THE UNIVERSITY OF CALGARY

Development of Executive Functions in Children

by

Simon McCrea

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF EDUCATIONAL PSYCHOLOGY

CALGARY, ALBERTA

March, 1998

0-612-31362-X

ABSTRACT

Executive functions and related constructs such as planning, strategy and working memory capacity enable one to develop and maintain a "cognitive set" across changing stimulus conditions in order to achieve a future goal. Reçent studies have examined neuropsychological tasks as potential indices of developing executive capacities among elementary school children. The Peabody Picture Vocabulary Test and three executive measures: the Wisconsin Card Sort Test, the Thurstone Word Fluency Test, and the WISC-III-R Mazes subtest were administered to a cross-section of 115 children aged 6 to 9. Using a school entrance cut-off design, the effects of formal schooling versus age contributions to the performance on these executive measures were separated. Chronological age as opposed to gender, schooling or IQ accounted for a significantly greater proportion of the variance in the indices of growth of executive capacities in children in this study. The implications of the findings for educators is discussed.

ACKNOWLEDGEMENTS

Special thanks to my supervisor Dr. John Mueller for his patience and guidance in this project, and for his encouragement at undertaking such an interdisciplinary endeavor. Dr. Eva Pajurkova co-supervised the project, and provided constructive criticism on neuropsychological-related issues. Thanks are extended to thesis committee members, Dr. Anne McKeough and Dr. Marilyn Samuels for their invaluable editorial assistance on earlier versions of this manuscript. Dr. Gregor Jason encouraged my participation at weekly meetings of the Foothills Neuropsychology Journal Club. Dr. Bryan Kolb of the University of Lethbridge and Dr. Robbie Case of the University of Toronto provided advice on experimental design considerations in the early stages of the project. Statistical consultation was provided by the Center for Research in Applied Measurement and Evaluation (CRAME) at the University of Alberta. Dr. J.P. Das of the University of Alberta made some helpful suggestions on the relation between planning and executive functions.

Finally, sincerest thanks are extended to the students, parents and staff of the participating schools within the Calgary Public School System. This research was supported by a University of Calgary Faculty of Graduate Studies Research Scholarship, Travel Grant and Research Grant. Parts of this research was previously presented at the VII Annual Meeting of the Canadian Society for Brain, Behavior and Cognitive Science at the University of Manitoba, Winnipeg, Canada in June of 1997.

Dedicated to Terra and Zanna,

and to my parents,

for their unwavering support.

TABLE OF CONTENTS

Page

Page

Page

LIST OF TABLES

LIST OF FIGURES

...an interest in neural anatomy and physiology may make more work for the midwife of psychological ideas than for the undertaker...

Donald Hebb (1951)
Montreal Neurological Institute
McGill University

BACKGROUND

Learning Processes and Neuroscience

The last two decades have witnessed unparalleled advances in the understanding of cognitive processing and its neural substrates. By way of background, in 1986 the US National Institute of Education, National Science Foundation and Alfred Sloan Foundations sponsored the volume *"The Brain, Cognition and Education"* in an effort to determine if any innovations within the cognitive neurosciences might also be applicable towards pressing educational problems (Friedman, Klivington & Peterson, 1986). This meeting broke new ground in paving the way towards future collaborations between educational psychologists and cognitive neuroscientists.

Again, in 1995 a group of cognitive neuroscientists and educational psychologists met at the University of Oregon to discuss the relation between educational learning processes and cognitive neuroscience (James S. McDonnell Foundation and the Institute of Cognitive and Decision Science, University of Oregon, 1995). The aim of this symposium was to examine how specific advances in neuroimaging techniques within the 1990's were helping to elucidate the neural underpinnings of cognition and hence our understanding of learning processes. One salient theme of the conference was that the tools of the cognitive psychologist (e.g., the reduction of cognitive processes into substituent elements) would be indispensable to the eventual understanding of the neural substrates of complex cognition, as exemplified in the work of Dehaene, (1996).

Education and Neuroscience: Caveats

Wittrock (1991) suggested two cautionary notes for those studying the relationship between instructional processes and cognitive neuroscience. First, Wittrock warned of the dangers of *naive reductionism* and suggested that the environmental demand characteristics of a specific cognitive task performed by a person must ultimately be taken into consideration. Investigations of the contextual influences on cognitive processing have revealed themselves to be integral to any comprehensive analysis of cognitive development even at vastly differing levels of analysis.

For instance in Just et al's (1996) study it was found that two superficially similar sentence comprehension tasks differing only in their level of difficulty (e.g., syntactical complexity) were processed such that additional adjacent neuroanatomical substrates were recruited for the more difficult task. Just et al's study suggests that contextually-dependent cognitive dimensions of tasks (e.g., task difficulty) which skeptics had previously dismissed as "mentalistic" are in fact essential for any comprehensive theory of cognitive processing.

The importance of context in skill performance has been demonstrated in macroanalytic sociocultural studies examining expert-novice interactions (Rogoff, 1990) and in microanalytic neural networks theory (Grossberg, 1988). The latter finding is exemplified when controlled processing (e.g., skilled action schemas) from higher levels of a cortically-based neural network match bottom-up input from the environment via the peripheral nervous system such that the network "resonates" to produce a different type of behaviour often at a much higher degree of complexity (Fischer & Rose, 1994, pp. 5-6). Since the environmental input matches templates for cognition already possessed by the individual, the *cognitive load* is decreased. It is hypothesized that such decreased working memory load allows for the eventual development of additional hierarchical control processes (e.g., associations intervening amongst pre-existent knowledge structures).

It is interesting to note that the neural network theorist's physical principle of "resonance" bears some theoretical resemblance to the Vygotskian (1978) concept of the *"zone of proximal development"* and the importance of *"mediation"* between the *"actual"* and *"potential"* levels of development. Likewise, the anomaly of decalage in Piagetian theory, (or instances of cognitive development beyond that which would be expected by stage theory), may also be partially explained by the phenomenon of "resonance" (Piaget, 1971).

In sum, although these disparate groups of researchers' levels of analyses are orders of magnitude removed from each other, there is a clear acknowledgment of the importance of context and culture in cognitive processing. This trend towards the incorporation of context in the understanding of development may be a reflection of the ecological Zeitgeist pervading the sciences (Bronfenbrenner, 1979) and is manifest in the present day's now dominate multidisciplinary approach (Simon, 1992). In this sense pivotal concepts like *"mediated-action"* between the actual and potential level of development advocated by sociocultural-orientated theorists (Wertsch & Tulviste, 1992) are perhaps plausible biologically.

As an aside, Vygotskian theory might prove to be a fruitful framework with which to bridge the widening gap between advances that have been made in our understanding of cognitive development both culturally and biologically (Das, 1995). Perhaps one impediment that exists to the large-scale adoption of a multidisciplinary approach to cognitive and socioemotional development may well rest in the pervasive *"causal epigenetic"* assumption behind much of past and current developmental theory. A distinction should be drawn between traditional "causal epigenetic" assumptions behind developmental theories versus the modern assumption of *"probabilistic epigenesis"* (Johnson, 1997). Causal epigenesis is essentially an extreme nativist position typified by Chomsky's (1965) hypothesized language acquisition device theories or psychometric general intelligence theories (Glover & Ronning, 1987); whereas probabilistic epigenesis is essentially a constructivist approach and would be exemplified by Vygotskian-inspired theory (Vygotsky, 1978), neural network theories of skill acquisition (Grossberg, 1988) and modern evolutionary theory (Eidelson, 1997).

Wittrock's (1991) second cautionary note for educational psychologist's interested in examining the relation between education and neuroscience was that an interest in the neural sciences does not in any way imply an exclusive interest in *immutable hereditary factors* involved in development. Perhaps, paradoxically neuroscience research is directly at odds with the psychometrically-oriented "g theorists" in the tradition of Galton, Spearman, Terman, Jensen and Vernon (Glover & Ronning, 1987) and suggests that there is tremendous plasticity and capacity for learning within the human central nervous system (Bruer, 1997). This predilection to emphasize immutable characteristics of cognitive development such as the omnipotent IQ has come mainly from within psychometric circles (Glover & Ronning, 1987) and not from within the neural sciences (Estes, 1976). The archaic psychometric "genes versus environment debate" which carries with it the connotation of "causal epigenesis" has been replaced by the notion of "probabilistic epigenesis" from the cognitive neurosciences (Johnson, 1997) in which genes and environment exert reciprocal influences upon one another.

Education and Neuroscience: Policy

Previous investigators have proposed that an understanding of the neural basis of cognitive processes will eventually influence educational policy decisions (Bruer, 1997; Friedman, Klivington & Peterson, 1986; Hudspeth & Pribram, 1990; James S. McDonnell Foundation and the Institute of Cognitive and Decision Sciences, University of Oregon, 1995; McCall, 1990; White House Conference on Early Learning and the Brain, 1997; Wittrock, 1985; 1991), although there has been considerable disagreement as to how such knowledge will influence current instructional processes, if at all.

Wittrock's position that an understanding of the link between educational psychology, cognitive psychology and the neural sciences can be made is in contrast to Bruer's (1997) recent position that a sound science of learning is already available to educators - that being cognitive science. Bruer argued that the first bridge between educational psychology and cognitive psychology is all that is necessary for educators to improve instructional processes. The second bridge between cognitive psychology and neuroscience would only indirectly influence educational practice, as cognitive psychology increasingly begins to incorporate neuroscientific findings, in Bruer's opinion. Implicit in Bruer's statement was that the instructional processes referred to were geared towards students without learning difficulties.

Bruer's argument never attempted to address these same questions within the fields of psychological assessment, psychometrics and exceptional education. Arguably, a basic understanding of the neural basis of cognitive processing will prove to be essential for psychometric test developers and specialized instructional psychologys of the future.

Ideological considerations aside, educational psychologists regularly utilize mental measurement tools where routinely decisions are made that affect individuals in important ways. Considering this fact, it would be prudent to know what basic cognitive processes psychometricians are measuring, how such instruments might aid in the design of individually-tailored teaching strategies, of what functional or evolutionary significance such elemental cognitive processes possess, and finally and perhaps most importantly for what purposes are such mental measurements being made in the first place. This need for theoretical rigor becomes all the more apparent when it is considered that most standardized IQ tests (e.g., Wechsler), although imbued with excellent psychometric properties, have essentially ignored the question as to what exactly it is that they measure (Fredericksen, 1986).

Thus, the second bridge between cognitive psychology and neuroscience is a bridge too far in Bruer's opinion. As an organizer of the 1995 Oregon symposium, Bruer's arguments do speak strongly to the dangers of incorporating ill-conceived *brain-based curricular* ideas such as the right versus left brain pedagogies prominent within educational circles a decade ago. Indeed, a strong argument can be made that current cognitive psychological principles will be satisfactory for teaching non-learning disabled children, although an equally strong argument can be made that such an empirical approach to instruction, based on cognitive psychological theory has yet to firmly take root on a wide scale within education (Das, Naglieri & Kirby, 1994). Cognitive psychological principles wedded with contemporary neuropsychological theory would undoubtedly provide a model of cognitive processing and hence instruction and remediation of superior validity and utility. Such a model would have the advantage of theoretically cementing instructional psychology, assessment and remediation.

Similarly, a significant proportion of educator's time and resources are directed at remediating the handicaps of children afflicted with learning and behavioural disorders (Lyon, 1995). Many such exceptional children's difficulties stem either from functional (cognitive processing) or structural (abnormal neural development and/or injury) pathologies (Lyon, 1995; Das, Naglieri & Kirby, 1994). Given the inadequate theoretical basis of many intellectual assessment instruments in identifying learning disabilities (Fredericksen, 1986; Gardner, 1983; Lezak, 1988), let alone addressing the question of specifying a rationale for subsequent remediation, the need for comprehensive instructional, assessment and remediative instruments that are consistent with cognitive and neuropsychological theory becomes all the more apparent.

Education and Neuroscience: The Future

Although cognitive abilities such as language and visuospatial skills have long been studied by educational psychologists (Glover & Ronning, 1987), the same cannot be said for executive functions or those skills that allow us to initiate, plan and organize our behaviours (Lezak, 1995) until relatively recently (Das, Naglieri & Kirby, 1994). Such executive abilities are not at present measured by traditional intelligence tests, and the importance such executive functions often only become apparent after head injury cases.

In such cases of localized prefrontal cortex damage it is not uncommon for IQ scores to remain within the normal range or even increase slightly from premorbid scores. However, in such patients measures of adaptive functioning or the ability to maintain a job or adjust socially is often severely compromised to the extent that the person can no longer care for themselves (Kolb & Whishaw, 1996). Such well-established neuropsychological findings suggest that many of the instruments that are currently utilized by educational psychologists and that are alleged to assess "general intelligence" may suffer from serious construct validity problems.

Furthermore, developmental psychologists have long recognized that maturation is periodically non-linear when individual growth is examined, whereas group averages tend to smooth out individual differences (Dawson & Fischer, 1994). Although Piaget's (1971) view of cognitive development emphasized the importance of an internally determined maturational timetable, cognitive developmental studies over the past few decades suggest that learning experiences interact synergistically in this dynamic process, culminating in many cross-domain cognitive and socioemotional developmental changes (Case, 1985; Fischer, 1980).

Recent, evidence suggests that the prefrontal cortices mature functionally in a periodically non-linear manner and that concurrent physiological changes at this neuroanatomical site may play a central role in the development of cycles of cortical reorganization of functions (Dawson & Fischer, 1994; Johnson, 1997). There are the beginnings of a consensus that both structural and functional neuroanatomical changes in the prefrontal cortices play a central role in concurrent changes across domains of cognitive and socioemotional functioning in developing children (Dawson & Fischer, 1994; Pennington & Ozonoff, 1996). The educational implications of the putative discovery of a hierarchical neural architecture subserving cognitive and socioemotional development have only begun to be examined thoroughly in a handful of cognitive psychological, neuropsychological and educational psychological laboratories.

In sum, an understanding appears to be emerging among researchers within educational and school psychology that findings within the neurosciences are not irrelevant to educational matters (D'Amato et al., 1992). These new insights into psychoeducational assessment appear to be particularly influenced by clinical neuropsychology and to a much lesser extent cognitive neuroscience. These two branches of "neuroscience" examine behaviour at a relatively high levels of analysis. It is unlikely that more basic levels of analyses within neuroscience can usefully inform educational policy decisions (Bruer, 1997).

Finally, the incorporation of neuropsychological frameworks has been most influential in those areas of the study of human abilities that are highly subject to biological maturation. The hierarchical control systems or executive functions of cognition appear to be heavily dependent on biological maturation of the prefrontal cortices. In Chapter 1, a statement of the experimental purpose will be followed by a discussion of the influences that schooling, age, language, expert collaboration and mediated learning experiences have on the development of executive capacities.

CHAPTER ONE

SCHOOLING, LANGUAGE AND EXECUTIVE FUNCTIONS

Statement of the Problem

Only relatively recently have normative-developmental studies of executive capacities been undertaken in children (Chelune & Baer, 1986; Welsh & Pennington, 1988; Pennington & Ozonoff, 1996). The purpose of this study was to examine the effects of formal schooling versus age on three common measures of executive function employed in clinical neuropsychology in a large sample of children. Peabody Picture Vocabulary Test Standardized Scores (Dunn, 1981), which have been used as an estimate of IQ (Bracken, Prasse & McCallum, 1984), were used as an IQ covariate to correct for interindividual differences.

The effects of formal schooling versus age on executive measure development could then be dissociated by employing a between-grade level (Bisanz, Dunn & Morrison, 1995; Cahan & Cohen, 1989, Cahan & Davis, 1987) or cutoff design. With this design the overall cross-sectional increase in mean raw scores on executive functions as a function of age is decomposed into within-grade and between-grade segments, which can then be unambiguously attributed to age and schooling effects, respectively. Unlike, traditional IQ tests which show considerable schooling effects (Cahan & Cohen, 1989) it is hypothesized that in this study the age should account for a larger proportion of the variance in the growth of executive function raw scores over that of schooling or gender. Cross-sectional studies support the contention that age exhibits significant affects over and above that of schooling on the cognitive developmental trajectories of student.

School Readiness

Children entering the first grade at an early age are more likely to be diagnosed as learning disabled later on than their older classmates (Diamond, 1983; Maddux, 1980), and gifted students are found to more often than not to have entered school late rather than early (Maddux, 1981). In addition, Kalk's (1982) extensive study found that age of entry into first grade proved to be a significant predictor of later achievement levels at the ages of 9, 13 and 17. Collectively, these "birthdate effects" suggest that maturational status exerts significant effects on the progress of individual students through the curriculum.

Such preliminary findings have been used by some school boards to implement purported age-readiness curricula which take a "wait until maturity" approach to the introduction of advanced material to students. Such initiatives have been viewed with skepticism by members of the educational and neuroscience research communities as being insufficiently grounded empirically (Friedman, Klivington & Peterson, 1986; Bruer, 1997). Such strict age-graded curricular approaches to pedagogy seem to assume that educators shouldn't bother teaching children advanced concepts at an early age. This philosophy would appear contradictory to the conclusions that one might draw from the recent studies of rudimentary infant reasoning abilities conducted by Spelke (1988) and her colleagues.

Spelke's findings suggest that there are strong predispositions within the developing infant's central nervous system to process stimuli in particular ways. These early predispositions could conceivably lay the later groundwork for children's elementary spatial and perhaps verbal reasoning skills in formal school settings.

Indeed, Jerome Bruner has asserted (Hirsch, 1996) that "...any subject can be taught effectively in some intellectually honest form to any child at any stage of development". In addition, Hirsch, (1996) has suggested that "...what nature is really saying about much learning much of the time is the earlier the better".

To digress, Gottlieb's (1991) influential work examining the concept of "behavioural canalization" and its clinically-orientated sister term of "developmental trajectories" (Mash & Barkley, 1996) provides an illuminating interpretation of these genetic influences on the eventual expression of behavioural phenotypes. A key issue in behavioural canalization is that genetic activity does not in itself produce finished traits, and that differentiation occurs as a consequence of events above, as well as below, the cellular level. In sum, the neurodevelopmental literature points towards the importance of early environments in fundamentally shaping and in eliciting the development of complex cognitive processes, but it argues against the causal epigenetic (Johnson, 1997) assumptions of strict age-dependent curricular approaches.

Schooling and Age Effects

Analyses of the respective effects of schooling and age on social and cognitive development is important for the empirical evaluation of the effectiveness of instruction. There is currently a paucity of carefully designed educational studies dissociating these equally important influences. As Wohlwill (1973) pointed out, age is not a causative variable in social and cognitive development but is an index of related factors. Generally, researchers have suggested that schooling tends to emphasize context-independent skill acquisition (Rogoff, 1981), whereas non-school learning characteristically has been portrayed as context-bound (Scribner & Cole, 1973).

Traditionally, the approach to dissociating the effects of schooling and age on social and cognitive development has taken two paths. The first approach has been to compare children of the same age, often of different cultures that have been schooled or have not been schooled (Scribner & Cole, 1973); whereas the second approach has utilized the school cutoff design (Bisanz, Morrison & Dunn, 1995).

The cutoff design has recently demonstrated its utility in addressing fundamental relationships between schooling and cognitive development. Cahan and Cohen's (1989) study found unambiguous schooling effects on the development of intelligence test scores (especially on verbal subtests in their sample of over 12 000 fourth, fifth and sixth graders in Israel), utilizing a logistic regression cutoff design. Morrison, Smith and Dow-Ehrensberger (1995) found that short-term memory was enhanced by schooling, whereas phonological segmentation, which is important in language skill, revealed both age and schooling effects. Finally, Bisanz, Dunn and Morrison (1995) found that understanding of conservation of number, a hallmark of concrete operational thought (Flavell, 1963) exhibited age-only effects. Bisanz et al (1995) found that the ability to perform mental arithmetic, a culturally valued skill, exhibited both age and schooling effects. Skill acquisition and development are constrained by the natural line of development and these constraints are most likely to be exhibited in cross-domain manifestations of the skill level. Furthermore, it appears that culturally valuing a skill may expedite the development of it along a more narrow path.

Schooling and Executive/Planning Processes

Is it possible that executive functions and related planning processes can be developed with schooling? Das, Kar and Parrila (1996) noted that very little research has been done in the area of schooling influences on executive-like processes like cognitive planning. A major focus of Das and colleagues's research is directed at characterizing planning processes.

However, Dreher and Oerter (1987) found that students enrolled in a home economics course, which might be presumed to require proficiency in daily planning tasks, performed better than expected on planning tasks as compared to age-mates. Furthermore, Das and Dash (1990) found that the effects of schooling on planning capacities demonstrated transfer characteristics. In this study it was found that schooled children outperformed their unschooled counterparts in rural India in simple planning tasks akin to those incorporated in the *Cognitive Assessment System* (Das & Naglieri, 1997). Finally in Tanon's (1991) study of schooled and unschooled weavers it was found that informal education in weaving which requires planning, fostered planning skills in other contexts.

Collectively these findings argue that the development of planning competency is benefited by schooling.
The developmental precursors associated with planning development may well rest with the relative opportunities provided to individuals to interact with a more competent individuals or experts (Das, Kar & Parrila, 1996). A salient dimension of planning is the learning of *strategic action sequences* (Das, Kar & Parrila, 1996), so perhaps these

sequences may only be learned non-verbally in the pragmatics of social interaction with a more capable peer.

Expert Collaboration

Clearly, cognitive development is not isolated within the child. Vygotsky (1978) and his intellectual successors, notably Rogoff (1990), have written extensively about the importance of sociocultural environments in development. For Rogoff (1990) children developed cognitively and socioemotionally by acquiring knowledge and skills in apprenticeship with more expert peers such as parents, friends and teachers. Thus, children learned in specific contexts with these peers and were provided with guided participation appropriate to the individual needs of the child by these peers.

There are two generalizations about expert collaboration that are suggested by Rogoff's work (Flavell, 1992). Firstly, multiple and specific cognitive and socioemotional outcomes are predicted depending upon the individual children's variable cultural experiences. Secondly, in Rogoff's view the distinction between individual and societal influences' relative role in interacting in this cognitive developmental process was artificial at best.

The Problem of Mediated Learning: Unasked Questions

Recently, computer assisted instruction (CAI) has been developed for use in classrooms, although problems have arisen in that little is known about how people learn with such artificial expert systems (Mayer, 1997). CAI has developed in sophistication in the past decade with the result that many types of problems, especially of a spatial nature, such as in science and physics courses, may be augmented by presentation in CAI multimedia format (Mayer, 1997).

CAI has only just begun to be exploited in educational settings (Mayer, 1997) and there is considerable optimism about its success for teaching within specific domains of knowledge. However, CAI has often been portrayed within the mass-media and some teaching circles as a panacea for society's ills. To date, few have asked the question of what neuroscience might tell us about what limits biology might have placed upon the practical utility of such a teaching paradigm.

In the James S. McDonnell Foundation et al.'s (1995) videoseries summary address, Bruer did pose such a question. Bruer asked what the pedagogical implications were of communication between two con-specifics or members of one's own species in a joint problem solving exercise. The plethora of studies accumulating from developmental psychology on the role of the intrinsically motivational properties of the human face and voice (e.g., Lewkowicz, 1996) suggest conservative upper limits dictated by biology on the utility of CAI teaching paradigms in facilitating transfer. That is to say human beings are "hard-wired" to respond preferentially towards human faces and voices as opposed to inanimate objects. It is unlikely that CAI technologies would be able to duplicate such species-specific properties within the foreseeable future. Such important distinctions have rarely if ever been mentioned by proponents of CAI and highlight the importance of how neuroscience might inform educational practice and policy.

Executive Functions, Biology and Language

The development of executive functions is an emerging field within cognitive psychology, ripe with intriguing questions. One such important question will undoubtedly be "why do some children develop poor planning skills?". There is a body of research suggesting that limbic fiber tracts reciprocally connecting the frontal lobes may be the neural substrate for individual differences in "reactivity" to stimuli (Benes, 1994). That is limbic substrates of basic emotive responses may very well demonstrate individual differences in their thresholds required for excitation and hence activation (Fox, 1989; Kagan, Resnick & Snidman, 1988).

Since the frontal lobe is heavily interconnected with the limbic lobe (Kolb & Whishaw, 1996), over or under excitability of limbic pathways to the frontal lobe could conceivably alter the "steady state" properties of the behavioural inhibitory capacities of the prefrontal cortices. Because a primary role of the prefrontal cortices is to inhibit prepotent or previously learned responses (Barkley, 1997), attenuated capacity of the frontal lobe to inhibit prepotent responses could conceivably result in a decreased capacity of an individual to program and organize behaviour temporally in an adaptive manner. Such a deficiencies would likely manifest themselves globally as severe planning deficits (Das, Kar & Parrila, 1996). Furthermore, working memory deficits, as a consequence of individual's inability to organize behaviour temporally in one's mind, before action is undertaken, have been speculated to play a prominent role in dysexecutive disorders such as attention deficit-hyperactivity disorder (Barkley, 1997).

There is some speculation that chronic traumatic environmental conditions could demonstrate lasting effects on the threshold of excitation of limbic pathways innervating the prefrontal cortices (Kolb, 1987). Such findings suggest the artificial distinction between cultural and biological development, and lend credence to Vygotsky's (1978) "general genetic law of cultural development" which postulated mutual and reciprocal influences of biology and culture in development.

Language's role in the development of executive or planning processes has been theorized to exert its influence by means of increasing the capacity for context-independent thought; by increasing the child's access to the accumulated knowledge of a culture; and by helping children to gain control over aspects of their internal and external environments (Das, Kar & Parrila, 1996). By way of example, an interesting phenomenon is observed when administering the Wisconsin Card Sort Test to young children. It is not uncommon for children to know that a card sorting strategy is no longer correct, that is often they will keep their hand on the incorrectly placed card such that their hand functions as a physical placeholder. Yet after voicing such sentiments these younger children typically will then proceed to sort the card to the previously incorrect sorting strategy.

When children no longer continue to touch the card they previously put down and had voiced uncertainty about, then they no longer make such errors. Such findings suggest that motoric competency (e.g., using the hand as a placeholder thereby decreasing the working memory load for the task, and hence aspects of speech which is after all linguistic motoric competency) precedes ontogenetically the development of abstracted internalized thought processes necessary for successful performance on such tasks. Such a phenomenon illustrate how "freeing up" working memory capacity with the use of a physical placeholder, such as one's hand could allow for mental mediation to arise, which only later in microgenesis takes hierarchical control over the action in the form of a verbal strategy. Such findings suggest that speech precedes thought ontogenetically as suggested by Vygotsky (1978).

Vygotsky on Language

Scholarly exchange with Russia, recent translations, potential applications to applied fields and disciplinary concerns regarding the ecological validity of previous theoretical models are all reasons for the resurgence of interest in Vygotskian theory (Wertch & Tulviste, 1992). Vygotsky rejected the artificial distinction between social and individual processes and viewed mental processes as "activity" in a functionalist perspective. Vygotsky's sociohistorical theory of the nature of cognitive development is a departure from traditional individualistic Western cognitive developmental theories in this regard. For Vygotsky cognitive development and cultural development were inextricably linked and his use of the term "cultural development" carries with it the same meaning as cognitive development in translations of his work.

Two Vygotskian concepts of direct relevance to educational psychology are "inner speech" and the "zone of proximal development" or (ZPD). By about the age of three years, children typically begin to speak out loud and describe their own actions while performing some activity. Both Piaget and Vygotsky described this phenomenon, which is commonly termed "egocentric speech", and agreed that it signaled the developmental transition of external socially-mediated language into inner speech or thought which could subsequently then be used by the child for both reflective and anticipatory or logical thinking ends (Das, 1995). For Vygotsky then a process in a child's development appeared in two planes, first as an intermental category and then as an intramental category.

Vygotsky claimed that inner speech enabled humans to plan and that it enabled humans to build up verbally constructed representations of outside reality, especially of a reality that was not yet realized (Vygotsky, 1978). Vygotsky's discussion of the mental plane which to some extent paralleled the outside physical world resembles recent animal learning theorist's theoretical principle of the isomorphism (Gallistel, 1989), in which aspects of brain-world parallelism are posited to exist. In a contemporary view language's role is often conceptualized as involving the emergence of a self-regulative role in the hierarchical control processes of the individual (Das, Kar & Parrila, 1996) - control processes which at lower levels of analysis have circumscribed neuropsychological substrates.

Vygotsky argued that ontogenetically, as have behavioural ecologists (de Jong, 1991), a sign originally is a means of influencing others of one's cultural group [or species] and that only later through learning does that sign becomes a tool for influencing oneself through internalization. In this sense for Vygotsky (1978) all learning was a collaborative effort, with all learned skills having a social origin. Finally, according to Vygotsky given that language was postulated to mediate the internalization of external socially-situated action, all cognitive processes would have a sociohistorical origin heavily dependent on language. Pedagodically, Vygotsky's theory suggests that mediators (e.g., teachers, peers) and the sociohistorical location of the individual in society are integral factors in determining the cognitive developmental outcome of an individual.

The zone of proximal development (ZPD) is the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem solving under the adult guidance or in collaboration with more capable peers (Wertsch & Tulviste, 1992). The ZPD is related to the concept of inner speech in that both have an origin rooted in social interaction. The ZPD is not a property of the learner but a property of the learner in interaction with a mediator. Hence the ZPD determines the transitions available to the individual under optimal conditions, and is a proactive concept in that it suggests where a student's development could possibly be with the aid of a more competent peer (Das, 1995).

The ZPD is important for studying cognitive development in a sociocultural context and in psychoeducational assessment in relation to educational psychological practice. Quantitative assessment techniques of the ZPD often include the number of prompts required by the learner to progress through a task (Das, 1995). Dynamic assessment and mediated learning strategies advocated by Feuerstein and colleagues utilize such techniques to characterize what is necessary to have a student functioning at their potential level of development (Feuerstein, Feuerstein & Gross, 1997). The ZPD has been a useful concept in discriminating between mentally-handicapped children and those that are only learning disabled (Das & Naglieri, 1996). For mentally handicapped children mediated instruction does not appear to elevate performance to the extent that it does with learning disabled children. Critical then to mental retardation may be that cognitive development and cultural development do not converge as in "normal" children (Das & Naglieri, 1996). These suggestions are interesting in light of genetic studies suggesting that frontal lobe neuropathology has been implicated in a host of mentally retarding genetic disorders (Jacobson & Mulick, 1996).

Vygotsky (1978) examined the implication of the ZPD for instruction, and in summation he thought that instruction should be geared towards the level of potential development rather than to student's level of actual development. Vygotsky recommended that both the actual and potential level of development were equally important for intellectual assessment, the focus of Chapter 2.

CHAPTER TWO

INTELLECTUAL ASSESSMENT: PAST, PRESENT AND FUTURE

Levels of Explanation

Herbert Simon (1992) argued that, although a unified reductive account of human behaviour might be possible, it would not be intelligible since it would reduce human behaviour to a series of exceedingly complex differential equations. Such an analyses, which if read might resemble the pages of a physics text, would have the effect of obscuring from view essential explanatory "aggregate properties" such as cultures and symbolic processes. Alternatively, Simon argued for a unified theory of human behaviour in which multiple levels of analyses would complement one another and not replace each other.

Physiological, symbolic, cultural, knowledge structure, and adaptive systems theories are essential to the construction of a unified model of human behaviour in Simon's (1992) account. The PASS model of intellectual functions is interpretable within this framework as one example of an attempt to account for psychological processing in a unified theory (Das, Naglieri & Kirby, 1994).

By way of example, the physiological level of analysis reveals that planning, attention, simultaneous and successive processes have approximately the frontal lobe, brain stem and posterior cortices as neural substrates, respectively (Das, Naglieri & Kirby, 1994). In addition, further neuroanatomical examination would reveal extensive longitudinal fiber tracts connecting the prefrontal cortices to the brain stem and posterior cortices such that the prefrontal cortices and its requisite cognitive correlate planning, exhibits hierarchical properties over the other three cognitive processes (Lezak, 1995). Further reductionist physiological analyses would reveal that at the level of synapses, NMDA receptor involved in long-term potentiation (the putative pharmacological basis of memory, Kolb & Whishaw, 1996), exhibits high densities of receptors in both the prefrontal cortices and aspects of the temporal lobe (McCrea et al, 1997a). The densities of these synaptic receptors is suggestive of the frontal-temporal lobe functional link in many elementary memory processes. However, perhaps more importantly, this last point illustrates that just as with high level cultural analysis, increasing levels of physiological reductionism do not necessarily lead to increasingly more determinant outcomes in terms of the neural substrates of cognitive processes.

At the symbolic or cognitive processing level it has been found that planning tasks require the invocation of a strategy by the person to complete the task, whereas attention tasks typically require the subject to attend to one and ignore another aspect of a stimulus array. Furthermore, simultaneous processing requires that the subject interrelate the component parts of the particular item to arrive at the correct answer; while successive processing requires that the subject appreciate and correctly interpret the serial nature of presented stimuli (Das, Kar & Parrila, 1996).

At the cultural level it has been found that the factorial structure of the four cognitive processes holds together in groups differing markedly in education, socio-economic status and language suggestive of the basic nature and cross-cultural validity of the PASS model (Das, Naglieri & Kirby, 1994). Furthermore, as to be expected cultural group differences have been found in the profile of PASS tasks. For instance, it has been found that First Nations peoples are more likely to be strong on simultaneous processing tasks, perhaps due to this traditional cultures' preference for emphasizing learning by modeling (Das, 1985). Such examples reveal in keeping with Vygotskian theory that although the biological substrates of such elementary cognitive processes would remain unchanged across cultures across the globe, the ultimate way in which these processes interact dynamically could be influenced entirely by cultural factors.

At the level of knowledge structure, it is known that the prior knowledge an individual brings to a task influences that individual's subsequent cognitive processing (Simon, 1981). Past research has clearly demonstrated that the knowledge that subjects bring to a problem state has a significant impact on both the processes and products associated with the resolution of the problem (Simon, 1981). If anything, this is an argument against factorial interpretations of cognitive ability because such approaches neglect the knowledge base that different individuals bring to a problem state (Das, Naglieri & Kirby, 1994). The characterization of this knowledge structure is important since pre-existing knowledge can influence not only what is attended to, but how strategies and/or plans might be implemented. Knowledge structure is represented as the pre-existing knowledge-base of the individual in the PASS model in which all the four PASS processes are based in.

The final level that the PASS model could be examined in is the adaptive systems theory. Simon (1991) suggests that an adaptive system is characterized by an evolutionary epistemology such that organisms engage in behaviours because they are of functional value to the survival of that organism. Implicit in an adaptive system is a tendency towards self-organization and a constructivist nature (Eidelson, 1997). Hence the PASS theory incorporates and acknowledges that children will construct their knowledge, and as a consequence the quality of their processing, especially with the example of planning, will change over time in contrast to other tests of cognitive ability (Das, Kar & Parrila, 1996).

A Brief History of Psychometrics

Empiricism concerns itself with the notion that knowledge consists of copying elements from the world into a sensory store in a mechanistic way, and it is aligned with Aristotelian associationism (Glover & Ronning, 1987). In the empiricist's account larger components, such as abstractions, were developed through associative links and hence complex knowledge could be reduced to smaller elements. Empiricist orientated learning theory is typically behavioural and functionalist in perspective and views the student as the passive recipient of information (Lachman, Lachman & Butterfield, 1979). Empirically based learning theories concern themselves with the production of uniform behavioural products and typically carry assumptions of causal epigenesis such that information inputs yield predictable behavioural products.

Rationalistic accounts of development emphasize reasoning, interpretation and comprehension processes or processes which are presumed to be present to some extent *a priori* (Glover & Ronning, 1987). Rationalistic accounts emphasize the innateness of certain mental activities that operate on experience to impose organization on input. Such a view of the nature of the mind is not inconsistent with modern cognitive neuroscience perspectives of the modularity of functions of the human brain (Johnson, 1997), because according to the rationalists, memory was not a carbon copy of reality but an interpretation of it. Categories and structures of the mind are emphasized in the rationalist account of development such that the remembrance of categories and not facts becomes most important. In this sense the rationalist stance places the learner as an active constructor of meaning in his/her environment.

Behavioural learning theory was a dominant approach among educational psychologists up until the 1960's (Glover & Ronning, 1987). The methods of the neo-behaviourists, among them verbal learning theorists, proved useful to the later information processing theorists who drew heavily from communications theory and human engineering theory (Lachman, Lachman & Butterfield, 1979). Verbal learning theorists were empirical in orientation and many readily shared an interest in operations with the information processors. At about this same time another group of researchers the Piagetians, the European rationalists, also began to study the processes by which children solve problems and the structure of children's thought at different ages (Glover & Ronning, 1987). This renewed interest in processes signaled the return of rationalist accounts of development.

Social learning theory was an attempt to contextualize the laboratory findings of the neo-behaviourists from a decidedly Western perspective, and although it met with some success perhaps more importantly it may have whetted the appetite for Vygostokian-inspired sociocultural theory.

Vygotskian theory and its progenitors are fundamentally more encompassing theories than previous ones in that both cultural development and cognitive development are viewed as merging within the individual (Wertsch & Tulviste, 1992). Vygotskian theory is essentially a monistic and constructivist position, a position that has also been argued for in the social and natural sciences and in the study of adaptive and complex systems (Bronfenbrenner, 1979; Eidelson, 1997; Simon, 1992). Consideration of epistemological assumptions behind learning and knowing are important in the discussion of how intelligence was operationalized in the early part of the twentieth century.

Spearman conceptualized intelligence as consisting of a general factor, and in the British empiricist tradition of Galton emphasized it's hereditary and immutable nature (Glover & Ronning, 1987). However, unlike Spearman, Thurstone (1938) emphasized the importance of specific factors underlying intelligence. On the European continent, Binet, one of the first designers of a test of mental ability, never really anticipated that his test would be utilized for other than academic placement usage and thus essentially built his test on empiricist assumptions (Glover & Ronning, 1987). The most widely used intelligence tests, the Wechsler scales follow in the tradition of Binet's original test of mental abilities, and like the previous tests are not theoretically specified (Das, 1992). Thereafter, psychometricians spent a good part of the first half of this century chasing after the elusive "g" until the advent of the cognitive revolution of the 1960's and 1970's (Glover & Ronning, 1987). Efforts to describe this general intelligence construct emphasized mathematical and measurement prowess over theoretical rigor. These psychometric efforts to characterise "g" have continued to the present day, and it will likely continue to prove to be a daunting task. The cognitive revolution of the 1960's ushered in a new era in which strategies and cognitive processes were given pre-eminence.

Memory versus Intelligence

Contemporary researchers have suggested that memory be divided into primary memory and working memory (Kolb & Whishaw, 1996). Information in primary memory is transient unless it is operated on in working memory (e.g., rehearsal of a telephone number). Neuropsychologically, primary memory consists of the sensory registers for each of the senses which have operational time frames of milliseconds.

Information in primary memory is thus lost if it is not worked on in working memory (which acts as a "on-line" buffer), or alternatively is sent directly to long-term memory (Kolb & Whishaw, 1996). Long-term memory consists of our entire knowledge base and it is composed of high level coded schemas that are richly interconnected (Das, Kar & Parrila, 1996). Long-term memory is not specifically located, although it is represented neocortically and the amount of neocortical loss after brain injury does correlate with the amount of long-term memory loss (Kolb & Whishaw, 1996).

According to Baddeley (1986) there are three distinct components of working memory, these being a central processing space (CPS), an articulatory loop and a visual spatial scratch pad. It is thought that working memory acts like the chalkboard of consciousness, and it is where currently active "documents" may be processed. Based on single cell recordings within the dorsolateral prefrontal cortex of monkeys, it is thought that the central processing space may be particularly prefrontally based (Goldman-Rakic, 1992). In such studies it has been found that during a delayed response task where the inhibition of prepotent response is required and the remembrance of a correct location will result in a reward to the animal, cells in the dorsolateral PFC fire only during the delay period. In effect holding the location information on-line during the delay period when it is not visually present to the monkey.

The articulatory loop is associated with the arcuate fasiculus fiber tract connecting Broca's and Wernicke's area, and it functions to transmit verbally based material to Baddeley's (1986) central processing space. The visual-spatial scratch pad is associated with the longitudinal fiber tracts connecting the posterior occipital-parietal-temporal junction with the anterior prefrontal cortices (Kolb & Whishaw, 1996).

The concept of coding within the PASS model is perhaps most relevant to these neural architectures subserving memory processes (Das, Naglieri & Kirby, 1994). In the PASS model coding has several salient dimensions including: level, content, and type. The level of coding concerns the amount of coding required for a particular representation. Within educational psychology there has typically been a distinction between verbal and spatial content which leads to the next distinction made in the PASS model, that being type of coding.

The type of coding, or the how of coding, has a somewhat confusing history because it has often been confused with the content of coding. It is suggested that there are two types of coding, simultaneous processing that is designated by its surveyable nature, and a sequential processing which is characterized by the linear sequential nature in which a stimulus is encoded (Das, Kirby & Jarman, 1979). Paivio (1986) has also suggested a similar dual coding model of cognitive processes involved in memory. That is, verbal and spatial content can be encoded either successively or simultaneously, but verbal stimuli may be more amenable to successive processing and visual-spatial stimuli may lend itself more easily to simultaneous processing.

Thus, there is close association between successive processing and auditory information since by its nature auditory information is presented serially, whereas a close association also exists between simultaneous processing and visually presented material since an essential feature of visual material is that it is presented all at once. Furthermore, in the hierarchy of representation it can be seen that simultaneous and successive processes occupy complementary roles. For instance, auditory stimuli that are processed initially successively (e.g., letters of an unfamiliar word) are subsequently processed simultaneously as a whole word during subsequent processing of the same stimuli (Das, Naglieri & Kirby, 1994).

In summation, the allocation of effort to process stimuli (attention) in combination with strategies invoked to process such stimuli (planning) work in synchrony with simultaneous and successive processes in conjunction with the knowledge base of the individual. This dynamic model designed on the basis of cognitive and neuropsychological theory gives pre-eminence to cognitive processes in contrast to classical ability tests founded on antiquated psychometric "g" theory which carries with it naive assumptions of causal epigenesis (Johnson, 1997).

CHAPTER THREE

COGNITIVE DEVELOPMENTAL AND NEURODEVELOPMENTAL STUDIES

Developmental Performance Studies and Neuroscience

By 3.5 to 4 years of age children relate one representation to another such that in pretending they relate a mother and child or a doctor and a patient in concrete social roles (Fischer et al., 1984). Theory-of-mind tasks demonstrate that at this age children understand that others have minds with secrets, which exemplifies this one-to-one relation of representations in the socioemotional realm (Marvin, Greenberg & Mossler, 1976). Fischer and Rose (1994) have called this the representational mapping level, whereby across domains of knowledge one-to-one correspondences are formed between representations. [One can refer to Case and colleagues' research (1985; 1991) for an extensive discussion of the cognitive and socioemotional performance capacities of children within the age ranges discussed in this brief review].

At the age of 6 or 7 years, Piagetian concrete operations tasks demonstrate that children can relate two dimensions of quantity in one container with two dimensions in the other (Inhelder & Piaget, 1964). At this age people understand that individuals can occupy multiple interrelated roles' such as father and doctor with daughter and child (Selman & Schultz, 1990). Fischer and Rose (1994) have referred to this as a representational system level during which time complex coordinations among subsets of representations are formed.

At the age of 10 to 12 years, Piaget's (1971) formal operations stage was purported to begin with the emergence of the abstract, so that concepts such as justice in the social domain and chance, addition or subtraction in the logico-mathematical realm begin to be articulated by children. Such abstractions deal with intangible properties, and include concepts as well as procedural knowledge for dealing with such properties. In Fischer and Rose's (1994) nomenclature the emergence of abstraction denotes a new tier in intellectual and socioemotional development, in which children coordinate two or more concrete representational systems to form a system of systems which is a single abstraction.

Fischer and Rose's model of the hierarchy of the development of skills is based on the hypothesis that each level involves the emergence of a new type of neural network. Furthermore, each tier (synonymous with a Piagetian stage) signals the establishment of a higher-order pattern in the emergence of neural networks, which appears to be marked by a particular pattern of change in prefrontal cortex functioning. Fischer and Rose's (1994) model of cognitive and socioemotional development resembles Case's (1993) model, whereby increases in working memory space as a function of prefrontal cortex maturation allows for the simultaneous coordination and eventual differentiation of disparate knowledge structures or central conceptual structures into increasingly complex and cohesive functional units.

Care must be taken in mentioning that individuals are not simply classifiable at one stage or tier in their cognitive or socioemotional development, because there is a systematic range of variation that changes with both development and the domain of the skill (Rogoff, 1990). A key concept to reconciling stages with continuous development of skills is that there is paradoxically both generality and specificity within the hierarchical control systems of working memory (Fischer & Farrar, 1987).

Generality views of working memory have been common in the past in cognitive psychology (Atkinson & Shifrin, 1968), whereas highly modularized views of working memory specific for particular sensory modalities have prevailed within neuroscience (Fischer & Rose, 1994). Both views are reconcilable within the framework of contemporary neural networks theory (Grossberg, 1988). In this framework, information is processed in massively parallel streams, quite unlike the linear sequential model of digital computers, and functioning is distributed across wide areas of the brain in vast interconnected Hebbian cell assemblies (Hebb, 1949). Therefore a given neuroanatomical site participates in a wide array of functional tasks, but at the same time is specialized for specific functions.

The Executive Functions

Working memory is an essential construct in contemporary cognitive neuroscience (Goldman-Rakic, 1992) and it does share some of the same properties as the neuropsychologist's executive functions. In Lezak's (1995) authoritative third edition of *Neuropsychological Assessment*, the executive functions were conceptualized as having four components:

> ...(1) volition; (2) planning; (3) purposive action; and (4) effective performance. Each involves a distinctive set of activity-related behaviors. All are necessary for appropriate, socially responsible, and effective self- serving adult conduct. Moreover, it is rare to find a patient with impaired capacity for self-direction or self-regulation who has defects in just one of these aspects of executive functioning. Rather, defective executive behavior typically involves a cluster of deficiencies of which one or two may be e specially prominent (p. 650).

One of the problems of assessing executive functions is the paradoxical need to structure an examination session to examine how well the examinee can make structures from an initially ambiguous situation for themselves. Currently many tests offer examinees little room for discretionary behavior (Fredericksen, 1986), and thus the task for the examiner becomes that of transferring goal setting, structuring and decision making from themselves to the examinee in a structured situation. A number of tasks utilized extensively in neuropsychology have been found to meet the above criteria satisfactorily and to reliably discriminate frontal head injury patients from non-frontal head injury patients (Lezak, 1995).

Pennington and Ozonoff (1996) have suggested:

> ...that the domain of executive functions is distinct from cognitive domains such as sensation, perception, and many aspects of language and memory. It overlaps with domains such as attention, reasoning, and problem-solving, but not perfectly. Typical lists of executive functions include set-shifting and set maintenance, interference control, inhibition, integration across space and time, planning and working memory. A central idea in the concept of executive function is context-specific action selection, especially in the face of strongly competing, but context-inappropriate, responses. Another central idea is maximal constraint satisfaction in action selection, which requires the integration of constraints from a variety of other domains, such as perception, memory, affect and motivation. Hence, much complex behavior requires executive function, especially much human social behavior (pp.54-55).

The executive functions in addition to being important in context-specific selection of adaptive behaviors, especially of a social nature to the individual, have also been linked theoretically to measures of divergent thinking and/or creativity. One clear neuropsychological finding has been that lesions to the posterior cortices of the neocortex (e.g., temporal, parietal, occipital lobes) result in reliable decrements on measures of IQ, whereas frontal lesions often do not result in large IQ decrements. In fact there are cases in which IQ has increased post-morbidly after a patient has sustained a frontal lesion (Kolb & Whishaw, 1996).

Guilford (1967) has suggested that traditional intelligence tests measure what is referred to as convergent thinking, where there is one right answer to a question. However, Guilford also suggested that there is another key facet of intelligent behavior referred to as divergent, productions in which the variety of unique responses to a question are emphasized rather than a particular answer. Zangwill (1966) demonstrated that frontal injury may be particularly detrimental to performance on divergent thinking and/or creativity tests.

Evolutionary theory would predict that such contingency-specific problem-solving ability as might be required in divergent thinking tasks would have been highly selected for in our human ancestors living in natural environments in the past, and probably so today (Povinelli & Preuss, 1995). Clearly, one realm of human behavior which captures the contextual nature of contingency-specific problem-solving ability is social interaction. The ability to engage in social reciprocity with one's familial group would be an example of a complex sociocognitive capacity that would have conferred obvious survival value to its inheritors. Perhaps it is no accident that the prefrontal cortex is the most recently evolved addition to the primate brain. It comprises the largest proportion, nearly 40% of the neocortex (Kolb & Whishaw, 1996; Passingham, 1993) in human beings as compared to our primate relatives, and it is *Homo Sapiens sapiens* who exhibit the most highly contextualized and most highly social behavior of all of the primates (Jurmain, Nelson & Kilgore, 1995). Thus, the evidence for the importance of the recently expanded prefrontal cortices phylogenetically in human social interaction, and learning of a social nature, is convergent in nature.

Functional Neuroanatomy

A brief discussion of the functional neuroanatomy of the prefrontal cortices may facilitate an understanding of their role in human performance. To that end, the primary motor cortex executes movements directly via its projections to the spinal cord and its one-to-one correspondence between muscle groups and motor effector sites aligned along the precentral gyrus (Passingham, 1993). The premotor cortex functions to select learned complex action sequences via its adjacent connections to these multiple effector sites (Passingham, 1993). The prefrontal cortex controls hierarchically organized cognitive processes so that appropriate actions are executed at the correct time and place on the basis of internal cues from the individual (cognitive and affective states) and external cues from the environment relayed from the posterior sensory processing cortices (Passingham, 1993).

To reiterate, the posterior sensory processing cortices consist of: the parietal lobes which process complex visual spatial and gestalt aspects of stimuli; the occipital lobes which process elementary and composite visual stimuli with the aid of built-in feature detectors; and finally the temporal lobes which assist in the processing of the sequential, temporal aspects of stimuli and in memory consolidation - which should not be confused with working memory (Lezak, 1995). Thus, with posterior lesions the sensory integration capacities of the brain are damaged at a critical level of information input with resultant reliable IQ decrements. The final pathway from the decision to plan, execute and monitor a motor act such as speech is from anterior to posterior (e.g., prefrontal cortex -> premotor cortex -> primary motor cortex -> spinal cord -> peripheral nervous system -> voluntary muscle groups in sequence).

See Figure 1 on the next page (common domain).

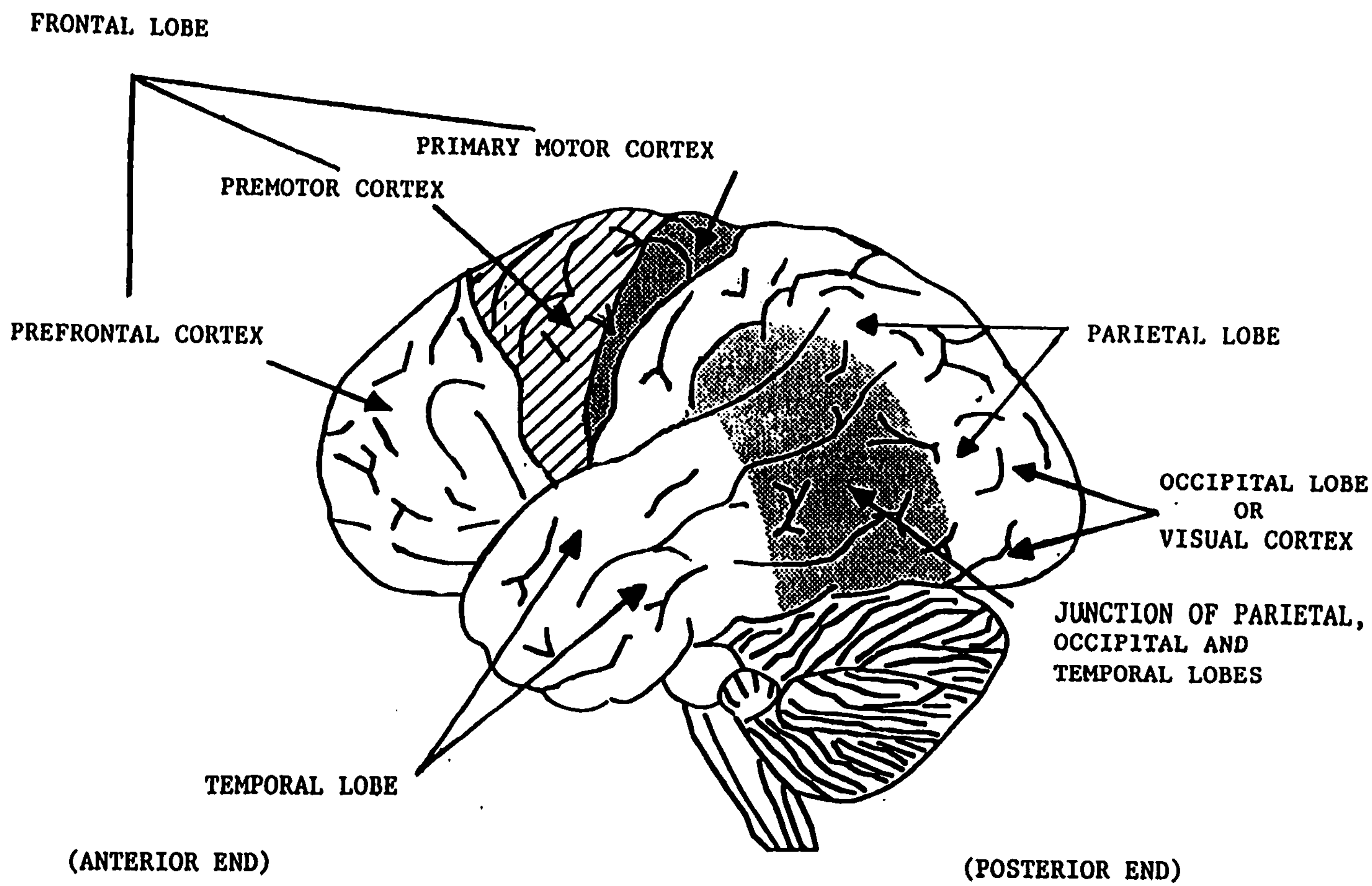


FIGURE 1: LEFT HEMISPHERE VIEW OF THE HUMAN CEREBRAL CORTEX

The dorsal and lateral aspects of the prefrontal cortex are especially involved in the selection of behavior on the basis of temporal memory (Kolb & Whishaw, 1996). Therefore, individuals with lesions to their dorsolateral prefrontal cortex, exhibit behavior that is no longer under the control of their own internalized knowledge structures and their behavior is highly determined by external cues (Kolb & Whishaw, 1996).

An example of just such behavior in a prefrontally-injured patient would be their impulsive picking up and pounding a hammer if such an object with a clearly designed use was laid out before them on an examination table. Although the memory of the features of a hammer and the action sequence associated with it would likely be still intact for the patient, the behavioural programming associated with the prefrontal cortex, as to the appropriate time and place where one should pound a hammer would be dissociated. Cognitive psychological studies have likewise revealed such perseverative actions in younger children that parallel some aspects of dysexecutive adult patients. Interesting parallels can be drawn between the actions of such older patients and the "action scripts" possessed by young children, with as yet immature prefrontal cortices, which characteristically center on sequences of stereotypic actions (McKeough, 1992).

A number of brain regions play a key role in the integration of emotion with higher cognitive function. Papez (1937) was among the first to characterize some of the central connections of the limbic system as it is now known. The "Papez loop" is only a small part of a much more extensive network integrating phylogenetically older and newer portions of the brain (Benes, 1994). The limbic lobe, or emotional brain as it is sometimes referred to, is nestled underneath the sheaths of the four lobules of the neocortex: frontal, temporal, parietal and occipital lobes, respectively, much like a nut in it's shell.

Among the connections of Papez loop is an extensive neocortical-limbic neural fiber tract reciprocally interconnecting the frontal lobes with key limbic structures important in regulating affective behaviors. It is hypothesized that in this way the hierarchical control systems mediated in part by the prefrontal cortex (Fischer & Rose, 1994) come to be strongly influenced by the affective valence that stimuli elicit either internally (e.g., from memory) or externally in the environment via limbic interconnections. Therefore, concomitant approach or avoidance behaviors mediated via the motor cortex can allow the organism to ignore or process the stimuli in more detail.

In sum, it is hypothesized that the frontal lobes and their requisite limbic connections collectively function as a attentional mechanism selectively directing the *spotlight* of hierarchical control systems on various aspects of the internal or external environment of the person (Posner & Petersen, 1990). This top-down attentional mechanism should not be confused with a posterior attentional mechanism which is considered to act more like a bottom-up processing filter which allows the person to selectively examine elements of a given stimulus array in more detail, but not hierarchically like the anterior system (Posner & Peterson, 1990). For the sake of brevity the discussion of the functional neuroanatomy of attentional mechanisms has been restricted to the anterior or prefrontal cortex mediated top-down control system.

Neurophysiological Studies

The role of the frontal lobes in executive functioning has come mainly from the study of head injury cases in adult clinical neuropsychology (Kolb & Whishaw, 1995). However, recently the maturation of the frontal lobes have been implicated in the developing executive spectrum capacities of neurologically intact children (Fischer & Dawson, 1994; Barkley, 1996, Johnson, 1997). Furthermore, developmental neuropsychological studies have begun to successfully employ derivations of such adult tasks to characterize the timeline of the acquisition of executive capacities in children (Passler, Isaac & Hynd, 1985; Chelune & Baer, 1986; Becker, Isaac, & Hynd, 1987; Levin et al., 1991; Welsh, Pennington & Grossier, 1991) and have found characteristic spurts in executive capacity between the ages of 6 and 8.

There are four different types of studies which all demonstrate persuasive evidence for discontinuities in the structural/functional development of the frontal lobes and requisite performance capacities in children cognitively and socioemotionally.

Electrophysiological Studies

Thatcher, Walker and Guidice (1987) demonstrated via quantitative electroencephalography (QEEG) that the left and right frontal lobes demonstrated peak activity levels (suggestive of developing functionality and connectivity with the posterior cortices), at different rates and at different postnatal onset times in children. Furthermore, the timing of these frontal lobe growth spurts coincided with the emergence of Piagetian (1971) developmental stages and/or alternatively Thatcher and Rose's (1994) developmental tiers. Although, these electrophysiological data are speculative, they nevertheless suggest frontal involvement in the emergence of qualitatively distinct hierarchies of skills across domains of knowledge at different ages.

Thatcher and colleagues' findings have been reproduced by utilizing the derivative technique of electro-encephalographic (EEG) coherence (Hudspeth & Pribram, 1990; Matousek & Petersen, 1973; Thatcher, 1991; 1992; 1994). Reliable spurts in EEG coherence, a measure of "connectivity" between frontal and posterior sensory processing areas, in both studies have been found at the ages 1-2, 3-4, 7-8, 11-12 and 14-15 years of age. One problem is that to date these EEG studies have often suffered from the design problem of not measuring individuals repeatedly, and therefore the question as to whether these peaks in activity are cohort effects or genuine age spurts within individuals remains to be established. However, given the extremely large sample populations utilized in these studies, and the fact that pronounced asynchronies in EEG coherence were found at precise ages throughout development in all of these samples, suggests that the outcome of these studies have validity.

Another common type of electrophysiological study that has been used in the examination of frontal involvement in cognitive development is contingent negative variation (CNV) or evoked potential (EP) studies. Such electrophysiological studies incorporate measurement of characteristic brain waves elicited at some period after presentation of a priming stimulus or during performance of a type of cognitive task (Kolb & Whishaw, 1996). Interestingly purported "marker" frontal tests such as the Trail Making Test (Das & Naglieri, 1997) have been shown to demonstrate reliable selective prefrontal activation (Segalowitz, Unsal & Dywan, 1992) during performance as measured by CNV.

Effects of Early Frontal Lobe Damage in Childhood

There are a number of documented cases of restricted prefrontal cortex damage in early childhood with subsequent longitudinal follow-up by clinicians. The clinical cases that are documented do show remarkable similarities in the long-term cognitive and socioemotional outcome.

Classical cases examined by Ackerly (1937) and Hebb (1945) described patients with circumscribed prefrontal cortex lesions in early childhood who were studied longitudinally. There were no marked declines on measures of general intelligence as measured by standardized IQ tests as a function of the lesions. A constellation of cognitive and sociocognitive deficits emerged in this patient group over time. These included: concrete thinking, lack of anxiety, impulsivity and weak or totally absent interpersonal bonds.

More recently, other investigators have described such unfortunate pediatric cases of prefrontal damage. Gratton and Eslinger (1991) described patient PL who sustained a penetrating injury to the right prefrontal cortex as a consequence of a mishap with a lawn dart. PL exhibited above average intelligence but exceptionally poor self-regulatory behaviors in complex social scenarios, difficulty in solving novel problems and interference in the normal development of adaptive living skills.

Another patient, DT, underwent amputation of the left prefrontal pole at the age of 7 in an attempt to surgically control a severe aneurysm (Gratton & Eslinger, 1991). Prior to the accident DT's developmental milestones, social, academic and emotional maturation were normal according to all available data. As an adult DT functioned with average intelligence with intact language, memory and visual perception. Severe impairments were noted on tasks of sustained concentration, cognitive flexibility, the organization of complex information and planning towards a remote goal.

Of interest was that DT was able to function rather normally in structured situations with a peer, but DT appeared to be unable to verbally guide him/herself through complex tasks in novel situations. This symptomatology appears to be characteristic of such children who have sustained prefrontal injury in early childhood, and suggests that such neurodevelopmental theoretical frameworks might prove useful in characterizing executive function development in neurologically intact children.

Vygotsky wrote extensively about the transition from egocentric to inner speech and the concomitant transition of cognition from the intermental to the intramental (Wertsch & Tulviste, 1992). Both Piaget and Vygotsky described this early childhood phenomenon, termed egocentric speech, and agreed that it signaled the developmental transition of external socially mediated language into inner speech or thought which then could be used by the child for both reflective, anticipatory or logical thinking ends (Das, Kar & Parrila, 1996). Vygotsky's student, Alexander Luria, later postulated a prefrontally-mediated mechanism by which verbally-mediated self-control emerges developmentally in children (Luria, 1973).

It has been speculated that prefrontal cortex damage may result in a dissociation between language behaviours and inner speech such that self-generated verbal cues are less likely to be used to guide behaviour (Shallice, 1988; Vilkki, 1984). Right hemispheric damage has been found to be particularly detrimental to executive capacities such as planning ability (Lezak, 1995), and a recent review article suggests a preeminent role of the right prefrontal cortex in action planning or "praxis" in neurological terms (Richards & Chiarello, 1997).

There are at least a dozen other well-documented cases of such developmental consequences of early prefrontal cortex damage in children. Posterior lesions of the neocortex do not result in such profound deficits in the sociocognitive realm, but may negatively impact visuospatial and language functions (Benton, 1991). A consistent finding has been that accidental damage to posterior aspects of either hemisphere of children before the age of six, will usually result in compensation by the reorganization of language to the normally non-dominant hemisphere (Kolb & Whishaw, 1995). Such children may demonstrate small decrements in IQ but generally, if the damage occurs early enough, the behavioural effects may be almost imperceptible.

These lesion studies point towards the organizational role of the prefrontal cortices in cognitive and socioemotional development, and toward the inadequacy of many traditional psychoeducational assessment instruments in capturing such innately human abilities. Furthermore, such studies suggest that the prefrontal cortex is integral in normal social development and that cognitive development of the highest levels (e.g., planning, see Das, Kar & Parrila, 1996) is closely aligned with the social developmental plane (Vygotsky, 1978).

Synaptic Density Studies

Until recently it was thought that the anatomical development of the human brain was completed between the ages of 2-3 (Huttenlocher, 1994) with myelination of subcortical pathways continuing into adulthood (Yakovlev & Lecours, 1967). Interest in the causal role of myelination has began to fall into disfavor, however, as recent studies have demonstrated that under-myelinated connections are still quite capable of transmitting signals (Johnson, 1997). Although there is no evidence for cyclic production of actual brain cells, at the microscopic level of synapses on the dendrites of neurons it is clear that major structural changes continue throughout childhood.

The brain contains many synapses that eventually connect brain cells into functional circuits. Newborn humans have fewer synapses per unit brain tissue than adults, but early in post-natal development the infant brain begins to form synapses far in excess of that of adult levels, a process which is termed synaptogenesis. After a peak in synapse density which occurs at about the age of one year in human beings, synaptic pruning or synapse elimination begins (Huttenlocher et al., 1982; Huttenlocher, 1990, 1994). The onset of the start of synapse elimination cycles has been found to closely parallel the onset of many qualitatively distinct classes of abilities in infant Rhesus monkeys (Dawson & Fischer, 1994).

Synapse elimination has been found to be complete in human occipital/visual cortex of the posterior cortices at about age 10, but in prefrontal cortex the process of elimination of synapses is much slower. In frontal cortex, synaptic densities do not begin to stabilize until late adolescence (Huttenlocher, 1994). Why nature might have preserved such a high degree of functional neuroplasticity within the frontal lobes until relatively late in cognitive and socioemotional development is not presently understood but the findings are nevertheless intriguing. These results await replication by independent laboratories.

Neuroimaging Studies

The fourth line of evidence implicating physiological changes within the prefrontal cortex with cognitive and socioemotional changes comes from neuroimaging studies. The essential deficiency associated with attention-deficit/hyperactivity disorder or ADHD (American Psychiatric Association, 1994) has been speculated to arise from executive dysfunction (Barkley, 1996). This disorder which educators encounter on a regular basis (McCormick & Pressley, 1997) appears to have a strong biological component (Barkley, 1996). However, there is continuing debate as to whether the physiological manifestations of the disorder are perhaps in part the end-products of an early childhood environment deficient in key socioemotional or cognitive elements (Barkley, 1996). Clearly the etiology of ADHD involves a combination of genetic vulnerability usually interacting with a double environmental risk.

Previous investigators have noted the striking similarities between symptoms of ADHD and the clinical profile of patients which have sustained injuries to the prefrontal cortex (Mattes, 1980). Studies examining "cerebral blood flow" have consistently demonstrated decreased blood flow to the prefrontal regions and pathways connecting these regions to the limbic systems of ADHD children in comparison to "normal" children (Lou, Henricksen & Bruhn, 1984; Lou et al., 1989). Another study demonstrated diminished cerebral metabolism in the prefrontal cortex of adults diagnosed with ADHD compared to controls (Zametkin et al, 1990). Together these studies suggest that children and adults afflicted with ADHD demonstrate subnormal activation of their prefrontal cortices, with the behavioural result of executive spectrum deficits.

The Wisconsin Card Sort Test (WCST) is perhaps one of the most studied of the "frontal tests" particularly in relation to its neuroanatomical substrates. Furthermore, activation of dorsolateral prefrontal cortex has been demonstrated to be necessary for adequate performance on the WCST in neuroimaging studies (Weinberger, Berman & Zec, 1986; Weinberger, Berman & Illowsky, 1988). In addition the trail making test, another "frontal marker" task (Das & Naglieri, 1997), has been utilized effectively to identify patients suffering from depression (Gass & Daniels, 1990) who typically exhibit hypoactivation of the prefrontal cortex as revealed by positron emission tomography (PET) scans (Baxter et al., 1989).

Differential functions of prefrontal cortex have been demonstrated recently in the finding that lateral prefrontal cortex is especially involved in inhibitory control of attentional selection, whereas the orbital-frontal cortex has been implicated in the alteration of behaviour in response to fluctuations in the emotional significance of stimuli (Dias, Robbins & Roberts, 1996). Furthermore, functional magnetic resonance imaging (fMRI) studies have also revealed that prefrontal association cortex and parietal cortex activation to be both necessary for the on-line manipulation of information (Cohen et al., 1996), which is consistent with cognitive psychologist's hypothesis of the central role of the prefrontal cortex as functioning as an on-line working memory buffer (Case, 1985; Fischer & Rose, 1994).

Summary

Developmental psychologists have characterized qualitative changes in children's cognitive and socioemotional development. Pronounced shifts occur between the ages of 3.5-4.5, 6-7, 10-12 and 14-16 years of age. Executive functions or those capacities which allow us to plan and organize our behaviors are deficient in patients with prefrontal cortex damage. Although such frontal patients often perform in the normal range on intelligence tests, they are often totally dependent on others for guidance in everyday living and cannot function on their own. Recent studies have examined developmental growth spurts of executive capacities in children. The prefrontal cortices undergo at least four characteristic neurophysiological changes during development, the timing of which shows a remarkable one-to-one correspondence with the emergence of executive capacities and cross-domain changes in cognitive and socioemotional development in children.

CHAPTER FOUR

METHOD

Experimental Design

Students of both genders (N=115) between the ages of 7,8,9 and within grades 1,2,3,4 participated in this study. Students were recruited from fourteen elementary schools within the Calgary Public School System. Upon staff approval at each school *"Letter of Information to Parents"* and *"Consent for Research Participation"* forms (APPENDICES A and B respectively) were sent home to parents of targeted children.

Within each of the three age groups only subjects with birthdays in either January/February or March/April in relation to the March 1st school entrance cut-off date were asked to participate. Thus, in each of the 3 age groups, there was a comparison "early and late school starter sub-group", which at most were two months apart in age. This design which has been used in previous studies (Cahan & Cohen, 1987; Cahan & Cohen, 1989; Bisanz, Dunn & Morrison, 1995; Morrison, Smith & Dow-Ehrensberger, 1995) can then be used as the basis for equating two groups of children developmentally with differential levels of formal instruction on some target skill. This two month chronological age difference between "early and late school starter pairings" has been judged small enough to circumvent gross age-related confounds from occurring (Cahan & Davis, 1987; Cahan & Cohen, 1989; Bisanz, Dunn & Morrison, 1995; Morrison, Smith & Dow-Ehrensberger, 1995).

Furthermore, for each of the three age ranges those children born in January or February of a particular year, the early starters, received one extra year of formal education than their age-matched late-starter pairings born in March or April. That age and schooling effects can be interpreted unambiguously in this study rests on two assumptions, 1) the allocation of children to birth dates is random, 2) and that grade level is a linear function of chronological age (Cahan & Cohen, 1989). Both assumptions can be safely met if children who have been held back a grade or accelerated a grade are excluded from the analysis (Cahan & Cohen, 1989).

The fourteen schools which participated within the Calgary Public School System represented a broad cross-section of socioeconomic groups in Northwest and Central Calgary. A significant proportion of the variance in socioeconomic status has been found to be reliably predicted from variability in scores on the Peabody Picture Vocabulary Test-Revised (Schliecker, White & Jacobs, 1991). Furthermore, receptive vocabulary scores as measured on the PPVT-R have been found to be reliably influenced by the socioeconomic status of examinees, perhaps as a function of cultural disadvantages and/or exposure to less access to learning resources (Dunn, 1981). Since PPVT-R standard scores were to be factored out of the analysis, more elaborate means of adjusting for socioeconomic differences among students were not undertaken.

The reason for the age-range selectivity was that the frontal lobes are presumably undergoing major growth spurts during this age range as discussed previously. The reason for the birth-month selectivity is that the study is focusing on formal schooling versus age-dependent influences on executive function development, and therefore age-matched groups of children with a difference of one year of formal schooling were needed. The study was conducted from January 1997 to May 1997 and eligible students were chosen to participate randomly throughout this 5 month period. That is, each of the six cells filled up at approximately the same rate so as not to exaggerate inter-group chronological age differences.

The experimental design consisted of a hierarchical sum-of-squares two-way analysis of covariance (ANCOVA): education (2 levels) by age (3 levels) with standard scores on the Peabody Picture Vocabulary Test-Revised (Dunn, 1981) functioning as the IQ covariate. PPVT-R standard scores were used as a covariate to correct for anticipated effects of inflation of aptitude scores with successive grades as a function of dropout effects (Cahan & Cohen, 1989) and to correct for individual student differences in receptive vocabulary development as a function of cultural and socioeconomic differences.

Measured Variables

There were five measured variables in this study including: the 3-point teacher ratings, the Peabody-Picture Vocabulary Test-Revised, The Wisconsin Card Sorting Test-Revised, the Thurstone Word Fluency Test, and finally the Wechsler Intelligence Scale for Children - Third Edition Revised Mazes Subtest. In addition to the measured variables there were three important non-randomized variables: age (7,8,9), education (early start, late start) and gender (male, female). These latter non-randomized variables rendered the experimental design quasi-experimental in nature.

Teacher Ratings

In order to obtain corroborative information as to the maturational status of each student a three-point teacher rating form was developed. Each teacher which supervised each respective student for the largest proportion of each teaching day filled out the form on the student's behalf. The two criteria on which each student was evaluated on were: 1) academic development and 2) social development. Each student was rated as either meeting the rating criteria for a 1, 2 or a 3. Where one (1) was below that of their peers, a two (2) was on par with their peers; while a three (3) was ahead of their peers. All teachers filled out the rating forms for all participating students at the same time before the testing began. The rating took no more than a minute to fill out for each student and teacher's commented that the rating was a simple assessment to make.

Peabody Picture Vocabulary Test- Revised

The Peabody Picture Vocabulary Test-Revised (Dunn, 1981) is:

> ...an individually administered, norm-referenced, wide range, power test of hearing vocabulary, available in two parallel forms - now designated L and M. Each form of this revision contains 5 training items, followed by 175 test items arranged in order of increasing difficulty. Each item has four simple, black and white illustrations arranged in multiple-choice format. The subject's task is to select the pictures considered to illustrate best the meaning of a stimulus word presented orally by the examiner (pg. x).

PPVT-R scores have been found to correlate highly with verbal intelligence measures (Bracken, Prasse & McCallum, 1984), and vocabulary measures such as the PPVT-R have consistently been found to be one of the highest loading factors on general intelligence or full-scale IQ measures as measured by traditional intelligence tests (Sattler, 1988). Therefore, in the interests of time constraints of each testing period PPVT-R standardized scores were utilized as an estimate of general intelligence.

Executive Measures

Although there are at least a dozen neuropsychological tests sensitive to frontal dysfunction (Lezak, 1995), variants of three of the most common executive function measures were utilized for the purposes of this study. The three executive function measures utilized for the purposes of this study were the Wisconsin Card Sort Test, the Thurstone Word Fluency Test, and a test similar to the Porteus Mazes, specifically the Wechsler Intelligence Scale for Children - III Revised Mazes Subtest.

Wisconsin Card Sort Test

The Wisconsin Card Sort Test Manual: Revised and Expanded (Heaton et al., 1993) consists of:

> ...four stimulus cards and 128 response cards that depict figures of varying forms (crosses, circles, triangles, or stars), colors (red, blue, yellow, or green) and numbers of figures (one, two, three, or four). As the task is usually administered, the four stimulus cards with the following characteristics are placed before the subject in left-to-right order: one red triangle, two green stars, three yellow crosses, and four blue circles. The client is then handed a deck of 64 response cards and instructed to match each consecutive card from the deck with one of the four stimulus cards, whichever one he or she thinks it matches. The client is told only whether each response is right or wrong and is never told the correct sorting principle (or category). Once the client has made a specified number of "correct" matches to the initial sorting principle (usually to Color), the sorting principle is changed - to Form or Number - without warning, requiring the client to use the examiner's feedback to develop a new sorting strategy. The WCST proceeds in this manner through a number of shifts in set (i.e., sorting principle) among the three possible sorting categories...Color, Form and Number...(p. 1).

The perseverative errors raw score has been found to be the score on the WCST most sensitive to frontal lobe and diffuse neocortical lesions (Heaton et al, 1993). The WCST has been found to be especially sensitive to dorsolateral prefrontal lesions (Drewe, 1974; Milner, 1963; Nelson, 1976; Robinson et al., 1980). Although the WCST was originally developed to assess abstract reasoning (Berg, 1948), it also measures the factor analytically derived construct of "mental flexibility" (Heaton et al, 1993) which bears a theoretical resemblance to Guilford's (1967) divergent productions facet of intelligence.

Perseverative errors are those responses made by the client in which a previously correct category is no longer correct and yet the client still persists in this incorrect pattern of responding. Barkley (1996) has characterized mental flexibility or set-shifting, modulation of impulsive responding or interference control and regulation of goal-directed behavior (which typically involves strategy usage), as all dependent on the superordinate construct of behavioural inhibition. Furthermore, there is a substantial body of research emerging that suggests that one of the fundamental functions of the prefrontal cortex is to inhibit the expression of prepotent or previously learned response (Barkley, 1997). Although there are other scores of interest on the WCST, the perseverative errors score was the sole criterion used here to gauge performance on the WCST.

Thurstone Word Fluency Test

The Thurstone Word Fluency Test or TWFT (Thurstone, 1938, Thurstone & Thurstone, 1962) has been shown to be especially sensitive to left hemispheric frontal lesions (Milner, 1964; 1975). The general pattern of performance on the TWFT is that frontal patients fare worse than non-frontal patients, left hemisphere patients fare worse than right hemisphere patients, and that left frontal patients fare worse than right frontal patients (Pendleton et al., 1982). Furthermore, like performance on the WCST diffuse cortically damaged patient's performance on the TWFT was indistinguishable from frontally damaged patient's performance on the TWFT. The equally debilitating effects of diffuse neocortical damage are understandable in the context of the fact that the neocortex and underlying white matter of the frontal lobes is the site of a multitude of longitudinal fiber tracts connecting the major sensory and motors systems at the highest levels (Lezak, 1995). Diffuse neocortical damage is particularly damaging to these reciprocal longitudinal fiber tracts interconnecting anterior motor with posterior sensory areas.

The TWFT involves two simple steps. In Part I clients are asked to verbalize as many five letter words that start with the letter "s" as they can think of in five minutes. In Part II clients are asked to verbalize as many four letter words that start with the letter "c" in 4 minutes. Part I functions as a warm-up session for the more difficult Part II. The total number of recalled words were summed over Parts I and Part II and this sum is used as the raw score measure of TWFT performance.

The TWFT examines the ability of individuals to spontaneously retrieve matching words from memory and to hold those words that they have already said in mind so as not make perseverative errors (Lezak, 1995). Estes (1974) has suggested that successful performance on word fluency tests requires that subjects "organize output in terms of clusters of meaningfully related words". Thus, competency on fluency tests require that the client generate and monitor the effectiveness of a strategy.

WISC-III-R Mazes Subtest

The Wechsler Intelligence Scale for Children, Third Edition, Revised Mazes Subtest (Wechsler, 1991) has been judged to be an adequate substitute for the lengthier Porteus Mazes test (Porteus, 1965) and a sensitive measure of prefrontal lobe dysfunction (Lezak, 1995, pp. 655-657).

The number of repeated entries into blind alleys of the Porteus Mazes test can be used as an index of perseverative responses (Daigneault et al, 1992) and is the primary means of scoring the WISC-III-R Mazes Subtest. Greater attenuation of Porteus maze performance was found in frontal as opposed to non-frontal patients in Daigneault et al's study. Practice effects have been reported with the Porteus Mazes (Daigneault et al, 1988), although these effects appear to give rise to only small increments in performance. The Porteus Mazes test has been reputed to load on a planning factor (Daigneault et al, 1988; 1992) in older patients. In younger patients the Porteus maze loaded with the Wisconsin Card Sort Test among a number of other "frontal marker" neuropsychological tests (Segalowitz, Unsal & Dywan, 1992).

The most difficult item on the WISC-III-R Mazes Subtest is almost as complex as the most difficult item in the Porteus series (Lezak, 1995). Summed raw scores for the entire set of the ten timed mazes constituted the third executive measure. The WISC-III-R mazes taps the ability of individuals to engage in planning and foresight (Lezak, 1995).

Testing Procedures

After parents had returned the signed *"Consent for Research Participation"* forms to the school, a date was set for the start of the testing session during school hours. The administration of each of the four tasks required approximately one hour to complete. Times of testing during the day were randomly chosen between 9:00 a.m. and 3:30 p.m. Monday to Friday at each respective school. Testing was not undertaken during recess periods or during noon hour. Every effort was made to ensure that students and teachers were not excessively interrupted by the in-school testing sessions.

Following an initial five-minutes period of making acquaintance with the child and the verification of parent-authorized personal information about the child (e.g., age, birthday, day of testing, school, grade, grade acceleration or retention questions) the tasks began. Probe trials indicated that the children genuinely enjoyed completing the four tasks. Students were informed before the testing began that "...*we will be doing some games today that kids* *like..and you can leave without penalty at any time during this session if you feel like you don't want to be here...".* If children exhibited grossly discomforting anxiety during the examination (e.g., agitation, rocking motion) they were asked if they *"...would you like to do something else and go back to your classroom?"* Only one student decided to discontinue with the tasks under these circumstances.

Participants first completed the Thurstone Word Fluency Test because it was the task that was potentially the most subject to confounds from student utilization of in-session cues. Every effort was made to remove external cues (e.g., posters, memos) from the walls of the testing room so as not to contaminate the testing sessions with "word give-aways". The testing room usually consisted of the school nurse's room or an empty office kindly provided by the school.

The Thurstone Word Fluency Test took approximately 10 minutes to administer. The Wisconsin Card Sort Test was administered next, because probe trials had revealed that this test suffered the most from fatigue effects in children of this age range. The Wisconsin Card Sort Test took approximately 20 minutes to complete. Participants were then administered the PPVT-R in approximately 10 minutes time, followed by the WISC-III-R Mazes Subtest in approximately 10 minutes time.

The Mazes was administered last since probe trials has revealed that this was the task most enjoyed by the children.

Thus administration of the mazes in such a sequence set a positive tone for all individuals upon completion of the session regardless of their performance on the other three tasks. Total testing periods varied between individuals from 40-60 minutes.

A thank-you letter along with a summary of the results was mailed out to the principal and staff of each participating school upon completion of the study. Parents were invited to contact the principal investigator with their questions regarding the study at any time during or after the completion of the study. Individual student information about performance on the tasks was only given in the context of group results, and it was made clear that the measures were not to be taken as indicative of their child's intelligence, scholastic aptitude or achievement.

CHAPTER FIVE

RESULTS

Data Transformations

A base ten logarithmic transformation was undertaken on the WCST score data to induce the distribution of scores into approximate normality (Glass & Hopkins, 1996, p. 98). Subsequently, the inverse function of the logarithm of the WCST was undertaken, since unlike the other two executive measures, increasing raw scores on the WCST are indicative of decreasing executive capacity. Finally, the inverse logarithmic transformation of WCST was multiplied by the constant of 30 to scale it with the other two executive measures for graphical comparative purposes.

Summary Statistics

The summary data for the dependent variables is listed in Table 1,2 and 3 by age by education. Means, standard deviations and cell counts are included.

Group Age Differences

Table 4 illustrates the group age differences by age by education. The average differences in age among the three early versus late school starter comparisons collapsed across gender ranged from 70-77 days, and none of these three age differences were significantly different from one another.

Table 1: Summary Statistics for the Dependent Variables (Age 7)

	EDUCATIONAL STATUS	
	LATE START	EARLY START
IQ Estimate	(n = 24)	(n = 16)
Mean	104.58	101.56
Std Deviation	13.51	11.55
Academic Development		
Mean	2.17	1.56
Std Deviation	.70	.63
Social Development		
Mean	2.25	1.88
Std Deviation	.61	.50
Wisconsin Card Sort Test		
Mean	21.29	20.55
Std Deviation	5.47	4.32
Thurstone Word Fluency		
Mean	13.33	15.25
Std Deviation	7.52	9.53
WISC-III-R Mazes Subtest		
Mean	16.08	17.13
Std Deviation	5.87	3.83

Table 2: Summary Statistics for the Dependent Variables (Age 8)

	EDUCATIONAL STATUS	
	LATE START	EARLY START
IQ Estimate	(n = 20)	(n = 10)
Mean	105.40	106.70
Std Deviation	8.94	20.28
Academic Development		
Mean	2.10	2.10
Std Deviation	.64	.32
Social Development		
Mean	2.10	1.80
Std Deviation	.55	.63
Wisconsin Card Sort Test		
Mean	21.72	23.82
Std Deviation	5.90	6.45
Thurstone Word Fluency		
Mean	19.00	25.90
Std Deviation	6.13	6.42
WISC-III-R Mazes Subtest		
Mean	19.65	19.50
Std Deviation	3.56	3.50

Table 3: Summary Statistics for the Dependent Variables (Age 9)

	EDUCATIONAL STATUS	
	LATE START	EARLY START
IQ Estimate	(*n* = 24)	(*n* = 21)
Mean	108.04	112.67
Std Deviation	10.99	13.19
Academic Development		
Mean	2.21	2.05
Std Deviation	.66	.67
Social Development		
Mean	2.13	1.86
Std Deviation	.45	.73
Wisconsin Card Sort Test		
Mean	23.64	27.27
Std Deviation	2.81	6.83
Thurstone Word Fluency		
Mean	33.04	32.29
Std Deviation	11.16	9.40
WISC-III-R Mazes Subtest		
Mean	19.75	21.62
Std Deviation	4.07	4.10

Table 4: Average Age Difference Among Groups (Year-Months-Days)

	Chronological Age		
	7	8	9
Late Starters Mar/Apr Birthday Born After Cut-off	6-11-17 (n = 24)	7-12-06 (n = 20)	8-11-14 (n = 24)
Early Starters Jan/Feb Birthday Born Before Cut-off	7-01-29 (n = 16)	8-02-11 (n = 10)	9-01-25 (n = 21)
Average Age Difference	77 days	70 days	76 days

Note: All between age-group comparisons of the three difference pairings are non-significant.

Spearman Rank Correlations

Spearman rank correlations were calculated for the nominal variables of age, education and gender and the teacher ratings of social and academic development due to the ordinal nature of the data - See Table 5. The critical alpha was adjusted to ($p < 0.01$) control for repeated comparisons. Social developmental and academic developmental ratings were highly correlated ($r = 0.50$, $p < 0.001$), whereas social developmental ratings were significantly negatively correlated with starting school early ($r = -0.26$, $p = 0.005$). Furthermore, the correlation between gender and social development approached significance such that girls were rated as more socially developed as compared to age-matched boys - See Figures 2 and 3.

Spearman rank correlations were also calculated for the executive measures, IQ estimate, teacher ratings and school since the scales of the various measures were on different metrics - See Table 6. The Mazes subtest and the IQ estimate were significantly correlated ($r = 0.29$, $p = 0.001$). Word Fluency was significantly correlated with academic development ($r = 0.28$, $p = 0.003$) and the Wisconsin Card Sort Test ($r = 0.31$, $p = 0.001$).

Table 5: Spearman Rank Correlation Coefficients of Teacher Ratings and Nominal Variables (Significant at $p < 0.01$, N=115)

	Academic Development	Social Development	Age	Educational Status
Social Development	.4967 $p < 0.0001$			
Chronological Age	NS	NS		
Educational Status	NS	-.2574 $p = 0.005$	NS	
Gender	NS	.2311 $p = 0.013$	NS	NS

Note: NS denotes non-significant.

TABLE 6: Spearman Rank Correlation Coefficients of Executive Measures, IQ Estimates and Teacher Ratings (Significant at $p < 0.01$, $N = 115$)

	Academic Develop	Social Develop	Wisconsin Card Sort	Word Fluency	Mazes
Social	.4967 $p = 0.000$				
Wisconsin Card Sort	NS	NS			
Word Fluency	.2755 $p = 0.003$	NS	.3147 $p = 0.001$		
WISC-III-R Subtest	NS	NS	NS	NS	
IQ Estimate	NS	NS	NS	NS	.2787 $p = 0.003$

Note: NS denotes non-significant.

School Differences

Table 7 illustrates group mean differences in the estimate of IQ among the fourteen schools participating in the study. A one-way analysis of variance of school by IQ revealed a main effect of school that approached significance [$F(13,101) = 2.17$, $p = 0.016$]. Subsequent multiple comparisons with correction ($p < 0.01$) for the large number of comparisons ($n = 90$) revealed that only two comparisons were statistically significant. Schools 3 and 5 were statistically different from school 11 on the IQ estimate. However, the four students at school 11 were enrolled in a gifted program. Furthermore, the gifted children's ($n = 4$) performance on the executive measures was not significantly different from the performance of age-mates not enrolled in a gifted program ($p > 0.01$). In summation, the assumption that school type exhibited non-significant effects on the outcome of the study appears to be a safe one.

Table 7: School Differences in the IQ Estimate

SCHOOL	IQ Estimate
1	
Mean	108.00
Std Deviation	10.49
Valid N	n = 16
Maximum	125.00
Minimum	89.00
2	
Mean	108.29
Std Deviation	10.13
Valid N	n = 7
Maximum	125.00
Minimum	97.00
3	
Mean	96.00
Std Deviation	16.16
Valid N	n = 7
Maximum	113.00
Minimum	63.00
4	
Mean	107.18
Std Deviation	13.27
Valid N	n = 22
Maximum	136.00
Minimum	82.00
5	
Mean	98.91
Std Deviation	17.19
Valid N	n = 11
Maximum	121.00
Minimum	61.00
6	
Mean	106.44
Std Deviation	8.59
Valid N	n = 16
Maximum	117.00
Minimum	88.00
7	
Mean	102.00
Std Deviation	.
Valid N	n = 1
Maximum	102.00
Minimum	102.00

SCHOOL	IQ ESTIMATE
8	
Mean	103.80
Std Deviation	6.69
Valid N	n = 5
Maximum	110.00
Minimum	93.00
9	
Mean	107.00
Std Deviation	.
Valid N	n = 1
Maximum	107.00
Minimum	107.00
10	
Mean	107.63
Std Deviation	11.84
Valid N	n = 16
Maximum	138.00
Minimum	87.00
11	
Mean	127.00
Std Deviation	10.95
Valid N	n = 4
Maximum	135.00
Minimum	111.00
12	
Mean	124.00
Std Deviation	11.36
Valid N	n = 3
Maximum	137.00
Minimum	116.00
13	
Mean	105.00
Std Deviation	8.49
Valid N	n = 2
Maximum	111.00
Minimum	99.00
14	
Mean	105.50
Std Deviation	10.28
Valid N	n = 4
Maximum	117.00
Minimum	92.00

Analysis of Effects of Gender

Table 8 illustrates the gender distribution by age by education. Four separate hierarchical sums of squares analysis of variance were calculated to examine the effects of gender on the three executive measures and the IQ measure. The critical alpha was adjusted to $p < 0.01$ to control for repeated comparisons. The fitting order was gender, education and then age such that the largest proportion of variance was initially allotted to gender. None of the gender main effects, two-way interactions or three-way interactions approached significance. In fact, gender accounted for at most 1 percent of the total variance on each of these four dependent measures. Therefore, detailed analyses of gender effects were not undertaken, and gender was collapsed across in subsequent analyses.

Table 8: Gender Distribution by Age by Education

	Chronological Age					
	7		8		9	
	Education		Education		Education	
	LS	ES	LS	ES	LS	ES
Male	10	8	8	1	14	9
Female	14	8	12	9	10	12
Total	24	16	20	10	24	21

Note: LS and ES denote late start, and early start.

Analysis of Covariance of Executive Measures

Three separate hierarchical sum of squares analysis of covariance (ANCOVA) were calculated for each of the executive measures. The critical alpha was adjusted to $p < 0.01$ to control for repeated comparisons. The variance attributable to the covariate IQ was partialled out of the analysis initially. The fitting order was education and then age such that the largest proportion of variance was initially allotted to the effect of educational status - the chief null hypothesis in question. The regression effects of IQ were non-significant for each of the three separate ANCOVA's and IQ accounted for at most 4 percent of the total variance for each of the three executive measures. For these reasons the analysis of the effects of the three executive measures was re-run as a two-way analysis of variance without the IQ covariate.

Analysis of Variance of Executive and IQ Measures

Four separate hierarchical sum of squares analysis of variance (ANOVA) were calculated for each of the three executive measures and the IQ measure. The critical alpha was adjusted to $p < 0.01$ to control for repeated comparisons. The fitting order was education and then age such that the largest proportion of variance was initially allotted to the effect of educational status.

An education by age ANOVA on the IQ Estimate revealed non-significant main effects and interactions with the model accounting for 7 percent of the total variance - See Figure 4. However, the effect of age approached significance [$F(2,109) = 3.03$, $p = 0.052$] such that IQ tended to increase with successive ages.

An ANOVA of education by age on the Wisconsin Card Sort Test scores revealed a violation of the Bartlett-Box F test of the assumption of the homogeneity of variances ($p < 0.01$), likely due to the unbalanced design. Subsequently, Brown-Forsythe F′ values were calculated to correct for violation of the homogeneity of variance assumption (Brown & Forsythe, 1974). Brown-Forsythe F′ tests revealed a significant age effect only [$F'(2,100) = 5.97$, $p < 0.01$]. Age accounted for 10 percent of the variance in the WCST scores - See Figure 5. Subsequent Dunn method multiple comparisons of the age effect revealed that the largest increment in WCST scores was between the ages of 8 and 9 ($p = 0.07$).

An ANOVA of education by age on word fluency scores revealed a significant age effect only [$F(2,109) = 6.75$, $p = 0.002$]. Age accounted for a 45 percent of the variance in word fluency scores - See Figure 6. Subsequent Dunn method multiple comparisons of the age effect revealed that the increment in fluency scores was significant between the ages of 7 and 8 ($p = 0.003$) and highly significant between the ages of 8 and 9 ($p = 0.0001$).

An ANOVA of education by age on the Mazes Subtest scores revealed a significant age effect only [$F(2,109) = 9.69$, $p < 0.0001$]. Age accounted for 15 percent of the variance in Mazes Subtest scores - See Figure 7. Subsequent Dunn method multiple comparisons of the age effect revealed that the largest increment in Maze scores was between the ages of 7 and 8 ($p = 0.012$). Figure 7 suggests that the 9 year old children may have found the maze test too easy (e.g., children had reached asymptotic levels of performance by age 9).

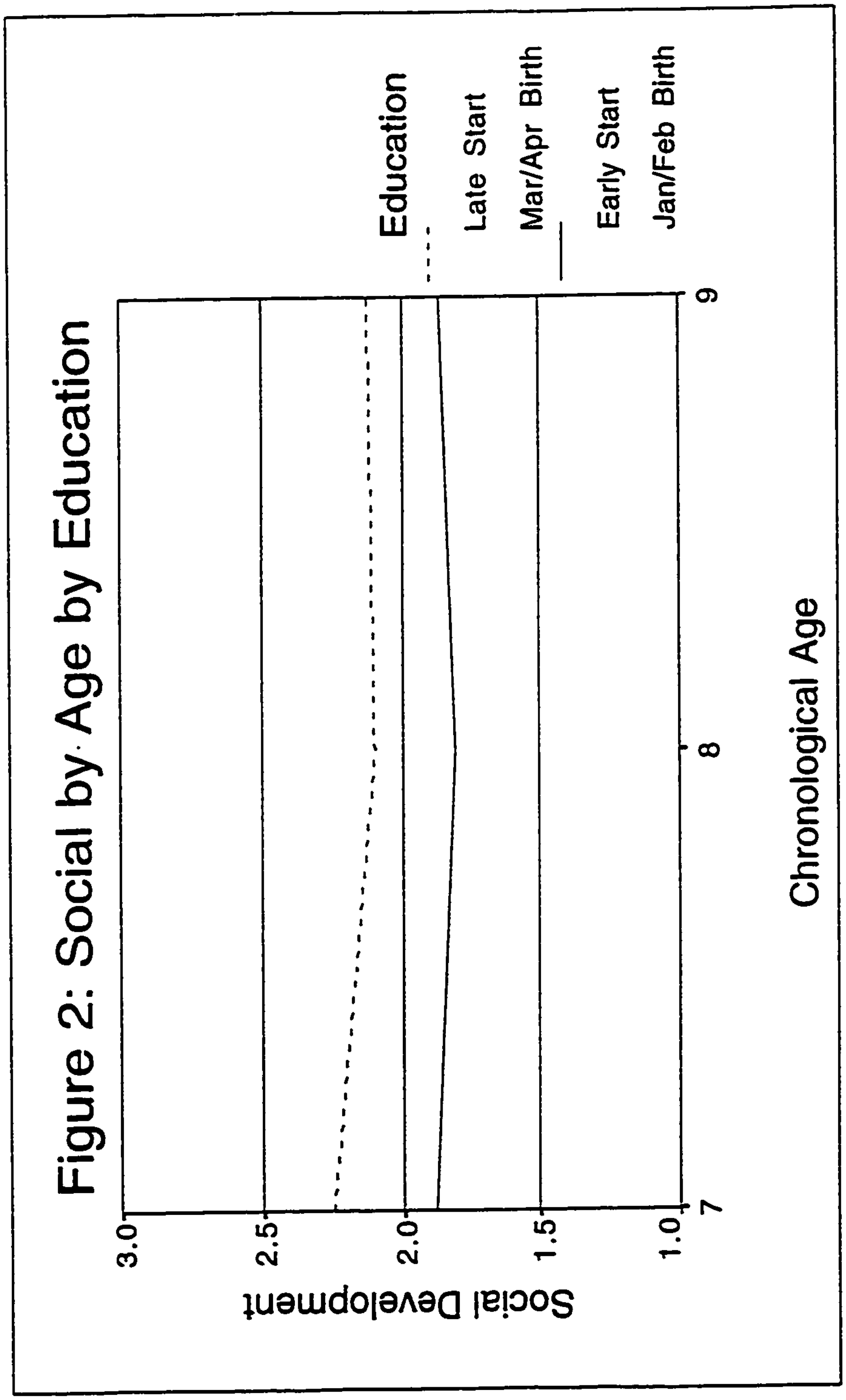


Figure 2: Social by Age by Education

Figure 3: Academic by Age by Education

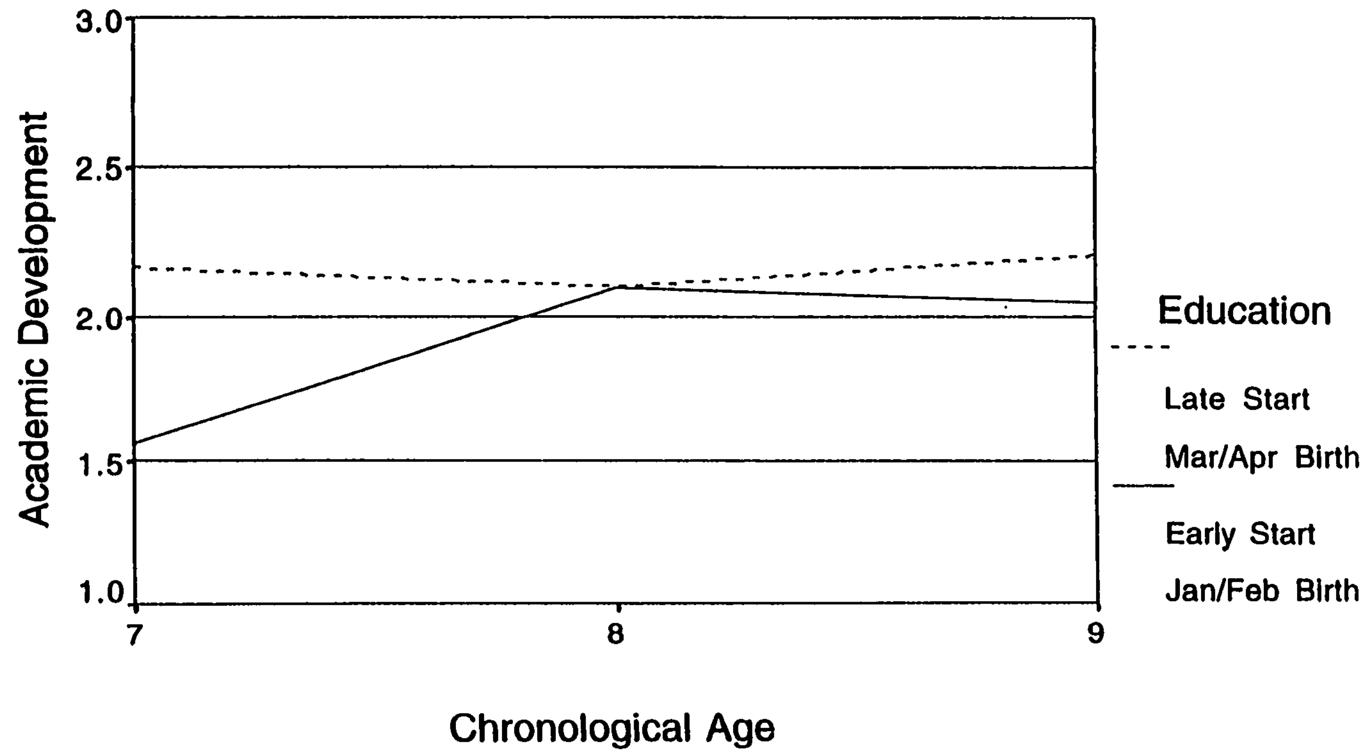


Figure 4: IQ Estimate by Age by Education

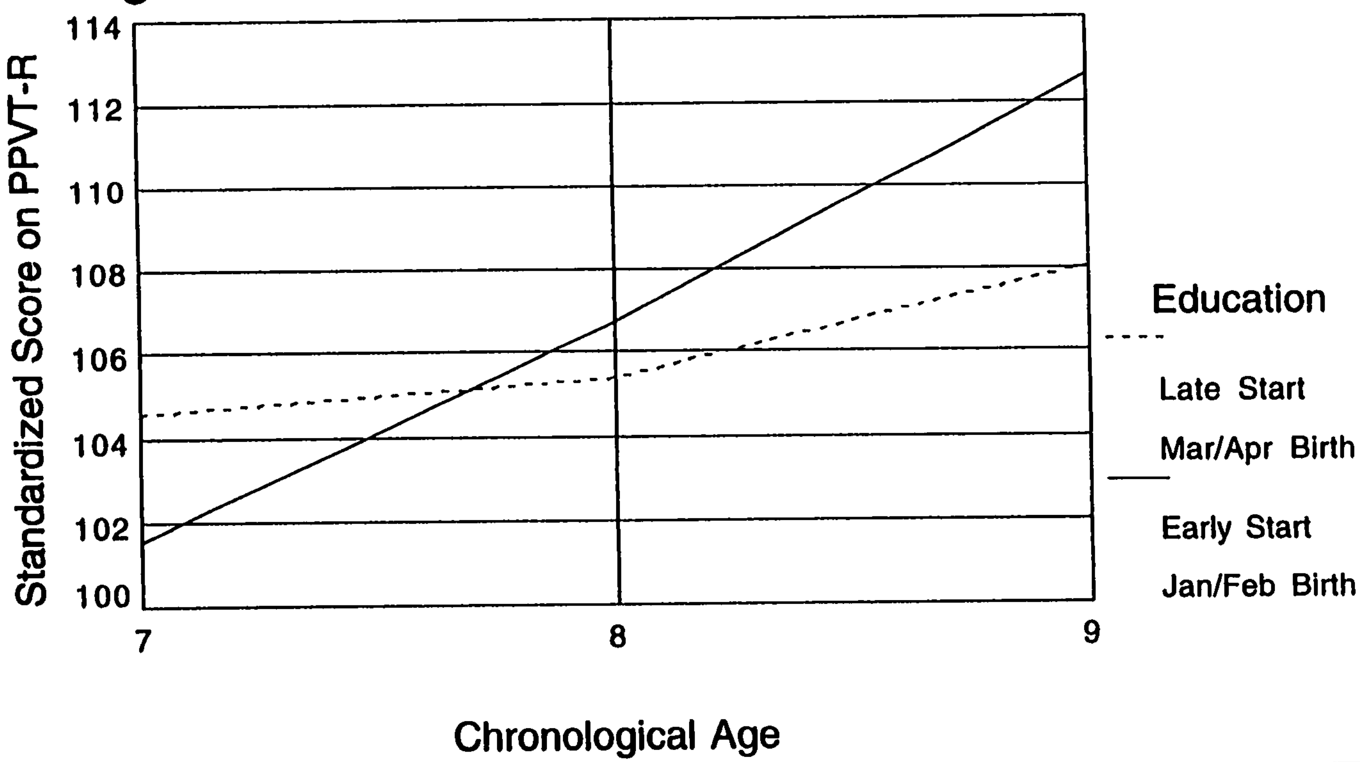
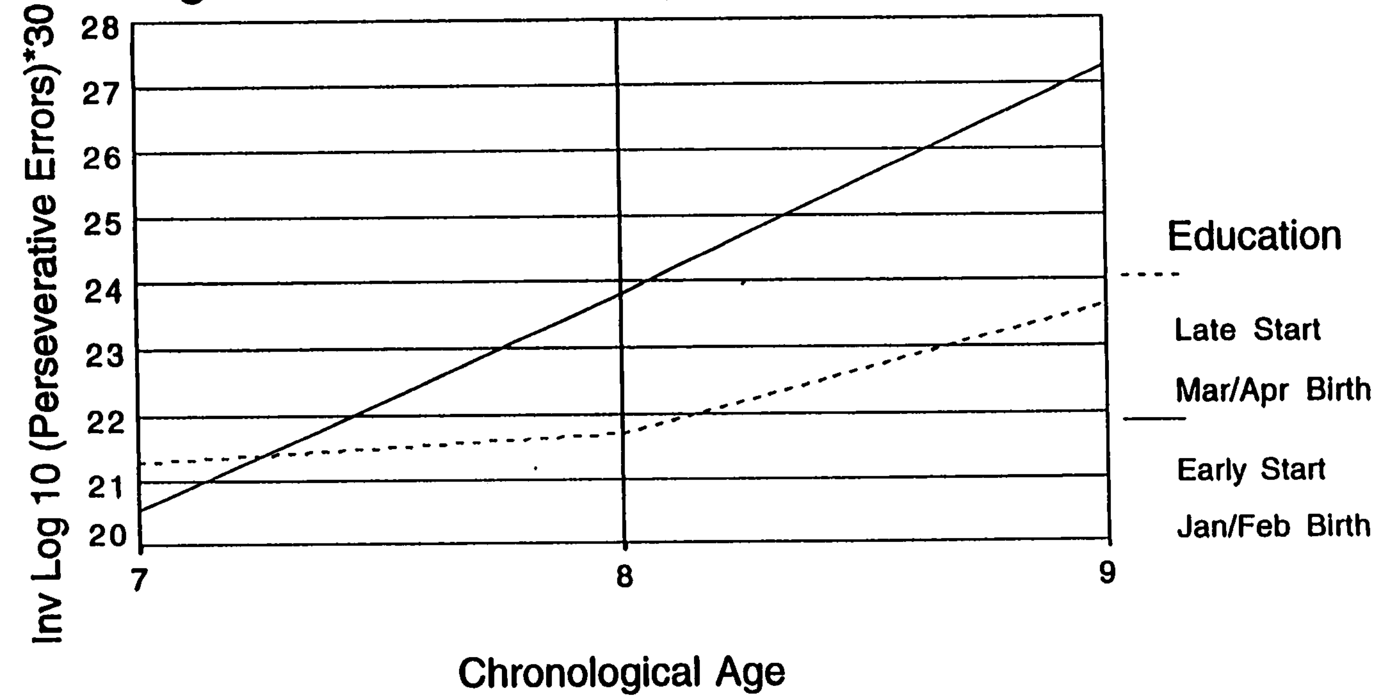


Figure 5: Card Sort by Age by Education



Increments in INLGWCST analogous to other executive measures.

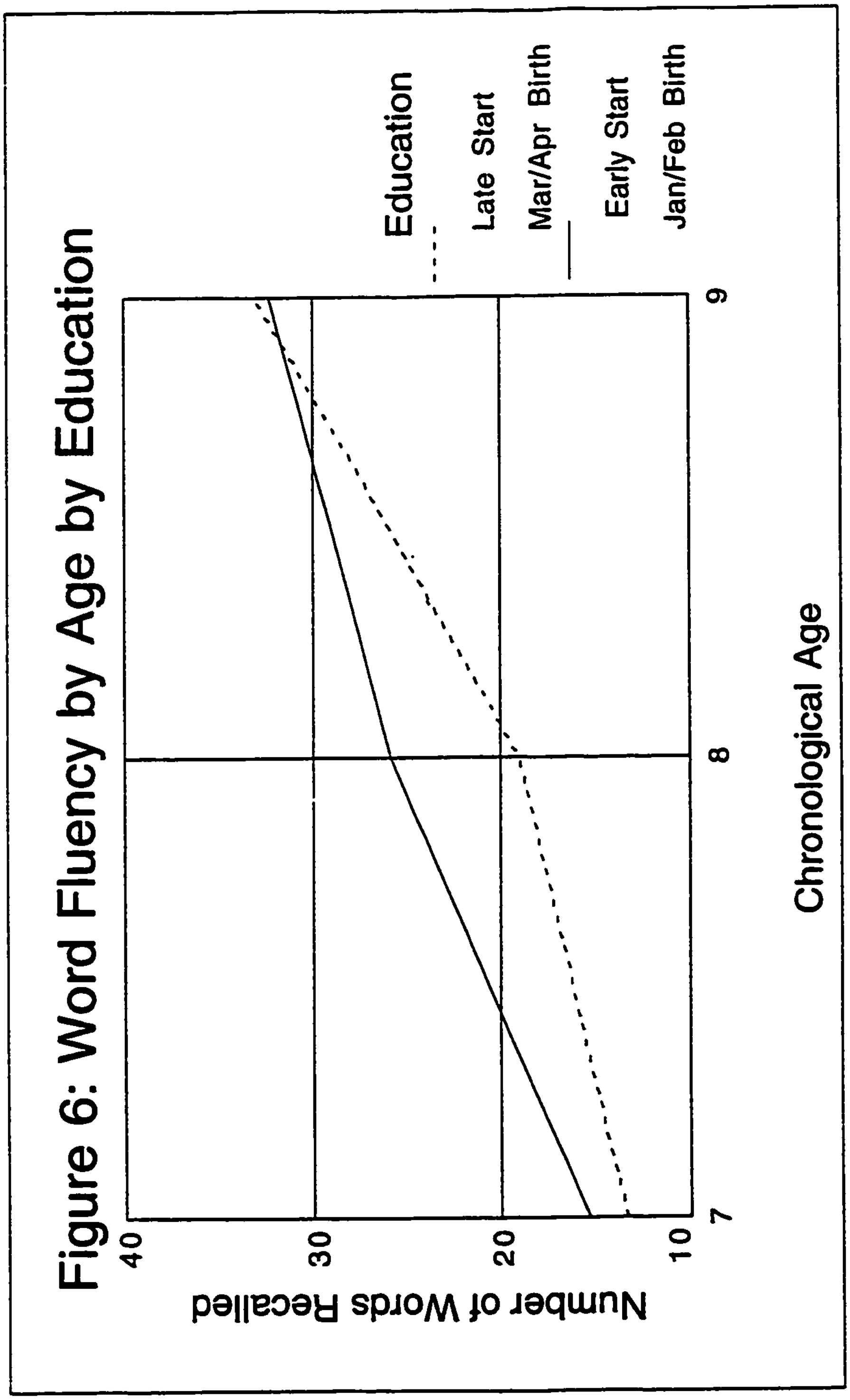
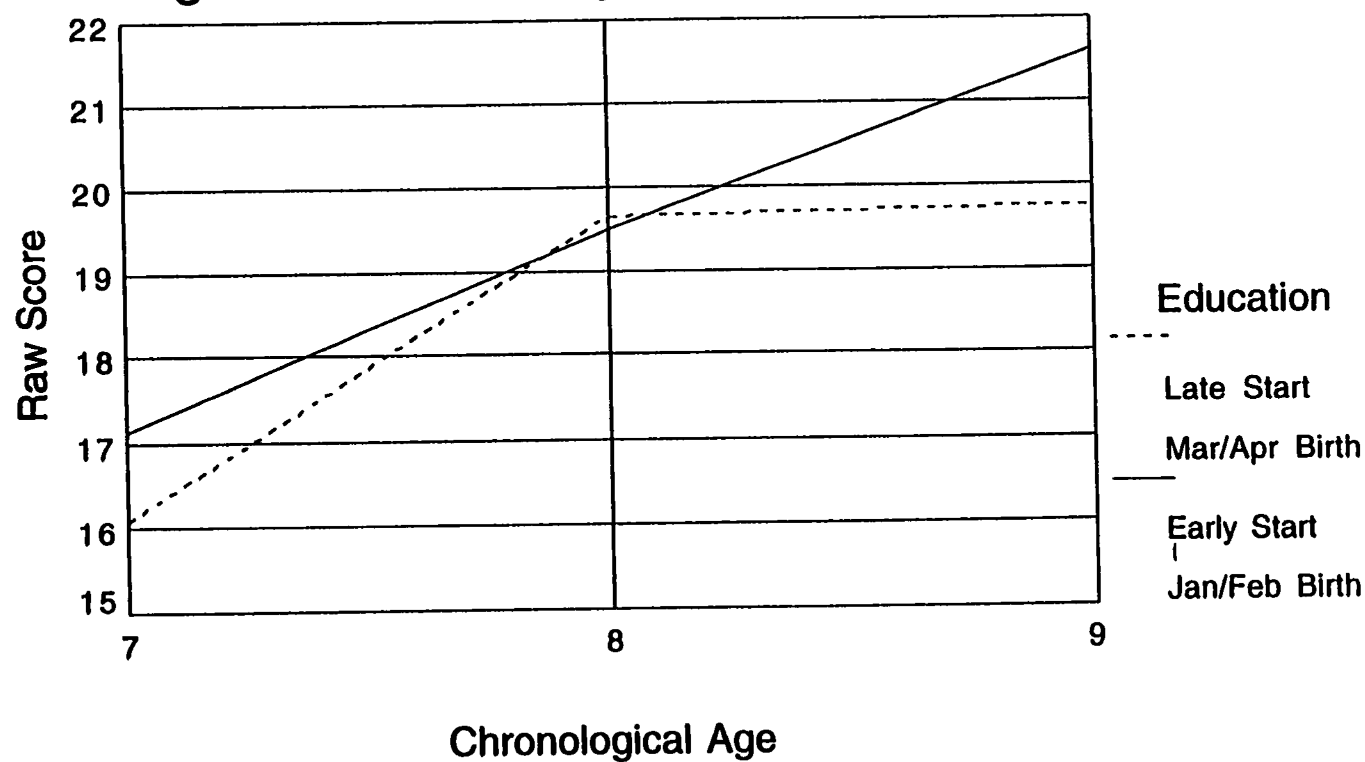


Figure 6: Word Fluency by Age by Education

Figure 7: Mazes by Age by Education



Summary

Tables 1-3 illustrate the means and standard deviations for each of the three age groups on the 6 dependent variables used in this study. Social and academic ratings were highly correlated, and social developmental ratings were noticeably negatively correlated with starting school early. Furthermore the social development of girls was rated as greater than that of boys in this age range. The executive measures were intercorrelated, except for the mazes subtest, and word fluency significantly predicted the variance in teacher ratings of academic development.

There were no effects of school type or gender, nor was there a significant difference in age between each of the three early versus late school starter comparison groups. Age and not education effects, were found on each of the executive measures, with the strongest of these effects found for the Word fluency measure. In addition, developmental discontinuities were found for each of the executive measures, with the verbal measure (e.g., Word fluency) exhibiting a delayed pattern of maturation. Finally, measures of verbal IQ exhibited an age by education interaction such that increased schooling and age led to greater IQ scores. Finally, the IQ measure and the executive measures were unrelated, except for the mazes subtest.

CHAPTER SIX

DISCUSSION

Executive Functions, Education and Age

Non-significant differences in the development of executive functions were found between early and late school starters. These results suggest that executive function development is either: (1) not accelerated by formal schooling, or that (2) elementary schooling is presently constructed in such a way that these intellectual capacities are under-utilised, or that (3) executive functioning development is more strongly influenced by a maturational timetable among elementary students. Proposition 1 is unlikely given that Das, Kar and Parrila (1997) have demonstrated that executive capacities do exhibit beneficial effects of educational opportunities. However, characteristically such beneficial educational opportunities are contextualized, mentored, are not overly rigidly structured, and provide opportunities for implementation of learned skills outside the school environment.

Proposition 2 also appears unlikely at least with regards to the population utilised in this study (e.g., first to fourth graders). Throughout the world, schooling, be it formal or informal, is orchestrated in part with the intent of inculcating culturally valued skills in children (Scribner & Cole, 1973). Typically between the ages of 3 to 9 children exhibit almost exponential vocabulary growth (Dunn, 1980), and they are well-equipped to internalise a tremendous amount of knowledge, both declarative and procedural. In this sense schooling functions in part as a cultural adaptation with which to take advantage of this period of accelerated acquisition of knowledge. Typically, and perhaps quite functionally then, the schooling experiences of first graders are far more structured than those of sixth graders.

This is not to suggest that the school experiences of students are presently constructed such that the development of executive functions are maximally facilitated. Arguably, one of the tasks of a skilled teacher is to *scaffold* the developing executive capacities (e.g., advanced volitional and reasoning abilities) of students towards productive and societally beneficial forms of behaviour. Perhaps, then the study of such late-emerging executive capacities would be more relevant to instructional psychology implemented in junior high, and high school settings.

In light of these last points the finding that formal education exhibited almost zero effects on the development of executive functions for children receiving one more year of formal education than their age-matched counterparts does suggest a significant role of neurophysiological maturation in executive function development. The physiological evidence reviewed thus far pertaining to executive function development further attests to these findings.

Despite this strong role of physiological maturation, it is puzzling that education exhibited almost no effects on executive function development in this study. Since these executive tasks share many of the same neuropsychological properties, it would be expected that any education effects on executive function development would be expected to generalise to all of the executive tasks. Indeed, Heaton et al (1993) noted marked education effects on the perseverative error scores of the WCST. Education effects have also been demonstrated on the Porteus mazes (Daigneault et al., 1988) which Lezak (1995, p. 659) recommended could be substituted with the shorter WISC-III-R Mazes Subtest. Furthermore, education effects have been found to be greatest for tests with a verbal memory component (Orsini et al, 1986; Wechsler, 1987) such as the Thurstone Word Fluency Test.

Furthermore, examinees are unlikely to experience tests which resemble these executive measures in their everyday lives, except for perhaps the Mazes Subtest. In fact, the prototypical executive task, the WCST (Lezak, 1995), is only ever administered once. These findings may suggest that perhaps more so than at any othe ·ge, the neurophysiological maturational component of the executive functions' development dwarfs that of any effect of formal schooling, at least between the first and third grades.

Finally, there were developmental trends in the development of the executive capacities. The WCST demonstrated significant improvements between the ages of 8 and 9, whereas the mazes demonstrated significant improvements between the ages of 7 and 8. The Thurstone Word Fluency Test in contrast demonstrated a progressively significantly increasing level of performance with successive ages such that asymptotic performance levels were not reached. Parrila, Das and Dash (1996) noted that by the age of 8 children should be proficient at mazes tasks and by the age of 10 they should be proficient on tasks such as the WCST. The mazes and the WCST are more non-verbal in description whereas the fluency test is unquestionably a more verbal task.

Development of more complex planning skills (e.g., and hence executive functions) may be especially prolonged and may proceed well into adolescence and perhaps beyond. The Thurstone Word Fluency Test may exemplify just such a complex planning task, indeed the average 18 year old can produce 65 words within the nine-minute writing time (Heaton, Grant & Matthews, 1986) in comparison to the average 9 year old in this study that thought of 32 words. Thus, it seems likely that late emerging and complex executive and planning capacities may be necessarily more verbal in nature.

Alternatively, in the proactive sense these findings may provide evidence in favour of more self-directed learning opportunities for children of this age group (e.g., individual projects and portfolios, discovery learning opportunities and networked learning opportunities within children's own communities) given that an extra year of education surprisingly exhibited non-significant increments in performance on executive measures. Such self-directed learning opportunities might be expected to accelerate executive function development (Das, Kar & Parrila, 1996).

Correlational Findings

Social and academic developmental ratings were significantly correlated, suggesting that teachers tend to rate children that behave well in class as more academically capable and/or vice-versa, perhaps indicative of the "halo effect". Interestingly, social developmental ratings and starting school early were significantly negatively related, suggesting that early starters' social development lagged behind that of their classmates in agreement with previous studies (Breznitz & Teltsch, 1989). Breznitz and Teltsch found that this lagging socioemotional development may increase anxiety which could in turn negatively impact academic performance.

Finally, girls were rated as more socially developed than their male counterparts, in agreement with previous investigators who have found that significantly more late-born boys as opposed to girls were referred for psychological referrals (DiPasquale, Moule & Flewelling, 1980). Whether such tendencies to refer behaviourally troubled boys more often is an artifact of different teacher baseline tolerance levels for misbehaviour among the genders is unclear (Mash & Barkley, 1996).

Word fluency was significantly related to teacher ratings of academic development, perhaps indicative of this neuropsychological measure's efficacy in tapping children's abilities to invoke a strategy to complete a task (Estes, 1974). Some cognitive psychological theorists have speculated on the role of the capacity to invoke strategies as a primary substituent of cognitive ability (Estes, 1974, Das, Naglieri & Kirby, 1994). Word fluency was significantly related to Wisconsin Card Sort scores in keeping with factor analytic studies which have found that both of these measures load together in a large neuropsychological battery of tests on an executive measure (Lezak, 1995). An unexpected finding was that the IQ Estimate and the Mazes Subtest scores were significantly related. This finding will be discussed shortly.

Executive Dysregulation and Psychopathology

Despite this study's findings that executive function development appears to occur largely as a function of age-dependent maturation (facilitated by educational opportunities, perhaps more so at later ages), there is evidence that individual differences in working memory capacity and hence executive function capacity do exist (Case, 1992). Executive deficits in children are implicated in a host of developmental psychopathologies including:

attention-deficit disorder, conduct disorder and a host of other learning disabilities (Mash & Barkley, 1996). Perhaps then future studies examining executive functioning development among children should more closely characterise the developmental trajectories of children developing differing executive function profiles.

For instance, there is ample evidence to suggest that there are innate differences in the optimal level of arousal needed by individuals (Kagan, Resnick & Snidman, 1988). Furthermore, a "match" between an individual's need for arousal and the amount of stimulation provided by an individual's environment determines in part that individual's performance (Mueller, 1992). Reduced capacity in working memory under high anxiety seems well-established, and anxiety may subsequently handicap the operation of the "central executive" (Mueller, 1992), Baddeley's (1986) precursor to the present day's executive functions. Furthermore, it is possible that individual differences in the developmental histories of individuals (e.g., trauma, neglect, abuse) could conceivably alter the functioning of the developing corticolimbic system (Bene, 1994) with long-term developmental ramifications. Indeed, Kolb (1987) postulated just such a mechanism in the long-term sequalae of post-traumatic stress symptomatology.

In a related avenue, tripartite catastrophe models of this anxiety-performance relationship have been modelled by cognitive psychologists (Hardy & Parfitt, 1991; Mueller, 1992). In this three-dimensional model the incorporation of cognitive attention, in addition to performance, and arousal, yields a special case of the violation of the U-shaped relation between anxiety and performance (Yerkes & Dodson, 1908). Catastrophic or sudden declines in performance can occur, rather than slow or gradual declines with the incorporation of cognitive arousal, since the three dimensional x-y-z co-ordinate surface may contain "folds" much like a tablecloth on a table - See Figure 8 on the next page, adapted by permission from Mueller (1992).

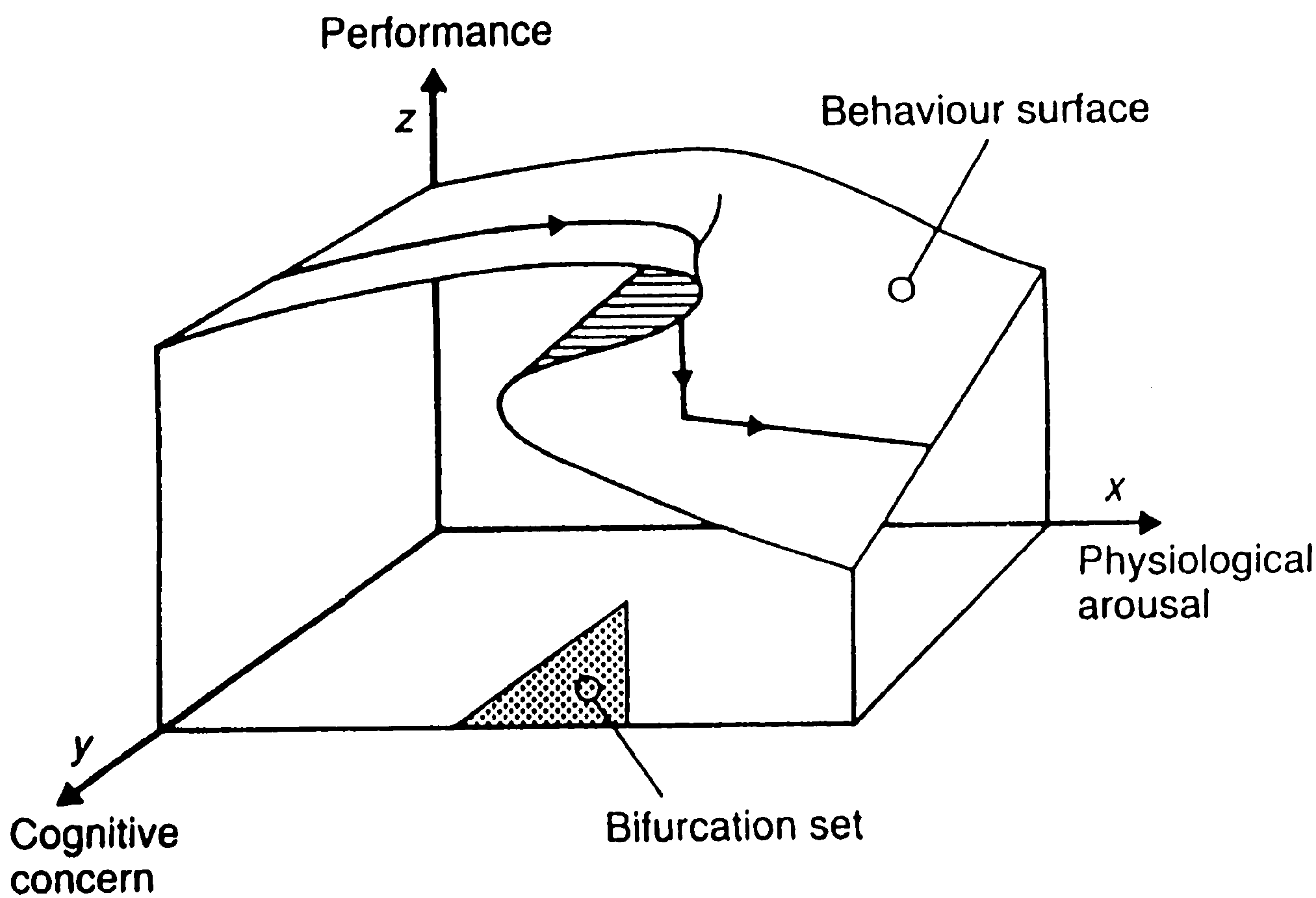


Figure 8: Catastrophe model of the relationship between performance, physiological arousal and cognitive concern

Such emergent or aggregate properties like "folds" are characteristic of complex and dynamic systems (Simon, 1992). Perhaps, a neuropsychological case could be made that the essential neural substrates of Figure 8's three components: cognitive concern [attention], performance [motor output], and arousal [limbic pathways] might reasonably consist of prefrontal, premotor and primary motor, and corticolimbic substrates, respectively. Of course the putative neural substrates of these three model components would operate in conjunction with other neocortical and subcortical areas. It is well-known that limbic and motor [performance] systems are highly integrated together within the prefrontal cortices (Lezak, 1995).

Recently, catastrophe models accommodating developmental findings of bimodal distributions of test scores at specific ages, and increased variability during cognitive transitions, have been proposed as a mechanism for qualitative discontinuities in cognitive and socioemotional development (Van der Maas & Molenaar, 1992). By way of example, such a catastrophe theory model might well provide the building blocks for models of explanation of psychopathologies such as developmentally inappropriate reasoning deficits in children. That is, the elaboration between action and mental states such as feelings and thought is hypothesised to be constrained by working memory capacity (Fischer & Rose, 1994). Such coordinations presumably allow the assembly of increasingly elaborate structures such as conflict resolution strategies. Of interest in this respect is that oppositional and conduct disordered children have been shown to demonstrate marked executive function impairment (Moffitt, 1993) as determined by neuropsychological assessment.

Oppositional and conduct disordered boys have been found to demonstrate developmentally naive reasoning in the domain of conflict resolution as compared to "normal" boys despite matching for intelligence and socio-economic status (McKeough, Yates & Marini, 1994). Furthermore, there is a clear link between such chronic anxiogenic psychosocial adversities such as financial impoverishment, crime-ridden neighbourhoods, family crowding, parental psychopathology, deviant peer groups and children's subsequent risk for the development of oppositional defiant disorder and/or conduct disorder (Hinshaw & Anderson, 1996). The question of how such pervasive societal factors might indirectly negatively impact children's capacity to reason and/or engage in prosocial behaviour, through the influence of dynamic maturational processes associated with the executive functions, should be a serious avenue of study for educational psychologists.

Executive Functions and Intelligence Theory

The executive measures were not significantly related to the verbal IQ estimate provided by the Peabody Picture Vocabulary Test. This finding is not surprising given the extensive literature pointing towards the inadequacy of IQ in characterising higher mental functions such as planning associated with the executive functions (Das, 1992; Fredericksen, 1986; Gardner, 1983; Lezak, 1988; Naglieri, 1997). However, it was found that IQ predicted a significant proportion of the variance of the Mazes Subtest. This result appears puzzling given that the Mazes Subtest is reputed to tap executive functions.

Given that the WCST and the Fluency test are both non-speeded tests, whereas since the WISC-III-R mazes was timed/speeded, the result could be interpreted in terms of a speed of processing effect. [Please note that although the Fluency test is a timed test, unlike the Mazes subtest, the former could not be considered to be a speeded test. The vast proportion of examinees competing the Fluency test had approximately one minute left, during which time they could not think of any more words. Therefore, the Fluency test would be considered a power test in Crocker and Algina's (1986, p. 145) nomenclature].

Jensen (1987) and Vernon (1987) have suggested that intelligence *is* speed of processing. Many traditional IQ measures do load on to a speed of processing factor and characteristically classical intelligence tests are timed. However, there is considerable disagreement in theoretical circles about this contention (e.g., Das, 1992), and the speed of processing hypothesis falls apart when trying to explain neuropsychological cases where processing is fast but totally uncoordinated temporally as in the case of frontal patients. For this and other reasons the speed of processing hypothesis has fallen into disrepute in recent years (Das, 1992).

Lezak's (1995, p. 659) suggestion that the WISC-III-R subtest was a good substitute for the lengthier Porteus Mazes is called into question by these results. Indeed the Porteus mazes in its original (1959) version was an untimed test, and substitution with the timed WISC-III-R mazes may tap speed of processing more than executive capacity. It is conceivable that the timing of the WISC-III-R Mazes Subtest could attenuate its executive capacity discriminating characteristics by confounding with speed of processing.

Recent evolutionary theorists have speculated that one of the essential functions of the prefrontal cortices was to form and maintain a mental representation, and to anticipate and envision future possible realities (Povinelli & Preuss, 1995). Evolutionary theory is the bedrock of modern biology and it suggests persuasive theoretical grounds to argue that general intelligence theorists such as Jensen who advocate the speed of processing imperative in intelligence are perhaps uninformed by contemporary biological theory. What if the functions of the neural architectures subserved by the prefrontal cortices are essentially long-range planning or the ability to model future scenarios?

Imagine for a moment, for thousands upon thousands of years as our ancestors battled to survive with their limited technological innovations against long winters, droughts, and/or famines. What cognitive processes would have been selected for in individuals that managed to survive under these circumstances? Clearly long-range planning would have been highly selected for. For instance, the ability to plan months in advance for a long and bitter winter at our latitude, in what is now Canada would surely meant the difference between life and death for ancestral hunter-gatherer peoples. What role then in this scenario is there for a cultural artifact of IQ test design that emphasises speed of processing as pre-eminent in intelligence? From an evolutionary epistemology this argument is moot, and unquestionably if intelligence theory is to advance, such that the plethora of recent findings within the neurosciences are to be incorporated, then intelligence theory will have to be informed by how the brain *actually does* process information and engage in decision-making processes.

The fact that the three executive functions and the IQ measure were correlated at all is interpretable in the sense that executive functions require the co-ordinated action of the entire neocortex not just the frontal lobes. Indeed, the co-ordination of percepts temporally, formed with the aid the posterior sensory processing modules and relayed via extensive longitudinal fiber tracts to the anterior motor cortex for behavioural programming, appears to be an essential function of the frontal lobes (Lezak, 1995). If a speed of processing factor-analytically derived construct does exist as advocated by Jensen and his colleagues, it would more likely be a function of the functional and structural integrity of the sensory integration capacities of the posterior cortices. Studies examining the hierarchical organisation of the human brain reviewed thus far, would not support the contention that the neural correlates of a "speed of processing" construct would occupy an utmost tier in the hierarchy of human abilities. Revealingly, in this respect, the most verbal of the executive measures, the Thurstone Word Fluency Test's variance was not significantly predicted by the verbal IQ measure which tapped receptive vocabulary.

Executive functions and classical notions of intelligence are related but the relationship is at present poorly understood. It will likely be worked out in the coming years with sophisticated functional neuroimaging studies in conjunction with multivariate statistical techniques that map complex cognition in real space-time contexts.

Limitations

There are a number of limitations to this study. Random assignment of participants is not possible with the cut-off design, and hence it is quasi-experimental in nature. With quasi-experimental designs the basis for strong inference can be made (Shauhhnessy & Zechmeister, 1994), but direct causal attributions cannot be made. Relatedly, the proportion of variance predicted by age alone, ($\underline{\Delta}$ = 10, $\underline{\Delta}$ = 45, and $\underline{\Delta}$ = 15), on the Wisconsin Card Sort, Thurstone Word Fluency and Mazes test, respectively, is indicative that a significant proportion of the variance has been unaccounted for. However, the two nominal variables of most interest, namely educational status and age were non-randomized, and therefore a large amount of extraneous variance was unavoidably introduced into the design. Finally, effect sizes within this range are deemed acceptable for educational research, where a high degree of experimental control is often not possible or ethically permissible (Glass & Hopkins, 1997, p. 303).

Given the background literature reviewed, implicating the potential role of chronic anxiety-inducing agents in dysexecutive pathology, it might be reasonably speculated that incorporation of measures of such variables (e.g., trait anxiety questionnaire) in future studies in this field might give rise to more powerful quasi-experimental designs.
In a number of instances, without solicitation, teachers noted that some children "...were the nervous type...". Anecdotally, such children demonstrated exceptionally poor performances on all of the executive measures. Indeed, recent psychometric and neuropsychological studies have demonstrated

a clear link between selective personality profiles and disorders in high-level cognitive processes such as planning (Das & Naglieri, 1997).

The age range of participants in this study was quite restrictive. Future investigators might choose to examine, pre-school, adolescent and even college-age student's performance on executive measures in a cut-off design. Incidentally, longitudinal studies are underway at Carnegie Mellon University utilising functional magnetic resonance imaging techniques to visualise the emergence of executive capacities in school-age children, in just such a cut-off design (Marcel Just, personal communication, June 1997).

The use of the three executive measures in this study were necessarily restrictive due to time constraints. Future studies should incorporate additional executive tasks, of which there are dozens (Lezak, 1995). Furthermore, the WCST has been criticised as not being specific enough in assessing frontal lobe functions because patients with diffuse brain damage also perform exceptionally poorly on this task (Reitan & Wolfson, 1994). The Thurstone Word Fluency Test has also been criticised on the grounds that it is sensitive to non-frontal lesions in addition to frontal lesions; although frontal lesions do give rise to more deficient performance (Reitan & Wolfson, 1994).

These criticisms in hand, it is important to note that one tenet of neuropsychological assessment generally is that one does not rely on one test to assess a putative neuropsychological deficit (Lezak, 1995). In addition, the functional neuroimaging studies alone, previously mentioned, indisputably demonstrate that the prefrontal cortex is preferentially activated during the performance of tasks tapping the executive functions such as the WCST. Although, individually these three tasks are far from perfect, collectively they are overall good measures of executive function (Lezak, 1995).

Educational Implications

The development of executive functions in young school age children may be largely guided by neurophysiological changes in patterns of cortical connectivity guided by the prefrontal cortices. These gross changes in cortical connectivity may be important in the emergence of fundamentally more complex neural networks enabling qualitatively distinct forms of thought. Although preliminary studies suggest that executive functions are capable of exhibiting improvement with schooling at least in older children, the effects of schooling between grades one and three may be dwarfed by the effects of age alone.

In addition, at older ages executive capacities may become necessarily more verbal in nature. Mediated learning experiences with potential applications outside the school environment which are not overly structured may be particularly beneficial to the development of executive functions (e.g., guided discovery learning). However, research on executive functions and planning capacities among educational psychologists is still in its infancy.

The developmental progression in the emergence of executive capacities among children in this study suggests that educators and parents should be wary that extra formal schooling may not compensate for starting school at a young age. The importance of executive functions to the social capacities and reasoning abilities of children (Lezak, 1995) suggests that young early school starters' parents (especially those parents of boys), might reasonably choose to delay school entrance for a year (West & Varlaam, 1990). Curiously, teacher social developmental ratings were unrelated to any of the executive measures, perhaps illustrating the primacy of the children's sociocultural milieu in determining this outcome, although, neuropsychologists have suggested the pre-eminent role of the prefrontal cortices in transducing this *psychosocial development* per se (Passingham, 1993). Evidence from the childhood frontal patients reviewed thus far strongly supports this contention.

In this study, across a wide range of student abilities, it was found that there was a timely consistency in the emergence of their executive functions irrespective of their schooling status. The importance of the executive functions to social interaction, reasoning abilities and activities of daily living cannot be overemphasised. At present, most intellectual assessment devices utilised by school psychologists do not characterise these essentially human socioemotional and cognitive processes (Das, Naglieri & Kirby, 1994; Fredericksen, 1986; Lezak, 1995). There is a need for alternative models of assessment if psycho-educational assessment is to be guided by empirical rationale(s).

Feuerstein, Feuerstein and Gross's (1997) *Learning Potential Assessment Device* (LPAD) is fundamentally different from most intellectual assessment instruments in this respect. The LPAD examines human modifiability in contrast to IQ tests which tap accumulated cultural knowledge or [unspecified] hard-wired traits, and in this respect, the LPAD carries with it a theoretical resemblance to the neuropsychologist's assessment of executive functions. Furthermore, the concept of human modifiability assessed by the LPAD is not incompatible with Guilford's (1967) divergent productions facet of intelligence, which may be analogous to certain aspects of executive functioning.

In sum, there is strong evidence, in part supported by the results of this study, that traditional conceptions of intelligence are outmoded and no longer tenable in light of recent neurobiological, neuropsychological and cognitive studies. Cognitive processing models of assessment such as dynamic assessment, aside from being of more utilitarian value to the examinee in that they easily lend themselves to the design of individually tailored instruction (Missiuna & Samuels, 1988), in all likelihood possess superior construct validity as revealed from neuroscience research insights.

The emergence of alternative models such as the LPAD, along with other cognitive processing models of ability such as the *Cognitive Assessment System* (Das & Naglieri, 1997) suggests that educational psychologists long pre-occupation with "general intelligence", along with this notion's errant causal epigenetic assumptions is fading. The question thus becomes what will psychologists replace the IQ test with...or will they? Given the imperative of assessment in psycho-educational settings, tests of cognitive ability will likely continue to be used. However, a new conception of intelligence and its substituent cognitive processes is emerging from neuroscientific insights into the functioning of the human brain, cognitive science and cross-cultural studies.

This new conception of intelligence places *problem-solving,* and not speed of processing, general intelligence, vocabulary acquisition, or even the ability to sit subservient while taking a timed test, as pre-eminent in intelligence. Cognitive science tells us that problem-solving is highly contextually determined, and is ultimately a constructivist process. This modern view of intelligence portrayed in cognitive science and systems neuroscience is fundamentally different from that view of intelligence presented in psychometric circles and currently in school psychology. Furthermore, since evidence is accumulating that intelligent behaviours are not accurately characterised by the traditional IQ, it may become increasingly difficult to make empirical justifications about allocating public resources to programs whose very existence is predicated on the viability of the Full-Scale IQ (e.g., gifted programs).

Although instruction will not likely be influenced by neuroscience research insights in the near future, psychometric assessment and the remediation of learning disabilities undoubtedly will become informed by such insights (John Bruer, personal communication, February, 1998). There are already indications that other disciplines (e.g., cognitive neuroscientists) have begun to develop sound empirically tested learning methodologies that have proven useful for the treatment of variants of dyslexia and other common learning disabilities (Wright, Buonomo, Mahnche & Merzenich, 1997). The question as to whether educational psychologists will choose to participate in the emergence of such educational applications of recent neuroscientific findings in the coming years or continue to utilise antiquated intellectual assessment devices that are almost 100 years out of date theoretically, is an open one.

Bibliography

Ackerly, S. (1937). Instinctive, emotional and mental changes following prefrontal extirpation. American Journal of Psychiatry. 92: 717-729.

American Psychiatric Association. (1994). Diagnostic and statistical manual of mental disorders (4th ed.). Washington, D.C.: Author.

Atkinson, R.C. & Shiffrin, R.M. (1968). Human memory: a propose system and its control processes. In K.W. Spence & J.T. Spence (Eds), Advances in psychology of learning and motivation (Vol. 2). Academic Press: New York.

Baddeley, A.D. (1986). Working memory. Oxford: Oxford University Press.

Barkley, R.A. (1996). Attention deficit/hyperactivity disorder. In E.J. Mash and R.A. Barkley (Eds.), Child Psychopathology. New York: The Guilford Press.

Barkley, R.A. (1997). Behavioral inhibition, sustained attention and executive function: Constructing a unifying theory of ADHD. Psychological Bulletin. 121(1): 65-94.

Baxter, L.R.. Schwartz, J.M., Phelphs, M.E., Mazziotta, J.C., Guze, B.H., Selin, C.E., Gerner, R.H. & Sumida, R.M. (1989). Reduction in prefrontal cortex glucose metabolism common to three types of depression. Archives of General Psychiatry. 46: 243-250.

Becker, M.G., Isaac, W. & Hynd, G.W. (1987). Neuropsychological development of nonverbal behaviors attributed to "frontal lobe" functioning. Developmental Neuropsychology. 3: 275-298.

Benes, F.M (1994). Development of the corticolimbic system. In G. Dawson & Fischer, K.W. (Eds.), Human behavior and the developing brain. New York: The Guilford Press.

Benton, A. (1991). Prefrontal injury and behavior in children. Developmental Neuropsychology. 7(3): 275-281.

Berg, E.A. (1948). A simple objective technique for measuring flexibility in thinking. Journal of General Psychology, 39: 15-22.

Bisanz, J., Dunn, M. & Morrison, F.J. (1995). Effects of age and schooling on the acquisition of elementary quantitative skills. Developmental Psychology. 31(2):221-236.

Bracken, B.A., Prasse, D.P. & McCallum, R.S. (1984). Peabody picture vocabulary test-revised: an appraisal and review. School Psychology Review. 13(1): 49-60.

Breznitz, Z. & Teltsch, T. (1989). The effect of school entrance age on academic achievement and social-emotional adjustment of children: follow-up study of fourth graders. Psychology in the Schools. 26: 62-68.

Bronfenbrenner, U. (1979). The ecology of human development. Cambridge, MA: Harvard University Press.

Brown, M.B. & Forsythe, A.B. (1974). The ANOVA and multiple comparisons for data with heterogeneous variances. Biometrics: 30: 719-724.

Bruer, J.T. (1997). Education and the Brain: A Bridge Too Far. Educational Researcher. 8: 4-16..

Cahan, S. & Davis, D. (1987). A between-grade levels approach to the investigation of the absolute effects of schooling on achievement. American Educational Research Journal. 24: 1-13.

Cahan, S. & Cohen, N. (1989). Age versus schooling effects on intelligence development. Child Development. 60: 1239-1249.

Case, R. (1985). Intellectual development: Birth to adulthood. New York: Academic Press.

Case, R. (1991). The mind's staircase. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Case, R. (1992). The role of the frontal lobes in the regulation of cognitive development. Brain and Cognition, 20: 51-73.

Case, R. (1993). Theories of learning and theories of development. Educational Psychologist, 28: 219-233.

Chelune, G.J. & Baer, R.A. (1986). Developmental norms for the Wisconsin Card Sorting Test. Journal of Clinical and Experimental Neuropsychology. 8: 219-228.

Chomsky, N. (1965). Aspects of theory of syntax. Cambridge, MA: M.I.T. Press.

Cohen, J.D., Perlstein, W.M., Braver, T.S., Nystrom, L.E., Noll, D.C., Jonides, J. and Smith, E.E. (1997). Temporal dynamics of brain activation during a working memory task. Nature. 386: 604-608.

Crocker, L. & Algina, J. (1986). Introduction to classical and modern test theory. Toronto: Holt, Rinehart & Winston.

Daigneault, S., Braun, C., Gilbert, B. & Proulx, R. (1988). Canonical and factorial structures of a battery of "frontal" neuropsychological measures. Journal of Clinical and Experimental Neuropsychology. 10: 58 (abstract).

Daigneault, S., Braun, C.M.J. & Whitaker, H.A. (1992). Early effects of normal aging in perseverative and nonperseverative prefrontal measures. Developmental Neuropsychology. 8: 99-114.

D'Amato, R.C., Hammons, P.F., Terminie, T.J. & Dean, R.S. (1992). Neuropsychological training in American Psychological Association-accredited and non-accredited school psychology programs. Journal of School Psychology. 30(2): 175-183.

Das, J.P. (1985). Coding, attention and planning: A cap for every head. In J.W. Berry, S.H. Irvine & E.B. Hunt (Eds.). Indigenous cognition: Functioning in cultural context. NATO ASI Series. Dordrecht, The Netherlands: Nijhoff.

Das, J.P. (1992). Beyond a unidimensional scale of merit. Intelligence. 16: 137-149.

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

Das, J.P. & Dash, U.N. (1990). Schooling, literacy and cognitive development: A study in rural India. In C.K. Leong & B.S. Randhawa (Eds.), Understanding literacy and cognition: Theory, research and application (pp.217-244). New York: Plenum Press.

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

Das, J.P., Naglieri, J.A. & Kirby, J. (1994). Assessment of Cognitive Processes: The PASS theory of intelligence. New York: Allyn & Bacon.

Das, J.P., Kar, B.C. & Parrila, R.K. (1996). Cognitive planning: the psychological basis of intelligent behaviour. Sage Publications: New Delhi.

Das, J.P. & Naglieri, J.A. (1996). Mental retardation and the assessment of cognitive processes. In J.W. Jacobsen & Murlick, J.A. (Eds). Manual of diagnosis and professional practice in mental retardation. American Psychological Association. Washington, D.C.

Das, J.P. & Naglieri, J.A. (1997). Das-Naglieri Cognitive Assessment System. Riverside Publishing Company: Chicago.

Dawson, G. & Fischer, K.W. (1994). Human behaviour and developing brain. New York: The Guilford Press.

Dehaene, S. (1996). The organization of brain activations in number comparison: Event related potentials and the additive-factors method. Journal of Cognitive Neuroscience. 8(1): 47-68.

de Jong, H.L. (1991). Intentionality and the ecological approach. Journal for the Theory of Social Behaviour. 21(1): 91-109.

Diamond, G.H. (1983). The birthdate effect: a maturational effect? Journal of Learning Disabilities, 16: 161-164.

Dias, R., Robbins, T.W. & Roberts, A.C. (1996). Dissociation in prefrontal cortex of affective and attentional shifts. Nature. 380: 69-72.

DiPasquale, G.W., Moule, A.D. & Flewelling, R.W. (1980). The birthdate effect. Journal of Learning Disabilities. 13: 4-7.

Dreher, M. & Oerter, R. (1987). Action planning competencies during adolescence and early adulthood. In S.L. Friedman, E.K. Skolnick, & R.R. Cocking (Eds.), Blueprints for thinking (pp. 321-355). New York: Cambridge University Press.

Drewe, E.A. (1974). The effect of type and area of brain lesion on Wisconsin Card Sorting Test performance. Cortex, 10: 159-170.

Dunn, L.M. (1981). Peabody Picture Vocabulary Test - Revised. Circle Pines, MN: American Guidance Service.

Eidelson, R.J. (1997). Complex adaptive systems in the behavioural and social sciences. Review of General Psychology. 1(1): 42-71.

Estes, W.K. (1974). Learning theory and intelligence. American Psychologist. 29: 740-749.

Estes, W.K. (1976). Intelligence and cognitive psychology. In L.B. Resnick (Eds.), The nature of intelligence (pp.295-305). Hillsdale, NJ: Erlbaum.

Feuerstein, R., Feuerstein, R. & Gross, S. (1997). The Learning Potential Assessment Device. New York: Guilford Press.

Fischer, K.W. (1980). A theory of cognitive development: The control and construction of hierarchies of skills. Psychological Review, 87: 477-531.

Fischer, K.W., Hand, H.H., Watson, M.W., Van Parys, M. & Tucker, J. (1984). The development of abstractions in adolescence and adulthood. In M. Commons, F.A. Richards & C. Armon (Eds.), Beyond formal operations (pp. 43-73). New York: Praeger.

Fischer, K.W. & Farrar, M.J. (1987). Generalizations about generalizations: How a theory of skill development explains both generality and specificity. International Journal of Psychology. 22: 643-677.

Fischer, K.W. & Rose, S.P. (1994). Dynamic development of coordination of components in brain and behavior: a framework for theory and research. In G. Dawson & Fischer, K.W. (Eds.), Human behavior and the developing brain. New York: The Guilford Press.

Flavell, J.H. (1963). The developmental psychology of Jean Piaget. New York: Van Nostrand Reinhold.

Flavell, J.H. (1992). Cognitive development: Past, present and future. Developmental Psychology. 28(6): 998-1005.

Fox, N.A. (1989). Psychophysiological correlates of emotional reactivity during the first year of life. Developmental Psychology. 25: 364-372.

Fredericksen, N. (1986). Toward a broader conception of human intelligence. American Psychologist, 41: 445-452.

Friedman, S.L., Klivington, K.A. & Peterson, R.W. (1986). The brain, cognition and education. Toronto: Academic Press.

Gallistel, C.R. (1989). Animal cognition: the representation of space, time and number. Annual Review of Psychology. 40: 155-189.

Gardner, H. (1983). Frames of mind: The theory of multiple intelligences. New York: Basic Books.

Gass, C.S. & Daniel, S.K. (1990). Emotional impact on Trail Making Test performance. Psychological Reports. 67: 435-438.

Glass, G. V. & Hopkins, K.D. (1996). Statistical methods in Education and Psychology - (3rd Ed.). Toronto: Allyn & Bacon.

Glover, J.A. & Ronning, R.R. (1987). Historical foundations of educational psychology (Eds.). New York: Plenum Press.

Goldman-Rakic, P.S. (1992). Working memory and the mind. Scientific American. 267(3): 111-117.

Gottlieb, G. (1991). Experiential canalization of behavioural development: Theory. Developmental Psychology. 27(1): 4-13.

Grattan, L.M. & Eslinger, P.J. (1991). Frontal lobe damage in children and adults: a comparative review. Developmental Neuropsychology. 7(3): 283-326.

Grossberg, S. (1988). Nonlinear neural networks: principles, mechanisms, and architectures. Neural Networks. 1: 17-61.

Guilford, J.P. (1967). The nature of human intelligence. New York: McGraw-Hill.

Hardy, S. & Parfitt, C. (1991). A catastrophe model of anxiety and performance. British Journal of Psychology. 82: 163-178.

Heaton, R.K., Grant, I. & Matthews, C.G. (1986). Differences in neuropsychological test performance associated with age, education and sex. In I. Grant & K.M. Adams (Eds.) Neuropsychological assessment of neuropsychiatric disorders. New York: Oxford University Press.

Heaton, R.K., Chelune, G.J., Talley, J.L., Kay, G.G. & Curtiss, G. (1993). Wisconsin Card Sorting Test Manual - Revised and Expanded. Odessa, FL: Psychological Assessment Resources.

Hebb, D.O. (1945). Man's frontal lobes: A critical review. Archives of Neurology and Psychiatry. 54: 10-24.

Hebb, D.O. (1949). The organization of behavior. New York: Wiley.

Hebb, D.O. (1951). The role of neurological ideas in psychology. Journal of Personality. 20: 39-55.

Hinshaw, S.P. & Anderson, C.A. (1996). Conduct and oppositional defiant disorders. In E.J. Mash & R.A. Barkley (Eds.). Child Psychopathology. New York: The Guilford Press.

Hirsch, E.D. (1996). The schools we need and why we dont have them. New York: Doubleday.

Hudspeth, W.J. & Pribram, K.H. (1990). Stages of brain and cognitive maturation. Journal of Educational Psychology. 82(4): 881-884.

Huttenlocher, P.R., de Courten, C., Garey, L.G. & van der Loos, H. (1982). Synaptogenesis in human visual cortex - evidence for synapse elimination during normal development. Neuroscience Letter. 33: 247-252.

Huttenlocher, P.R. (1990). Morphometric study of human cerebral cortex development. Neuropsychologia. 28: 517-527.

Huttenlocher, P.R. (1994). Synaptogenesis in human cerebral cortex. In G. Dawson & K.W. Fischer (Eds.), Human brain and developing behavior. New York: Guilford Press.

Inhelder, B. & Piaget, J. (1964). The early growth of logic in the child (G.A. Lunzer & D. Papert, Trans.). New York: Harper & Row. Original work published in 1959.

Jacobson, J.W. & Murlick, J.A. (1996). Manual of diagnosis and professional practice in mental retardation. Washington, D.C: American Psychological Association.

James S. McDonnell Foundation and The Institute of Cognitive and Decision Sciences, University of Oregon (1995). Cognitive neuroscience and education: Brain mechanisms underlying school subjects. (Videoseries Parts 1-6). Portland, OR: University of Oregon.

Jensen, A.R. (1987). Individual differences in hick paradigm. In P.A. Vernon (Eds.), Speed of processing and intelligence (pp. 101-175). Norwood, NJ: Ablex.

Johnson, M.H. (1997). Developmental Cognitive Neuroscience. Cambridge, MA: Blackwell Publishers Inc.

Jurmaine, R., Nelson, H. & Kilgore, L. (1995). Essentials of physical anthropology. West Publishing Co. St. Paul, MN.

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

Kagan, J., Resnick, J.S. & Snidman, N. (1988). Biological basis of childhood shyness. Science. 240: 167-171.

Kalk, J.M. (1982). A closer look at school cutoff dates and achievement. Denver, CO: National Assessment of Educational Progress.

Kolb, L.C. (1987). A neuropsychological hypothesis explaining post-traumatic stress disorders. American Journal of Psychiatry. 144: 989-995.

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

Lachman, R., Lachman, J. & Butterfield, E. (1979). Cognitive psychology and information processing: An introduction. Hillsdale, NJ: Erlbaum.

Levin, H.S., Culhane, K.A., Hartman, J., Evankovich, K., Mattson, A.J., Harward, H., Ringholz, G., Ewing-Cobbs, L. & Fletcher, J.M. (1991). Developmental changes in performance on tests of purported frontal lobe functioning. Developmental Neuropsychology. 6: 377-395.

Lewkowicz, D.J. (1996). Infant's response to the audible and visible properties of the human face. I. Role of lexical-syntactic content, temporal synchrony, gender and manner of speech. Developmental Psychology. 32(2): 347-366.

Lezak, M.D. (1988). IQ: RIP. Journal of Clinical and Experimental Neuropsychology. 10: 111-123.

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

Lou, H.C., Henriksen, L. & Bruhn, P. (1984). Focal cerebral hypoperfusion in children with dysphasia and/or attention deficit disorder. Archives of Neurology. 41: 825-829.

Lou, H.C., Henriksen, L., Bruhn, P., Borner, H. & Nielsen, J.B. (1989).Striatal dysfunction in attention deficit and hyperkinetic disorder. Archives of Neurology. 46: 48-52.

Luria, A.R. (1973). The working brain: An introduction to neuropsychology. Basic Books: New York.

Lyon, G.R. (1995). Learning disabilities. In E.J. Mash & R.A. Barkley (Eds.). Child Psychopathology. New York: The Guilford Press.

Maddux, C.D. (1980). First-grade entry age in a sample of children labelled learning disabled. Learning Disability Quarterly, 3: 79-83.

Maddux, C.D., Stacy, D. & Scott, M. (1981). School entry age in a group of gifted children. Gifted Child Quarterly, 25: 180-184.

Marvin, R.S., Greenberg, M.T. & Mossler, D.G. (1976). The early development of conceptual perspective taking: Distinguishing among multiple perspectives. Child Development. 47: 511-514.

Mash, E.J. & Barkley, R.A. (1996). Child psychopathology. New York: Guilford Press.

Matousek, M. & Peterson, I. (1973). Frequency analysis of the EEG in normal children and adults. In P. Kellaway & I. Petersen, (Eds.), Automation of clinical encephalography (pp. 75-102). New York: Raven Press.

Mattes, J.A. (1980). The role of frontal lobe dysfunction in childhood hyperkinesis. Comprehensive Psychiatry. 21: 358-369.

McCall, R.B. (1990). The neuroscience of education: more research is needed before application. Journal of Educational Psychology. 82(4): 885-888.

Mayer, R.E. (1997). Multimedia learning: Are we asking the right questions? Educational Psychologist. 32(1): 1-19.

McCormick, C.B. & Pressley, M. (1997). Educational Psychology: Learning, instruction and assessment. Don Mills, ON: Addison Wesley Longman Inc.

McCrea, S., Mueller, J. & Pajurkova, E. (1997). A cross-sectional cut-off design study of the development of executive functions in young children. (VII Annual Meeting of the Canadian Society for Brain, Behaviour and Cognitive Science: University of Manitoba. Winnipeg, Manitoba).

McCrea, S., Wishart, T., Miyashita, H., Ijaz, S., Howlett, W. & Shuaib, A. (1997a). Attenuated glutamate release during ischemia in ethanol-administered gerbils. Neuroreport. 8(15): 3385-3388.

McKeough, A. (1992). Testing for the presence of a central conceptual structure: Use of the transfer paradigm. In R. Case Ed.), The mind's staircase: Stages in the development of human intelligence (pp. 207-225). Hillsdale, NJ: Erlbaum.

McKeough, A., Yates, T. & Marini, A. (1994). Intentional reasoning: a developmental study of behaviorally aggressive and normal boys. Development and Psychopathology. 6(2): 285-304.

Milner, B. (1963). Effects of different brain lesions on card sorting. Archives of Neurology, 9: 90-100.

Milner, B. (1964). Some effects of frontal lobectomy in man. In J.M. Warren & K. Akert (Eds.) The Frontal Granular Cortex and Behavior. New York: McGraw Hill.

Milner, B. (1975). Psychological aspects of focal epilepsy and its neurological management. In D.P. Purpura, J.K. Penry & R.D. Walter (Eds.), Advances in Neurology (Vol. 8). New York: Raven Press.

Missiuna, C. & Samuels, M. (1988). Dynamic assessment: review and critique. Special services in the schools. 5(1-2): 1-22.

Moffitt, T.E. (1993). The neuropsychology of conduct disorder. Special issue: Towards a developmental perspective on conduct disorder. Development and Psychopathology. 5(1-2): 135-151.

Morrison, F.J., Smith, L. & Dow-Ehrensberger, M. (1995). Education and cognitive development: a natural experiment. Developmental Psychology. 31(5): 789-799.

Mueller, J.H. (1992). Anxiety and performance. In A.P. Smith & D.M. Jones (Eds.). Handbook of human performance Vol 3: State and Trait. Academic Press: London, UK.

Naglieri, J.A. (1997). IQ: Knowns and unknowns, hits and misses. American Psychologist. 52(1): 75-76.

Nelson, H.E. (1976). A modified card sorting test sensitive to frontal lobe deficits. Cortex, 12: 313-324.

Orsini, A., Chiacchio, L. & Cinque, M. (1986). Effects of age, education and sex on two tests of immediate memory: A study of normal subjects from 20-99 years of age. Perceptual and Motor Skills. 63: 727-732.

Paivio, A. (1986). Mental representations: a dual coding approach. New York: Oxford University Press.

Parrila, R.K., Das, J.P. & Dash, U.N. (1996). Development of planning and its relation to other cognitive processes. Journal of Applied Developmental Psychology. 17(4): 597-624.

Papez, J.W. (1937). A proposed mechanism of emotion. Archives of Neurology and Psychiatry. 38: 725-743.

Passingham, R.E. (1993). The frontal lobes and voluntary action. Oxford: Oxford University Press.

Passler, M.A., Isaac, W., Hynd, G.W. (1985). Neuropsychological development of behaviors attributed to frontal lobe functioning in children. Developmental Neuropsychology. 1: 349-370.

Pendleton, M.G., Heaton, R.K., Lehman, R.A.W. & Hulihan, D. (1982). Diagnostic utility of the Thurstone Word Fluency Test in neuropsychological evaluations. Journal of Clinical Neuropsychology. 4: 307-318.

Pennington, B.F. & Ozonoff, S. (1996). Executive functions and developmental psychopathology. Journal of Child Psychology and Psychiatry. 37(1): 51-87.

Piaget, J. (1971). Biology and knowledge. (B. Walsh, Trans.). Chicago: University of Chicago Press.(Original work published 1967).

Porteus, S.D. (1965). Porteus Maze Test. Fifty years' application. New York: The Psychological Corporation.

Posner, M.I. & Petersen, S.E. (1990). The attention system of the human brain. Annual Review of Neuroscience. 13: 25-42.

Povinelli, D.J. & Preuss, T.M. (1995). Theory of mind: Evolutionary history of a cognitive specialization. Trends in Neurosciences. 18(9): 418-424.

Reitan, R.M. & Wolfson, D. (1994). A selective and critical review of neuropsychological deficits and the frontal lobes. Neuropsychology Review. 4(3): 161-198.

Richards, L. & Chiarello, C. (1997). Activation without selection: parallel right hemisphere roles in language and intentional movement? Brain and Language. 57(1): 151-178.

Robinson, A.L., Heaton, R.K., Lehman, R.A. & Stilson, D. (1980). The utility of the Wisconsin Card Sorting test in detecting and localizing frontal lobe lesions. Journal of Consulting and Clinical Psychology. 48: 605-614.

Rogoff, B. (1981). Schooling and the development of cognitive skills. In H.C. Triandis & A. Heron, (Eds.). Handbook of cross-cultural psychology: Vol. 4. Developmental Psychology. (pp. 233-294). Boston: Allyn & Bacon.

Rogoff, B. (1990). Apprenticeship in thinking: Cognitive development in social context. New York: Oxford University Press.

Sattler, J.M. (1988). Assessment of children (3rd Ed). San Diego: Jerome Sattler.

Schliecker, E., White, D.R. & Jacobs, F. (1991). The role of day care quality in the prediction of children's vocabulary. Canadian Journal of Behavioural Science. 23(1): 12-24.

Scribner, S. & Cole, M. (1973). Cognitive consequences of formal and informal education. Science. 182: 553-559.

Segalowitz, S.J., Unsal, A. & Dywan, J. (1992). CNV evidence for the distinctiveness of frontal and posterior neural processes in a traumatic brain-injured population. Journal of Clinical and Experimental Neuropsychology. 14: 545-565.

Selman, R.L. & Schultz, L.H. (1990). Making a friend in youth. Chicago: University of Chicago Press.

Shallice, T. (1988). From neuropsychology to mental structure. New York: Cambridge University Press.

Shaughnessy, J.J. & Zechmeister, E.B. (1994). Research methods in psychology - (3rd Ed). Toronto: McGraw-Hill Inc.

Simon, H.A. (1981). Studying human intelligence by creating artificial intelligence. American Scientist. 69: 300-309.

Simon, H.A. (1992). What is an "explanation" of behavior? Psychological Science. 3(3): 150-161.

Spelke, E.S. (1988). Where perceiving ends and thinking begins: The apprehension of objects in infancy. In A. Yonas (Ed.), Perceptual development in infancy: Minnesota Symposia on Child Psychology (Vol. 20, pp. 197-234). Hillsdale, NJ: Erlbaum.

Tanon, F. (1991). The influences of formal versus informal education on planning skills: A cultural perspective. In J.D. Sinnott & J.C. Cavanaugh (Eds), Bridging paradigms (pp. 221-235). New York: Praeger.

Thatcher, R.W., Walker, R.A. & Guidice, S. (1987). Human cerebral hemispheres develop at different rates and ages. Science. 236: 1110-1113.

Thatcher, R.W. (1991). Maturation of the human frontal lobes: Physiological evidence for staging. Developmental Neuropsychology. 7: 397-419.

Thatcher, R.W. (1992). Cyclic cortical reorganization during early childhood. Brain and Cognition. 20: 24-50.

Thatcher, R.W. (1994). Cyclic cortical reorganization: Origins of human cognitive development. In G. Dawson & K.W. Fischer (Eds.). Human behavior and the developing brain. New York: The Guilford Press.

Thurstone, L.L. (1938). Primary mental abilities. Chicago: University of Chicago Press.

Thurstone, L.L. & Thurstone, T.G. (1962). Primary Mental Abilities (Rev.). Chicago: Science Research Associates.

Van der Maas, H.L. & Molenaar, P.C. (1992). Stagewise cognitive development: an application of catastrophe theory. Psychological Review. 99(3): 395-417.

Vernon, P.A. (1987). Speed of information-processing and intelligence. Norwood, NJ: Ablex.

Vilkki, J. (1984). Problem solving deficits after focal cerebral lesions. Cortex. 24: 119-127.

Vygotsky, L.S. (1978). Mind in society: The development of higher psychological processes (M. Cole, V. John-Steiner, S. Scribner & E. Souberman, Eds.). Cambridge, MA: Harvard University Press.

Wechsler, D. (1987). The Wechsler Memory Scale-Revised manual.San Antonio, TX: The Psychological Corporation.

Wechsler, D. (1991). Wechsler Intelligence Scale for Children (3rd Ed.). San Antonio, TX: The Psychological Corporation.

Weinberger, D.R., Berman, K.F., & Zec, R.F. (1986). Physiological dysfunction of dorsolateral prefrontal cortex in schizophrenia: I. Regional cerebral blood flow (rCBF) evidence. Archives of General Psychiatry. 43: 114-124.

Weinberger, D.R., Berman, K.F. & Illowsky, B.P. (1988). Physiological dysfunction of dorsolateral prefrontal cortex in schizophrenia: III. A new cohort and evidence for a monoaminergic mechanism. Archives of General Psychiatry. 45: 609-615.

Welsh, M.C. & Pennington, B.F. (1988). Assessing frontal lobe functioning in children: Views from developmental psychology. Developmental Psychology, 4: 199-230.

Welsh, M.C., Pennington, B.F. & Grossier, D.B. (1991). A normative-developmental study of executive function. Developmental Neuropsychology. 7: 131-149.

Wertsch, J.W. & Tulviste, P. (1994). Lev Semyonovich Vygotsky and contemporary developmental psychology. Developmental Psychology. 28: 548-557.

West, A. & Varlaam, A. (1990). 'Does it matter when children start school?' Educational Research. 32(3): 10-21.

White House Conference on Early Learning and the Brain. (1997). As quoted in "Neuroscience Newsletter". July/August 1997. Washington, DC: Society for Neuroscience.

Wittrock, M.C. (1985). Education and recent neuropsychological and cognitive research. In D.F. Benson & E. Zaidel (Eds.) The Dual Brain. New York: The Guilford Press.

Wittrock, M.C. (1991). Relations among educational research and neural and cognitive sciences. Learning and Individual Differences. 3(4): 257-263.

Wolhwill, J.F. (1973). The study of behavioral development. New York: Academic Press.

Wright, B.A., Buonomono, D.V., Mahnche, H.W. & Merzenich, M.M. (1997). Learning and generalization of auditory temporal interval discrimination in humans. Journal of Neuroscience. 17(10): 3956-3963.

Yakovlev, P.I. & Lecours, A.R. (1967). The myelogenetic cycles of regional maturation of the brain. In A. Minkowski (Ed.), Regional development of the brain in early life (pp. 3-64). Oxford: Blackwell.

Yerkes, R.M. & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative Neurology and Psychology. 18: 459-482.

Zametkin, A.J., Nordahl, T.E., Gross, M., King, A.C., Semple, W.E., Rumsey, J., Hamburger, S. & Cohen, R.M. (1990). Cerebral glucose metabolism in adults with hyperactivity of childhood onset. New England Journal of Medicine. 323: 1361-1366.

Zangwill, O.L. (1966). Psychological deficits associated with frontal lobe lesions. International Journal of Neurology. 5: 395-400.

APPENDIX A

Letter Of Information to Parents

For Parents of children born in the following months and years:

Jan/Feb of 1990, 1989, 1988 in grades 2, 3 and 4 respectively, or

Mar/Apr of 1990, 1989, 1988 in grades 1, 2 and 3 respectively.

Simon McCrea (Graduate Student)
Dept of Educational Psychology
University of Calgary
Calgary, Alberta T2N 1N4

(School's Name)
(School's Address)

Dear Parent(s)/Guardian(s):

I am a graduate student in the Department of Educational Psychology at the University of Calgary. I am conducting a research project under the dual supervision of Dr. John Mueller (Professor of Educational Psychology, University of Calgary) and Dr. Eva Pajurkova (Clinical Neuropsychologist, Foothills Hospital) as part of the requirements for a Master of Science degree.

I am writing to provide information regarding my research project "Development of Executive Functions in Children" so that you can make an informed decision regarding your child's participation.

The ethics review committee of the Faculty of Education, University of Calgary as well as the Calgary Public School Board Research Project Review Committee has given ethics approval for this research protocol to proceed.

Parents are familiar with the differences in the rates at which children develop emotionally, intellectually and socially. Differences in individual student's rate of developmental progression have implications for educational matters such as the appropriate time at which students should start school as well as the structure of curriculum content.

The purpose of the study is thus to examine the impact that maturation has on children's cognitive development. Executive functions will be assessed indirectly with three tasks: a "game-like" card-sorting task, the Wisconsin Card Sorting Test; a "maze-like" test; as well as a measure of verbal fluency. The Peabody Picture Vocabulary Test will be administered to provide the investigator with a measure of intellectual development. The four tests will take approximately 1 hour to administer.

You should be aware that even if you give your permission, your child is free to withdraw at any time for any reason without penalty. **Furthermore, participation in this study will involve no greater risks than those ordinarily experienced in daily life.**

Data will be gathered in such a way as to ensure anonymity. Once collected, responses will be kept in strictest confidence and only group results will be reported in any published studies. The raw data will be kept in a locked filing cabinet in the researchers office in the Education Tower at the University of Calgary. The data will only be accessible to the researcher and will be destroyed after two years.

If you have any questions, please feel free to contact me at 289-1564 (home) or 220-5728 (office); my supervisor(s) Dr. John Mueller at 220-5664 and Dr. Eva Pajurkova at 670-4786; the Office of the Chair, Faculty of Joint Education Ethics Committee at 220-5626, or the Office of the Vice-President (Research) at 220-3381. Two copies of the consent form are provided. Please return one signed copy to your child's school by ________________ and retain the other copy for your records.

Thank-you very much for your cooperation.

Sincerely,

Simon McCrea

(Principal Investigator)

APPENDIX B

CONSENT FOR RESEARCH PARTICIPATION

I/We, the undersigned, hereby give my/our consent for ________________________ to participate in a research entitled: "Development of Executive Functions in Children?".

I/We, understand that such consent means that ________________________ will perform the Wisconsin Card Sorting Test, WISC-III mazes subtest, a measure of verbal fluency and Picture Peabody Vocabulary Test which should take about one hour maximum to administer.

I/We understand that participation in this study may be terminated at any time by my/our request, or of the investigators. Participation in this project and/or withdrawal from this project will not affect my/our request or receipt of other services from the school board or the university.

I/We understand that this study will not involve any greater risks than those ordinarily occurring in daily life.

I/We understand that the responses will be obtained anonymously and kept in strictest confidence.

I/We understand that only group data will be reported in any published reports.

I/We understand that all raw data will be kept in locked file cabinets and destroyed two years after publication of study results.

I/We have been given a copy of this consent form for my (our) records. I/We understand that if at any time I have questions, I/We can contact the researcher at 289-1564 (Home) or 220-5728 (Office), my supervisor(s), Dr. John Mueller at 220-5664 or Dr. Eva Pajurkova at 670-4786, the Office of the Chair, Faculty of Education Joint Ethics Committee, at 220-5626, or the Office of the Vice-President (Research) at 220-3381.

______________________	______________________
Signature Parent/Guardian	Signature Parent/Guardian
______________________	______________________
Date	Date

IMAGE EVALUATION
TEST TARGET (QA-3)

150mm

6"

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989