognized theory of cognitive-intellectual development will be reviewed to support the developmental heirarchy postulated by the SI theory. Evidence for Piaget's theory has come from many investigations with children of different ages and backgrounds (Hilgard, Atkinson, & Atkinson, 1979). In particular, the former model will be utilized to strengthen the SI position regarding the relationship between sensory-perceptual-motor and cognitive development development at the higher levels.

According to Piaget, the development of higher level cognitions depends upon the process of adaptation to the environment. During the process, periods of stability occur in which new experiences are easily assimilated into the individual's view of the world. However, periods of instability (characterized by tension, frustration and striving) arise when new experiences are no longer understood within the old world view. Transition to a new balance is therefore achieved by the accommodation of the old world view to the new experience (Piaget, 1954). The movement to the new balance is believed to be qualitative and represents the developmental progression to a higher stage (period). Throughout the developmental process, cognitive schemes or schematas provide the structural framework of the individual's perceptions and world view. Hence, it is through these schematas that assimilation and accommodation operate (Piaget, 1954).

Piaget presents four main periods of development: sensorimotor, preoperational, concrete operational, and formal operational thought. The first stage, the sensorimotor, lasts from birth to approximately two years of age. During the sensorimotor period the child is learning about the relationships between sensations and motor behaviour. Initially unable to distinguish internal from external stimuli, or self from the external world, these distinctions begin to emerge for the child. The primary neurodevelopmental task of this stage is the integration of the primitive reflexes enabling the child to gain more control over motor processes. The child moves from being the "subject" of reflexes, movements, sensations, and movements to "having" these experiences. Gradually, the ability to perceive the permanence of objects and object constancy is developed. Constant interaction between the environment and the child's senses (especially proprioceptive, haptic, and gross visual perception) moves the child toward the next period.

The preoperational period is characterized by the development of language, perceptions, images and symbols, which are non-integrated and are not organized/categorized by principles of logic or order. This stage which typically occurs between the ages of two to seven, is given its title because the child is still unable to understand certain rules or "operations" of mentation. The individual may tend to confuse the visual perceptual appearance (qualitative or quantitative) of objects, and is naive regarding the laws of conservation of mass and weight. For example, when pouring the same amount of water from a narrow cylindrical container to a wider one, children younger than seven commonly state that the amount of water has decreased. The child's response is based on the visual perception of the water having risen to a lower level on the wider container. Older children recognize the equivalence of the water contained in the two containers.

The emphasis in the concrete operational period, which is between the ages of two to twelve, is on the development of the ability to move back and forth between linked perceptions. Having mastered the conservation concepts, the child's ability to think along operational lines is furthered. The physical world is concentrated upon in terms of its quantitative and divisible nature (e.g., classification and groupings of objects). Logical or abstract processes at this stage are tied to the physical or "concrete" realm.

The final period is that of formal operations in which the ability to think and reason abstractly is cultivated. Thought may now be applied to the non-material, non-tangible, non-real or hypothetical. Furthermore, beginning at age 12, the individual at this stage begins to develop the type of intellectual skills necessary to solve a problem in a systematic experimental manner, constructing and testing hypotheses to find the solution.

Due to their heirarchical nature, periods of lower order must be achieved prior to the establishment of a higher period. All age-related time frames given by Piaget were estimates of what may be expected for the average child and not strict periods. Transitional phases may be characterized by features of the two stages surrounding the transition. Therefore, an individual may be capable of abstacting in one realm but may be extremely concrete in another. Such a phenomenon is particularly interesting in light of similar characteristics which have been observed in the TBI population (Levin, Benton, & Grossman, 1982).

In contrast to Piaget's stages, Ayres SI levels are much more staggered in nature. According to SI theory, at two months the nervous system is heavily involved at the first level of SI, and marginal emphasis on the second level; by one year of age the nervous system of the infant focuses on the first and second levels, and begins to introduce elements of the third; by age three, some developmental tasks of the fourth stage begin to emerge, while the other three remain prominent; generally, age six marks the completion of the primary level, with the secondary level being near completion, the third still active and the fourth becoming the next developmental hurdle.

Based on the chronology, it would appear then that Piaget's sensorimotor period highly corresponds to Ayres' primary and secondary levels of SI, both of which place a strong emphasis on sensory processing, rudimentary perceptual processes, body perception and motor planning. While the intermediate stages are not as easily equated due to the different areas of emphasis, it is evident that the final stages--the formal operational and the fourth level of SI-- are similar in that they both desribe the development of academic learning ability and abstract thought and reasoning, as an outcome of previously developed neurological and cognitive processes. Naturally, the orientation of each theory dictates that Piaget's final stage is more reflective of its cognitive basis while Ayres' level four accentuates the neuropsychological foundation of prior development. As is recommended by Kulkarni (1987), taken together these theories offer a rich and comprehensive framework to guide the assessment and treatment of TBI patients.

Empirical Considerations

Although no direct applications of sensory integration to head injured persons exists in the literature, other relevant findings will be considered below. It is the intent of this next section to draw significant parallels between other populations in which SI therapy and assessment is utilized, and its potential use with the closed head injured.

Theoretical investigations

In several studies using factor analysis, Ayres has demonstrated the existence of several syndromes characteristic of learning disabled children. In an extensive controlled investigation of 50 heterogeneous learning disabled children, the investigator identified 23 factors based on a battery of 35 perceptual-motor tests (including the SCSIT), six of which accounted for most of the variance (Ayres, 1965). Of these six factors, five were "interpretable patterns of perceptual-motor dysfunction." These same factors were generally found only in the dysfunctional group and not in the control group. The factors were: developmental apraxia, perceptual dysfunction form and position in space, tactile defensiveness, bilateral integration of the body, and visual figure-ground discrimination.

In this study, one-legged standing balance was not strongly related to visual perceptual dysfunction vis-a-vis form perception, position in space, nor figure-ground perception. Rather, in the control group, standing balance was much more highly related to age, suggesting normal developmental progress. However, tactile perception (stereognosis) and kinesthetic perception were highly related to both types of visual perception. In the case of figure-ground perception, a strong link was also found with motor processes. Using a similar methodology, studies have supported specific deficit patterns in the areas of audition/language and postural/bilateral integration (Ayres, 1969b). Furthermore, Ayres (1971) found a significant association between auditory-language impairment and right hand involvement.

Generally, methodologies using R- and Q-technique factor analysis (Ayres, 1965, 1966, 1969b, 1972b), and step-wise regression analysis (N=148, Ayres, 1971) have been supportive of the presence of the aforementioned symptom clusters in the learning disabled population. All of these investigations have been suggestive of certain symptom constellations. However, these constellations are usually neither statistically, nor clinically, discrete. The studies do provide some consistent evidence of specific neural functional systems. On the other hand, they probably lack sufficiently sensitive measurement techniques and/or sufficiently homogeneous populations to give further clarity to the issue.

Related research

From a somewhat different perspective, Meeder (1982) studied a group of 61 heterogeneous head injured individuals using a cognitive-perceptual-motor (CPM) evaluation. These patients were 29 percent female aged 15 to 60, and 65 percent were positive for single or bilateral hemisphere involvement on CAT Scanning (12 percent had no CAT scan performed). The subjects were evaluated at intervals of two, four, six and twelve months post injury. They were divided into three groups (less than seven days, eight to thirty-one days, and more than thirty-one days in coma) based on their Glasgow Coma Scale which ranged from one to 225 days in coma. The CPM measures included in the study were: visual attentiveness, ocular pursuit, graphic praxis, figure ground perception, position-in-space perception and depth perception.

It is noteworthy that two of Ayres' (1972a) tests, the Position-In-Space Test, and the Figure-Ground Perception Test, were used in the study to measure their respective domains. Meeder utilized a linear regression model to project the length of post-injury recovery to "zero impairment" for each variable domain based on the four time points. Her results may be summarized as follows:

> Preliminary research findings suggest that the "return" of CPM skills in adult head injury patients follows a hierarchical sequence. It has also been found that coma length does make a difference for recovery of some CPM functions and that recovery of these skills continues well beyond one year post-injury. Some skills, such as visual attentiveness are noted to "return" early and some, such as figure ground perception, late. This implies that there may be critical periods for treatment of CPM deficits.

> For example, the clinician may want to focus on early returning skills initially in establishing the treatment regime, and then as the foundation is laid, concentrate on more complex or returning skills. (p. 171)

The investigator emphasizes that although no precise correspondence exists between adult TBI recouperation and infant development, she posits that some loose parallels may be drawn. Parenthetically, the investigation also revealed evidence supporting the Ayres Figure-Ground Test as being more sensitive to "complex and subtle deficits" than the Frostig Figure-Ground Test. However, no significant difference was found between the Ayres and Frostig position-in-space tests.

The above investigation is relevant to our purposes here from several perspectives. First, it represents a CPM analysis which evidences a hierarchical recovery process. Secondly, it provides support for the contentions that behavioural recovery is possible in several (all of those studied in Meeder's report) CPM modes, and that recovery may extend beyond one years' time. Thirdly, it supports the tenet made in this paper that figure-ground perception is a significanly higher order (and/or more slowly remediable) visual skill. Fourthly, it lends construct validity to Ayres' Position-in-Space, and Figure-Ground Perception test, both of which will be used in the analysis of this study.

Given these factors, Meeder's study provides a good spring board for the present investigation, because she highlights a developmental recovery process but does not present an explanation regarding the underlying recovery mechanism. Sensory integration theory may help to provide such an explanation, by elucidating other variables that are believed to mediate visual perception and development.

Therapeutic Investigations

Using a meta-analysis of 8 studies with a total of 47 statistical hypotheses, Ottenbacher (1982) concluded that sensory integration participants performed significantly better than control group members. These groups focussed primarily on the treatment of learning disabled children, but in one case, included mentally retarded children. No studies involving stroke patients were found to meet the criteria for the analysis despite some favourable results reported in the literature. The researcher stated that despite some claims for the use of sensory integration in the literature, empirical validation has been hampered by methodological constraints. He calls for improved experimental control and the use of control/placebo groups in this research and similar research with schizophrenics. Further, Ottenbacher draws attention to possible confounds which may exist in some research due to the failure to control for psychiatric, geriatric, or physical (stroke/head injury) conditions.

The same investigator (Ottenbacher, 1978) demonstrated that in school-age children diagnosed as exhibiting learning disabilities, minimal brain dysfunction, or perceptual disorders, the Southern California Postural Nystagmus Test (SCPNT)--an adjunct test to Ayres' complete battery--is related to other "soft" neurological signs. Among other factors, the test was found to be associated with vestibular and proprioceptive functioning. Following up on this finding, Ottenbacher, Short, and Watson (1980) successfully used the soft neurological signs of standing balance, muscle tone, and prone extension posture to predict which learning disabled children with postrotary nystagmus would respond with increases of duration following sensory integration therapy.

Shuer (1980), investigating the role of vestibular dysfunction in mental retardation, utilized a control group and 16 mentally retarded males ages 18 to 33. Both groups were administered SCPNT. The results of the study indicated that mildly mentally retarded adults demonstrated attenuated nystagmus in comparison to normal adults. This finding is highly suggestive of vestibular involvement. The study recommended further research in terms of replicated verification and comparative treatment strategies between mentally retarded groups. This writer was unable to find any related follow-up studies.

In a study by Angelo (1980), twelve college-age students, who had either a low grade point average or visual perceptual problems, were provided a sensory integration program for 50 minutes three times per week in a group setting, and twice a week on an individual basis. The program lasted a total of ten weeks. On the Wide Range Achievement Test (WRAT) and the Nelson-Deny Reading Test significant improvement in reading skills were found post treatment. Thus the study served to support the use of sensory integration therapy for these low-achieving students at the college level. The main criticism which this writer has towards the study is that neither a control group nor a placebo group was used as a baseline for comparative measure. Furthermore, proper norms for the use of the SCSIT with this particular age group is not yet available for all of the subtests which were utilized in the study.

Other research is beginning to highlight the efficacy of sensory integration therapy in the rehabilitation of the blind (Baker-Nobles, 1979; VonBenschoten, 1975), mentally ill (King, 1979), aphasics (DePauw, 1978; Ayres, 1981), and autistic children (Ayres and Tickle, 1980). Research regarding the effectiveness of sensory integration with various types and degrees of learning disability is generally favourable (as attested to by the meta-analysis of Ottenbacher, discussed previously). Such literature is too lengthy to be presented in full.

Summary of Sensory Integration and Related Research

The aim of the last section of the literature review was to describe SI theory in a comprehensive manner and to establish its credibility by reviewing the empirical literature supporting it. The Southern California Sensory Integration Tests were introduced as a means to evaluate SI processes and indirectly, brain stem integrity. The major constructs and construct relationships were described in their full complexity. In the final section of this chapter, a more simplistic and operational model will be presented as a framework for the methodology to follow.

The previous section also related Piaget's theory of cognitive/intellectual development to SI theory. Piaget's theory was discussed in order to establish a more direct link between the primarily sensory-perceptual-motor focus of Ayres, to the higher level cognitive processes addressed by Piaget. This liaison further substantiates the existence of the third and fourth levels of SI, and the theory's developmental nature. It also facilitates the selection of a variable to represent abstract reasoning in the reseach methodology, because the selection of this variable will be based on Piagetian concepts.

Brain Stem Insult and Recovery

As the SI theory and its related treatment approach emphasize brain stem integrity, it is important to establish the likelihood that this structure is prone to injury during a TBI, and that bio-behavioral recovery is possible in this region. The next section of the chapter will address these issues through a discussion of the relevant research.

Brain Stem Involvement as a Consequence of TBI

Some reports of mild head injury (with normal neurological findings) have indicated that despite evidence of neuropsychological deficit upon initial testing, this presentation improves with time, despite its assumed organic, as opposed to psychological, basis (Gentilini et al., 1985; Levin et al., 1987). These patients are usually classified as having a "post-concussive syndrome" with symptoms including: headaches and dizziness (the former 79% and the latter 59% in a study by Rimel, Giordani, Barth, Bell, Jane, 1984); problems in memory, concentration, insomnia, irritability, anxiety, depression (Rutherford, Merrett, McDonald, 1977); and, light and noise intolerance (Mamelak et al., 1987). Although the organic nature of this sydrome has long been challenged (Baloh and Honrubia, 1979), remarkably similar symptom clusters have been documented specifically in whiplash injuries (Wiley et al., 1986; Koteff,1986).

Koteff (1986) cited both human and animal research studies which have been conducted by Walter Vanast, a neurologist at Edmonton General Hospital. Vanast's work with whiplash in monkeys has revealed that: (a) unconsciousness and concussion may be produced by rotational acceleration over as little time as 50 to 100 milliseconds; (b) medial temporal seizure discharges occured six weeks post injury depite normal surface EEG and electrocorticogram tests; (c) rotational acceleration in the coronal plane resulted in a significant increase in the amount of diffuse axonal damage; and, (d) of those cases in which diffuse damage was observed, 90% sufferred significant hypocampal changes, perhaps accounting for short-term memory loss in human patients. Much of Vanast's work focuses on the consequences of whiplashes sustained from motor vehical accidents (MVA) and simulations thereof. In such situations he emphazises the trumendous force (nearly three times the force applied to the car being hit) which first accelerates the shoulders and later, the head.

Many of Vanest's findings support the theory that rotational injuries do more damage to peripheral structures and least to central ones vis-a-vis the centripital force generated:

> The converse of this, of course, if you find any changes in the brain stem then their must be changes in the periphery and to a more marked degree. And we are beginning to have some evidence that this is occurring in whiplash patients... In human whiplash patients we find a high incidence of vertigo and a high incidence of changes in the brain stem auditory evoked response. Clinically the other evidence for brain stem involvement is the marked changes in these patients'

> sleep patterns... Given all that experimental and clinical sort of evidence, then there must be more diffuse damage here and it's more likely to be marked in those regions close to bony prominences, and that may explain why these patients have decreased concentration, and why they don't complete many tasks and have a decreased ability to comprehend new material. (Koteff, 1986, p. 31)

Presumably, significant force would be applied to the brain stem given its anatomically-vulnerable positioning not only in MVAs, but in all but the most cranially-immobile insults e.g. missile wounds (Levin et al., 1982). Loss of consciousness often occurs as a result of head trauma, and is likely the consequence of the shearing effects of accelerational stress on the reticular formation (Grubb & Coxe, 1978), or the result of traumatic hyperextension of the head tearing fibres at the pontomedullary junction (Lindenberg & Freytag, 1970). The investigations of Ommaya et al. (1973) and Walton (1977) have illustrated a correlation between the occurance of concussion and damage to the brain stem. "Loss of consciousness that is prolonged beyond a day or that sets in following a period of lucidity signals the effects of elevated intracranial pressure on the reticular formation" (Lezak, 1983, p. 168). Regardless of whether the brain stem is encroached upon by direct insult, or indirectly by intracranial pressure, there is little question that the primary cause of concussion is brain stem (particularily reticular) involvement (Levin et al., 1982).

<u>Recovery from Brain Stem Insult</u>

While no conclusive proof may be gleened from just one study, Frommer (1978) does provide some substantive information regarding brain stem recovery:

> A remarkable redundancy can be observed after lesions in the cord and brain stem pathways, such that sparing of a fraction of the pathway(s) that appear to mediate a discrimination, permits recovery of the disriminative performance to preoperative levels. (p. 259)

Frommer's statement is based primarily on research with lower primates. It addresses the concepts of sparing and redundancy, neither of which necessarily implies true recovery in a biological sense, although behavioral recovery certainly is implied. Such a model may be hard-pressed to account for successful treatment in the learning disabled population. The reason for this is that redundany or sparing would not be applicable because presumably the particular function in question would not have been intact in the first place. However, a brain stem insult that occurs as a result of a traumatic accident may partially or extensively impair a given function. In such cases the sparing or redundancy models may indeed be applicable, especially in this brain area which is largely undifferentiated anotomically.

Summary of Review of Brian Stem Involvement

The previous section has reviewed several sources of literature pertaining to brain stem insult as a result of TBI. It was established that this region of the brain is almost inevitably involved any time that brain trauma results in loss of consciousness. Furthermore, there is strong evidence to suggest that many of the symptoms of post-concussive syndrome may be the result of damage to the brain stem, and that rotational acceleration of the head at the time of trauma is likely to cause pathology to this region. Finally, although conclusive research is not yet available to determine whether, and to what extent, bio-behavioural recovery is possible in the brain stem, some supportive evidence does exist.

In light of the SI model these findings may have implications for lesions which occur in brain areas involved in the primary and secondary SI levels. In particular, much of the activity of the brain stem surrounds the synthesis of tactile, vestibular, and kinesthetic information --the first level of SI-- prior to sensory processing at the higher cortical (and SI) levels. This hypothetical relationship suggests that sensory input, which can be distorted/disrupted at lower levels due to subcortical damage, may impair higher sensory integrative processes and final cortical output. Disturbance of higher cortical processes (SI levels three and four) may take the form of impairments in: memory, abstract reasoning, academic learning ability, acute sensory perception, and fine motor skills.

To date, little if any, behavioural measures have been utilized with the TBI population to assess, diagnose, and treat subtle subcortical dysfunctions which may superficially appear to be cortical in nature, or which may otherwise impede rehabilitation (Kulkarni, 1987, personal communication). The standardized SCSIT battery may provide a behavioural approach to determining the status of the brain stem and thereafter help guide rehabilitative efforts (Ayres, 1973; Kulkarni, 1987).

Theoretical Framework for Empirical Analysis

This final section of the literature review will present a heuristic model from which the research questions may be addressed. The experimental variables will be directly linked to the theoretical constructs in the model. Finally, the shemata will be reformulated to depict the relationships of the experimental variables.

Theoretical Review and Presentation of Constructs

Sensory integration theory suggests that accurate perception and memory of sensory input, fine motor skills, and verbal and abstract reasoning ability are all contingent upon proper sensory processing at subcortical levels. More specifically, Ayres' model emphasizes the integral nature of the vestibular, tactile and proprioceptive channels in the development of more sophisticated cognitive-perceptual-motor skill. At various levels of the central nervous system--the spinal cord, brain stem, thalamus, and cortex--these inputs are combined with auditory and visual information to make higher level skills possible. These higher cortical functions include speech perception (and expression), visual perception, ability to attend/concentrate, capacity for abstract thought, and academic learning. It is believed that remediation of cognitive-perceptual-motor deficits therefore depends upon: the restoration of vestibular, tactile and proprioceptive functioning at subcortical levels; the integrity of the cortical areas; and, efficient relays between cortical and subcortical regions (Ayres, 1973, 1974; Kulkarni, 1987).

The present investigation will attempt to establish whether strong relationships do indeed exist between higher and lower-order functions, as is hypothesized in the hierarchical SI model. At this juncture, it is necessary to simplify the relationships between the variables in order to establish testable hypotheses. Figure 3 depicts the hierarchical and developmental nature of the sensory integration process for research purposes. The representation is a simplified version of Ayres' schematic (Figure 2). Each box represents a level of sensory integration. The arrows denote a progression of inputs and synthesizing activities from the lowest to the highest SI level. Thus each box may be thought of a function of the ones preceding it. The quality of the output of any given level is contingent upon the degree to which sensory input is accurately processed and synthesized at early levels.

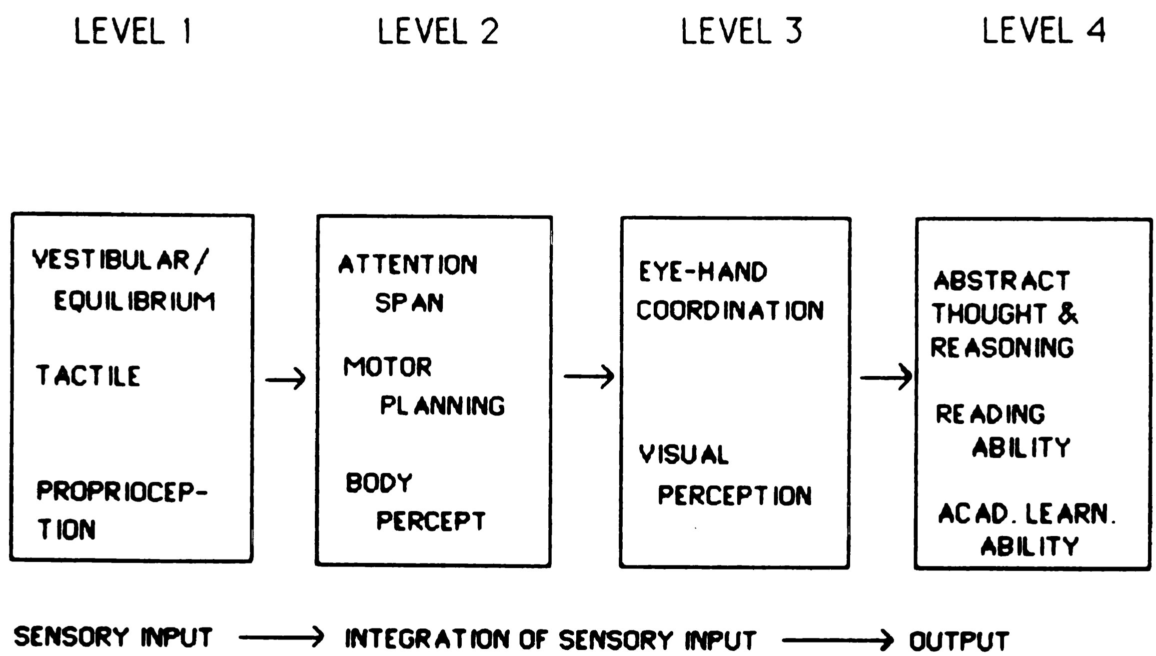

Figure 3. Simplified representation of the SI theoretical constructs and their relationships.

Figure 3 depicts a linear progression from the primary to the fourth level of sensory integration. Also suggested by the diagram is the possibility that variables may interact with one another in order to produce an output based upon synthesized input. The existence of these linear relationships between the various SI levels, and the construct interactions suggested, will be directly tested by the empirical analysis in later chapters.

The Measurement of the Constructs: Experimental Variables

With the theoretical constructs and their relationships explained, the experimental variables may be presented. The reliability and validity discussion in Chapter III will address the salient questions regarding the appropriateness of each experimental variable to measure the domain of the relevant theoretical construct. Suffice it here to state that all of the measures are various subtests of the SCSIT and the Weschler Adult Intelligence Test-Revised.

Theoretical Constructs		Experimental Measures
Vestibular Input/Equilibrium	---	Standing Balance Tests
Tactile Input	---	Tactile Tests
Proprioception	---	Kinesthesia Test
Attention Span	---	Digit Span
Motor Planning/Eye-Hand Coord.	---	Motor Accuracy Test
Visual Perception	---	Position-In-Space Test
	---	Figure Ground Perception
Abstract Thought/Reasoning	---	Arithmatic Test (WAIS-R)

Figure 4. Each empirical measure, or experimental variable on the right is depicted opposite the corresponding theoretical construct on the left right.

Experimental Variable Relationships: Heuristic Model

Figure 5 is a representation of the final model which will be used to test the tenets of SI theory as adopted for the present empirical investigation. This schemata is identical to Figure 3 presented earlier to depict the theoretical relationships. However, the theoretical constructs have been replaced by the empirical variables or measures.

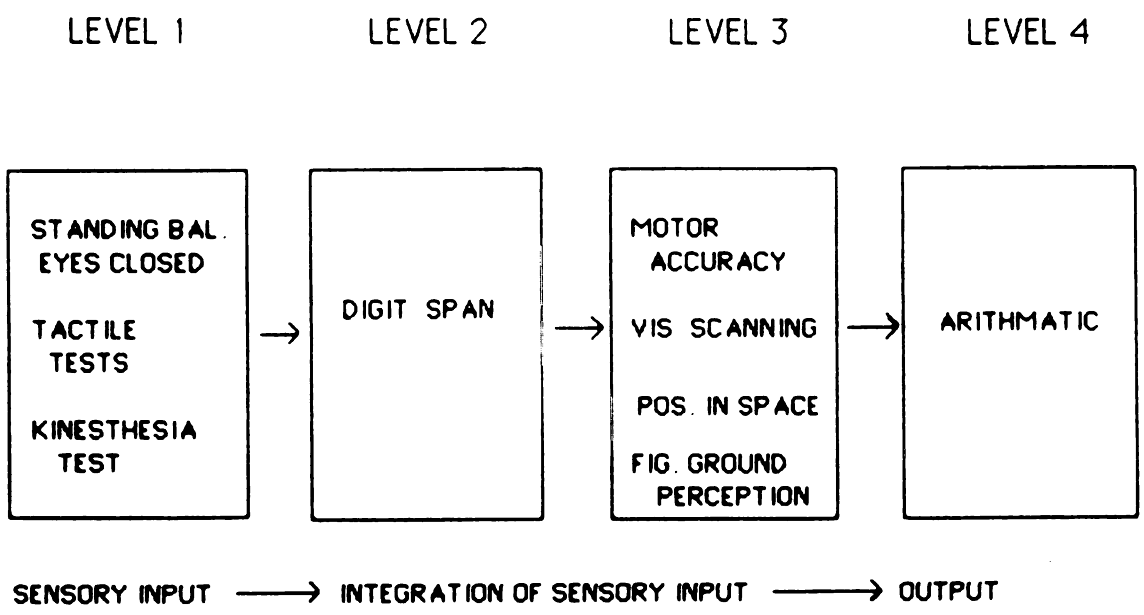

Figure 5. Final model for testing of empirical hypotheses with experimental variables substituting for theoretical constructs.

Section Summary

The intent of the final section of the literature review was to establish a theoretical framework from which the research hypotheses may be tested. This framework was first presented theoretically, followed by a pairing of the theoretical concepts with the corresponding measurement variables, and a reformulation of the heuristic model.

Chapter Summary

The preceding literature review elucidated the following points:
(1) Biological and behavioural recovery of function following TBI occurs through a variety of means, and may be enhanced through appropriately designed remedial programs; (2) SI is a neurodevelopmental model of assessment and treatment which has been successfully applied to a variety of clinical populations. The theory emphasizes the importance of subcortical integrity, and efficient sensory-perceptual-motor processing, prior to the establishment of higher cortical operations; (3) SI theory proposes heirarchical stages which to some degree overlap with the cognitive development model of Piaget; (4) Subcortical damage, particularly to the brain stem, is very common as a result of TBI, but is rarely evaluated in a comprehensive and standardized manner from a behavioural or functional standpoint. Recovery theories/research in general, and brain stem recovery research specifically, suggest that bio-behavioural recovery in this region is possible; and, (5) These observations give rise to the notion that behavioural impairment from lesions in the brain stem may be remediable. Finally, the SCSIT is an

assessment instrument which enables one to evaluate certain aspects of subcortical area functioning and the integrity of the various SI levels.

CHAPTER III

METHODOLOGY

Introduction

The purpose of this investigation is to determine whether the conceptual relationship posited by SI theory are empirically validated when the constructs are measured on persons with TBI. This study is a preliminary step in evaluating the practicality and efficacy of SI theory, as a comprehensive analytical framework for assessing brain integrity. To date, such a comprehensive model is lacking in the literature. If the underlying constructs of the theory are validated, this finding would suggest that SI intervention strategies (Ayres, 1973) may also be applicable to the TBI population.

The following questions will be addressed by this investigation: Are the major constructs, and the theoretical relationships of the constructs expounded by SI theory empirically varifiable within a heterogenous group of TBI patients? Do certain demographic variables (namely, age, sex, education, socioeconomic status) significantly differentiate subgroups of this TBI group in terms of these constructs and their theoretical relationships? Is their empirical support to suggest that the utilization of SI theory may provide a useful conceptual framework for determining the nature of neuropsychological impairment in a TBI patient, and for neurorehabilitation planning?

Subjects

This investigation is a retrospective study of 49 TBI patients. It drew upon existing data in the files of patients who were referred to the Cognitive-Perceptual-Motor therapy program at the Michigan State University Rehabilitation Medicine Clinic between 1983 and 1987. Each individual underwent an initial assessment comprised of several Southern California Sensory Integration Tests, as well as other tests which will be discussed later. It is this test data that will be utilized for the purposes of the study.

The primary selection criteria for subjects in this study were that: (1) A subject must have sustained a brain lesion (e.g. TBI, cerebral vascular accident, tumor, anoxia, etc.) with onset in adulthood, according to the clinical diagnosis made in the Clinic's admission report; and, (2) A subject's file must have contained all of the variables represented in at least one hypothesis test. This second criterion was established to prevent an unacceptably high number of missing cases from occuring in any given regression analysis. Consequently, some subjects were included in certain hypothesis tests, but not in others. The first criterion served to exclude 26 subjects, who had been tested for suspected sensory integrative dysfunction, secondary to learning disabilities, or other childhood or non-cerebral disorders. The second criterion resulted in the exclusion of 20 subjects, primarily because of missing data for the Digit Span, Standing Balance Closed, and Arithmetic tests. Demographic data pertaining to the subjects in the study are presented in Table 1.

TABLE 1

Demographic Data

Variables	Mean	Median	St. Dev.	Minimum	Maximum
Age (Years)	32.8	29.5	12.2	17.0	70.0
Education(Years)	13.1	12.0	2.7	8.0	20.0
Socioeconomic Status(Index Value)	40.6	35.2	16.0	24.3	72.3

The group was comprised of 16 (33%) women and 33 (67%) men. The socioeconomic status (SES) was determined for the 35 (71%) individuals who were working at the time of the onset of their condition, using the revised Blishen Socioeconomic Index for Occupations (Blishen & McRoberts, 1976). This index ranges from 14.4 index points for occupations with the lowest combined income/education determinants, to a high of 75.3 index points. The mean and median values for the sample, therefore represent occupational groups in the lower one-third to one-half of the index, and are essentially semi-skilled in nature. Those persons not included in the SES figures were either students (10, or 20%), retired (1, or 2%), homemakers (1, or 2%), or their status was not known (2, or 4%). At the time of admission to the clinic, all subjects reported their residence to be in Michigan, with 15 (30.6%) subjects coming form rural areas, 19 (38.8%) from urban/suburban areas, and the remainder unknown.

Table 2 addresses the etiological categories which the subjects represent. The majority (53%) of subjects had been directly involved in motor vehicle accidents (MVA), while another 10% were struck by cars as pedestrians or while riding a bicycle. Only 22% of subjects had "non-impact" induced lesions such as cerebrovascular accidents, tumors, or anoxic conditions.

TABLE 2

Etiology of Subjects' Condition

Etiology	Number	%
Motor Vehicle Accident (MVA)	26	53
Pedestrian/Bicycle Struck	5	10
Fell/Struck Head	7	15
Cerebrovascular Accident (CVA)	6	12
Other (tumor, anoxia, CO poisoning)	5	10
Total	49	100

The nature of a person's condition as measured by post traumatic amnesia (PTA), coma length, and/or CT Scan results (Levin, Benton & Grossman, 1982) was not consistently and reliably reported within the existing data base. Levin et al. (1982) emphasize the high frequency with which PTA and coma degree/length are unreliably determined due to a lack of adherence to standardized procedures. The criticism is appropriate here. Therefore, the following descriptive data is to be accepted with caution. The length of PTA was reported in only 11 (22%) cases, and ranged from a few minutes to 23 days. Coma length, reported for 37 (76%) subjects, ranged from none at all, to approximately 90 days, with a mean of 11.89 days. Table 3 presents a more rigorous categorization of the coma duration data. CT scan results were reported in 15 (31%) cases, roughly two-thirds of which were positive.

TABLE 3

Coma Duration

Duration	N	%
Nil	14	28.5
< 1 hr.	6	12.2
1-24 hrs.	0	--
1-7 days	3	6.1
8-14 days	4	8.2
15-21 days	3	6.1
> 22 days	7	14.3
No record	12	24.5
Total	49	≈100

Procedure

Each subject had previously undergone an extensive initial assessment comprised of all or some of the following: several Southern California Sensory Integration Tests; the Arithmetic, Digit Span, and Digit Symbol subtests of the Weschler Adult Intelligence Scale - Revised (WAIS - R); the Minnesota Spatial Relations Test (MSRT); one cancellation and two number/letter sequencing tests; the Purdue Pegboard; and a test of grip strength. All tests were administered by one of three experienced Occupational Therapists. Each examiner was qualified for, and experienced in, the administration of the SCSIT, but only one had completed formalized training in the WAIS - R administration. The cancellation and sequencing tasks were standardized at the Rehabilitation Clinic; hence, all examiners were well qualified to administer these subtests. Of these assessment data, only the following will be utilized to address the research questions being posed: standing balance tests, tactile test, Kinesthesia test, Digit Span (WAIS-R), Motor Accuracy test, Position-In-Space test, Figure Ground Perception, and Arithmetic test (WAIS-R).

Reliability and Validity of Experiemental Variables

With the exception of the Digit Span and Arithmetic subtests of the WAIS-R, all tests are from the SCSIT presented by Ayres (1972a). This battery of neuropsychological tests was initially developed and standardized on children between the ages of four to eight and for some tests, upto age ten. For certain tests, further standardization data has been made available for the adult population. Both sources of information regarding the tests will be provided.

Standing Balance Eyes Open (SBO) and Closed (SBC) Tests

These tests measure the ability of the individual to balance while standing on one foot with the eyes open and closed, respectively. Split-half reliability of both tests using the Rulon formula was .89 based on 100 learning disabled children ranging in age from six to eight years (Ayres, 1965). The domain being tested here is that of equilibrium (balance) or vestibular-bilateral integration. In thier search for concurrent validity of various equilibrium tests for children with learning disabilties (using the total sample and two subgroups, one with and one without vestibular involvement), Bundy et al. (1987) found statistically significant correlation coefficients: between SBO and Standing Balance Eyes Closed

(SBC) of .31 for the total sample, and .40 for the nonvestibular-involved group (p<.05); and between SBO and the Flat Board Reach test of -.27 for the total sample (p<.05). Similarly, SBC was found to be correlated with the Briuninks-Oseretsky Balance Subtest with coefficients of .38 for the vestibular-involved group (p<.05), .46 for the total sample (p<.005), and .58 for the nonvestibular impaired group (p<.005).

The standing balance (SBC) function has been associated with vestibular dysfunction (Ayres, 1971), and a postural-ocular grouping factor (Ayres,1971). Both standing balance tests have been correlated with a visual discrimination task (Ayres, 1968). Of the six equilibrium measures (including SBO and SBC) studied, Bundy et al. (1978) conluded that on the whole, all tests contributed significantly to a different aspect of equilbrium, as low correlations were found between the variables in a correlation maitrix. While acknowledging the validity of the standing balance tests in the evaluation of vestibular and equilibrium integrity, they felt that in particular, "tilt tests should be routinely used in the evaluation of equilibrium and that these tests may evaluate an aspect of equilibrium that is very different from one-legged standing tests" (p. 34). This conclusion supported their previous findings (Fisher and Bundy, 1982) which encouraged the use of multiple measurements of equilibrium. Ayres, however would hold a different and less favourable interpretation of these findings,, and of the state of the research in this area. Her opinion may be best summarized in her test battery manual (1972a), as follows:

> Unfortunately, SBO and SBC have not yielded consistentl reliable indices of status of the syndrome hypothesized from the factor analyses, although there has always been some positive relationship demostated... The discrepancy between the

> statistical data on SBO and SBC and the common belief that standing balance is a valid and reliable indication of postural mechanism maturity [and integrity] may be due to several conditions: (1) Since standing balance is easily and commonly measured, its validity has been accepted without sufficient question; (2) Standing balance may be an expression of many sensory integrative systems in addition to those mediating postural mechanisms related to interhemispheral integration. That this is the case is suggested by the higher loading of SBO on a praxis factor than on postural-ocular factor in one study (Ayres,1971). (p. 9)

Despite the shortcomings of these instruments, they will remain a part of this investigation as they are integral components of the test battery and the theory upon which it is based. No research pertaining to the use of these tests with adults was found in the literature.

Tactile Tests

Table 4 presents the split-half reliability from (i) Ayres' (1965) study of 100 learning disabled children, (ii) Ayres' (1972b) study of 49 learning disabled children, at the age of eight and, (iii) Hsu and Nelson's study of 51 normal men and women. The tactile tests are the following: Graphesthesia (GRA), requiring the participant to repeat a drawing previously drawn on the back of the hand by the examiner; Manual Form Perception (MFP), in which the subject must visually identify a shape previously held in the hand; Finger Identification (FI), requiring the subject to touch the same finger touched by the examiner when the subject is blindfolded; and Kinesthesia (KIN), involving the subject (vision occluded) placing his/her finger on a point previously positioned by the examiner.

TABLE 4

Reliability for the Tactile Tests

	Variables			
	GRA	MFP	FI	KIN
(i) CHILDREN (1965) (split-half rel.)	.86	.65	.78	.78
(ii) CHILDREN (1972b) (test-retest)	.31	.50	.56	.13
(iii) ADULTS (test-retest)	.56	.29	.49	.28

It is important to note, that Hsu and Nelson were concerned about the limitted variability in the test scores of the adults and the tendency for many of these subjects to reach the maximum test scores, i.e. the test score distributions were negatively skewed due to a ceiling effect. Nevertheless, these investigators felt that the tests were still able to discriminate between normals and significantly tactile-kinesthetically impaired adults. They suggested that clients scores falling below the lowest normal subject's score, in each category "would be a conservative indicator of somatosensory dysfunction" (p. 791). While no specific validity studies are available for the above tests, Ayres emphasizes that these tests were all derived from traditional neurological examination items. Thus, their clinical face validity is high, especially when considered in combinations and in the presence of other neurological signs. As was discussed previously, all of these variables have been implicated in numerous factor, cluster, and regression analyses of sensory integrative dysfunction (Ayres, 1965, 1966, 1969, 1969b, 1971, 1972b) and have individually been found to discriminate between normals and learning disabled children at the .01 level of significance (Ayres, 1965).

Visual Perceptual Tests

These tests include the Figure-Ground Perception Test (FG) and the Position-In-Space Test (PS). The former test requires the subject to select a foreground figure from the overlapping background of figures. The latter test, involves the recognition of various geometric forms in different orientations and sequences.

Reliability data for both tests based on an adult population was not available. However, Ayres (1972a) reports the test-retest reliability correlation coefficient to be .73 for the Position-In-Space test (N=40 ten year olds). Test-retest reliability of the Figure-Ground Perception Test has been consistently reported to be around 0.50 with children age four through ten years, eleven months (Petersen and Wikoff, 1983). Petersen and Wikoff suggest that in regards to the latter test, "perhaps the inconsistency in testing skills of the children sampled prevented a higher reliability coefficient. The multiple-choice format for identifying answers may be a weakness because of the 'lucky guess' factor" (p. 556).

Construct validity for both tests based on adult populations is available. In an investigation reported upon earlier, Meeder (1982) correlated several indices of cognitive perceptual functioning in her attempt to measure the process of behavioral recovery in 61 head injured patients. In terms of spatial perception, she utilized three instruments: the Ayres Position-In-Space test, the Frostig Position-In-Space test, and the Three Dimensional Spatial Orientation Task (TDSOT). She considers the first two tests to be quite synonomous in terms of content and procedure, and distinguishes the last one as relying more heavily upon language ability and manual manipulation of objects. The two position-in-space tests had a Pearson correlation coefficient of 0.94 ($p<.01$), while the correlation coefficient between the Ayres' PS and the TDSOT was 0.89 ($p<.01$). All measures were taken at two months post head injury. A further analysis (serial analysis at four, six, and twelve months post-injury) comparing these tests indicated that the two position-in-space tests are equally sensitive to changes in the criterion variable over time, and that "either one appears to be more sensitive and can be used over a longer period of time than the Three Dimensional Spatial Orientation Task" (p. 167). The investigator concluded that only one of the two position-in-space tests need be used to measure spatial orientation.

Meeder, in the same investigation measured figure-ground perception using both the Ayres and Frostig figure-ground perception tests, and a similar "functionally-based" test. The functional test required the subject to select and identify six objects from a box of objects. Again the scores were correlated at the initial two month point and then at four, six, and twelve months post-injury. At time of initial evaluation, the two figure-ground perception tests had a Pearson r of 0.87, while the same statistic between the Ayres and functional tests was 0.75 (both at $p<.01$). In this case however, the Ayres showed "the highest percentage of impairment on [the] three coma groups (less than seven days, seven to 31 days, and more than 31 days in coma) . . . and [appears to be] a more sensitive test to more complex deficits" (p. 165). Furthermore, all three figure ground tests indicated statistically significant differences between the means of the moderate versus long term coma groups ($p<.05$).

Another construct validity study of the Ayres FG test was conducted by Petersen and Wikoff (1983). These investigators correlated the test with the Embedded Figures Test--a well known test of figure ground perceptual ability (Lezak, 1983)--on a sample of 100 normal adult males. A correlation coefficient of -0.67 was found (with the negative sign reflecting opposite scoring procedures) at the .001 level of significance. The FG scores in this study were not found to be related to age, education, or socioeconomic status. Further, the FG test was reported to be characterized by a normal disribution curve and no ceiling effect, in contrast to the tactile/kinesthetic tests assessed by Hsu and Nelson (1981).

Digit Span

This verbal subtest of the Wechsler Adult Intelligence Scale-Revised is well accepted as a measure of attention and concentration (Lezak, 1983; Hartlage, Asken, & Hornsby, 1987). The test is comprised of Digits Forward (a measure of immediate auditory memory span and attention) and Digits Backward (a measure of active or working memory), involving the storage and manipulation of information. Reliability and validity are well established for this test and need not be reviewed here (Wechsler, 1981).

Arithmetic

The Arithmetic subtest of the WAIS-R is also well established in terms of its reliability (Wechsler,1981). However, it is not a pure measure of arithmetical ability nor abstract reasoning because of its oral and timed format.

Concentration, immediate memory and conceptual manipulation and tracking are also required for the task (Lezak, 1983; Hartlage, Asken, & Hornsby, 1987). Nevertheless, as this metric is the one most reflective of abstract reasoning abilities available for all candidates, it will be utilized here.

In the previous chapter Piaget's theory of cognitive development was introduced to establish the hierarchical link betwen perceptual--motor abilities and higher cognitive functions such as formal operations or "abstract reasoning." Piaget defined structures or schemata as being the highest-order mental organizations. Structures may be broken into three different types, each of which can be described through various mathematical operations (Wadsworth, 1978). "...these three types of [mathematical] structures appear to be highly abstract. Nonetheless, in the thinking of children as young as 6 or 7 years of age we find structures resembling each of these three types" (Piaget, 1970, p.26). In his summary to a subsection entitled "Mathematical Structures and Structures of Logical Thought", Wadsworth (1978) concludes that Piaget and his coworkers believe that "the logical aspects of the structures of thought are similar to the logical aspects of mathematics" (p. 62).

It is not the mandate of this chapter to fully explore the evidence which drew Piaget and others to the above conclusion. The interested reader is referred to Piaget (1970) or Wadsworth (1978) for a more thorough discussion of these concepts. More relevant here is the establishment of face validity and suggested construct validity for the use of an arithmetically based test to estimate abstract reasoning ability.

Overview

In closing this discussion of the reliabilty and validity of the various instruments, it is important to reflect upon the words of Ayres regarding the rather low correlation coefficients of certain tests. Although she was predominantly addressing the work done with learning disabled children, the comments are equally appropriate to the adult population:

> It is hypothesized that the very nature of the neurophysiological processes which are under attempted measurement by some of the SCSIT are unstable when compared to the usual psychologically measured parameters. This instability contributes to lower test-retest stability than found in cognitive or conventional motor coordination tests. The postulate arises not only from years of direct experience in administering the tests but also from comparison of the test-retest stability coefficients of all the SCSIT. The fact that these coefficients vary from .01 to .89 cannot be attributed to variations in interscorer reliability, or, reasonably, to test design... Users of SCSIT are reminded that many of the tests are derivatives of clinical procedures with established usefulness in work with brain-injured adults and that they are designed to help determine the nature of certain types of dysfunction. They are not designed for discrimination among neurologically average [persons]...
> ....in measuring somatosensory perception, the factor of attending to stimuli to which one is unaccustomed and of the eliciting of

> aversive responses to tactile stimuli, alter the situation. [The Kinesthesia test] requires a type of attention seldom demanded of individuals and difficult to sustain by anyone, let alone children with disorders...The tests of tactile discrimination tend to show low test-retest reliability because neurophysiolgical considerations necessitate tests of short duration. (All quotations from Ayres, 1972, p. 53.)

Null and Alternate Hypotheses

The six null and alternate hypotheses below will be used to test the theoretical relationships posited by SI theory. The linear functions and interaction effects represent the theoretical concepts established by the theory and found to exist in other populations.

Hypotheses

H1: Attention span (DS) is a function of vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

$$Y_i = a + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 (X_1 \cdot X_2) + \beta_5 (X_1 \cdot X_3) + \beta_6 (X_2 \cdot X_3)$$

where, Y_i = DS scores
X_1 = SBC scores
X_2 = KIN scores
X_3 = TAC scores
$X_i \cdot X_j$ = interaction effect

Ho: All $\beta_j = 0$
H_1: All $\beta_j > 0$

H2: Visual scanning (VS) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

$$Y_i = a + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 (X_1 \cdot X_2) + \beta_6 (X_1 \cdot X_3) + \beta_7 (X_1 \cdot X_4) + \beta_8 (X_2 \cdot X_3) + \beta_9 (X_2 \cdot X_4) + \beta_{10} (X_3 \cdot X_4)$$

where, Y_i = VS scores
X_1 = DS scores
X_2 = SBC scores
X_3 = KIN scores
X_4 = TAC scores
$X_j \cdot X_j$ = interaction effect

Ho: All $\beta_j = 0$
H_1: All $\beta_j > 0$

H3: Position-in-space perception (PS) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

$$Y_i = a + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 (X_1 \cdot X_2) + \beta_6 (X_1 \cdot X_3) + \beta_7 (X_1 \cdot X_4) + \beta_8 (X_2 \cdot X_3) + \beta_9 (X_2 \cdot X_4) + \beta_{10} (X_3 \cdot X_4)$$

where, Y_i = PS scores
X_1 = DS scores
X_2 = SBC scores
X_3 = KIN scores
X_4 = TAC scores
$X_j \cdot X_j$ = interaction effect

Ho: All $\beta_j = 0$
H_1: All $\beta_j > 0$

H4: Figure-ground perception (FG) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

$$Y_i = a + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 (X_1 \cdot X_2) + \beta_6 (X_1 \cdot X_3) + \beta_7 (X_1 \cdot X_4) + \beta_8 (X_2 \cdot X_3) + \beta_9 (X_2 \cdot X_4) + \beta_{10} (X_3 \cdot X_4)$$

where, Y_i = FG scores
X_1 = DS scores
X_2 = SBC scores
X_3 = KIN scores
X_4 = TAC scores
$X_j \cdot X_j$ = interaction effect

Ho: All $\beta_j = 0$
H_1: All $\beta_j > 0$

H5: Motor accuracy (MAC) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

$$Y_i = a + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 (X_1 \cdot X_2) + \beta_6 (X_1 \cdot X_3) + \beta_7 (X_1 \cdot X_4) + \beta_8 (X_2 \cdot X_3) + \beta_9 (X_2 \cdot X_4) + \beta_{10} (X_3 \cdot X_4)$$

where, Y_i = MAC scores
X_1 = DS scores
X_2 = SBC scores
X_3 = KIN scores
X_4 = TAC scores
$X_j \cdot X_j$ = interaction effect

Ho: All $\beta_j = 0$
H_1: All $\beta_j > 0$

H6: Arithmetic ability (AR) is a function of visuo-spatial ability (VS) and attention span (DS).

$$Y_i = a + \beta_1 X_1 + \beta_2 X_2 + \beta_5 (X_1 \cdot X_2)$$

where, Y_i = AR scores
X_1 = VS scores
X_2 = DS score
$X_j \cdot X_j$ = interaction effect

Ho: $\beta_1 = \beta_2 = 0$

H_1: All $\beta_j > 0$

Analysis

The six hypotheses will be assessed using multiple-regression analyses. All tests will be based upon an alpha level of .05. The full models presented above will initially be tested with an omnibus F-test, followed by t-tests of each variable coefficient. In each case the most parsimonious and rational models will be retained as (statistically) non-contributory variables are systematically removed from the original formulations.

In each regression analysis the influence of the following demographic variables on the dependent variable were assessed for their contributions in the models using a correlation matrix and preliminary regression analyses: age, sex, and education. Insufficient data was available to include socioeconomic status, length of coma, and post traumatic amnesia (PTA).

CHAPTER IV

ANALYSIS OF RESULTS

Introduction

This chapter presents an analysis of the research data. First, the preliminary data preparation process will be explained. Each hypothesis will then be restated, followed by the related data, and analysis. For all *F* and *t* statistics, alpha is set at the .05 level.

Preliminary Data Preparation

Prior to the formal data analysis and hypothesis tests, it was necessary to construct two hypothetical variables. These constructs were the "Tactile" (TAC) and "Visual Perception " (VP) variables. The TAC variable was meant to represent the single best predictor of the tests (MFP, FI, GRA) which were used to measure the tactile sense. The VP variable was similarly constructed to represent the single best predictor for the visual perceptual subcomponents (input variables) of figure ground perception, position in space, and visual scanning. This data reduction procedure was undertaken so that one measure of visual perception and tactile sensation respectively could be utilized in the hypothesis tests. Such composite variables would prevent the over representation of visual perceptual or tactile inputs vis-a-vis other variables in the regression models to be tested.

The procedure used to determine the most appropriate variable combination to represent VP and TAC (hereafter termed the "domain areas") was three phased. The first phase involved the selection of potential single and multiple variable combinations that could be used to determine the single best composite predictor.

The list of potential variables/variable combinations included weighted and non-weighted procedures. The weighting procedure simply reflected the ratio necessary to make the ranges of the subcomponent scales equivalent, that is, providing a "lowest common denominator", so that each subscale would be equally represented in the domain variable. The following input variables were considered: (a) weighted and non-weighted single variables, represented by the subtest scores for the respective domain areas; (b) weighted and non-weighted two-variable additive combinations of the input variables; and, (c) weighted and non-weighted three-variable combinations of the input variables. The second phase involved the generation of a correlation matrix using the above variables/combinations. The matrix was then used to determine which variable/variable combination most highly correlated with each of the primary input variables for TAC and VP, respectively. In the final phase, the most highly correlated predictor variables were further assessed using regression procedures.

"Tactile" (TAC) Variable Determination

The following variables were considered as possible predictors (hence, possible values for TAC) of the three input variables (Manual Form Perception (MFP), Finger Indentification (FI), and Graphesthesia (GRA)):

1) MFP (Scale Range = 0-12)
2) FI (Scale Range = 0-16)
3) GRA (Scale Range = 0-24)
4) MFP + FI
5) FI +GRA
6) MFP + GRA
7) MFP + FI + GRA
8) 2 (MFP)
9) 1.5 (FI)
10) 2 MFP + 1.5 FI
11) 1.5 FI + GRA
12) 2 MFP + GRA
13) 2 MFP + 1.5 FI + GRA

Items eight through thirteen above were derived through the weighting procedure previously described. (The weights reflect the scale ranges noted in parentheses on lines one to three above.) The correlation matrix for these predictor variables against the subtest variables (MFP, FI, GRA) is presented in Table 5. The matrix only depicts those correlations that were considered for the three subtest variables, because predictor variables were being sought to represent each of the three. All correlations in the table were found to be significant at the $p < .05$ level. The data were missing four cases resulting in 45 cases being used for the matrix. Based on the correlation matrix, variable 10 and 7 were most highly correlated with the three input variables.

TABLE 5

Correlation Matrix for "Tactile" Variable

	Variable 1	2	3	4	5	6	7	8	9	10	11	12	13
1	--	.45*	.44*	.88*	.50*	.79*	.76*	1.0*	.45*	.92*	.50*	.90*	.85*
2	--	--	.55*	.82*	.81*	.60*	.79*	.40*	1.0*	.77*	.87*	.58*	.78*
3	--	--	--	.57*	.93*	.90*	.87*	.44*	.55*	.56*	.89*	.78*	.78*

* = significant at $p < .05$

Regression analysis confirmed the weighted three-variable combination as the most highly predictive of the three input variables. (Although variable 7 was also supported, the smaller variance of the correlations for variable 10, made the latter more attractive as a domain.) F tests for regressions using variable 10 as the independent variable against the independent input variables were all significant beyond the $p < .001$ level. The R^2 for the MFP, FI, and GRA regressions were .72, .61, and .62 respectively. In each case the regression residuals were found to approximate a normal distribution, and showed no evidence of heteroscedasticity. In conclusion, the following equation was selected to represent the TACTILE variable:

$$TAC = 2\,MFP + 1.5\,FI + GRA \quad [\,F(1,43) = 7.6,\ p < .000]$$

The Visual Perception (VP) Variable

The following variables were considered as possible predictors (hence, possible values for VP) of the three input variables (Figure Ground

Perception (FG), Position in Space (PS), and Visual Scanning (VS)):

1. FG
2. PS
3. VS
4. FG + PS
5. FG + VS
6. PS + VS
7. FG + PS +VS
8. 4 FG
9. 6.3 PS
10. 4 FG + 6.3 PS
11. 4 FG + VS
12. 6.3 PS + VS
13. 4 FG + 6.3 PS +VS

Lines eight through thirteen above were derived through the weighting procedure. Table 6 presents the correlation matrix for the predictor variables against the subtest variables (FG, PS, and VS). Eighteen missing cases were identified, resulting in 31 cases being used for the matrix. Variables 4 and 10 were found to be the most highly correlated with the three target variables. Variable 10 was preferred, due to the smaller variance for the correlations, and improved correlation coefficient for Variable 2 (PS). Negative signs on some correlation coefficients reflect opposite scoring procedures.

TABLE 6

Correlation Matrix for "Visual Perception" Variable

	Variable												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	--	.24*	-.45*	.92*	-.23	-.42*	-.20	1.0	.24*	.85*	.48*	-.23	.50*
2	--	--	-.06	.60*	0.0	.05	.12	.24*	.10	.72*	.17	.55*	.66*
3	--	--	--	-.40*	.97*	.99*	.96*	-.45*	-.06	-.36*	.56*	.80*	.39*

* = significant at p <.05

Regression analysis supported accepting Variable 10 as the single best predictor of the three target variables. The relatively low coefficient and thus, $\underline{R}^2$ for the Visual Scanning variable may partially reflect the large number of missing cases (12) for this variable, compared to most others in the study. However, the cognitive-perceptual act of visual scanning in this context (i.e., a letter cancellation task), is more complex than either the figure-ground or position-in-space tasks. Not only does visual scanning require adequate attention and figure-ground perception (distinguishing the target letter from background ones) but it also necessitates rapid and systematic conjugate eye movements, accurate letter recognition, response shifting, and a rapid motor (manual) response (Lezak, 1983). Hence it is a much less pure test of visual perception than the other two tests. This factor likely accounts for the inability of variable 10 to be highly predictive of VS.

When VS was removed from the correlation matrix, and regression equation, only one missing case was present. Based on 48 cases, the $\underline{R}^2$ for variable 10 regressed on FG and PS was .74 and .59, respectively. These statistics corresponded to $\underline{F}$-values significant beyond the $\underline{p} < .001$ level. In each case, the regression residuals were found to approximate a normal distribution, and showed no evidence of heteroscedasticity. In conclusion, the following equation was selected to represent the Visual Perception variable:

$$VP = 4FG + 6.3\ PS \quad [\ \underline{F}\,(1, 29) = 16.3,\ \underline{p} < .000]$$

Demographic Variables

Five demographic variables were considered for inclusion in the study. Those variables were: age, sex, education, socioeconomic status (SES), and post-traumatic amnesia (PTA).

As only 11 subject files had PTA data available, this variable was omitted. Although 35 data points were available for the SES variable, preliminary analyses showed this number to be very restrictive in terms of the degrees of freedom available when missing cases from other regression variables were factored in. Preliminary analysis (correlation coefficients for this variable, and initial regression runs) also indicated that SES was not statistically significant in any of the test precedures. Furthermore, as the correlation between SES and the education variable was found to be .62, this would imply that about 38% of the SES variance would be accounted for by the more useful education variable. (This is not surprising as the Blishen and McRoberts (1976) SES index is based on regression equation with income and education as the sole independent variables.)

Based upon preliminary analyses of the initial five demographic variables considered for inclusion in the investigation, only age, sex, and education were selected to remain in the final regression analyses.

Hypothesis Testing Procedure

Each hypothesis test commenced with a regression analysis of the full model as defined by the corresponding hypothesis. When no significant F or t values emerged, a systematic procedure was introduced to determine the most parsimonious and significant model. The acceptance or elimination of a particular variable was contingent upon: whether its coefficients were significant in any regression t-tests; the degree to which its exclusion resulted in a significant decrease in the F statistic; and, the degree to which its exclusion resulted in a significant decrease in the R^2 value. The interaction variables were given lesser importance especially whenever the full model was disconfirmed. This procedure was established for all of the hypotheses and will hereafter be referred to as the "backwards stepwise procedure". As well as significant F and t values, the minimum criterion for acceptance as a final model was an R^2 value of .20 or greater. This R^2 value corresponds to a model's ability to account for 20% or more of the variance of the criterion variable.

A correlation table denoting the Pearson correlation coefficient for all of the criterion-predictor variable combinations will be presented for each hypothesis.

Hypothesis 1

H_0: Attention span (DS) is not a function of vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

H_1: Attention span (DS) is a function of vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

This hypothesis was formulated to test the theoretical relationships proposed at the second level of sensory integration. Sensory Integration theory posits that adequate attentional faculties are contingent upon satisfactory reception, processing, and integration of vestibular, proprioceptive, and tactile inputs. The purpose of this hypothesis was to test this tenet.

A backwards stepwise regression analysis began with a regression of the full model which included the interaction effects of independent variables, and the three demographic variables (age, sex, and education). Preliminary analyses resulted in regression residuals with a heteroscedastic pattern. Investigation of the plots of the dependent variable versus each of the independents, coupled with an outlier analysis, suggested a natural logarithmic (lnX) relationship between SBC and DS. This transformation proved useful, and was utilized in the final regression analysis whenever SBC was called for (i.e. SBC became ln (SBC) for interaction variables as well).

Table 7 lists the backward stepwise procedure used for this hypothesis. (Note that the first variable in the list has become "ln(SBC)" as opposed to "SBC".) The full model yielded no significant beta coefficients, and a non-significant $\underline{F}$-Test at the .05 alpha level. In order to determine whether any variable combination could produce a statistically significant regression model; the backwards stepwise regression procedure was used. The final model accepted for this hypothesis was the following:

$$DS = \ln(SBC) + Education \quad [\, \underline{F}(2, 31) = 5.6,\ \underline{p} < .008 \,]$$

TABLE 7

Backward Stepwise Procedure for Digit Span

Variables In	Variables Added	Variables Deleted	Signif.(p<.05) Variables	F (p)	R^2	Variable Decision
All	---	---	---	2.0(.08)	.43	---
	---	X_6	X_{2-5}	2.3(.05)	.43	---
	X_6	$X_{7,8}$	---	singular matrix		---
	X_8	---	---	2.2 (.06)	.42	Eliminate X_8
	X_7	X_8	X_9	2.1(.08)	.40	Eliminate X_7
	---	X_{6-8}	---	singular matrix		---
X_{1-5}	---	X_5	---	singular matrix		---
	X_5	X_1	---	singular matrix		---
	X_4	X_3	---	singular matrix		Elim. $X_{4,5}$
$X_{1-3,6,9}$	$X_{3,6,9}$	$X_{4,5}$	X_9	2.2(.09)	.28	---
	---	X_6	X_9	2.6(.05)	.27	---
	X_6	X_2	X_9	2.7(.05)	.27	---
	X_2	X_3	X_9	2.7(.05)	.27	---
	X_3	X_1	X_9	2.0(.11)	.21	---
	X_1	X_9	X_1	1.4(.27)	.16	Eliminate X_3
$X_{1,2,6,9}$	---	X_2	X_9	3.7(.02)	.27	---
	X_2	X_6	X_9	3.6(.02)	.27	---
	X_6	X_1	X_9	2.5(.07)	.20	---
	X_1	X_9	X_1	1.9(.16)	.16	Eliminate X_2
$X_{1,6,9}$	---	X_1	X_9	3.9(.03)	.20	---
	X_1	X_6	X_9	5.6(.008)	.27	Accept Model
	X_6	X_9	X_1	2.8(.07)	.16	Eliminate X_6
$X_{1,9}$	---	X_9	X_1	5.8(.02)	.15	---
	X_9	X_1	X_9	7.1(.01)	.18	---

X_1 = ln (SBC)
X_2 = KIN
X_3 = TAC
X_4 = ln(SBC) X KIN
X_5 = ln(SBC) X TAC
X_6 = KIN X TAC
X_7 = Age
X_8 = Sex
X_9 = Education

This model explained 27% of the variance of DS. The education variable coefficient was significant at the .01 level, while the ln(SBC) variable was significant at the .10 alpha level. However, as ln(SBC) was significant when regressed alone, and as it significantly improved the $\underline{R}^2$ and significance of the $\underline{F}$ in the two variable model, this variable was allowed to remain in the model. Finally, the regression residuals approximated normalcy and did not evidence heteroscedasticity. A correlation table of the Pearson coefficients for the criterion variable with each of the singular (non-interaction) variables, including the demographic variables is presented in Table 8.

TABLE 8

Independent Variable Correlations with DS

DS X Variable					
ln(SBC)	KIN	TAC	Age	Sex	Ed.
.39*	.08	.06	.07	.08	.42*

* = significant at $p < .05$

In sum, only one of the theory's relationships, that is, the one between vestibular functioning (standing balance) and attention/concentration (digit span), was supported at the second level of Sensory Integration. This relation- ship was stronger when the natural logarthm of SBC was used, and when this variable was combined with the education variable. Nevertheless, the ln (SBC) variable was not highly significant in the model, and the model itself did not account for a large portion of the variance.

Hypothesis 2

$\underline{H}_0$: Visual scanning (VS) is not a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

$\underline{H}_1$: Visual scanning (VS) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

A theoretical relationship posited at the third level of sensory integration is being tested by this hypothesis. At this level, satisfactory visual perceptual skills generally, are purported to be dependent upon adequate reception, processing and integration of attentional, vestibular, kinesthetic, and tactile inputs. As a specific type of visual perceptual skill, visual scanning was introduced as an operationalized concept to test this hypothesis.

The backwards stepwise analysis initially included all interation effects and demographic variables. A heteroscedastic pattern was identified for the regression residuals in the preliminary analyses. Outlier analysis combined with plots of the dependent and independent variables revealed an inverse (1/X) relationship between VS and SBC. The SBC and corresponding interaction variables were then transformed to reflect this relationship, thereby improving the regression residual patterns.

Table 9 documents the backward stepwise analysis used for this hypothesis. The full model yielded no significant coefficients, and a

TABLE 9

Backward Stepwise Procedure for Visual Scanning

Variables In	Variables Added	Variables Deleted	Signif.($p<.05$) Variables	F (p)	R^2	Variable Decision
All	---	---	---	singular matrix		---
	---	X_{5-10}	---	.96(.50)	.34	Elim. X_{5-10}
$X_{1-4,11-13}$	---	X_{11-13}	---	1.6(.22)	.29	---
	X_{11}	---	---	1.3(.32)	.30	---
	X_{12}	X_{11}	---	1.4(.28)	.32	---
	X_{13}	X_{12}	---	1.3(.30)	.31	Elim.X_{11-13}
X_{1-4}	---	X_3	---	1.4(.27)	.20	---
	X_3	X_4	---	1.9(.17)	.25	---
	X_4	X_2	---	1.3(.32)	.18	---
	X_2	X_1	---	2.0(.15)	.26	Eliminate X_1
X_{2-4}	---	X_2	---	1.1(.37)	.10	---
	X_2	X_4	---	2.8(.09)	.23	---
	X_4	X_3	---	1.8(.19)	.17	Eliminate X_4
$X_{2,3}$		X_2	---	1.8(.20)	.08	Eliminate X_3
X_2	---	---	X_2	5.2(.03)	.18	---

X_1 = DS
X_2 = 1/SBC
X_3 = KIN
X_4 = TAC
X_5 = (1/SBC) X KIN
X_6 = (1/SBC) X TAC
X_7 = KIN X TAC
X_8 = DS X (1/SBC)
X_9 = DS X KIN
X_{10} = DS X TAC
X_{11} = Age
X_{12} = Sex
X_{13} = Education

non-significant F test at the .05 alpha level. Further analysis did not reveal any models that met the established criteria. The 1/SBC and KIN variables were found to have significant correlation coefficients with the criterion variable. A correlation table of the Pearson coefficients for the criterion variable with each of the singular (non-interaction) variables, including the demographic variables is presented in Table 10.

TABLE 10

Independent Variable Correlations with VS

VS X Variable						
DS	1/SBC	KIN	TAC	Age	Sex	Ed.
-.22	-.43*	-.40*	-.04	.02	-.28	.17

* = significant at $p < .05$

In summary, the null hypothesis as a complete model was accepted. However, when the subcomponents (predictor variables) were analysed individually, SBC and KIN were found to correlate directly with the criterion variable.

Hypothesis 3

H_0: Position in space (PS) is not a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

H_1: Position in space (PS) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

The purpose of this hypothesis was to test the SI tenet that position-in-space (a specific type of visual perceptual skill) is contingent upon satisfactory reception, processing, and integration of attentional, vestibular, kinesthetic, and tactile inputs.

The three demographic variables (age, sex, education) and all first-order interation effects were initially included in the backwards stepwise regression analysis. Preliminary regression and plot analysis suggested the need to transform the SBC variable. A natural logarithmic transformation of SBC and of the corresponding interaction variables removed the heteroscedastic pattern of the related residuals.

The backward stepwise procedure is recorded in Table 11. The final model was a substantially reduced version of the original, which was found to have neither a significant $\underline{F}$ statistic, nor significant beta coefficients. The final model is:

$$PS = DS + Age \quad [\, \underline{F}\,(2, 33) = 8.8 \; \underline{p} < .001].$$

The model was able to account for 35% of the variance. The residual plots approximated normalcy, and showed no evidence of a heteroscedastic trend.

A correlation table of the Pearson coefficients for the criterion variable with each of the singular (non-interaction) variables, including the demographic variables is presented in Table 12.

TABLE 11

Backward Stepwise Procedure for Position-In-Space

Variables In	Variables Added	Variables Deleted	Signif.($p<.05$) Variables	F (p)	R^2	Variable Decision
All	---	---	---	1.3(.29)	.36	---
	---	X_{5-14}	X_1	1.9(.13)	.21	Elim. X_{5-10}
X_{1-4}	---	X_4	X_1	2.4(.08)	.20	---
	X_4	X_3	X_1	2.5(.07)	.21	---
	X_3	X_2	X_1	2.3(.09)	.19	---
	X_2	X_1	---	.99(.41)	.09	Keep X_1
X_1, X_{2-4}	---	$X_{3,4}$	X_1	3.7(.03)	.20	---
	X_3	X_2	X_1	3.4(.05)	.18	---
	X_4	X_3	---	3.6(.04)	.19	---
	---	X_4	X_1	6.9(.01)	.17	Elim. X_{2-4}
X_1	X_{11-13}	---	$X_{1,11}$	5.8(.002)	.43	---
X_1, X_{11-13}	---	X_{12}	$X_{1,11}$	7.4(.001)	.41	---
	---	X_{13}	$X_{1,11}$	8.8(.001)	.35	Accept. Model

X_1 = DS
X_2 = ln (SBC)
X_3 = KIN
X_4 = TAC
X_5 = ln (SBC) X KIN
X_6 = ln (SBC) X TAC
X_7 = KIN X TAC
X_8 = DS X ln (SBC)
X_9 = DS X KIN
X_{10} = DS X TAC
X_{11} = Age
X_{12} = Sex
X_{13} = Education

TABLE 12

Independent Variable Correlations with PS

PS X Variable						
DS	ln(SBC)	KIN	TAC	Age	Sex	Ed.
.32*	.26	.25	.45*	-.33*	.09	.24

* = significant at $p < .05$

In sum, the relationship between attention span (DS) and position-in-space (PS), at the third level of sensory integration was supported. This relationship was much stronger when the subjects' age was incorporated into the model. However, the model itself accounted for a limited portion of the dependent variable's variance. A significant correlation was also found between PS and TAC.

Hypothesis 4:

H_0: Figure ground perception is not a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity

H_1: Figure ground perception is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

A theoretical relationship established at the third level of sensory integration is being tested by this hypothesis. The question addressed is whether figure-ground perception (a particular type of visual perceptual skill) is related to reception, processing and integration of attentional, vestibular, kinesthetic, and tactile inputs.

The backwards stepwise regression analysis began with a regression of the full model which included the first-order interaction effects of the independent variables, and the three demographic variables. No variable transformations were suggested during the initial residual plot, and independent versus dependent variable plot analyses.

Table 13 documents the backward stepwise procedure used to address this hypothesis. The full model yielded no significant beta coefficients, and a non-significant $\underline{F}$-test at the .05 alpha level. The final model accepted for this hypothesis was the following:

$$FG = SBC + Sex \ [\underline{F}(2, 33) = 6.5 \ \underline{p} < .005].$$

This model explained 28% of the variance of FG. The sex variable was significant at the .01 level, while SBC was significant at the .05 level. When plotted, the regression residuals of the final model, showed no evidence of heterscedasticity, and approximated the normal curve.

A correlation table of the Pearson coefficients for the criterion variable with each of the singular (non-interaction) variables, including the demographic variables is presented in Table 14.

TABLE 13

Backward Stepwise Procedure for Figure-Ground Perception

Variables In	Variables Added	Variables Deleted	Signif.(p<.05) Variables	F (p)	R^2	Variable Decision
All	---	---	---	1.3(.30)	.43	---
		X_{5-10}	---	1.8(.18)	.14	Elim. X_{4-10}
X_{1-4}, X_{18-20}	---	X_4	X_{12}	2.4(.06)	.33	---
	X_4	X_3	X_{12}	2.9(.03)	.33	---
	X_3	X_2	X_{12}	2.3(.07)	.28	---
	X_2	X_1	X_{12}	2.8(.03)	.32	---
$X_{1,2}, X_{11-13}$	X_1	---	X_{12}	2.7(.08)	.14	---
$X_{1,3}, X_{11-13}$	X_3	X_2	---	1.8(.18)	.10	---
$X_{1,4}, X_{11-13}$	X_4	X_3	---	1.6(.22)	.09	---
$X_{2,4}, X_{11-13}$	X_2	X_1	---	2.0(.15)	.11	---
$X_{3,4}, X_{11-13}$	X_3	X_2	---	0.4(.68)	.02	---
$X_{2,3}, X_{11-13}$	X_2	X_4	---	2.1(.14)	.11	---
	X_1	$X_{2,3}$	X_{12}	2.9(.04)	.27	---
	X_2	X_1	X_{12}	3.7(.01)	.32	---
	X_3	X_2	X_{12}	2.6(.05)	.25	Keep X_2
X_2, X_{11-13}	---	X_{13}	X_2, X_{12}	4.7(.008)	.30	---
	X_{13}	X_{12}	---	2.3(.09)	.18	---
	X_{12}	X_{11}	X_{12}	4.7(.008)	.31	Elim. $X_{11,13}$
X_2, X_{12}	---	---	X_2, X_{12}	6.5(.005)	.28	Accept Model
	---	X_2	X_{12}	7.5(.009)	.18	---
	X_2	X_{12}	X_2	4.0(.05)	.10	---

X_1 = DS
X_2 = SBC
X_3 = KIN
X_4 = TAC
X_5 = SBC X KIN
X_6 = SBC X TAC
X_7 = KIN X TAC
X_8 = DS X SBC
X_9 = DS X KIN
X_{10} = DS X TAC
X_{11} = Age
X_{12} = Sex
X_{13} = Education

TABLE 14

Independent Variable Correlations with FG

FG X Variable						
DS	SBC	KIN	TAC	Age	Sex	Ed.
.23	.24	.31*	.22	.26	.29*	.16

* = significant at $p < .05$

In conclusion, the full model of predictor variables was not supported in terms of its ability to account for the variance of FG. However when coupled with the demographic variable of sex, vestibular functioning (SBC) was found to have a direct relationship with the criterion variable. Although statistically significant, this relationship did not account for a large percentage of the variance of the dependent variable. An association between proprioceptive/kinesthetic (KIN) functioning and figure-ground perception was also supported.

Hypothesis 5

H_0: Motor accuracy (MAC) is not a function of attention span (DS), vestibular (SBC), proprioceptive (KIN) and tactile (TAC) integrity.

H_1: Motor accuracy (MAC) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN) and tactile (TAC) integrity.

At the third level of sensory integration, fine motor skills area also said to be mediated by the reception, processing and integration of attentional, vestibular, kinesthetic and tactile inputs. Test scores for the Motor Accuracy test were used to test this hypothesis.

Analysis of the residual plot patterns and plots of the dependent versus each of the independent variables did not suggest the need for variable transformations. Interaction effects and demographic variables were initially included in the backwards stepwise analysis, which is presented in Table 15. No significant coefficients nor F-test were yielded from thefirst model. In fact, no suitable model was identified in the analysis because of the lack of any strong correlation between the criterion and independent variables, in the regression analyses. However, the kinesthesia (KIN) variable was found to correlate significantly with motor accuracy. A correlation table of the Pearson coefficients for the criterion variable with each of the singular (non-interaction) variables, including the demographic variables is presented in Table 16.

TABLE 15

Backward Stepwise Procedure for Motor Accuracy

Variables In	Variables Added	Variables Deleted	Signif. ($p<.05$) Variables	F (p)	R^2	Variable Decision
All	---	---	---	.65(.78)	.33	---
	---	X_{11}	---	.73(.71)	.33	---
	---	X_{5-10}	---	1.3(.28)	.25	---
$X_{1-4}, X_{12,13}$	---	X_4	---	1.2(.32)	.20	---
	X_4	X_3	---	1.4(.24)	.22	---
	X_3	X_2	---	1.6(.20)	.24	---
	X_2	X_1	---	1.6(.21)	.24	---
X_3, X_1	---	---	X_3	3.0(.06)	.18	---
X_3, X_2	---	---	---	2.8(.08)	.16	---
X_4, X_1	---	---	X_4	3.3(.05)	.19	---
X_4, X_2	---	---	X_4	3.4(.05)	.19	---
X_1	---	---	---	1.9(.18)	.06	---
X_2	---	---	---	1.5(.13)	.07	---
X_3	---	---	X_3	4.7(.04)	.14	---
X_4	---	---	X_4	5.5(.03)	.16	Elim. X_1, X_2
X_3, X_4	---	---	---	3.6(.04)	.21	---
$X_3, X_{12,13}$	---	---	X_3	1.6(.22)	.15	---
	---	X_{13}	X_3	2.4(.10)	.15	---
	X_{13}	X_{12}	---	2.3(.12)	.14	---
$X_4, X_{12,13}$	---	---	X_4	2.0(.13)	.18	---
	---	X_{13}	X_4	3.1(.06)	.18	---
	X_{13}	X_{12}	X_4	2.7(.08)	.16	---

X_1 = DS
X_2 = SBC
X_3 = KIN
X_4 = TAC
X_5 = SBC X KIN
X_6 = SBC X TAC
X_7 = KIN X TAC
X_8 = DS X SBC
X_9 = DS X KIN
X_{10} = DS X TAC
X_{11} = Age
X_{12} = Sex
X_{13} = Education

TABLE 16

Independent Variable Correlations with MAC

MAC X Variable						
DS	I/SBC	KIN	TAC	Age	Sex	Ed.
-.22	-.43*	-.40*	-.04	.02	-.28	.17

* = significant at $p < .05$

In conclusion, the null hypothesis as a complete model was accepted. However, when the sub-components (predictor variables) were analysed individually, both tactile and kinesthetic input was found to correlate directly with the Motor Accuracy criterion variable.

Hypothesis 6

H_0: Arithmetic ability (AR) is not a function of visual perception (VP) and attention span (DS).

H_1: Arithmetic ability (AR) is a function of visual perception (VP) and attention span (DS).

The fourth level of sensory integration postulates that the development of abstract reasoning ability relies upon satisfactory sensory input and processing at lower SI levels. In order to test this hypothesis, the Arithmetic subtest of the Weschler Adult Intelligence Scale, Revised, was used as the criterion variable to represent abstract reasoning, while visual perception and attention span were used to represent the lower level SI processes.

Preliminary data analysis including residual and independent versus dependent, variable plots, and outlier analysis, revealed no necessity for variable transformations.

Table 17 summarizes the backward stepwise regression analysis for this hypothesis. The full model was not found to have any significant beta coefficient, nor a significant F-test at the .05 alpha level. A substantially reduced version of the original model was accepted, as follows:

$$AR = VP + Ed. \quad [\, F(2, 35) = 7.1 \; p < .003].$$

Although the VP variable alone accounted for 21% of the variance, the inclusion of the Education variable increased the R^2 to .29 despite its rather low beta coefficient in the final equation. Retaining this variable in the model may be justified intuitively, and on the basis of the highly significant Pearson correlation (at the .01 level) between Ed. and Arithmetic. The beta coefficients for Visual Perception and Education were significant at the .05 and .10 alpha levels, respectively. The regression residuals approximated the normal curve and did not evidence heteroscedisticity.

A correlation table of the Pearson coefficients for the criterion variable with each of the singular (non-interaction) variables, including the demographic variables is presented in Table 18. Although not included in the regression analysis, KIN and TAC were included in the correlation study.

TABLE 17

Backward Stepwise Procedure for Arithmetic

Variables In	Variables Added	Variables Deleted	Signif.($p<.05$) Variables	F (p)	R^2	Variable Decision
All	---	---	---	2.1(.07)	.33	---
	---	X_1	---	3.0(.02)	.32	---
	X_1	X_2	---	3.1(.02)	.33	---
	X_2	X_3	---	3.0(.03)	.32	---
	X_3	X_{4-6}	---	3.9(.02)	.25	---
X_1	---	---	---	3.5(.07)	.09	---
X_2	---	---	X_2	9.8(.004)	.21	---
X_3	---	---	X_3	8.9(.005)	.20	Eliminate X_1
X_2, X_{4-6}	---	X_6	X_2	3.8(.02)	.25	---
	X_6	X_5	X_2, X_6	4.7(.007)	.29	---
	X_5	X_4	---	5.1(.005)	.31	---
X_2, X_4	---	---	X_2	5.2(.01)	.23	---
X_2, X_5	---	---	X_2	5.4(.009)	.24	---
X_2, X_6	---	---	X_2, X_6	7.1(.003)	.29	Accept Model
X_3, X_{4-6}	---	X_6	X_3	3.5(.03)	.24	---
	X_6	X_5	---	4.3(.01)	.28	---
	X_5	X_4	---	5.0(.006)	.31	---
X_3, X_4	---	---	X_2	4.5(.02)	.20	---
X_3, X_5	---	---	X_2	5.3(.01)	.23	---
X_3, X_6	---	---	---	6.6(.004)	.27	---

X_1 = DS
X_2 = VP
X_3 = DS X VP
X_4 = Age
X_5 = Sex
X_6 = Education

TABLE 18

Independent Variable Correlations with AR

AR X Variable							
DS	VP	SBC	KIN	TAC	Age	Sex	Ed.
.28	.41**	.22	.19	.36*	-.14	.14	.44**

* = significant at $p < .05$, ** = significant at $p < .01$

In conclusion, the full model of predictor variables was not supported in terms of its ability to predict the dependent variable. However, when coupled with the demographic variable of education, visual perception was found to have a direct relationship with the criterion variable. This model failed to explain a large percentage of the variance of Arithmetic.

Visual Perception (VP) Correlations

Table 19 is a correlation table of the Pearson coefficients for the VP variable and was created as part of a post hoc analysis. The table provides evidence for relationships between VP and DS, SBC, and TAC.

TABLE 19

Independent Variable Correlations with VP

VP X Variable			
DS	SBC	KIN	TAC
.33*	.30*	.28	.02*

* = significant at $p < .05$

Summary and Synthesis of Results

The results of the regression analyses and correlational studies are summarized in Table 20. None of the final regression models were found to be highly predictive of the relevant criterion variable. The R^2 values ranging from .21 to .35 attest to the poor predictive power. The individual Pearson correlations between the predictors and the criterion variables also tended to show relatively weak relationships. The last column in the table indicates relationships with the criterion variable that are not represented in the final model. These correlations were significant at the .05 level.

TABLE 20

Summary of Results

Hypothesis/ Criterion Variable	Full Model	Final Model	R2	Var. Correl.
1 - Digit Span	Accept Ho	DS = ln(SBC) + Ed.	.27	----
2 - Vis. Scan.	Accept Ho	----	---	SBC, KIN
3 - P. Space	Accept Ho	PS = DS + Age	.35	TAC
4 - F. Ground	Accept Ho	FG = SBC + Sex	.28	KIN
5 - M. Accur.	Accept Ho	----	---	KIN
6 - Arith.	Accept Ho	AR = VP + Ed.	.21	TAC
7 - V. Percep.	----	----	---	DS, SBC, TAC

Independently, the individual correlations and regression models offer weak, if any, support for the Sensory Integration model. However, synthesis of the data into the model's dynamic structure allows for a more comprehensive analysis. Figure 6 depicts the theoretical relationships which were supported by the multiple regression and correlational findings. Light lines on the figure represent Pearson correlational relationships, while the dark lines represent the selected regression models. The numerical values assigned to each of the lines are the probability values that correspond to the relevant t or F - test. It is noteworthy that although a criterion p value of .10 was established for a correlation to be entered onto the figure, only two correlations were found to have a p value greater than .05. (Readers are reminded that the directionality implied by the arrows on the figure is a tenuous assumption of causality based upon theoretical principles. Causal relationships cannot be directly established from strictly correlational studies.) Taken collectively, the data is much more supportive of the theory's postulates.

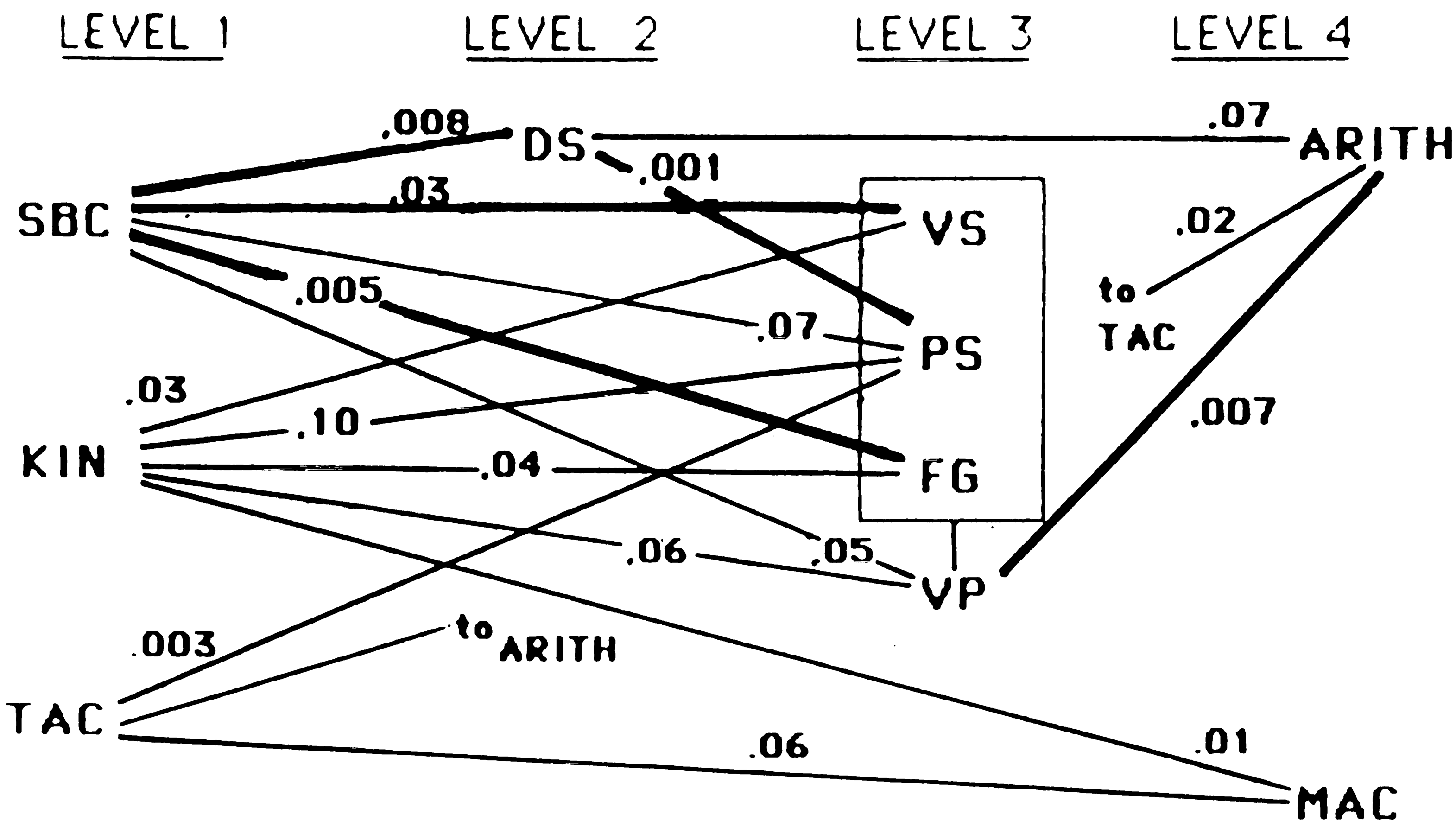

Figure 6. Schematic of correlational/regression p- values for variable relationships within the Sensory Integration theoretical framework.

CHAPTER V

SUMMARY, DISCUSSION, AND CONCLUSIONS

Summary

At present, neurorehabilitation tends to be guided by empirically based methods as opposed to comprehensive theories of brain-behaviour relationships. Furthermore, the emphasis in both treatment and assessment is placed on higher cortical functions, neglecting the role of subcortical structures acting independently, and interactively, with higher brain structures. The theory of Sensory Integration may provide a comprehensive framework for cognitive rehabilitation, and a test battery from which both cortical and subcortical deficits may be identified.

Both theoretical and empirical evidence substantiate short and long term recovery from brain damage. The theoretical perspectives are divided into three schools of thought: the structuralist position with an emphasis on static brain relationships and composition; mechanisms involving physiological processes; and, behavioural mechanisms which are oriented towards functional goal attainment utilizing alternate intact brain structures. Research evidence is supportive of all three approaches, which by are by no means mutually exclusive. Singularly and in combination these models provide the underpinnings for spontaneous recovery, and should likewise formulate the guidepost for intervention. Rarely is cognitive remediation articulated in this manner with a clear explanation (hypothesis) of the recovery processes involved. Such atheoretical approaches on the part of program planners/clinicians often results in a lack of direction for meaningful and systematic research and program development.

Sensory Integration is a neurodevelopmental model which has been well researched in learning disabled populations. The theory posits that accurate sensory perception, memory, motor coordination/skills, and higher cognitive functioning are all contingent upon proper sensory processing at subcortical levels. In particular, the theory highlights the integral role of vestibular, tactile, proprioceptive, and kinesthetic activity in the evolution of cognitive-perceptual-motor skills. These inputs are integrated at various levels of the central nervous system such as the spinal cord, brain stem, thalmus, and cortex. Combined with the processing of auditory and visual information, higher level skills become possible. These higher cortical functions include speech perception and expression, acute visual-spatial perception and discrimination, attention/concentration, verbal and non-verbal abstract thought, and academic learning ability. The link between sensory-motor functioning and cognitive/intellectual development is strongly supported by Piaget's developmental theory. Together the Ayres and Piagetian concepts provide a comprehensive model of both static and dynamic neurobehaviour relationships, and provide a heuristic model for CR intervention and research.

Three primary processes are viewed as being responsible for successful remediation of cognitive-perceptual-motor deficits: (1) the restoration of vestibular, tactile, proprioceptive, and kinesthetic functioning at subcortical levels; (2) bio-behavioural recovery of cortical areas and peripheral subsystems; and, (3) efficient relays between subcortical and cortical areas. The majority of CR programs focus exclusively on the second process. Since, the cortex receives input from the subcortical structures, failure to remediate the first (thereby influencing the third) process would limit the success of treatment aimed exclusively at cortical (and peripheral) activities. A fourth process which may enhance recovery also focusses on brain stem integrity, as this structure may replace the behavioural function of an impaired cortical area e.g. the collicular region has been known to take over visual discrimination in animals whose visual cortex has been distroyed (Dr. Andrew Kertesz, personal communication, June 1, 1988). This final phenomenon is an example of the radical reorganization hypothesis.

Review of the literature reveals that brain stem insult is almost inevitably involved whenever brain trauma results in loss of consciousness. The most likely cause of (typically microscopic) pathology to this region of the brain is rotational acceleration of the head, and the tremendous forces applied to the brain stem. There is also evidence to suggest that a significant proportion of the symptoms of patients suffering from post-concussion syndrome may be the result of damage to the brain stem. Finally, preliminary animal research lends optomism to the possibility of brain stem recovery, especially given the high degree of anotomic and cellular undifferentation within this structure. Both the sparing and redundancy models may be relevant to recovery in this region of the brain.

Currently, there is a lack of behavioural measures to evaluate, diagnose and provide treatment direction for subtle subcortical deficits which may first appear to be cortical in nature. The standardized Southern California Sensory Integration Tests battery may usefull towards this end.

The purpose of this investigation was to provide a preliminary evaluation of the SI theory as a possible model for the understanding and treatment of deficits arrising from brain trauma. The study focussed on determining whether strong relationships do exist between higher and lower order functions as hypothesized in the heirarchical SI theory.

Six general hypotheses were formulated to test this theory:

H1:

Attention span (DS) is a function of vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

H2:

Visual scanning (VS) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

H3:

Position-in-space perception (PS) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

H4:

Figure-ground perception (FG) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

H5:

Motor accuracy (MAC) is a function of attention span (DS), vestibular (SBC), proprioceptive (KIN), and tactile (TAC) integrity.

H6:

Arithmetic ability (AR) is a function of visual perception (VP) and attention span (DS).

The visual perception (VP) and tactile (TAC) variables were created using the predictor variables from the respective domain areas prior to hypothesis testing. All hypotheses were tested using a backwards stepwise regression procedure, and correlation t- tests with alpha set at .05 (N=49). A regression model had to explain at least 20% (R^2= .20) of the variance to be accepted as the final model. Regression results and Pearson correlation coefficients representing the relationship between the criterion variable and each of the predictor variables were presented in the analysis of results. This data yielded the following results.

Hypothesis 1: Attention/Concentration

The final model accepted for this hypothesis explained 27% of the variance and was significant at the .01 level. The equation for the model is:

$$DS = \ln(SBC) + Education.$$

This model supports the theory's proposed relationship between vestibular functioning and attention/concentration. Education was also found to be related to attention/concentration. Correlation analysis did not yield statistically significant t-tests for coefficients which represent relationships between DS-TAC or DS-KIN. Therefore, this hypothesis test did not provide evidence to support a correlation between tactile or kinesthetic functioning and attention/concentration.

Hypothesis 2: Visual Scanning

No regression model was accepted for this hypothesis. A significant correlation was found for VS-1/SBC and VS-KIN. This hypothesis test provides evidence of a correlation between visual scanning ability and vestibular and kinesthetic functioning, respectively. The demographic variables were not found to be related to the criterion variable.

Hypothesis 3: Position-in-Space

The final model accepted for this hypothesis explained 35% of the variance and was significant at the .001 level. The equation for the model is:

$$PS = DS + Age.$$

This model supports the theory's proposed relationship between attention/concentration and the visual perceptual skill of position-in-space. Correlation analysis yielded statistically significant t-tests for the coefficient which represents the relationship between PS and TAC. At the .10 level of significance, a correlation was found to exist between PS-KIN and PS-SBC. Therefore, this hypothesis test provides evidence to support an association between position-in-space and tactile functioning and, weaker support for a link between position-in-space and both kinesthetic and vestibular functioning, respectively.

Hypothesis 4: Figure-Ground Perception

The model accepted for this hypothesis explained 28% of the variance and was significant at the .005 level. The equation for the model is:

$$FG = SBC + Sex.$$

This model supports the theory's proposed relationship between vestibular functioning and figure-ground perception. Gender was also found to be related to this aspect of visual perception in the sense that women consistently scored more highly than men. Correlation analysis yielded statistically significant t-tests for the coefficient which represents the relationship between FG and KIN. Therefore, this hypothesis test also provides evidence of a correlation between figure-ground perception and kinesthetic functioning.

Hypothesis 5: Motor Accuracy

No regression model was accepted for this hypothesis. A significant correlation was found between MAC and KIN. At the .10 significance level, a relationship was also supported between MAC and TAC. This hypothesis test provides evidence of an association between manual motor accuracy and tactile and kinesthetic functioning, respectively. The demographic variables were not found to be related to the criterion variable.

Hypothesis 6: Arithmetic

The final model accepted for this hypothesis explained 29% of the variance and was significant at the .005 level. The equation for the model is:

AR = VP + Education.

This model supports the theory's proposed relationship between visual perception and arithmetic ability. Education was also found to be related to arithmetic ability. Correlation analysis yielded statistically significant t-tests for the coefficient which represents the relationship between DS and AR. Therefore, this hypothesis test also provides evidence of a link between attention/concentration and kinesthetic functioning.

Analysis Overview

None of the regression models were found to be highly predictive of the relevant criterion variables. Although many were statistically significant, the individual correlation coefficients were not found to be very high. However, when the data was synthesized into the theoretical schematic, it was found to be much more supportive of the theoretical constructs. Variables at each theoretical stage were found to be correlated with at least one variable from previous stages. The figural summary will be presented again in Figure 7 to facilitate following the discussion section for the reader. Frequent reference to the diagram may be helpfull.

Discussion

This section will discuss conclusions drawn from the statistical analysis, and limitations of the study.

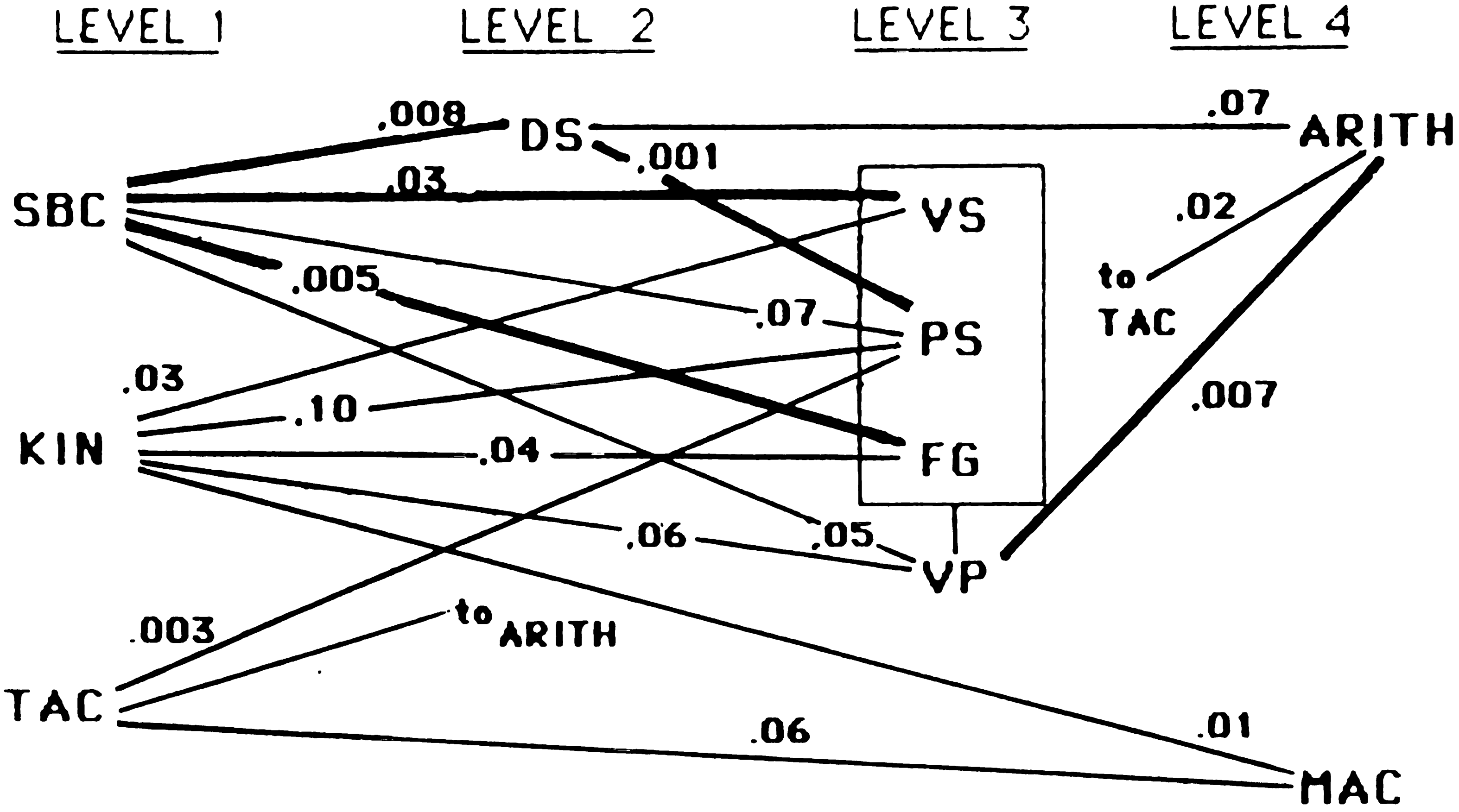

Figure 7. Schematic of correlational/regression p-values for variable relationships within the Sensory Integration theoretical framework. This figure remains unaltered from that in Figure 6.

Taken at face value the results of this investigation are an encouraging preliminary evaluation of Sensory Integration's appropriateness for assessment and treatment of brain injured adults. While no definitive conclusions may be drawn from such a correlational study, multiple theoretical relationships were nevertheless supported between all of the SI levels.

Of particular interest are the numerous direct relationships found between the variables at the first and third SI levels. This pattern suggests that vestibular, kinesthetic and tactile processes may influence visual perceptual functioning (VP) in general, and specific visual perceptual skills in particular. Figure-ground perception and visual scanning were found to be related to both vestibular and kinesthetic measures, while position-in-space was related to all three level 1 variables. This finding is consistent with those of several studies in other populations previously cited in the literature review. If these theoretical relationships are indeed valid in the TBI population, as they appear to be in other clinical populations, then perhaps there is optimism for the SI treatment being proven effective with TBI patients as well.

The practical implications of such treatment are far reaching. Reading skills in particular are dependent upon adequate visual scanning ability and figure-ground perception, as are the simple daily tasks of searching for an object on a shelf, or looking for a face in a crowd. The skill of position-in-space is necessary for adequate judgement of oncoming traffic, estimating distances, and discriminating between similarly shaped objects. Therefore remediation of these higher level skills may be achieved by improving their underlying components according to SI theory.

The other variable clusters which emerged were less strongly supported largely due to the design of the study i.e. fewer hypotheses were oriented towards addressing them. The first of these clusters involved the direct relationships between the SI fourth level motor accuracy variable and the tactile and kinesthetic variables at level one. This finding has significant face validity because of the well established relationship between the sensory and motor systems for any motor task, especially this type which requires a high degree of precision. Adequate sensory reception and processing is required to provide feedback and guidance for the motor movements. Likewise, one would not necessarily intuitively anticipate a direct relationship (which did not occur) between vestibular processing and a precision motor skill, although an indirect influence would be expected if mediated through the sound visual skills required to complete the task. Thus, it is surprising that no relationship was found between motor accuracy and any of the level three (visual) variables. Two possible explanations for this are: that the visual skill level required for this task is not very great relative to that required for the visually oriented tests; and, that the motor accuracy test requires a visual perceptual skill domain not tested by the visual tests. The former exlanation is likely more accurate, given the relative simplicity of the visual demands compared to that of the visual tests.

At the fourth level of sensory integration, represented by AR, there was evidence of direct relationships with level three (represented by the constructed VP variable) and level two (represented by the DS variable), and an indirect relationship with level one mediated by VP at level three, and DS at level two. This cluster encompasses the complete heirarchy of the abbreviated methodological schemata (Figures 3 and 4), and therefore, a significant subcomponent of Ayres full theoretical model (Figure 2).

The regression model for hypothesis six which involved Arithmetic as the criterion variable, also has a high degree of face validity because this Wais-R subtest is known to correlate highly with other visual spatial measures such as the Block Design subtest, and is also highly correlated with education (Wechsler, 1981). Furthermore, the relationship between attention/concentration (Digit Span) and Arithmetic was previously elucidated.

The final theoretical relationship that was established is the one between vestibular integrity (Standing Balance Closed) and attention/ concentration (Digit Span). This finding is noteworthy because of the hypothesized association between these two phenomena and the tendency for TBI victims to tire easily. The reasoning behind this conjecture is that these individuals must use continuous conscious effort to maintain their eqilibrium--a function which is normally controlled subconsciously at the brain stem level. Since they must direct so much effort into maintaining thier balance, people recovering from a TBI are less able to focus their attention, and are prone to tire easily.

Finally, each of the three demographic variables were found to play a role in one final regression model. Age was associated with position- in-space, sex with figure-ground perception, and education with arithmetic.

The last of these has already been addressed. While the link between age and position-in-space holds some face validity (certainly visual perceptual skills have been shown to decline with advanced age) it is not clear why this relationship was not found in the other visual domains. It is possible that the very good reliabity in all three model variables (Position-in-Space, Digit Span and age) enabled this association to emerge, while the instability of the Figure-Ground test may have barried its true relationship with age. Future research will be left to answer this query, and the one regarding the sex difference in the figure-ground perception model.

Limitations of the Study

A major conclusion drawn from this research is that preliminary empirical support exists for the principles and conceptual relationships of Sensory Integration in the context of adult brain trauma. This conclusion is more comfortably drawn from the aggregate results of the data as opposed to that of any one hypothesis. While the rather weak R^2 and correlation coefficient values are of concern, three factors may help to explain their occurrence.

First, the reliability of several of the measures utilized is somewhat poor. In particular, the reliability of the the Kinesthesia test, the Figure-Ground Perception test, and the three tests which comprised the Tactile variable, all fell between .28 and .56. Although the use of the Tactile variable, which had tripple the number of items of its composite variables, likely improved reliability, its stability must also be questioned. Poor reliability of instrumentation is typically a significant source of correlation and $\underline{R}^2$ deflation in an analysis (Draper & Smith, 1966). Given that low reliability affects two variables at the first SI level, and one variable at the third, and that there were ten variables with possible correlations between them, one may expect the majority of these correlations to be susceptible to statistical deflation. Such a factor bodes well for the findings of the investigation, as it suggests that the true correlation parameters (and hence, $\underline{R}^2$ values) are greater in size than the ones estimated by the measures. Unfortunately, these types of instruments tend to be inherently unstable by the very nature of the neurophysiological processes which they attempt to measure (Ayres, 1972a). The problem of instrument reliability may have been exacerbated by the fact that the test examiners had not been professionally trained on the use of certain tests (particularly the WAIS-R measures).

The second factor which may have reduced the strength of the correlations, pertains to the possible confound introduced into the analysis by other disabilities that may have been sustained by the subjects either separately or concurrent to their brain injury. For example, a peripheral dominant arm/hand injury may not have been severe enough for the test to be waived, but nonetheless may have adversly affected the Motor Accuracy test score; likewise, peripheral impairment in either the upper or lower extremities may have reduced the individual's performance in the tactile/kinesthetic or vestibular tests, respectively. The confound introduced by any such cases is that if the biases had occurred systematically, they may either have lowered or raised the values of the correlation coefficients. Furthermore, it may have introduced the peripheral nervous system as a possible source of variance for the criterion variables in the regression analyses. Although a systematic bias may seem unlikely, the fact that head injury victims in general often sustain multiple bodily injuries, and that the majority of subjects in the study had been injured in automobile accidents, precludes one from readily dismissing this possibility.

The third explanation may rest in a reminder of the complexity of the central nervous system itself. Perhaps such a statistical model --but perhaps not the broader theory it represents-- depicting linear and minimally interactive relationships is too simplistic to capture the complexity of the true underlining statistical relationships. This interpretation suggests that despite generally valid theoretical constructs, low correlations and poor predictive regression equations might be accounted for by: overlooked parameters; the existance of higher-order interaction variables; and/or, non-linear relationships.

Alternately, SI theory itself might be invalid on account of its strictly behavioural focus. This viewpoint would imply that only concepts which employ in thier formulation actual neuroanatomical, neurophysiological, neurochemical processes and the like, may be reliable and valid determinants of behavioural as well as of biological recovery. Taken to its extreme, this criticism leaves no place for behavioural intervention or research whatsoever.

With respect to the methodology of the study, correlational analyses by themselves cannot firmly establish that the levels of SI are dependent upon one another. At best, these regression analysis may determine to what extent the variance of the dependent variable in any given equation explained (in a correlational sense) the variance of the predictor variables. Interpretation of the findings becomes even more difficult when trying to tease out the degree to which both cortical and subcortical processes are influencing the variables. This problem is not limited to correlational investigations, but would most likely present itself in controlled studies, and any other approach which aims to isolate the independent contribution of cortical, subcortical, cortical-subcortical relays, and interaction effects. Indeed this is a major obstacle facing future SI and other researchers, if the true brain-behaviour processes are to be determined.

These findings may only be generalized to a population similar to the one studied. The present subjects are characterized as having sustained a TBI as an adult, and as having been evaluated between 1982 and 1988 at a medical facility associated with a large mid-western university in the United States. Given the nature and mandate of the facility, and the fact that most patients were covered by insurance (mandatory no-fault automobile insurance exists in the state of Michigan for those involved in MVAs), it is likely that some sampling bias occurred relative to the population at large. Persons at the lowest and highest ends of the socioeconomic spectrum may be underrepresented: the former due to a lack of financial means to pay for services, or a higher incidence of unawareness regarding their condition; and, the latter perhaps due to their financial ability to seek what they perceive as being a higher quality of care elsewhere. The latter group would not likely present much differently from the sample in terms of their neuropsychological satus.

However, the former group may present with a higher proportion of health related problems (including vitamin deficiency, and drug/alcohol abuse), and previous head trauma (which may have resulted from physical abuse, street fights, etc.), both of which may alter their neuropsychological profile, and may interact synergistically with their recent traumatic brain injury.

Finally, variables which may have confounded the interpretation of the data, aside from possible mild sensory/motor impairment, include: concurrent learning disability and alcohol/drug abuse. While an effort was made to screen individuals with such characteristics from the study, such information was not likely to have been consistently reported.

Implications for Future Research

The difficulty in finding a methodological approach that will enable the isolation of cortical from subcortical functioning has already been acknowledged. In a similar vein, the determination of the appropriate control groups for future research would have to be given a great deal of consideration. It may be desireable to approach the "isolation" problem from the standpoint of two separate groups with known (as confirmed by MRI, for example) distinct cortical and subcortical (brain stem) lesions, respectively, coupled with normal and diffuse brain impairment groups. The problem with this approach however, may be in finding the required numbers of subjects to form the two "pure" groups, that would also have to be matched on sex, age and education/SES, and have no prior history of peripheral or central nervous system impairment (including alcohol or drug abuse, and learning disability). CVA patients, whose lesions tend to be more circumscribed, likely represent the most promising source for such distinct groups.

Another worthwhile comparitive group would be learning disabled adults. Test score comparisons between LD and minor TBI subjects may help to elucidate underlying neurobehavioural similarities and differences between the two groups. It may also indirectly help support the appropriateness of utilizing SI with less severe brain injured victims, and persons suffering from post-concussion syndrome. Again the generation of a sufficient number of matched subjects may be problematic.

An interesting question to pose is how SI impairment due brain trauma may differ between a person who is pre-adult and developing neurologically, adult and stable, and late-adult and declining, from a bio-behavioral recovery point of view. SI theory should very much so be studied across the developmental spectrum. Related to this issue is whether adults may be able to maintain many specific higher cortical functions (e.g. abstract reasoning ability), when brain stem structures are impared. If so such a finding may imply that the initial development of higher functions relies upon subcortical integrity, but that once developed, these higher functions may be able to operate autonomously. Certainly the high prevelance of "frontal lobe signs" in patients who have (subcortical) basal gangliar disorders such as Parkinsons disease would argue aginst this hypothesis, and in favour of SI processes being involved in every aspect of brain behaviour.

Finally, SI research that is focussed on program evaluation and treatment efficacy, may consider empoloying case study methodologies as well as appropriate control groups. Such research will inevitably be much less adept at the probing of underlying recovery processes. Likely this research would also be confounded by multidisciplinary treatment involvement, the restriction of which, could not be justified ethically. For this reason, systematic case study methodologies have been encouraged in all types of neuropsychological research (Parsons & Prigatano, 1978). The present investigation provides sufficient evidence to warrant further study in this area.

In closing, the following directions for future research are offerred:

1. Replication in another setting by different investigators to control for experimenter bias;
2. Similar research focussing on the relationship between lower level (subcortical) SI functions and verbal functioning;
3. The development of more reliable instrumentation to measure brain stem integrity;
4. The establishment of adult norms for the SCSIT battery across the age and socio-cultural-economic and educational span;
5. Program evaluation and treatment efficacy methods that employ pre-tests and multiple interval testing to reveal dynamic processes;
6. Research focussing on the possible relationship between post-consussive syndrome in minor head injury and SI.
7. Pure research focussing on brain stem characteristics, and recovery processes;

8. The development of alternative rival models that will attempt to present a comprehensive framework for the understanding of brain-behaviour relationships, and that will provide an heuristic basis for pure and applied (joint and separate) research.

Appendix A

TABLE 21

Table of Variable

Subject	DS	SBC	KIN	TAC	VP	VS	PS	FG	MAC	AR
1	11	3	73	57	179	57	17	18	128	---
2	15	0	76	50	264	64	21	33	157	16
3	24	49	83	50	280	44	26	29	164	14
4	14	20	75	53	205	23	--	15	158	15
5	15	39	75	63	324	62	26	40	162	14
6	16	5	68	44	201	51	16	25	154	11
7	26	6	59	58	259	135	29	19	160	--
8	16	--	54	--	206	--	13	31	--	8
9	14	3	81	63	293	120	23	37	167	14
10	12	11	76	57	257	84	23	28	163	11
11	15	4	87	52	234	83	25	19	161	10
12	11	11	73	53	215	116	22	19	121	6
13	11	16	80	67	171	--	17	16	166	12
14	17	--	36	17	167	--	17	15	--	11
15	11	0	78	46	250	70	25	23	163	7
16	14	8	--	38	197	85	18	21	167	6
17	15	14	79	59	212	--	21	20	--	6
18	18	5	76	53	222	--	20	24	--	13
19	16	25	75	59	243	90	24	23	159	9
20	5	3	77	63	223	--	24	18	--	16
21	14	28	89	62	275	--	24	31	166	14
22	11	5	39	26	--	--	--	--	--	1
23	11	2	--	30	126	--	13	11	--	5
24	12	16	67	55	245	83	23	25	165	17
25	4	4	79	51	220	141	21	22	157	6
26	7	19	75	--	275	--	24	31	157	--
27	16	5	59	46	234	98	25	19	151	9
28	14	17	71	43	251	45	24	25	162	12
29	24	16	86	63	283	81	29	25	170	13
30	13	27	85	67	202	--	20	12	169	12
31	23	10	85	66	227	69	24	19	175	11
32	7	0	78	53	165	--	16	16	159	11
33	16	10	63	42	188	130	19	17	--	5
34	15	--	--	--	152	139	14	16	--	12
35	22	20	79	64	363	--	29	45	159	19
36	11	13	73	57	264	101	28	22	175	6

37	10	5	64	57	220	--	19	25	--	11
38	--	0	--	53	209	115	23	16	174	--
39	16	6	84	53	253	--	23	27	166	11
40	14	9	60	38	303	82	24	38	148	16
41	12	3	68	58	220	--	26	14	167	19
42	11	4	63	47	222	187	25	16	144	10
43	14	32	76	--	246	56	25	22	160	5
44	15	2	63	--	240	115	26	19	148	13
45	--	29	80	55	171	101	17	16	--	14
46	17	34	77	49	276	83	28	25	173	15
47	10	3	83	59	234	--	25	19	--	6
48	--	6	87	56	350	57	25	48	168	--
49	12	11	70	67	251	81	24	25	175	8

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