Predicting Performance on Fluid Intelligence from Speed of Processing, Working Memory, and Controlled Attention

By

Adote Anum

A thesis

Submitted in partial fulfillment

of the requirements for the degree

Doctor of Philosophy

Department of Psychology

BROCK UNIVERSITY

St. Catharines, Ontario

October 2006

ABSTRACT

Fluid intelligence has been defined as an innate ability to reason which is measured commonly by the Raven's Progressive Matrices (RPM). Individual differences in fluid intelligence are currently explained by the Cascade model (Fry & Hale, 1996) and the Controlled Attention hypothesis (Engle, Kane, & Tuholski, 1999; Kane & Engle, 2002). The first theory is based on a complex relation among age, speed, and working memory which is described as a Cascade. The alternative to this theory, the Controlled Attention hypothesis, is based on the proposition that it is the executive attention component of working memory that explains performance on fluid intelligence tests.

The first goal of this study was to examine whether the Cascade model is consistent within the visuo-spatial and verbal-numerical modalities. The second goal was to examine whether the executive attention component of working memory accounts for the relation between working memory and fluid intelligence.

Two hundred and six undergraduate students between the ages of 18 and 28 completed a battery of cognitive tests selected to measure processing speed, working memory, and controlled attention which were selected from two cognitive modalities, verbal-numerical and visuo-spatial. These were used to predict performance on two standard measures of fluid intelligence: the Raven's Progressive Matrices (RPM) and the Shipley Institute of Living Scales (SILS) subtests. Multiple regression and Structural Equation Modeling (SEM) were used to test the Cascade model and to determine the independent and joint effects of controlled attention and working memory on general fluid intelligence.

Among the processing speed measures only spatial scan was related to the RPM. No other significant relations were observed between processing speed and fluid intelligence. As

a construct, working memory was related to the fluid intelligence tests. Consistent with the predictions for the RPM there was support for the Cascade model within the visuo-spatial modality but not within the verbal-numerical modality. There was no support for the Cascade model with respect to the SILS tests. SEM revealed that there was a direct path between controlled attention and RPM and between working memory and RPM. However, a significant path between set switching and RPM explained the relation between controlled attention and RPM. The prediction that controlled attention mediated the relation between working memory and RPM was therefore not supported.

The findings support the view that the Cascade model may not adequately explain individual differences in fluid intelligence and this may be due to the differential relations observed between working memory and fluid intelligence across different modalities. The findings also show that working memory is not a domain-general construct and as a result its relation with fluid intelligence may be dependent on the nature of the working memory modality.

ACKNOWLEDGEMENTS

I am indebted to many people who have provided me with various support throughout my time spent in school and especially in my graduate programme at Brock University. I would first like to thank Dr. Sidney Segalowitz, my advisor for giving me the opportunity to pursue a PhD at Brock. I have learnt critical thinking is the beginning of knowledge acquisition. He has taught me to appreciate learning and to understand that achieving excellence is a life-long process. I owe the completion of this part of my academic achievement to him. I am completely indebted to him.

I would also like to thank my committee members, Dr. Jane Dywan and Dr. Karen Arnell for their time and help at different stages of the thesis. I would also like to acknowledge the support of Dr. Nancy Decourville and Mike Busseri for their help with the analysis.

I have had different types of support from different people at Brock. I would like to mention the following people: John Kaethler, Geeta Powell, Frank Ohemeng, Richard Kennedy, Kelly Campbell, Danielle Molnar, Dr. Drew Dane, Mr. Bill Hemelczi, Dr. M. Ashton, Dr. Dawn Good, Dr. John Walker, and Dr. Kojo Saffu. I would also like to mention Mr. James Desjardin and other members of the Brock Neuropsychology lab.

My family has been a great source of strength and inspiration. My wife, Jackie has worked very hard night and day to support my two kids and me and never complained even when all the long hours at work had adverse effect on her health. I would also like to thank our two children, Julian and Naa-Aku who wanted to know when I would be finished with school "so I can get a real job". Finally, I would like to thank my family, especially my parents for their prayers and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviations	Description
MEN_ROT	Mental rotation
MSKILL	Motor Speed
NUM_SCAN	Number scan
LET_SCAN	Letter scan
LET_WM 1	Letter working memory (1-back)
LET_WM 2	Letter working memory (2-back)
NUM_WM 1	Number working memory (1-back)
NUM_WM 2	Number working memory (2-back)
SEM	Structural Equation Modeling
SET_SWIT 1	Set switching measures (50% targets)
SET_SWIT 2	Set switching measures (20% targets)
Ship_Verb	Shipley verbal test
Ship_Abs	Shipley abstract test
SILS	Shipley Institute of Living Scales
SPAT_SCAN	Spatial scan
SPAT_WM	Spatial working memory measures
STROOP_CON 1	Stroop Congruent (25% targets)
STROOP_CON 2	Stroop Congruent (50% targets)
STROOP_INC 1	Stroop Incongruent (25% targets)
STROOP_INC 2	Stroop Incongruent (50% targets)
Road Map	Road map
RPM	Raven's Progressive Matrices
VIS_SCAN	Visual Scan
VIS_SCAN_CO	Coloured visual scan

INTRODUCTION

The conceptualisation and measurement of intelligence is one of the most controversial topics in psychology. Over time, psychologists have agreed to disagree on the nature of intelligence and have focused more on its measurement, as well as the different forms in which intelligence can be conceptualised. More recently, the debate on intelligence has also included an attempt to understand the cognitive processes that are involved in task performance.

There are several definitions of intelligence and no one definition has been universally accepted. However, for our purposes intelligence can be conceptually defined as the ability to operate effectively within one's environment. Although this definition is vague in many respects, it seems to be the main focus in most definitions, as in David Wechsler's definition in which he defines intelligence as "the aggregate or global capacity of the individual to act purposefully, to think rationally and deal effectively with his environment" (Wechsler, 1974; pp. 32). This definition seems to encompass a very general view of what intelligence is. However, for scientific investigation it has been useful for psychologists to divide intelligence into two broad terms – general and specific mental abilities.

In 1904, Spearman used factor analysis to show that the positive correlations among a variety of mental tests resulted from a one common underlying factor, which led him to conclude that intelligence could be best be conceptualized as two separate levels for individual differences in scores on mental tests. He called the first factor general intelligence or the general factor, represented as *'g'*. According to Spearman, *'g'* underlies all intellectual tasks and mental abilities. Spearman postulated the '*g*' factor to explain correlations he found to exist among diverse tests of perceiving, reasoning, and thinking. The second factor was the specific factor, or *s*. The specific factor related to whatever unique abilities a particular test required, so it differed from test to test. There has been little emphasis on the ability-specific factors identified by Spearman. Spearman concluded that the degree of correlation between any two tests depended on the amount of general factor operating in each. This correlation is said to be very high in test materials used to assess word meanings, arithmetical reasoning, sentence completion, reasoning by analogy and perception of relationships in geometric forms and picture completion (Gottfredson, 1997; Johnson, Bouchard, Krueger, Mcgue, & Gottesman, 2004).

In 1938, Louis Thurstone also examined the relation among several tests and concluded that most mental or cognitive abilities loaded onto not one but onto several mental abilities, which he labelled Primary Mental Abilities. This finding contrasted with Spearman's conceptualisation that a single factor '*g*' underlies all mental abilities. Despite Thurstone's findings, the notion of a general factor of intelligence is still widely accepted and used to classify test takers for several purposes (e.g., Jensen, 1987, 1998). As a construct, *g* has been used as an index of intelligence and general mental ability that is predictive of multiple skills and abilities (Jensen, 1987; Vernon, 1989). It is interpreted as explaining the individual differences in performance on diverse mental tests. According to proponents of '*g*', this is true regardless of what specific ability a test is intended to measure or the contents of the test. In essence, a test may have verbal, numerical or spatial content and yet still be a good measure of general intelligence.

Fluid and Crystallized Intelligence

General intelligence was classified into fluid and crystallised intelligence by Raymond Cattell and John Horn. Fluid intelligence refers to cognitive functions associated with general reasoning ability and is said to reflect Spearman's general intelligence. Fluid intelligence is commonly referred to as native intelligence because it is assumed to be part of the human intellect that is not learned or influenced by culture and education. It is thought by many to be innate or tied to the general function of the nervous system (Belsky, 1990). In contrast, crystallized intelligence refers to intelligence acquired through the accumulation of knowledge. This knowledge could be accumulated formally through education or more casually through social and cultural interaction.

Although the definition of fluid intelligence suggests that it has nothing to do with learning, empirical research that suggests that some individual differences in performance on fluid intelligence tests are due to cultural and educational differences, (e.g., Dugbartey, Sanchez, Rosenbaum, et al. 1999; Haavisto & Lehto, 2005; Lohman, 1993; Stelzl, Merz, Ehlers, & Remer, 1995). Debate about this controversy is beyond the scope of this thesis. Nonetheless, for the purposes of this study, fluid intelligence is defined in the standard way, as those skills required on reasoning tasks.

Measurement of fluid intelligence

Raven's Progressive Matrices

Fluid intelligence is commonly measured by the performance subtests on the Wechsler Adult Intelligence Scale (WAIS), Cattell Culture Fair Test, the Raven's Progressive Matrices (RPM) and the Shipley Institute of Living Scale (SILS). The most prominent of these tests is the Raven's Progressive Matrices designed primarily to measure

Spearman's 'g' factor. The test is non-verbal and can be administered individually or in groups. There are three versions of the test, a standard form, an advanced form, and a partly coloured form for children between 5 and 12 years. The Progressive Matrices measure the ability to reason by analogy and to organise abstract, spatial perceptions into a related whole (Raven & Court, 1989). Apart from this, the test has been reported to assess other abilities such as visual- perceptual processing, abstract reasoning, and concept formation (Buros, 1975). The RPM has therefore been used widely as an assessment tool to measure several abilities but it is popular universally as a test that measures general fluid intelligence. For example, O'Leary, Rusch and Guastello (1991) showed in a study among subjects between 16 and 65 that the standard version of RPM was positively correlated with WAIS full scale IQ. In a much earlier study, Vincent and Cox (1974) also reported that where there is no need for IQ accuracy over 120, the standard version of RPM provided a good estimate of IQ.

The RPM is popular for a number of reasons. First, it was designed specifically to measure Spearman's '*g*' and has been considered by adherents of a general ability factor as the best test of fluid intelligence (e.g., Jensen, 1987). It is also popular because it is considered culture-fair. Results from studies that have tested the culture-fairness of the RPM, however, have been inconsistent (e.g., Boghle & Prakash, 1992; Kaniel & Fisherman, 1991; Kaniel & Tzuriel, 1990). Most of these studies have found differences among different populations, specifically between different socio-economic groups. Education has mostly been found to influence performance on the RPM, contrary to what has been expected (Measso, Zappala, Cavarzeran, Crook, et al., 1993). A similar finding was reported in a study conducted in Ghana where the test is used for school and job placement and as an important clinical assessment tool (Anum, 1996).

The primary objective of the study in Ghana was to standardize the coloured version of the progressive matrices and to test whether performance on RPM would be influenced by socio-economic status. The Raven's matrices were administered to seven hundred children between the ages of five and twelve. To assess concurrent validity, the digit span (Forward), a subscale of the Wechsler intelligence test for children (WISC-R) and a school achievement test, the Wide Range Achievement Test (WRAT), were also administered. It was found that performance of children from the economically-advantaged group was similar to the published norms (Raven, 1986), but their performance was significantly different from the economically disadvantaged group across all age levels except among the youngest age group, the six-year olds. The difference between the groups begins widening at about 8 years and this gap is widest at 12 years.. It appeared that children from the two populations had a similar developmental trend from age 6 to age 8 when the difference between the two groups increased substantially.

This result was similar to what was obtained on the WRAT. On this test, children from the low SES group had lower scores than children from the high SES group at all ages. This difference was not reflected on the forward digit span test though, which is considered a measure of attention span. The conclusions from this study were that the difference in performance between the two populations on the RPM test was due not to innate differences in problem solving abilities but to other factors that are external to the development and acquisition of the skills needed for the RPM. These external factors were primarily education and possibly social and economically related factors such as nutrition.

The evidence available, therefore, suggests that the RPM may be limited in scope and may not be able to capture the essence of intelligence, that is, as something more basic than knowledge and skills acquired through schooling. This raises the question of why the Raven's matrices is used as a "gold standard" of measuring general fluid intelligence or '*g*' even though there is some evidence to suggest that its purity as an intelligence test that reflects general mental ability or *g* is in question.

Shipley Institute of Living Scale (SILS)

Another test used to measure general cognitive ability is the Shipley Institute of Living Scale. Since its development in the 1940s, the Shipley Institute of Living Scale (SILS) has also been used as a brief screening test of intellectual functioning and to detect cognitive deterioration (Phay, 1990a; Zachary, 1986; Zachary, Crumpton, & Speigel, 1985). The SILS is a two-part paper and pencil test which can be administered in groups or individually. The two parts, a verbal test and a test of abstraction, are considered to be near equivalents of the WAIS verbal and performance scales although studies that have examined the relation between SILS and WAIS subtests have not yielded consistent results (Bowers, 1986). For example, Zachary (1986) and Zachary, Crumpton, and Speigel, (1985) reported correlations of about .85 between SILS total score and WAIS full scale IQ. Other researchers, however have reported varying correlations between .46 and .85 (e.g.,, Dalton, Pederson, & McEntyre, 1987; Retzlaff, Slicner, & Gibertini, 1986; Weiss & Schell, 1991; Bowers & Pantle, 1998) Findings from these studies suggest that the SILS correlates moderately with some intelligence tests.

The focus of the current study is on the assessment of general intelligence using the RPM. The SILS tests were also selected to provide a measure of fluid intelligence which is not based on spatial relations. The two tests measure cognitive function in two broad modalities, spatial visualisation and the verbal-numerical modalities. The aim in this study was to examine how the individual and combined effects of processing speed and working memory help explain individual differences in fluid intelligence, especially as measured by the RPM.

Processing speed, working memory, and fluid intelligence

Cognitive neuroscientists are generally interested in understanding the mechanisms involved in cognitive functioning and in determining what constitutes general intelligence. In this context, the construct of fluid intelligence has been studied extensively for a variety of reasons, the most important of which is that it is believed to be both a reflection and a predictor of other cognitive abilities. The emphasis in the current study is to explore the cognitive processes involved in our measures of fluid intelligence and understand how they explain individual differences. As stated previously, two cognitive factors identified in the literature to predict performance on tests purported to measure fluid intelligence are the speed of processing information and working memory (e.g., Danthiir, Roberts, Schulze, & Wilhelm, 2005; Fry & Hale, 1996, Fry & Hale, 2000; Kail, 1992, Kail & Salthouse, 1994; Salthouse, 1998). There are two general views in the literature concerning the relation among indices of processing speed, working memory and fluid intelligence. In the first place, some researchers have shown that processing speed accounts for age-related differences in indices of intelligence without reference to working memory (Jensen, 1978; Kail, 2000; Salthouse, 1998). A second position is that it is working memory that accounts for individual differences in measures of fluid intelligence (Fry & Hale, 1996; Kane & Engle, 2002; Süß, Oberauer, Wittmann, Wilhelm, Schule, 2002) and in fact accounts for the relation typically found between indices of processing speed and intelligence.

Processing speed

Processing speed can be defined as the total time taken for an individual to make a correct response to a cognitive task. It can also be referred to as the rate at which stimuli are perceived, attended to and integrated by the cortex in order to perform a task or make a required response (Bors & Forrin, 1995). Processing speed has been discussed in the developmental literature as an important index of cognitive development. For example, Kail, Salthouse and other researchers have all emphasised that the superior performance exhibited by older children and adults on cognitive tasks compared to younger children is due to their ability to process information faster (e.g., Jensen, 1993, Kail, 1996; Salthouse, 1994, 1996). Salthouse in particular has emphasised that the general slowing in processing speed among aging adults is the most important factor that accounts for age differences in cognitive performance (Salthouse, 1996).

The association between speed and intelligence stems from the speed-intelligence correlation that tends to diminish as age increases (Salthouse, 1992, 1996). According to Salthouse (1996), increasing age is associated with a decrease in speed of processing which is important for performing complex cognitive tasks. Jensen (1993) has also emphasised that speed is important because of "... the brain's limited capacity for processing information." (Jensen, 1993, pp. 54). The brain processes information it receives as fast as possible or else the information will be lost. According to Jensen (1993) faster processing therefore will ensure faster responses on cognitive tasks and faster acquisition of skills and knowledge. Kail (1992) and Kail and Salthouse (1994) have reported that not only does speed improve with age (between childhood and adulthood) but that as speed improves there is a corresponding improvement in intellectual performance. This supports the notion that an increase in speed allows for an increase in amount of information processed and this has a positive effect on mental tests or IQ. For example, Kail and Salthouse reported age-related differences in performance on two perceptual speed tests from the Woodcock-Johnson Tests of Cognitive Ability (1990). According to the authors, performance on perceptual speed tests has consistently been found to be significantly related to measures of higher-order cognition such as fluid intelligence.

Kail and Salthouse (1994) have acknowledged that speed is a general mechanism that influences performance on speeded tasks but further stated that processing speed can be used to predict performance on tasks that lack speeded components such as reasoning tasks.

There is copious literature in support of speed and intelligence relations especially in the developmental literature. One such study was conducted to examine the effect of inspection time among young children. Wilson, Nettelbeck, Turnbull and Young (1992) investigated the relation between age, IQ test scores based on inspection time (an index of speed) between two age groups (6 to 8 and 10 to12 years). The authors reported that speed improved with childhood maturation among the children with average and above-average IQ, however, within this age range, speed was more related to chronological age than to IQ. The authors concluded that while processing speed was important for IQ it was not entirely essential in contributing to the development of IQ.

Despite the claims by Kail and Salthouse, and the evidence in support of the speed-intelligence relations, available research with working memory seems to suggest that there is a stronger relation between working memory and fluid intelligence (Ackerman, Beier, & Boyle, 2002; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Kyllonen, 1994; Kyllonen & Christal, 1990; Sub, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). For example, it has been stated by Wilhelm and Oberauer (2006) that normally the correlation between intelligence test scores and variables extracted from individual RT tasks rarely exceeds .30; however, these correlations can be much higher when several tasks are combined or aggregated into a single latent factor (Kyllonen, 1994; Neubauer & Bucik, 1996; Vernon, 1983), that is, combining speed tasks likely increases the stability of the speed measure.

The above discussion suggests that there could be some intervening variables that influence the speed-intelligence relation. There are other constraints that need to be brought into focus when discussing the speed-intelligence correlations. For example, maturational effects and superior test strategies may be significant in influencing this relationship.

The varying relation among age and speed and intelligence also challenges the global speed factor suggested by Hale (1990) and Kail (1991a). Hale (1990) reported in a study among children and young adults that regardless of specific components of a test, response latencies of children should be a function of age and that children's response latencies can be predicted from that of adults.

Another constraint in the discussion of the speed and intelligence correlation is the lack of speed measures that are applicable across different age groups. A simple speed task that is appropriate for a 6 year old may be too easy for a 10 year old or an older child. The implication here is that there may be some intermediate or intervening variables. As suggested by Salthouse (2000), some of these intermediate variables are task characteristics and experience with the task that actually affect performance.

Working memory

Several researchers have considered working memory to be central to cognitive functioning (e.g., Colom, Flores-Medoza, & Rebollo, 2003; Jensen, 1998; Kyllonen & Christall, 1990; Kane & Engle, 2002; Süß et al. 2003). This is supported by findings from several studies that have reported moderate to high correlations between tests of working memory and intelligence tests. This section will focus on the nature of working memory and how it influences cognitive functions.

Working memory is conceptualized as an information processing system used to keep information active (or online) during problem-solving situations. Working memory tasks typically require subjects to maintain short lists or pieces of information in an active state while simultaneously processing other information. These different pieces of information should be relevant to the particular task in question although this latter condition is not always adhered to. In one of the original conceptualisations, working memory was conceived of as having three main components, two slave systems known as the phonological loop and the visuospatial sketchpad, and a central executive which serves as a supervisor or coordinator of the slave systems (Baddeley & Hitch, 1974). The two slave systems are specialized temporary memory systems. The phonological loop serves as a verbal memory store used to process auditory information while the visuospatial sketchpad is used to store and process visual and spatial information. These stores are used to keep information active and make them accessible when needed for information processing. The major role of the central executive is the control (and regulation) of the working memory system. In coordinating activities in working memory, the central executive helps in focusing and switching attention.

This early model of working memory has undergone significant changes without changing the main concept of a central executive involved in coordinating information within two separate slave systems or modalities (e.g., Baddeley & Hitch, 1974; Baddeley & Logie, 1999). Baddeley and Logie (1999) suggested that there is evidence to support an interaction between the two storage systems – auditory and visuo-spatial. Because of this, working memory is presumed to play a significant role in cognitive functions that require coordination and maintenance of information from different domains or modalities (Shah & Miyake, 1999).

There are two views on how the working memory system is configured. Proponents of a unitary system suggest that working memory operates as a single component with no clear separation between the 'slave systems' (e.g., Kane, 2003; Kane & Engle, 1999). This appears to be the basis for current models in the literature that support a direct relationship between working memory and intelligence. Kane and Engle and their colleagues have argued that working memory is a domain-general construct because of the significant correlations among several working memory measures. According to the proponents of a domain-general working memory the correlation among working memory measures is due to the executive component of the working memory construct. Subscribing to a domain-general system implies that individual differences in working memory capacity are due mainly to differences in executive attention, whereas a non-unitary working memory system differentiates between different cognitive modalities (e.g., Oberauer, Süß, Oliver, & Wittmann, 2003, Shah and Miyake, 1999). This view is consistent with Baddeley's conceptualisation of separate slave systems for each modality.

Research in support of multiple working memory systems has come from cognitive, developmental, and imaging studies (e.g., Baddeley & Hitch, 1994; Shah & Miyake, 1996; Smith & Jonides, 1997). Shah and Miyake (1996) for example demonstrated among college students that spatial and verbal working memory constructs are separable. In their study, the authors found that the spatial span tasks correlated with spatial ability measures but not with verbal ability measures. Reading span tasks also correlated with verbal ability measures but not with spatial ability measures. The authors concluded that their data supported the existence of a domain-specific working memory resource.

In a review of several studies, Smith and Jonides (1997) also reported that there are separate working memory systems for spatial, object and verbal processing. The authors reported that spatial working memory activated four areas in the right hemisphere. Two of these were located in the posterior parietal cortex and the other two in the anterior occipital cortex. They further claimed that the parietal cortex has been implicated in spatial processing and spatial memory in studies of brain-damaged patients. They reported data indicating that verbal working memory activated six areas in the left hemisphere, three in the posterior region and three in the anterior region. According to the authors, structures at the back of the brain mediate storage while structures at the front mediate rehearsal. The posterior parietal cortex (in the left hemisphere) is the region most frequently damaged in patients who show a deficit in verbal short-term memory. These findings show that spatial and verbal working memory are mediated by different neural circuits and therefore support cognitive distinctions among the different working memory constructs. The findings also provide support for a physiological explanation of a multiple construct working memory system.

Oberauer, Süß, Oliver, and Wittmann (2003) have also provided support for the existence of multiple working memory systems using the statistical method of structural equation modeling. The authors administered a battery of 24 working memory measures to young adults. Oberauer et al. (2003) showed that working memory can be categorized into factors associated primarily with content or primarily with function. There was also evidence for a dissociation between verbal-numerical working memory and spatial working memory.

In the light of these findings, one can expect to have differential associations between the different working memory constructs and intelligence. Given this, it would be necessary to explore the effects of different working memory systems if we are to adequately explain the relation between working memory and fluid intelligence.

Relation among speed, working memory and general fluid intelligence

The first study to examine the simultaneous effects of age, processing speed, and working memory on fluid intelligence was conducted by Fry and Hale (1996). Studies conducted prior to this had examined only two-factor relations, that is, between processing speed and fluid intelligence or between working memory and fluid intelligence. Fry and Hale (1996) also examined the nature of the relations among these variables as well as their joint effects. They proposed that it was an increasing developmental pattern in processing speed and working memory that explains performance on fluid intelligence tests. Fry and Hale (1996) predicted that age-related improvements in fluid intelligence would be mediated by changes in working memory. They also proposed that age-related improvements in working memory would mediate the relation between age-related differences in processing speed and fluid intelligence. Controlling for age-related differences in processing speed, working memory and fluid intelligence, the authors predicted that differences in working memory would mediate the relationship between speed and fluid intelligence.

Fry and Hale administered the RPM along with working memory tasks that tested for digits and spatial locations, and four processing speed tasks to 214 children, adolescents and young adults. Using path analysis, the authors reported that despite the significant path between age and fluid intelligence measured by the RPM, age-related differences in working memory mediated the relationship between age and fluid intelligence. They also found that age-related changes in working memory mediated the relation between age and speed and fluid intelligence. While the path between age and fluid intelligence was significant, the path between speed and fluid intelligence was not, implying that speed had no direct effect on fluid intelligence. The authors revealed that even after controlling for age and speed, working memory had a substantially significant effect on fluid intelligence.

The implication of this finding is that age-related improvements in processing speed and working memory both predict differences in fluid intelligence but the relationship between processing speed and fluid intelligence was not direct. Fry and Hale proposed that the age-processing speed-working memory-fluid intelligence relation is a "developmental Cascade" in which improvements in processing speed lead to improvement in working memory which in turn affects fluid intelligence abilities. The influence of processing speed on fluid intelligence can therefore be accounted for by differences in working memory. The observed relations between age and processing speed and to some extent between processing speed and fluid intelligence were generally consistent with earlier studies (e.g., Kail, 1992; Just & Carpenter, 1992; Salthouse, 1994).

The Fry and Hale study was unique in its attempt to explain the three-way relation among processing speed, working memory and fluid intelligence. However, this leaves the question open as to the nature of the causal relation and potential confounds. For one thing, some of the speed and working memory measures were spatial, which could account for the variance common to processing speed, working memory and the RPM, their index of fluid intelligence.

There have been different attempts at replicating the Cascade model with the aim of explaining the nature of the relationship between working memory and fluid intelligence. To explore developmental trends Ferlisi and Segalowitz (1998) tested 204 participants in four age groups, 7, 10, 13, and 18-year-olds constituting children, middle childhood, adolescents, and young adults. Apart from attempting to replicate Fry and Hale's (1996) study, the authors also explored the role of inhibition and dual attention, both aspects of executive function that are related to working memory. Their study did not support the developmental Cascade model proposed by Fry and Hale (1996). Speed of processing and spatial ability were significant predictors of fluid intelligence as measured by the RPM whereas none of the executive function measures were significant. Spatial ability significantly predicted fluid intelligence among the older children and young adults. The authors concluded that factors that underlie RPM indices of fluid intelligence may vary for different age groups, "indicating the complexity of cognitive relationships."

Other studies have not directly tested the Cascade model but have examined the relation between working memory and general fluid intelligence (e.g., Ackerman, Beier & Boyle, 2002; Conway, Cowan, Bunting, Theriault, & Minkoff, 2002; Engle, Tuholski, et al., 1999; Kane & Engle, 2002). The reported correlations between working memory and fluid intelligence have varied from one study to another. Ackerman, Beier and Boyle (2002) have reported, however, that this relation is complex and that the reported correlations are mostly overestimated.

Ackerman, Beier and Boyle (2002) attempted to "evaluate the claim of unequivocal identification of working memory with '*g*' and to show that working memory is more related to aspects of processing speed." Using a composite fluid intelligence measure referred to as '*g'*, they tested the hypothesis that although working memory ability is related to a general intellectual ability, it is not the sole predictor. One hundred and thirty-five young adults were administered seven working memory tests (including backward digit span, computation span, word spatial span, figural span, and spatial span), 19 cognitive ability tests, 16 perceptual tests, and the Raven's matrices. Of relevance to this thesis, the study showed that Raven's moderately correlated with working memory (r =. 48) but correlated highly with spatial ability (.70). They also found significant partial correlations between different measures of processing speed (memory and complex) and working memory, and with Raven's matrices in a structural equation model. The authors concluded that working memory is "a promiscuous variable" because of its association with several factors.

This and findings from other studies suggest that effects of age, processing speed and working memory on fluid intelligence should be examined more broadly. One way to do this is to examine the relations between fluid intelligence and both processing speed and working memory within multiple modalities in order to account for individual differences attributable to specific measures. With this approach, one can examine effects due to both task parameters and task modalities. While Fry and Hale studied the question in a developmental context, in the current research the focus is on young adults. The reasoning was that if current models were adequate in explaining speed-working memory-intelligence relations then one would expect that this relation would exist wherever there is adequate variability in performance on the measures, including among young adults.

Therefore, in the current study the relation between speed, working memory and general fluid intelligence is examined from a multiple modality perspective in which processing speed, is measured within multiple modalities – verbal, numerical, spatial, and visual – and working memory is also measured within multiple modalities.

Working Memory, Controlled Attention and Fluid Intelligence

Working memory typically refers to the controlled process or mechanism of not only keeping cognitive representations active but also manipulating or transforming them in the service of some task or goal. The central executive component in Baddeley's model, and also Norman and Shallice's (1986) Supervisory Attention System (SAS), are central to this control function. There appears to be a link between working memory and these complex cognitive processes, the mechanisms involved in the relationship are not very clear but it must subsume the construct of controlled attention (discussed below).

Working memory in these higher order cognitive functions is required for complex mental processes that involve goal-directed behaviours, the monitoring of response output, and the comparison of response output with the desired output. The implication is that an inability to hold information active in memory will result in a generally poor processing of complex information.

One way to show the effects of working memory on higher order cognitive functioning is to demonstrate how individuals with low working memory capacity differ in performance on cognitive tasks from those with high working memory capacity. To discriminate between low and high working memory capacity and to examine whether working memory is important to retrieval in a verbal fluency task, Rosen and Engle (1997) conducted four experiments to explore the role of working memory. Each experiment had a different dependent measure. In each experiment, participants were required to generate names from a given category. The participants were not to repeat any names during the session. The participants were first given an operation span screening task. The participants were then placed into one of two groups based on whether their performance fell into the lower (low-span) or upper (high-span).

The authors found that there was a consistently superior performance among high span participants in working memory capacity over those with low span participants in all the four experiments. The major conclusions were that the difference between high and low span participants was due to the ability to effectively monitor errors and to avoid repetition of responses. This requires a controlled processing or executive attention. Based on this, the authors suggested that the prefrontal cortex played an intermediary role in the processes involved in these activities. The connection between controlled, effortful retrieval and the frontal lobes, according to the authors, is supported by current developmental literature which suggests that improvement in cognitive performance during early childhood and decline in adulthood are often attributed to the developmental changes in the frontal lobes (e.g., Phillips & Della, 1998). A limitation of this study is that they used groups considerably separated by working memory capacity. This prevents an analysis of mechanism and introduces potential confounds because the groups differed in knowledge base in addition to working memory capacity.

verbal fluency or memory retrieval such as reasoning, is not clear and would need to be researched further.

Further evidence for the link between controlled processes and fluid intelligence comes from several studies. For example, Engle, Tuholski, Laughlin, and Conway (1999) statistically examined short-term and working memory as predictors of fluid intelligence as measured by the Raven's Progressive Matrices. Engle et al. (1999) conceptualized working memory to be a system that includes a short term memory and a central executive. They considered short-term memory as a simple storage system whereas working memory was considered as that storage component as well as an attention component.

To test for the effects of short-term and working memory on fluid intelligence, the authors extracted variance common to both memory constructs (which itself predicted fluid intelligence significantly) and showed that of the two residualised constructs, only working memory was significantly related to fluid intelligence. They therefore concluded that, while there is variance in fluid intelligence related to the common variance in short-term and working memory, the unique relation between working memory and fluid intelligence is based on the engagement of its central executive component to maintain activation of information relevant to the task.

In a related study, Conway, Cowan, Bunting, Therriault and Minkoff (2002) proposed that the more a task requires controlled attention, the more the task will tap working memory. A structural equation model testing the relation between working memory and fluid general intelligence (measured by Raven's matrices and Cattell's culture fair test) revealed a significant path between working memory and general fluid intelligence. According to the authors, the link between working memory and general fluid intelligence is "… the demand for active maintenance of information in the face of concurrent processing of information and/or attention shifts'' (Conway et al. 2002, pp. 178) and this is a demand for controlled attention. Although the study did not directly examine executive function processes they concluded from their findings that the central executive and working memory 'are intimately linked'. Furthermore, they concluded that tasks that do not require controlled attention are not likely to be related to fluid intelligence.

Controlled attention and Fluid intelligence

The 'Controlled Attention hypothesis' provides some insight into the nature of the relation between working memory and fluid intelligence, measured by Raven's matrices and other tests of higher order cognitive processes. However, there are limitations. First, any controlled attention task involves, like working memory, both complex cognition and specific modality parameters. Second, there has not been direct empirical support of this hypothesis teasing these factors apart. For example, tasks that require controlled attention processes involve operations such as inhibition, divided attention, and set switching. One way to do this is to examine the relations among different cognitive processes that require different levels of controlled attention and derive a modality-controlled value for controlled attention processes. These constructs can then be related to fluid intelligence. In the current study, we sought to examine the effects of inhibition and set switching, two constructs that have been associated with intelligence.

Inhibition. One executive process that has been studied extensively is inhibition (e.g., Dempster, 1991; Dempster & Cooney, 1982). Inhibition requires an attentional mechanism that is necessary in excluding information that is not relevant within a particular task situation. Inhibition has been linked to working memory and intelligence (Bjorkland &

Harnishfeger, 1990; Zook, Davalos, DeLosh, & Davis, 2004). It has also has been associated with executive function because of its association with activities of the frontal cortex. In aging studies, it has been proposed that a reduction in inhibitory control is one of the prominent cognitive changes expected as people grow older and that this is a possible underlying factor in the poor cognitive performance among older adults (Hasher and Zacks, 1988). Inhibition may play a role in higher order cognitive tasks by suppressing inappropriate responses. Very few studies have examined the direct effects of inhibition on fluid intelligence. The joint effects of working memory and controlled attention on fluid intelligence have also not been examined. In this study, we examined inhibition measured by the Stroop task as an index of controlled attentional processes.

Set Switching. There have been studies in the literature that have linked set switching to higher cognitive functioning (e.g., Allport Styles, & Hsieh, 1994; Harvey, 1984; Wager, Jonides, Smith & Nichols, 2005). The general finding from most of these studies is that the ability to minimize the cost of switching has a positive effect on cognitive functioning. Very few studies, however, have examined direct effects of set switching ability on intelligence. It appears that the link between set switching and intelligence seems to tie in with the existing association between prefrontal cortex and intelligence (e.g. Miller & Cohen, 2001; Wager, Jonides, Smith & Nichols, 2005). Wager, Jonides, Smith, and Nichols (2005), for example, have reported that activation in the ventromedial prefrontal cortex and the rostral anterior cingulate is consistently correlated with good performance on attention switching tasks. They believed that their data supported the view that these areas play a general role in efficient attention shifting.

Relation between prefrontal cortex activity and fluid intelligence

Most of the previous discussion has focused on explaining fluid intelligence from a cognitive perspective. A neural perspective that has gained prominence in the psychological literature is the association between activity in the prefrontal cortex as a basis for performance on general intelligence tests. This has come from studies in which both working memory and general fluid intelligence appeared to activate the same or similar neural circuits in the prefrontal cortex. Evidence from brain activation studies and brain injury studies have served to reinforce the view that the efficiency of the prefrontal cortex (PFC) underlies the working memory and executive function relationship. Other studies have also established an association between working memory and fluid intelligence.

Two studies have been particularly illuminating in this regard. Prabhakaran, Smith, Desmond, Glover, and Grabieli (1997) examined brain activation in an fMRI study while a set of participants solved selected problems from Raven's progressive matrices. There were three conditions, an analytical reasoning condition, a figural or visuospatial reasoning condition, and a simple pattern matching condition that served as a perceptual-motor control. The most significant of the results was the finding that the analytical reasoning condition activated bilateral frontal, left parietal, occipital, and temporal regions more than did the control condition. These regions are also associated with working memory. This finding provides some circumstantial evidence that working memory and analytical reasoning abilities associated with RPM activate the same neural pathways. It does not explain, however, the frontal processes or mechanisms associated with both RPM and working memory or how are they are related.

Duncan, Burgess, and Emslie (1995) compared patients with frontal lesions to matched patients with posterior lesions and a normal control group on a general intelligence measure using Cattell's culture fair test which is another common general fluid intelligence measure. The authors found that the frontal patients performed worse on the general intelligence measure compared with the posterior patients and the normal controls whereas their performance on the WAIS performance test was comparable. This suggested a close association between general fluid intelligence and the frontal cortex.

These findings should be interpreted with caution for a number of reasons. The sample sizes in both studies were relatively small. Frontal lobe patients are generally disadvantaged on a variety of cognitive skills that include inhibitory control and attention, and therefore the finding that they perform poorly on RPM or Cattell's Culture Fair tests does not explain the relationship between frontal activity and fluid intelligence nor does it explain the relationship between working memory and general intelligence any more than suggesting that executive function skills are associated with the frontal lobes. However, the findings do provide a rationale for examining cognitive processes that are not only related in function but also have a probably similar physiological origin. This can be approached by examining both task and cognitive modalities.

The aim of the current study is to examine the relation between measures of controlled attention and working memory and how both affect tests purported to measure fluid intelligence.

Summary of Literature

There are two general views held about fluid intelligence. These relate to the effects of processing speed and working memory on one hand and the effects of working memory and its executive mechanism on the other hand. The second view also implicates the frontal lobe as playing an important role in general fluid intelligence. With respect to processing speed, it has been suggested that both children and adults who process information faster are more likely to perform better on fluid intelligence tests (Jensen, 1993; Kail, 1991b; Kail & Salthouse, 1994). There is also some consensus that working memory is more strongly associated with fluid intelligence than with processing speed (Fry & Hale, 1996) or short term memory (Engle, Kane, et al., 1999; Engle, Tuholski et al. 1999; Kane & Engle, 2002; Kane, Hambrick, & Conway, 2005).

The second view of the working memory-fluid intelligence relations suggests that working memory is a domain-general resource that is strongly related to general fluid intelligence. Furthermore, the proponents of this view state that working memory is closely linked with attentional control and it is this (attentional control) that mediates the strong relation between working memory and fluid intelligence. Some proponents are of the view that attentional control may not completely explain general fluid intelligence but they state that it is largely responsible for the shared variance between working memory and general fluid intelligence (Kane, Hambrick, & Conway, 2005).

Cognitive and neuropsychological evidence has suggested that there are multiple working memory systems separated by cognitive modalities. There is also evidence that correlations between different fluid intelligence tests and working memory tests have not always been consistent. These have challenged current models that explain working memory and fluid intelligence relations with single factor models without examining task or cognitive modalities.

Hypotheses

In their developmental Cascade model, Fry and Hale (1996) proposed that as children grow older, they process information faster, which in turn improves their working memory and this in turn leads to an improved performance on fluid intelligence tests (Figure 1). This model suggested that the relation between working memory and fluid intelligence is not only stronger than processing speed but also accounts for the relation between speed and fluid intelligence. In the current thesis we propose that given that working memory has multiple constructs and that individual differences in working memory may be attributable to individual differences within a specific modality, a model based on single factor working memory would not adequately explain the relation between working memory and fluid intelligence. The Cascade model would be examined within the visuo-spatial and verbal-numerical modalities. This separation in modalities has some precedent in the literature in that recent studies have shown that spatial and verbal working memory are distinct and separable constructs (Shah & Miyake, 1996; Oberauer et al., 2002; Süß et al., 2000).

******Insert Figure 1 about here******

The first model examined here tests two broad hypotheses. The first is that the link among speed, working memory and performance on the RPM or Shipley test of abstraction will be through the visuo-spatial modality, and the link with the Shipley verbal test will be through the verbal-numerical modality. Specifically, the hypotheses are

1) Visuo-spatial processing speed would have a stronger relation with RPM than verbal-numerical speed;

2) Visuo-spatial working memory should have a stronger relation with RPM than verbal-numerical working memory measures;
3) Visuo-spatial processing speed should have a stronger relation with Shipley test of abstraction than verbal-numerical speed;
4) Visuo-spatial working memory should have a stronger relation with Shipley test of abstraction than verbal-numerical working memory;
5) Verbal-numerical processing speed should have a stronger relation with Shipley verbal than Visuo-spatial speed;
6) Verbal-numerical working memory should have a stronger relation with Shipley verbal than Visuo-spatial working memory measures.

*********Insert Figure 2 about here*********

*********Insert Figure 3 about here*********

*********Insert Figure 4 about here*********

In the second model examined here, we tested the hypothesis that fluid intelligence is better accounted for by controlled processing than working memory (Figure 5). Following from the assertion of Kane and Engle (2002), we predicted that

1) Controlled attention measures should have direct effects individually and collectively in a latent variable on RPM, Shipley verbal test, and Shipley test of abstraction;
2) In a model with both the controlled attention latent variable and working memory latent variable, controlled attention would mediate the relation

between working memory and RPM, Shipley verbal test, and Shipley test of abstraction (Figures 6 and 7).

*********Insert Figure 5 (RPM) about here*********

********Insert Figure 6 (Shipley verbal) about here*********

********Insert Figure 7 (Shipley abstract) about here*********

METHOD

Subjects

Participants were 212 (18 to 28 years of age) university students recruited from the Introduction to Psychology class, who received research participation course credit for their experience. Eighty percent of the participants were females. Due to missing observations or incorrectly completed tests, 206 were used for the analysis.

Selection criteria. Participants were screened for anxiety disorders, learning disorders, attention deficit disorders, mild brain injury and any other disorders that may possibly influence their performance in the study. This led to elimination of one person's data from the data set due to an indication of learning disabilities. The distribution of subjects by sex is presented in Table 1.

Measures (see Appendix C for sample of measures)

All the tasks were paper and pencil based. This method was adopted to enable group administration of all the tasks. Some of the selected tasks were designed originally to be administered individually. These tasks were therefore modified to enable group administration. On the 1- and 2-back tasks for example, participants have to respond immediately following the presentation of a target. In our study, participants have to count the number of targets in memory and respond in writing on the answer sheet at the end of the presentation.

The tasks used in the study were designed to measure the four constructs of processing speed, working memory, controlled attention and fluid intelligence. Processing speed and working memory latent variables were derived from two specific modalities:

visuo-spatial and verbal-numerical with two tests for each construct in each modality. The Controlled attention latent variable was created from a test of Inhibition (Stroop) and set switching. Motor speed variable was added to the measures to assess individual differences in motor speed. It was not part of the specified constructs. This task was made up of numbers and uppercase letters presented in alternate columns on a table, that is, numbers were presented in one column and letters were presented in the alternate column. The participants were required to quickly scan through the table and draw a line through all the numbers one at a time. The participants had 15 seconds to complete the test. The score on the test was the number of items they were able to cross out within the specified time. The list of tests and their abbreviations are presented in Table 2.

*********Insert Table 2 about here*****

Processing speed

Verbal-numerical processing speed measures

Number comparison test (Kail, 1992). In the original version used by Kail (1992), participants were required to quickly make comparisons between pairs of numbers and indicate when the pairs were not identical. In the current thesis, pairs of 3- to 12-digit numbers were presented separated by a dash. Half of the pairs were identical while the other half were not. The participants were presented with two test sheets. On the first sheet, the pairs ranged in increasing order from 3 to 12. On the second sheet, the pairs ranged between 6 to 12 digits and were presented in a random order. The participants were required to mark 'X' on the dash where the pairs were not identical. Participants had 60 seconds to complete the task. At the end of the test they were then to draw a line beneath the last pair of numbers they were able to complete before time ran out.

Letter comparison. This is similar to the number comparison test described previously except that letters rather than numbers were the targets. The requirements of the test were the same. There were two pages and for each page participants were required to quickly compare pairs of letters and indicate with an 'X' between the pair of letters when they were not identical.

For both number and letter comparison tests, the total number of correctly identified pairs was the score on the test.

Visual-spatial processing speed measures

Visual scan and coloured visual scan test. In this task, participants were required to quickly scan a page of Os and Qs and to cross out the Qs. There were two forms of this test. The first was the standard visual scan test which has just been described. On the second test, some of the letters were coloured. Participants were required to identify the targets (Q) that were coloured green. The target stimulus constituted about 15% of the total stimuli in each condition. This test was timed and had to be completed within 40 seconds. The total number of correctly identified targets within the time permitted was the score used for each condition.

Spatial scan. This test was based on the Kail (1992) number and letter comparison test. Pairs of dot patterns were placed in a square and separated by a dash. For each square the number of dots ranged between 2 and 4. As was the case in the number and letter comparison tests, participants were presented with two sheets. On the first sheet, the number of boxes within the squares increased from 1 to 5. On the second sheet, the order of presentation was random. Participants had to complete the task within 60 seconds. The number of correctly identified patterns was the total score for the test. Participants were asked to draw a line beneath the last pair of numbers they were able to compare before time ran out.

Working Memory Measures

Verbal and numerical working memory tests. The verbal and numerical working memory tests were designed using the n-back paradigm. The targets in the verbal working memory were letters presented in uppercase and for the number working memory the targets were numbers. As was the case in the visual working memory, each item was presented for 200 ms with an ISI of 500 ms. There were 40 trials and 25% targets in each condition. There were two conditions for each test, the 1- and 2-back conditions. On the 1-back condition the participants were required to count the number of items the same number or letter is repeated (that is, immediately followed by the same number).

Visual working memory test. This test was also designed to follow an n-back paradigm using Arabic characters. The test required that participants monitor an overhead screen as a series of 'characters' appeared. There were two conditions, 1-back and 2-back conditions. In the 1-back condition the participants had to keep count of the number of times they saw the same character appear twice in a row (consecutively), that is, when the character was same as the previous stimulus. In the 2-back condition, participants had to keep count of the number of times a presented stimulus was the same as the one presented two items earlier. Each item was presented for 200ms with an ISI of 1 second.

For all three working memory tests participants were required to write the correct response in an answer booklet. Each condition had 40 trials. The number of targets ranged between 20 and 25% for each condition. The number of correctly identified targets was the total score on the test.

Spatial working memory. On this test, participants were presented with a series of boxes coloured green and black presented in a 4 X 4 grid. There were two parts to this task. On the first part, participants were required to make a judgment on the alignment of the boxes. They had to indicate by checking a 'YES' response when the boxes were presented in a straight line or a 'NO" response when they were in a random order. On the second part of the test, which was at the end of the series they were made to recall the location of the green boxes within the grid. Each trial had one box that was coloured green and three coloured black. There were four trials per session. Each table was presented for 1 second with and an ISI of 2 seconds. There were three sessions on this test. For each trial, the score was the number of green boxes correctly located within each grid. The dependent measure was the sum total of scores.

Controlled Attention Measures

Test of Inhibition (Stroop test). The Stroop test is a test of inhibition that consists of two parts in which 4 colour names are either printed in colours consistent with the name or inconsistent with the name. For example, GREEN may be printed in the colour green or may be printed in the colour red. The original version of the Stroop test is administered individually because the participants are required to respond verbally. In this study, the test was modified into a paper and pencil test version in order to administer the test in a group situation. There were two conditions of the modified Stroop. In condition 1 (Congruent condition), participants had to underline the word or colour name if it was consistent with the ink in which it was printed. A correct response is therefore GREEN printed in the colour green. In the second condition (Inconguent condition), participants were asked to underline the name of the colour when it was inconsistent with the colour in which it is printed. For example, responses were expected when, for example, the name GREEN was printed in the coloured Red. Each condition had two stimulus sets, the first trial with 25% targets and the second with 50% targets. The dependent measure is the number of items marked correctly in 40 seconds.

Set Switching (Rogers and Monsell, 1995). Participants were presented with a series of numbers between 1 and 9 (omitting 5). The participants were to decide either (a) whether it is odd or even, or (b) whether it is greater or less than 5, indicating the response by marking in the box below the number '+' when it was odd or when it was greater than 5 and '–' when it was even or less than 5. The odd/even judgment was cued by underlining the number. That is, participants had to change the decision rule when the underlining of a number changes. Participants had 80 seconds to complete as many items as they could. There were two conditions with 110 trails. One had 50% switch trials where there is a repeat trial followed by a switch trial followed by a repeat trial, etc., i.e., judgments in the ordering a, a, b, b, a, a, b, b, a, a, b, b.... The second has 20% switch trials, i.e., ordering of a, a, a, a, a, b, b, b, b, b, a, a, a, a, a, b.... The total number of correct responses was the score for each condition.

The set with more alternating switching should be more difficult. The dependent measure is the number of stimuli responded to correctly within the set time period of 80 seconds per trial.

Fluid Intelligence

Raven's Progressive Standard Matrices. The Raven's Progressive Matrices (RPM) is a nonverbal, individually or group administered test of reasoning ability based on figural materials. The test measures ability to form comparisons, and to reason by analogy. This is not a timed test but usually takes about 25 to 30 minutes to complete.

Shipley tests. The Shipley Institute of Living Scale (SILS) is a test of general ability for adults (Zachary, 1990). There are two subscales, a Verbal and an Abstraction subscale. The Verbal subscale is designed to measure general ability relating to word knowledge and reading comprehension. This subscale requires respondents to choose from a set of four words one that is closest in meaning to a target word. The Abstraction subscale is designed to measure general reasoning ability. The participants were required to complete a series of reasoning tasks with letters or numbers. They were expected to complete each subscale within ten minutes. The number of correct items for each scale was the score for test.

Procedure

The original intention was to administer the tests to participants in groups of 10. Due to scheduling difficulties, tests were administered to participants in groups between 4 and 10. Each testing lasted for about 2 hours and 30 minutes. Participants had to make all responses in an answer booklet. Some of the tests were presented on PowerPoint and projected onto an overhead screen while some were presented in the booklet.

The processing speed tests were presented first followed by the working memory tests. After these, spatial tasks, fluid intelligence tests, and controlled attention tasks were presented in succession.

There were no breaks longer than 5 minutes between tests.

Data Analyses

Structural equation modeling and hierarchical multiple regression analyses were used to test the major hypothesized models.

Model specification. The major latent variables examined were processing speed, working memory and controlled attention. The measured variables are described in the measures section in the previous section. Two mediational models were proposed. In the first model shown in Figure 2 (Model 1), working memory mediates the relation between processing speed and fluid intelligence as indexed by the RPM. There are two hypothesized paths, a visuo-spatial path and a verbal-numerical path. Each path has processing speed and working memory latent variables indicated by two variables each. The two processing speed latent variables are correlated and the two working memory latent variables are also correlated. This model is replicated for each of the SILS subtests (Figures 3 and 4).

In the second hypothesized model shown in Figure 5 (Model 2), a new latent variable, controlled attention, is indicated by six observed variables: two versions of Stroop (congruent), two versions of Stroop (Incongruent), and two versions of set switching. Controlled attention has a direct path to fluid intelligence as indicated by RPM. Working memory is indicated by 7 variables; spatial working memory, 2 conditions each of visual, number, and letter working memory variables. The model was used to test the hypotheses that working memory mediates the relation between controlled attention and the RPM index of fluid intelligence. This model is again replicated for the SILS subtests (Figures 6 and 7).

RESULTS

Distribution of data

Distributions were examined to establish the presence of outliers in the data. The descriptive statistics including tests of normality for the measures are presented in Table 3. The 1-back condition of letter and number working memory had kurtosis and skewness values greater than the acceptable limits (Tabachnik & Fidel, 2001). The scores were examined for outliers. There were five outliers among the 1-back condition of letter and number working memory. Removing the outliers did not improve the distribution of the variables implying that the large kurtosis and skewness values were not due to the outliers. The two working memory variables are relatively easy requiring very little cognitive processing. This resulted in a ceiling effect. The mean scores were 8.7 and 8.9 for the number and letter working memory variables respectively out of a maximum score of 10. It is likely that this had an effect on the skewness and kurtosis values.

******Insert Table 3 about here******

Treatment of Missing Data

Missing data ranged between less than 1% and about 9% across all variables. Number working memory (2-back condition) had the highest number of missing observations. Table 4 provides a summary of the variables and the percentage of missing observations. With listwise deletion, the percentage of missing data increased to 14%. The missing observations were deemed to be random since they did not appear to follow any systematic order. On two measures, set switching (20% switches) and Shipley (abstraction), three records were deleted for unexplained extreme scores on the test. Missing values were imputed for respondents with missing values for all variables using the expectation maximization (EM) method since the data were considered missing completely at random (MCAR). This method is recommended by Alison (2004) over the more common methods of mean substitution, listwise and pairwise deletion when data are not missing in a systematic manner. With the imputation, all missing observations were substituted through the iterative process used by the EM method in SPSS.

******_**Insert Table 4 about here**_******

Data Analyses

The original intention was to test each set of hypotheses associated with the two models using structural equation modeling (SEM). SEM was conducted to test i) the confirmatory factor analyses for each latent factor, ii) the structural model, and iii) the hypothesized model. The same set of analyses were conducted for each indicator of fluid intelligence. When it was discovered that SEM modeling was not possible because of negative variance obtained for some of the latent factors, multiple regression analyses were conducted to test the relation between each latent factor and the fluid intelligence tests and also to test the Cascade model within each cognitive modality. The initial results from the SEM analyses are first presented.

Structural equation modeling (SEM)

See Table 3 for percentage of missing data by task. The total sample size used was 206.

Model Assessment

The chi-square (χ^2) and four indices were selected to assess the fit of the models. These are Root mean square error of approximation (RMSEA), Standardised Root mean square residual (SRMR), Comparative fit index (CFI), Global fit index (GFI). The chi-square is the overall test of the model that assesses the discrepancy between the sample and fitted covariance matrix (Hu & Bentler, 1998). The bigger the discrepancy the bigger the chi square is likely to be. A significant and large chi-square implies a poor fit. However, chi-square is sensitive to sample size (and number of parameters) and therefore it is important that other indices are considered. The RMSEA is a robust index that corrects for model complexity (Kline, 2005). Hu and Bentler (1999) have suggested $\leq$ .5 for a good fitting model. Good fitting models also have CFI $\geq$ .95, SRMR $\leq$ .05, GFI $\geq$ .90, and RMSEA <.05.

Testing the hypotheses that Working Memory mediates the Relation Between Processing Speed and Fluid intelligence

Correlations among processing speed, working memory, and fluid intelligence tests

Correlations among the processing speed, working memory variables, and RPM are presented in Table 5. The general expectation was that measures within specified latent factors would correlate more highly with each other than with other measures in other latent factors. Contrary to our expectation, the correlations among measures within the visuo-spatial working memory latent factor were not strong. The highest correlations were observed between number and letter scans and also between spatial working memory and RPM. Visual scan also correlated significantly with coloured visual scan but not with spatial working memory. Spatial working memory was significantly correlated with most measures with the exception of visual scan, number scan, and visual working memory (1-back condition). Although significant, most of these correlations were relatively low. There were significant correlations between RPM and spatial scan, number working memory (1- and 2-back conditions), and letter working memory (2-back condition). No significant correlations were observed between RPM and number scan, letter scan, visual scan, and with visual working memory (1-back condition). It should be noted that while significant correlations were observed between RPM and coloured visual scan these were low (rs = .14 and .15 respectively).

The Shipley verbal and abstraction tests were not significantly correlated with any of the speed measures. They were both correlated with the 2-back conditions of verbal and number working memory and also with spatial working memory. The correlations were highest between Shipley abstraction and spatial working memory. Consistent with expectations, the observed correlation was higher between Shipley verbal test and letter working memory than between Shipley test of abstraction and letter working memory. We also found a stronger relation between Shipley test of abstraction and number working memory than between Shipley verbal test and number and letter working memory.

*******Insert Table 5 about here*******

Preliminary Model Evaluation

The main interest here was to test two broad hypotheses that 1) working memory accounts for the relation between processing speed and RPM, and that 2) the visuo-spatial measures would have a stronger relation with RPM than the verbal-numerical measures. To address these questions, structural equation model (SEM) was conducted to test the model described in Figure 2 (Model1).

As specified earlier, the initial analysis involved a confirmatory factor analysis for each of the latent factors testing the hypothesised model.

The Verbal-Numerical speed factor was made up of the motor speed test, number scan, and letter scan variables. The motor speed test was initially designed to measure individual differences in motor speed. The content is made up of letters and numbers and was therefore conveniently added to the indicators of the verbal-numerical latent variable to achieve identification. The Verbal-Numerical working memory factor was made up of the 1- and 2-back conditions of the number and letter working memory variables. The Visual-Spatial speed factor was made of the Visual scan, Coloured visual scan, and Spatial scan variables. The Visual-Spatial working memory factor was composed of the mean score of the spatial working memory variable and 1- and 2-back conditions of the Visual working memory.

The measurement models were tested for the four latent factors (verbal-numerical processing speed, verbal-numerical working memory, and visual-spatial processing speed, and visual-spatial working memory). Three of the measurement models had reasonable chi square coefficients and fit indices. The results are presented in Table 6. With respect to visuo-spatial (VS) speed, there was a negative variance on the error of the coloured visual scan. The solution therefore was not admissible. Given that the correlations among the variables within this latent factor were very low, VS speed latent factor was modified by dropping spatial scan which had no significant correlation with the other two measures. The two paths were constrained to 1.0 in order for the model to be identified. The subsequent model yielded a chi-square of 0. A low chi square coefficient is usually an indication of a good fitting model however a chi square of 0 is obtained when there is no degree of freedom. This is not necessarily an indication of a good fit (Kline, 2005).

The full measurement model had negative variance and was therefore rejected. Subsequently, five modifications were made to the model to improve fit. The residuals of letter working memory (2-back condition), spatial working memory, and visual working memory (2-back condition) were correlated. The residuals of number working memory (1-back condition) and spatial scan were correlated. Direct paths were added between visuo-spatial speed to motor speed and from verbal-numerical speed to spatial scan. Finally, the residuals of the 2-back conditions of verbal-numerical working memory and visuo-spatial working memory were correlated. The modified measurement model had a significant chi-square. However, the fit indices met the criteria for good fit, χ^2 (55) = 76.324, p =.03, RMSEA =.043, SRMR = .060, CFI = .944, GFI = .949. The results are presented in Table 6. The modified model is shown in Figure 8 (Model 1b).

*********Insert Table 6 about here*********

*********Insert Table 7 about here*********

*********Insert Figure 8 about here*********

The structural model resulted in a negative variance. The hypothesized relationships among processing speed, working memory and fluid intelligence could therefore not be tested further using SEM. Additional modifications to the model did not resolve the problem. The observed negative variance occurred probably because of the low correlations among some of the indicators of the latent factors, for example, within visuo-spatial speed and visuo-spatial working memory. Secondly, modifications involving coloured visual scan and visual working memory resulted in significant changes to the results of the model indicating that the inclusion of those variables will provide unstable results. Multiple regression analyses were therefore used to test the predicted hypotheses.

Multiple Regression Analyses

This section of the analysis tested the hypothesis that i) working memory accounts for the relation between processing speed and RPM and that ii) the Cascade model is supported within the visuo-spatial modality and not within the verbal-numerical modality.

Two sets of multiple regression analyses were conducted for each fluid intelligence test. The first set tested the broad relations among processing speed and working memory constructs on one hand and the fluid intelligence test on the other and the second set tested the Cascade model within the visuo-spatial and verbal-numerical modalities separately.

Processing Speed and RPM

To test for the variance in RPM accounted for by the processing speed variables, a standard multiple regression was computed between the set of six variables that measure processing speed and RPM. The results were significant accounting for 11.3% of the variance explained in RPM, $F\ (6, 199) = 4.22$, $p < .001$. Only two of the measures accounted for unique variance, spatial scan and motor speed. The squared semipartial correlation for spatial scan was .068 ($p < .001$). The significant result observed for the motor speed test was not expected. This is due to suppression since it was not significant when there was no other variable in the model. The original intention was to use the motor speed measure as an estimate of respondents' motor response speed and when significant remove the effects from the responses on the other measures. The results for Letter scan was close to significance ($p < .055$). Its squared semipartial correlation was .02. The results from this analysis are presented in Table 8.

******Insert Table 8 about here******

Working Memory and RPM

Multiple regression was computed to predict scores on RPM from the set of seven variables that measure working memory. The overall results were significant, $R^2 = .235$, $F(7, 198) = 8.681$ $p < .001$. The working memory variables accounted for about 23.5% of the variance in RPM. Spatial working memory accounted for unique variance in RPM ($sr^2 = .07$, $p < .001$). Letter working memory (2-back) also had a unique variance ($sr^2 = .02$, $p < .05$). None of the other working memory measures reached significance level. Results from this analysis are presented in Table 9.

******Insert Table 9 about here******

Test for the Cascade model (processing speed, working memory, and RPM)

To test for mediation (Cascade model), certain conditions must be met (Baron & Kenny, 1986). The first condition is that there must be a significant relation between the predictor and the hypothesised mediator. The second condition is that the predictor should significantly predict the dependent variable. The third condition is that the hypothesised mediator should be significantly related to the dependent variable in the context of the predictor and finally the relationship between the predictor and the dependent variable is attenuated in the presence of the mediator. With this in mind, three multiple regression analyses are computed. The first analysis is between the dependent variable and the predictor, the second between the dependent variable and the mediator, and the third is between both predictor and mediator and the dependent variable.

To test for the Cascade model, a simultaneous multiple regression was conducted between the significant predictor measures within the processing speed latent variable (i.e., spatial scan) and working memory latent variable (i.e., letter working memory (2-back) and spatial working memory) and the outcome variable RPM. The overall results were significant, $R^2 = .234$, $F(3, 205) = 20.513$, $p < .001$. (See results in Table 10). Spatial scan, letter working memory, and spatial working memory accounted for unique variance in RPM ($sr^2 = .03, .04, .09$).The unstandardised regression coefficient associated with spatial scan was reduced by about 33%. The Sobel test (Baron and Kenny, 1986) which tests the significance of the change in regression coefficients could not be used here because there were multiple variables in the model. There were increases in the unstandardised regression coefficients associated with letter working memory and spatial working memory. This is possibly due to the fewer number of variables in the model compared to previously tested models. The significant (although reduced) relation between spatial scan and RPM suggests that working memory partially mediated the relation between spatial scan and RPM.

In previous research (e.g., Fry & Hale, 1996), the authors examined the effects of the latent factors of processing speed and working memory on RPM and not the individual effects of the measures. To be consistent with analyses from these studies, we conducted another multiple regression to test the hypothesized relationship among processing speed, working memory and RPM. In this analysis we examined the effects of all the variables within processing speed and working memory (both significant and non-significant) on RPM. It must be mentioned that this is not consistent with all the conditions for mediational analysis mentioned earlier (Baron & Kenny, 1986).

The results from this analysis showed that the overall results were significant, $R^2 = .323$, $F(13, 192) = 7.051$, $p < .001$. Results are presented in Table 11. Results from this analysis showed that number scan and letter scan accounted for significant variance in RPM contrary to what was observed in the previous regression analysis. This implied that there is some suppression between these predictors and the working memory variables. Consistent with the previous results, spatial scan accounted for significant variance in RPM. The unstandardised regression coefficients associated with number, letter, and spatial scans were significant (B = .398, 665, and .329 respectively). With respect to the working memory predictors, there was some consistency in the results. Spatial working memory and letter working memory (2-back condition) accounted for significant variance in RPM just as had been observed previously. There was a reduction in the regression coefficients associated with spatial scan. Spatial scan, which was the only predictor that accounted for unique variance when only the processing speed measures were estimated was reduced by about 34%. The Sobel test which tests the significance of the change in regression coefficients could not be used here since there were multiple predictors and mediators in the model.

When both mediational analyses testing the Cascade model are put together we find that there appears to be partial mediation between working memory and processing speed.

This provides only partial support for the Cascade model. The expected significant relation between the processing speed measures and RPM was not completely supported. Secondly, working memory only partially reduced the variance shared between spatial scan and RPM. The significant variance accounted for by letter and number scans were due to suppression which indicates that it is their association with the working memory measures that make them stronger predictors of RPM.

*********Insert Table 10 about here*********

*********Insert Table 11 about here*********

Test for the Cascade model within the verbal-numerical modality

Multiple regressions were again conducted to test if the Cascade model was true within the verbal-numerical modality. In other words, does working memory account for the relation between processing speed and RPM within the verbal-numerical modality? The first multiple regression conducted showed that verbal-numerical processing speed did not significantly predict RPM, $R^2 = .03$, $F (3, 202) = 2.106$, $p < .101$. The B weight associated with number scan however was significant ($B = .423$, $p = .034$). Results of this analysis are presented in Table 12. A second multiple regression analysis was conducted in which working memory was used to predict RPM. The results showed a significant multiple R squared, $R^2 = .157$, $F (4, 201) = 9.333$, $p < .001$. The 1-back condition of number working memory and 2-back condition of letter working memory accounted for unique variance in RPM. One of the conditions for a mediational analysis is a significant relation between the predictor (processing speed) and the outcome (RPM). We could not compute a third multiple regression to test for the Cascade since there was no significant relation between processing speed and RPM. Within the verbal-numerical modality, the results support a stronger relation between working memory and RPM than between processing speed and RPM. The results are presented in Table 13.

*********Insert Table 12 about here*********

*********Insert Table 13 about here*********

Test of the Cascade model within the visuo-spatial modality

Another series of multiple regression analyses were conducted to test the independent and joint effects of processing speed and working memory on RPM within the visuo-spatial modality. The results showed that visuo-spatial processing speed accounted for significant variance in RPM, R^2=.076, F (3, 202) = 5.186, $p < .002$. Only spatial scan accounted for unique variance in RPM (B = .448, $sr^2 = .05$, $p <.001$). The results are presented in Table 14. A second multiple regression to test for relation between visuo-spatial working memory and RPM showed that the working memory measures accounted for 18.8% of the variance in RPM, R^2=.188, F (3, 202) = 15.596, $p < .001$. Visual working memory (2-back) and spatial working memory accounted for unique variance in RPM ($srs^2 = .03$, $p < .013$ and .14, $p <$ .001 respectively). The results are presented in Table 15. A third multiple regression was conducted to test for the Cascade model. In this analysis, both processing speed and working memory variables were included in the model. The overall model was significant accounting for 22.3% of the variance in RPM, R^2=.223, F (6, 199) = 9.499, $p < .001$. The 2-back condition of visual working memory and spatial working memory unique for significant variance in RPM. Spatial scan also accounted for unique variance. However the B weight associated with spatial scan was reduced by 22.1%. This indicates that the working memory variables partially mediated the relation between spatial scan and RPM. Results from the mediational analysis are presented in Table 16.

*********Insert Table 14 about here*********

*********Insert Table 15 about here*********

*********Insert Table 16 about here*********

To sum up, compared to processing speed, working memory was a consistent predictor of RPM in both the visuo-spatial and verbal-numerical modality. However, the results provide only partial support for the Cascade model within the visuo-spatial modality but not the verbal-numerical modality.

Processing Speed, working memory and Shipley verbal test

Multiple regression analyses were conducted to test the hypothesis that working memory accounted for the relation between processing speed and Shipley verbal test. Initial multiple regression analyses tested the relationship between processing speed and working memory on one hand and the Shipley verbal test on other. Subsequent multiple regression were also conducted to test the same hypothesis within the verbal-numerical and visuo-spatial modalities.

Processing speed and Shipley verbal test

Processing speed did not account for significant variance in the Shipley verbal test, F (6, 199) = .899, $p = .497$, accounting for only 2.6% of the variance in the Shipley verbal test. The results therefore do not support a significant relation between any of the measures of the processing speed construct and the Shipley verbal test. The results are presented in Table 17.

*********Insert Table 17 about here*********

Working memory and Shipley verbal test

Working memory accounted for significant variance in the Shipley verbal test, $R^2 = .117$, F (7, 198) = 3.757, $p < .001$. The working memory variables accounted for 11.7% of the variance in RPM. Only the 2-back condition of the letter working memory accounted for significant variance in RPM ($sr^2 = .06$, $p < .001$). Results from this analysis are presented in Table 18.

*********Insert Table 18 about here*********

Test for the Cascade model (processing speed, working memory, and Shipley verbal test)

As stated earlier, certain conditions must be met to test for mediation. One of the conditions is that the predictor (processing speed) should be significantly related to the outcome (Shipley verbal test). This condition was not met and therefore we could not test the hypothesized relation among speed, working memory and Shipley verbal test. The data therefore does not support Cascade model.

Testing for the Cascade model within the verbal-numerical modality - Shipley verbal

To test whether the measures of working memory accounted for the relation between measures of processing speed and the Shipley verbal test within the verbal-numerical modality, we again conducted three multiple regression analyses. The first analysis tested the relation between measures of processing speed and Shipley verbal test, the second tested the relation between working memory and Shipley verbal test, and the third tested the simultaneous effects of both measures of both processing speed and working memory and the Shipley verbal test.

Consistent with the previous results on the relation between processing speed and the Shipley test, processing speed was not significantly related to performance on the Shipley verbal test, $F\ (2, 202) = .954, p = .415$. The results are presented in Table 19.

The results from the second multiple regression analysis showed a significant R squared, $R^2 = .106$, $F\ (4, 201) = 5.590, p < .001$). The 2-back condition of letter working memory accounted for unique variance in Shipley verbal test ($sr^2 = .06, p <.001$). (See Table 20 for the results).

Since there was no significant relation between processing speed and the Shipley verbal test, we could not test for mediation. The data does not support the Cascade model for the Shipley verbal test within the verbal-numerical modality.

*********Insert Table 19 about here*********

*********Insert Table 20 about here*********

Testing for the Cascade model within the visuo-spatial modality - Shipley verbal test

Within the visuo-spatial modality, the processing speed construct was not significantly related to the Shipley verbal test, F (3, 202) = .650, $p < .584$. As a set, the measures accounted for a total of 1% of the variance in the Shipley verbal test. Working memory was also not significantly related to the Shipley verbal test within the visuo-spatial modality, $R^2 = .034$, F (3, 202) = .233, $p < .075$). The model accounted for 4.5% of the variance in Shipley verbal test. Spatial working memory accounted for 3% of the unique variance in the fluid intelligence measure ($p < .01$). The results did not provide support for the Cascade model for the Shipley verbal test within the visuo-spatial modality. The results are presented in Tables 21 and 22.

******Insert Table 21 about here******

******Insert Table 22 about here******

Processing Speed, working memory and Shipley test of abstraction

Processing speed and Shipley test of abstraction

With respect to Shipley test of abstraction, the multiple regression conducted to estimate the amount of variance accounted for by measures of processing speed was not significant, F (6, 199) = .534, $p = .782$, accounting for 1.6% of the variance in the fluid intelligence measure. Consistent with the results on the Shipley verbal test none of the processing speed measures in the model accounted for significant variance in the Shipley test of abstraction indicating a weak relation between speed and Shipley test of abstraction. The results are presented in Table 23.

*********Insert Table 23 about here*********

Working memory and Shipley test of abstraction

The multiple regression analysis testing the effects of working memory on Shipley test of abstraction showed a significant R squared, $R^2 = .165$, $F(7, 198) = 5.601$, $p < .001$. The working memory variables accounted for about 16.5% of the variance in the Shipley abstract test. However, only the spatial working memory accounted for significant variance in Shipley abstract test ($sr^2 = .05$, $p < .001$). Results from this analysis are presented in Table 24.

*********Insert Table 24 about here*********

Test for the Cascade model – processing speed, working memory, and Shipley test of abstraction

Since there was no significant relation between processing speed and the Shipley abstract test, we could not test for mediation. The data does not support the Cascade model for the Shipley test of abstraction.

Testing for the Cascade model within the verbal-numerical modality - Shipley test of Abstraction

As a construct, verbal-numerical processing speed did not account for significant variance in the Shipley test of Abstraction, $F(3, 202) = .378$, $p < .769$, and neither did any of the processing speed measures. The overall multiple R squared was less than 1%. There was however, a significant relation between the working memory variables and the Shipley test of abstraction $R^2 = .109$, $F(4, 201) = 6.156$, $p < .001$. Only the 2-back condition of letter working memory accounted for unique variance in the Shipley test of abstraction ($sr^2 = .03$, $p < .017$).

Since there was no significant relation between verbal-numerical processing speed and the Shipley test of abstraction, we could not test for mediation between working memory and processing speed. The data therefore do not support the Cascade model within the verbal-numerical modality. Results are presented in Tables in 25 and 26.

*********Insert Table 25 about here*********

*********Insert Table 26 about here*********

Testing for the Cascade model within the visuo-spatial modality - Shipley test of Abstraction

It was hypothesised that visuo-spatial working memory would mediate the relation between visuo-spatial processing speed and the Shipley test of abstraction. The initial multiple regression analysis showed that visuo-spatial processing speed did not account for significant variance in the Shipley test of abstraction, $F(3, 202) = .607$, $p < .611$. Visuo-spatial processing speed accounted for less than 1% of the total variance in the Shipley test of abstraction. None of the measures in the analysis accounted for unique variance. A second multiple regression showed that working memory was significantly related to the Shipley test of abstraction. The overall multiple R squared was significant, $R^2 = .125$, $F(3, 202) = 9.658$, $p < .001$. Only spatial working memory had unique variance in the Shipley test of abstraction ($sr^2 = .10$). Results are presented in Tables in 27 and 28.

*********Insert Table 27 about here*********

*********Insert Table 28 about here*********

The mediational analysis could not be tested because the relationship between processing speed and working memory was not significant. The data therefore does not support the Cascade model for Shipley test of abstraction within the visuo-spatial modality.

To summarise these analyses, it was observed that there was some differentiation between the working memory measures and the Shipley tests. Visuo-spatial working memory accounted for significant variance in the Shipley test of abstraction but not in the Shipley verbal test. Verbal-numerical working memory accounted for significant variance in both Shipley tests, however the magnitude of the variance shared with the Shipley verbal test was larger than with Shipley test of abstraction. It appeared that the relation between working memory and the Shipley tests was stronger when the Shipley and working memory tests were measured within the same cognitive modality. Processing speed did not account for significant variance in the Shipley tests and therefore there was no support for the hypothesis that working memory accounted for the relationship between processing speed and the Shipley tests.

Correlations among Controlled attention, working memory and Fluid intelligence

Correlations for controlled attention working memory, and fluid intelligence measures are presented in Table 29. It was expected that the measures within a latent factor would correlate more strongly with each other than with other measures. The correlations were consistent with the expectation especially among the variables measuring the controlled attention construct. The highest correlation was observed between the two Set switching measures. The next highest correlations were observed among the Stroop measures. With respect to the working memory measures, the correlations ranged from low to moderate. Correlations between visual working memory (2-back) and the other measures were weak.

*********Insert Table 29 about here*********

Controlled Attention, Working Memory and Fluid intelligence

In this section SEM was used to test the relation among controlled attention, working memory, and the fluid intelligence tests. We tested the hypotheses that i) both controlled attention and working memory had significant effects on RPM, and that ii) controlled attention explained the relation between working memory and the fluid intelligence tests. The analyses included Confirmatory factor analysis (CFA) and analyses of the structural model. The third part of the analysis involved estimating the effects of controlled attention and working memory on each of the fluid intelligence tests.

Preliminary Model Evaluation

Figure 5 illustrates the general hypothesis that both controlled attention and working memory directly affect RPM, and that the relation between controlled attention and RPM will be accounted for by working memory. The controlled attention latent variable had six indicators. There were four measures of Stroop (two measures each of the two conditions described earlier) and the two measures of Set Switching. The working memory latent variable had seven indicators made up of two conditions each of number, letter, and visual working memory and spatial working memory. The spatial working memory was the only unpaired measure.

The measurement models were tested for working memory and controlled attention. Working memory had satisfactory fit (χ^2 (14) = 21.771, p =.083, RMSEA =.052, SRMR =

.050, CFI = .946, GFI = .975). One modification was made to the model by correlating the residuals of number working memory and visual working memory.

Results for the controlled attention were rejected based on a significant chi-square and fit indices outside the acceptance criteria. Two modifications were made to the model by correlating residuals of the set switching measures and also correlating the residuals of Stroop (Congruent 50% targets) and Stroop (Incongruent 50% targets). Subsequent results showed a significant chi square. However, three of the fit indices were good, χ^2 (7) = 15.487, p =.030, RMSEA =.077, SRMR = .045, CFI = .986, GFI = .975.

The full measurement model also had significant chi-square. Four modifications were made to the model by correlating the residuals of spatial working memory and the set switching measures and between number working memory (1-back) and the set switching measures. The model fit improved significantly following the modifications, χ^2 (66) = 79.544, p =.122, RMSEA =.032, SRMR = .050, CFI = .984, GFI = .949. The results for the confirmatory factor analyses are presented in Table 30 and the results for the standardized parameter estimates are presented in Table 31.

******Insert Table 30 about here******

******Insert Table 31 about here******

The hypothesis that controlled attention accounted for the relation between working memory and RPM was rejected based on a significant chi-square. One post hoc model modification was performed by adding a path from set switching (20% switches) to RPM and from spatial working memory to RPM. The revised model (Model 2b) had a reasonable chi-square and reasonable fit indices, χ^2 (66) = 79.544, p =.122, RMSEA =.032, SRMR = .050, CFI = .984, GFI = .949. (See Table 32 for SEM results). With the exception of visual working memory (1-back condition), all the measured variables had significant factor loadings on the respective latent variables. The factor loadings for the two set switching measures were relatively lower than the other measures on the controlled attention latent factor. The correlation between the residuals was .71 indicating that about 50% of the variance shared between the factors is not related to the controlled attention construct.

******_**Insert Table 32 about here**_******

******_**Insert Table 33 about here**_******

The correlation between the two latent factors was significant (r = .51). The predicted relation between working memory and RPM was significant (β = .33) however the relation between the controlled attention latent factor and RPM was not significant. It is important to note here that the direct path between controlled attention and RPM was significant in initial analysis (β = .24). When the model was modified by adding a unique path between the more difficult version of set switching (50% switches) and RPM, the path between controlled attention and RPM was no longer significant. This indicates that most of the variance between controlled attention and RPM is accounted for by the more difficult version of the set switching measure (50% switches). The paths between spatial working memory and RPM, and between set switching (50% switches) and RPM were both significant (βs = .19 and .24 respectively).

******_**Insert Figure 9 about here**_******

Testing for Mediation between working memory and controlled attention on RPM

The hypothesised model between controlled attention and RPM was significant, χ^2 (7) = 15.49, p=.030, however, all the fit indices were good and therefore meet the criteria for a good fit. As mentioned previously, the factor loading between controlled attention and RPM was initially significant (β = .24). This dropped significantly with the addition of a unique path between set switching and RPM.

With the inclusion of working memory in the analysis, the path coefficient between the Controlled attention latent factor dropped by 62.5% while that of working memory dropped by less than 6%. The results therefore showed that working memory mediated the relation between controlled attention and RPM.

To sum up the results, it was observed that both working memory and controlled attention had significant paths leading to RPM. Spatial working memory and set switching (50% switches) had unique paths to RPM. The hypothesised model that controlled attention mediated the relation between working memory and RPM was not supported.

Controlled Attention, Working Memory and Shipley verbal test

Another SEM was conducted to examine the relations among controlled attention, working memory, and Shipley verbal test. The preliminary model estimation results are presented in Table 33. The model testing the independent and joint effects of controlled attention and working memory on the Shipley verbal test had a significant chi square (χ^2 (72) = 130.0, p < .001). With the exception of RMSEA, the fit indices were reasonable. One post hoc modification was made by adding a path between letter working memory (2-back) and Shipley verbal test. The subsequent model resulted in a significant chi square but had reasonable fit indices, χ^2 (70) = 113.5, p =.001, RMSEA =.054, SRMR = .06, CFI = .939, GFI = .932.This led to an improvement in the fit indices but the chi square remained significant (Table 32). With the addition of the path, the factor loading between working memory and Shipley verbal test was reduced to 0 implying that the effect of working memory on Shipley is explained by the letter working memory task. The path between controlled attention and Shipley verbal test remained significant.

******Insert Figure 10 about here*******

Controlled Attention, Working Memory and Shipley test of Abstraction

Consistent with the results from the previous section, the initial analysis resulted in a significant chi square and poor RMSEA value. A path was added between spatial working memory and Shipley test of abstraction. Although the fit indices improved the chi square remained significant (Table 32). The results showed a significant path between working memory and Shipley test of abstraction. The path between spatial working memory and Shipley test of abstraction was also significant. The path between controlled attention and Shipley test of abstraction was not significant. The parameter estimates for CFA and structural models are presented in Tables 31 and 33.

******Insert Figure 11 about here*******

Testing for Mediation between working memory and controlled attention on the Shipley tests

There is no support for mediation between working memory and controlled attention with respect to Shipley verbal test. Controlled attention had a significant effect on Shipley verbal test. This however did not affect the relation between letter working memory and Shipley verbal test.

With respect to Shipley test of abstraction, working memory appears to mediate the relation between controlled attention and Shipley test of abstraction. With both working memory and controlled attention in the model, the path between controlled attention and Shipley test of abstraction was reduced to .07 from .18.

DISCUSSION

Two theories that are currently used to explain individual differences in fluid intelligence are the Cascade model and the Controlled Attention hypothesis. Fry and Hale (1996, 2000) proposed that age-related differences in processing speed, working memory and fluid intelligence is a Cascade in which the age-related changes in tests of fluid intelligence are accounted for by individual differences in tests of working memory which in turn are depended on processing speed. Kane and Engle (2002, 2003) have suggested, on the other hand, that the relation between working memory and fluid intelligence is mediated by controlled attention. Their main contention is that there is a common variance between working memory and controlled attention and it is this variance that predicts performance on fluid intelligence tests. Thus, for both approaches, the working memory and fluid intelligence relation can be explained by single-factor models.

There is one difficulty with these assertions. In the first place, there is evidence that suggests that working memory is a multiple construct system and so a model that does not take this into account will not adequately explain individual differences in fluid intelligence. In order to study this, we examined the relation between processing speed, working memory and fluid intelligence within two cognitive modalities, verbal-numerical and visuo-spatial. The goal was to test if the correlation between measures that required resources within one cognitive modality would be more strongly related than measures from a different cognitive modality. The relation was examined using two measures of fluid intelligence that tap resources from the visuo-spatial and verbal-numerical domains.

The second goal of this study was to empirically test how the relation between working memory and controlled attention accounts for individual differences in fluid intelligence. Specifically, we examined whether variance common to working memory and controlled attention predicted performance on RPM and fluid intelligence in general.

Processing speed and Fluid intelligence

The primary goal in this thesis was to examine the relation between processing speed and fluid intelligence and to examine whether the observed relations would be the same for both RPM and the Shipley tests. The multiple regression analyses showed a significant but limited association between the speed construct and performance on RPM. This association did not hold for the verbal-numerical speed measures but did for the spatial scan measures. For the Shipley tests, there were no significant relations with the processing speed tasks.

These findings are not entirely consistent with those from several previous studies (e.g., Kail and Salthouse, 1994; Kail, 1991; Salthouse, 1996) in which processing speed did predict performance on intelligence tests, especially by adulthood although not necessarily in childhood. Because the current study was conducted with young adults, we expected that the association between the processing speed measures and fluid intelligence would be stable and consistent. One reason for the observed differences may be the measures used in the current study. For example, Kail (1991) used six speed tests to examine changes in response time among children and young adults. Three of the tests required that participants make some judgment pertaining to codes, numbers or pictures. These are tests that require some amount of complex processing and therefore demand complex cognition. The cognitive requirements for these tasks are likely to tap into higher cognitive skills so that performance may reflect more than mere speed of processing. In fact, Kail noted that one possible mechanism for increased speed is acquisition of task-specific knowledge (Kail, 1991). Task specific knowledge is always a confound when examining speed and intelligence relations especially among different age groups, and may also explain possible individual differences in performance. In the current study the processing speed measures were based on Sternberg's number and letter comparison test which required very little cognitive processing, and therefore individual differences may be attributed mainly to speed in performance.

Multiple Working Memory Systems

One of the major findings of this thesis was the demonstration that visuo-spatial and verbal-numerical working memory relate to intelligence differentially. The visuo-spatial working memory construct was more strongly related to RPM than the verbal-numerical working memory whereas the verbal-numerical working memory was more strongly related to Shipley verbal tests. This challenges the hypothesis that working memory is a domain-general construct, a view espoused by Kane and Engle (1992; but cf. Shah & Miyake, 1996) and which also forms part of the basis for attributing a strong relation between working memory and fluid intelligence. If working memory were a domain-general construct, one would expect a consistent relation between working memory and fluid intelligence irrespective of the modality. This, as we have shown, is not the case.

Previous evidence in support of the domain-specific working memory hypothesis came from research from both cognitive and neurophysiological studies (Haavisto & Lehto, 2004; Shah & Miyake, 1996; Smith, & Jonides, 1997). Shah and Miyake (1996) provided empirical support for the separation of working memory into spatial thinking and verbal or language processing. According to Shah and Miyake (1996) there appears to be a multiple resource system; spatial and language resources which support the "... execution of complex processes necessary to perform a spatial visualization task and the maintenance of various intermediate results of the spatial manipulations. Likewise, the verbal pool should support both the execution of various language processes and the maintenance of partial products of comprehension to be operated on further …" spatial visualisation and language processes" (Shah & Miyake, 1996, pp. 21). The authors concluded that their data support the separation of spatial and verbal aspects of working memory. Our findings support this separation.

Working memory and fluid intelligence

For a better understanding of the relation between working memory and fluid intelligence, one needs to examine multiple measures within separable cognitive modalities to account for variance due to both the content and executive attention aspects in working memory. The effect of working memory on RPM was significant. However, as mentioned previously, the spatial working memory task accounted for more variance than any of the other working memory measures. The only other task that accounted for significant variance in RPM was the two-back condition of the letter working memory test.

The significant relation between fluid intelligence tests and some of the working memory tasks is consistent with previous findings (Ackerman et al., 2002; 2005; Buehner, Krumm, & Pick, 2005; Carpenter, et al., 1990; Colom et al, 2003; Conway, Cowan, Bunting, Theriault, & Minkoff, 2002; Engle, Tuholski, et al., 1999; Haavisto & Lehto, 2004; Kyllonen & Christal, 1990; Kane, Hambrick, and Conway, 2005). However, these studies did not systematically examine working memory within separate modalities. Across the various tasks, these associations between working memory and fluid intelligence have varied from between .20 (Ackerman et al. 2005) and .93 (Kyllonen & Christal, 1990) depending on the tasks used. It could be that much of this variation in results is due to the choice of working memory modality.

Consistent with these findings with the RPM, both Shipley tests related significantly to working memory. Letter working memory accounted uniquely for variance in the Shipley verbal test and spatial working memory for the Shipley test of abstraction. The effect of letter working memory on the Shipley verbal test is not surprising because of the similarity in the content of the two. These results support the need to examine both task content (verbal versus spatial) and executive attention (task parameters and requirements) in the relation between working memory and fluid intelligence.

As our findings show, there is no question about the effect of working memory on fluid intelligence; however, there is controversy about whether we can assume working memory to be a single cognitive construct and thereby explain its relation with fluid intelligence in a single factor model. In a review of studies that have examined the relation between working memory and fluid intelligence, Ackerman et al. (2005) stressed that the working memory and fluid intelligence correlations are usually exaggerated and have often been interpreted as if working memory and intelligence are isomorphic (Ackerman et al., 2005, pp. 38). Consistent with the findings from this study, Ackerman (2005) observed that the highest correlations in the literature are observed within modalities. For example, they found that RPM had higher correlations with spatial working memory and spatial reasoning tasks than it did with verbal or numerical working memory, although no study had examined both modalities in the same subject sample.

We can draw three conclusions from the preceding discussion: (i) that working memory has separable constructs; and (ii) that spatial working memory is more significantly related to RPM than verbal-numerical working memory; and (iii) that the modality factor accounts for more variance than factors surrounding the controlled attention demands of the tasks.

Processing speed, working memory and fluid intelligence

According to the Cascade model, age-related increases in speed of processing lead to increases in working memory performance which leads to increases in fluid intelligence performance. While we did not explore developmental trends in this study, it was our contention that this Cascade pattern of the speed and working memory relations would be found only within the visuo-spatial modality or in situations when processing speed, working memory, and fluid intelligence tests are measured in the same modality. We believe this is case because tasks within the same cognitive modality are more likely to be related than with tasks from other modalities. We tested this as a single factor model in which processing speed and working memory were aggregated as single latent constructs (domain-free) and then tested the single factor model within the visuo-spatial and verbal-numerical modalities separately. In the first instance, the Cascade model appeared to be partially supported with working memory accounting for some of the variance between processing speed and RPM. In the second set of analyses, the Cascade model was partially supported within the visuo-spatial modality but not within the verbal-numerical modality. Partial support within the visuo-spatial modality was due to the significant association between spatial speed and RPM. There was no other significant association between any of the speed tasks and RPM or the Shipley tests, findings which would have been necessary to provide support for the validation of the Cascade model.

The partial support for the Cascade model within the visuo-spatial domain is not completely surprising. The spatial scan, spatial working memory, and RPM are all tasks based on spatial relations. However, Fry and Hale's (1996) Cascade model is based on working memory in general and what we have shown is that this may be the case only within the visuo-spatial modality. They in fact presented only measures assessing the spatial modality and yet interpreted them as if they represented general cognition.

In conclusion, it can be emphasised that the Cascade model may only explain the relation between processing speed, working memory and RPM within the visual-spatial modality and may be replicated among speed, working memory and fluid intelligence tasks from the same cognitive modality. We must however state that this conclusion is done with some caution as the correlations within modalities were lower than we expected. This in turn led to difficulties in the SEM analysis. These are discussed in more detail below.

Controlled attention and fluid intelligence

Engle (2002), Engle, Kane, Tuholski et al. (1999), and Kane and Engle (2002) have argued that it is the executive attention mechanism of working memory that predicts intelligence, i.e., that *g* is a reflection of executive attention. To test this, we examined whether the variance common to controlled attention and working memory explained the individual differences in RPM and Shipley tests. Results from the SEM analysis showed that there was a direct path between controlled attention and RPM. This path however, was accounted for specifically by the more difficult version of set switching (50% targets) and not by other aspects of executive attention. Furthermore, we isolated the variance common to the two set-switching tasks in order to separate variance stemming from the particular modality of this task and variance due to the set-switching per se. When task-independent variance is isolated by means of the additive factor technique (partialing out the 20%-set-switching performance from the 50%-set-switching performance), the relation to RPM diminishes. This means that the relation between set switching and RPM may be explained more by task modality than by the executive attention mechanism. This is discussed further below.

The results were a little less direct with regard to the Shipley tests. Results from the SEM showed a direct path between controlled attention construct and Shipley verbal test, but no significant path to Shipley abstract test. In both cases, however, and consistent with the RPM results, there was no significant effect between the residualised set switching measure and the Shipley tests.

Set switching and fluid intelligence

Our research showed that set switching has a stronger effect on RPM than Stroop but this was not found for the Shipley tests. In fact, no significant relations were observed between Stroop and any of the fluid intelligence tests. One cannot however conclude firmly that set switching and not inhibition may be related to RPM since the effect of set switching on the fluid intelligence tests were not consistent. It should however be emphasised that the Stroop measures were paper and pencil versions adopted for the current study and so its validity has not been clearly established in previous research. However, the resulting RTs did conform to the pattern expected.

The available evidence suggests that the effect of set switching may be related to the modality of the task. On set switching, subjects needed to keep a set of decision rules in memory and apply one rule or another when a specific target is encountered. There is some similarity between this and RPM in which for each problem subjects will try different rules until a solution is found. The difference however is that the decision rules in set switching are known and fixed (in our case, there are only two rules).

Very few studies have directly examined the relation between set switching and fluid intelligence. One of these examined whether it was set switching or processing speed that mediated the relation between age and higher order cognition such as fluid intelligence (Salthouse, Fristoe, McGuthry & Hambrick, 1998). They showed that while cost of switching had a negative impact on performance on the fluid intelligence tasks, the relation between processing speed and fluid intelligence was stronger. Furthermore, the variance shared between set switching and fluid intelligence was accounted for by speed. However, the participants in that study were between 20 and 80 years. It is possible that in such a sample, processing speed will account for most of the difference in cognitive function simply because of the wide disparities in speed across this large span.

The relations among controlled attention, working memory and fluid intelligence

Our findings showed that the working memory construct had a direct path to both RPM and the Shipley abstract test. On the other hand, the controlled attention construct accounted for variance only on the Shipley verbal test, and this effect disappeared when letter working memory was entered first.

The first model which tested the simultaneous effects of working memory and controlled attention on RPM suggests that it was working memory that explained the effects of controlled attention on RPM with unique variance, i.e., this effect was obtained even when the variance due to controlled attention was removed. The implication is that there is some variance common to controlled attention and working memory which is partly reflected in the RPM performance. This contrasts with the view postulated by Kane, Engle, and colleagues that it is controlled attention that mediates the relation between working memory and fluid intelligence. Rather, the available evidence indicates that it is working memory that mediates the relation between controlled attention and fluid intelligence. This has implications. For example, the effect of working memory on RPM is probably due more to the content than to the executive attention components. This was also demonstrated on the Shipley verbal test.

Another conclusion concerns the need to differentiate modality of the tests in this research paradigm. Kane and Engle (2002) did not directly test the relation between controlled or executive attention on fluid intelligence. Their main source of inference comes from the notion that since different working tasks correlated reasonably with fluid intelligence, variance common to all working memory tasks (executive attention) explains the relation between working memory and fluid intelligence. As we have seen, when all measures are studied simultaneously, a different picture emerges.

The implications of this discussion for the relation between controlled attention, working memory and fluid intelligence are quite instructive. There appears to be some overlap in variance between controlled attention and the RPM. However, this relation is not strong and appears to be dependent on the specific task requirements of set switching rather than the executive or controlled attention properties as has been suggested by Kane and Engle. Of particular interest, the reversed situation obtained with the Shipley verbal test: controlled attention appear to mediate the relation between working memory and Shipley verbal test rather than the other way round as found for the RPM.

Implications for measuring cognitive functions

We know from this thesis that the relation among processing speed, working memory and fluid intelligence is modality-specific. This pattern was also observed for the relation among controlled attention, working memory, and fluid intelligence. This model differs from previous models that postulate that the mechanisms that explain the relations are based purely on the process aspects of working memory. Our demonstration that while there may be some variance attributable to the process aspects or the executive mechanism of the tasks, the relations may depend more on the task modality has implications for the measurement of *g* in neurocognitive research. It also has implications for current conceptualisation of *g* as unitary construct that relates to all cognitive abilities. The findings also provide some insight into the difficulties that may arise when we try to localize *g* in the brain.

RPM has been used widely as a fluid intelligence test as well as a test that measures Spearman's *g* and has been labelled as the "gold standard" for inductive reasoning tasks (Alderton & Larson, 1990; Jensen, 1998; Mills, Ablard, & Brody, 1993). As this study showed, performance on RPM was more strongly related to the spatial tasks than to other tasks. We believe this was the case because RPM is based on abstract spatial relations, i.e., on nonverbal inductive reasoning. We propose therefore that performance on RPM is based on an underlying spatial ability which may be necessary for superior performance on the test.

There is some agreement among neurocognitive scientists that the prefrontal cortex is involved in problem-solving, especially when it involves coordinating or supervision such as in working memory tasks (Duncan, 1990; Duncan, Emslie, Williams, 1996; Duncan, Seitz, Kolodny, Bor, Herzog, et al., 2000; Fuster, 2005; Morton, 2005). In several contributions to the literature on *g*, John Duncan and his colleagues have suggested that general intelligence is largely a reflection of the controlled functions of the frontal lobes. For example, Duncan, Seitz, Kolodny, Bor, Herzog, et al. (2000) have indicated in a PET study that spatial and verbal tasks that measured *g* activated similar areas in the frontal cortex. They concluded that *g* is associated with a neural system restricted to the frontal cortex. This has two implications. First, tasks that measure *g* assess specific abilities that are unique to the frontal cortex, and second, *g* represents a single factor of intelligence. These conclusions are not entirely supported by research, especially research on frontal lobe functions. Our findings also contradict both these assertions. In fact, we showed that both RPM and the Shipley tests have unique variance attributable not only to the executive mechanisms but also to task modality that may not necessarily be related to frontal lobe function. We therefore support the notion that *g* may be a cognitive construct that taps skills from multiple resources (which may possibly include the frontal lobe). This is consistent with more recent suggestions by John Duncan that a single factor *g* model may not be an adequate explanation. According to Duncan (2005), linking frontal lobe to general intelligence is at best at the preliminary level, and further states that available data do not fully support an exclusive account of general intelligence in terms of a prefrontal function.

Limitations of the present study

There are some limitations in this study that pertain to subject composition and selection of measures. There was overrepresentation of female participants among the participants as a result of the demographic distribution of the subject pool (females = 80%). The participants were all first year university students selected from Southern Ontario. Some caution should therefore be exercised in generalising these results to all males or all young adult females for that matter. The bias in subject participation also made it difficult to examine gender differences.

One thing that may have improved this study is the use of multiple tasks for each construct within each modality. The use of a single task for each construct (e.g., n-back visual working, etc.) while adequate, did not allow for flexibility in creating the latent factors, especially when applying the complex statistical method of structural equation modeling, which is based on moderate to high correlations among variables within a factor. A more stringent approach would have been the use of two or three tasks for each latent factor. For example, there could have been a second or third visual working memory task in addition to the 1- and 2-back visual working memory task. This, however, has implications for resources and time. The current study took over two hours. Studies that last longer than two hours will give rise to different concerns because of potential fatigue and boredom.

In this study, working memory was defined and measured as the continuous processing and transformation of different pieces of information during problem-solving without making distinction between different types of processing. However, some studies have shown that working memory can be categorised into content and functional components. According to Oberauer et al. (2003), the functional component can be further categorised into "storage in the context of processing", coordination, and supervision. Oberauer et al. (2003) have reported that the storage and coordination aspects are highly correlated and therefore not separable. Supervision, however, is a separable component in working memory. We did not consider separating supervision and coordination in this thesis. Findings from this study can therefore only associate working memory and intelligence in a more general sense (a general executive attention component). Future research should consider examining the relation between these different constructs (executive processes) and fluid intelligence.

Another limitation in this study pertains to the measurement of the processing speed and working memory constructs, especially within specific modalities. The tests that measured the visuo-spatial and verbal-numerical processing speed and visuo-spatial working memory constructs did not seem to share a lot of variance. This probably resulted in the poor fit indices obtained for some of the latent factors in the SEM analyses. On the one hand, this seems to be a reflection of the difficulties involved in trying to group together different tasks purported to measure the same construct. On the other hand, it might also be related to the attempt in this study to control for task parameters across modalities. For example, it was observed in this study that spatial scan correlated with number and letter scans than it did with the visual scan tests. The spatial, number, and letter scans were based on Sternberg's comparison task. As stated earlier, one of the objectives that guided the selection and construction of tests was to maintain consistency of task requirements across tests and modalities when possible. Creating composite variables helps minimize this problem. However, when there is the need to examine the effects of individual measures as was the case in this study, the use of multiple tests described earlier in this section might be more appropriate. The use of multiple tests would give the researcher the opportunity during initial analyses to exclude tests with low correlations to other same-modality tests. This is only possible when there are enough measures to reliably measure a construct.

The final limitation to this study concerns conclusions drawn from mediational analyses. Mediational analyses are generally designed to examine the mechanisms of how two variables, a predictor and a mediator cause an outcome variable. The conclusions drawn from the results must be taken with some caution because results from mediational analyses only confirm that the data are consistent with the hypothesis and do not explicitly exclude the possibility of other relations between the predictor and the outcome. For example, our results do not necessarily imply that individual differences in fluid intelligence cannot underlie differences in working memory and processing speed. In most cases, this conclusion can only be drawn after directly testing for the relation, which we cannot do because we have multiple predictors. However, Fry and Hale (1996) found that when they predicted processing speed from RPM, the path between processing speed and RPM is significant. However, this relation is weak when compared to the path between age and processing speed implying that processing speed is predicted more by changes in age than by changes in RPM.

Considerations for future research

The separability of cognitive modality for the working memory, processing speed and fluid intelligence tests was confirmed in this study. We examined verbal and numerical measures as a single modality and spatial and visual measures within as another modality. Future research should also examine all four cognitive modalities separately. This would involve including more tasks in order to adequately measure each modality, which would of course lengthen testing time and complicate the analyses.

The primary goal of this study was to examine the relation of speed and working memory on RPM. Although the effects of speed and working memory on the Shipley tests were also examined, it is also important for future researchers to focus on measuring general intelligence from a broader perspective that is, measuring general intelligence by using multiple tasks in order to cover multiple cognitive modalities and skills. This can be also be approached by creating a latent intelligence factor by measuring fluid intelligence using different tests.

Future research should focus on the design of paradigms that can expand the technique of additive factors used in this study in order to test different levels of difficulty within each cognitive modality. The use of the additive factor in this study was limited to some of the tasks. A study that fully incorporates the method on all tasks will be able to measure two aspects of the task, effects due to difficulty level or increased demands on controlled attention and task modality.

Another area of research that will greatly contribute to the understanding of cognitive processes in fluid intelligence is the use of neurophysiological methods to investigate speed and working memory relations. Electrophysiological techniques can provide more accurate measures of processing speed than paper and pencil based cognitive tasks. This can help measure individual differences in processing speed before motor response and in effect control for confound of motor response delays. With appropriate paradigms the use of ERPs can also help us understand (to a limited extent) specific brain regions involved in the solving the tasks. We also need to explore the relation between executive functions and intelligence controlling for working memory and processing speed in order to isolate the effects of frontal lobe function. This will help address questions about executive control influence on intelligence. Current research in neuropsychology suggests that there is no single construct that explains the brain and executive function relation. One way to understand these complex relations is to explore the relation between different cognitive modalities and functions while relating these to intelligence. These will broaden the purview of executive attention, working memory and intelligence relation.

Summary of findings

There two main goals in this study. One was to test the Cascade model using two different fluid intelligence tests covering two modalities (Fry & Hale, 1996). The second goal was to test the hypothesis that working memory mediates the relation between controlled attention and fluid intelligence (Kane & Engle, 2002). In this study, it was decided to examine processing speed and working memory as modality-specific constructs. Based on previous research, two modalities, the visuo-spatial and verbal-numeric modalities were used. Based on this, it was decided that task requirements be consistent across modalities in order to facilitate comparison both within and across modalities. For some of the speed and working memory tasks the additive method was adopted to enable us compare and relate performance at different levels of difficulty to the fluid intelligence measure.

As a construct, processing speed was not consistently related to fluid intelligence. The spatial scan test was the only measure that was reliably associated with the RPM. In contrast, the working memory construct was consistently related to fluid intelligence although the relations varied across domains between the tests. Tests of spatial working memory had higher correlations with RPM and the Shipley test of abstraction while letter working memory had higher correlation with the Shipley verbal test.

There was limited support for the Cascade model, but only within the visuo-spatial domain and not the verbal-numerical domain. More importantly, the Cascade model was partially supported only for the RPM and not the Shipley tests. This suggests that shared content between the spatial measures and RPM was the major source of the shared variance (Haavisto & Lehto, 2004), especially due to the lack of relation with the Shipley test within the verbal-numerical domain.

There was partial support for the hypothesis that controlled attention and working memory both predict performance on fluid intelligence. Controlled attention and working memory latent factors were correlated moderately. They both predicted RPM and the Shipley test of abstraction but not the Shipley verbal test. The results did not support the hypothesis that controlled attention mediates the relation between working memory and fluid intelligence, but potentially the contrary; working memory may mediate the relation between controlled attention and fluid intelligence for the RPM and the Shipley test of abstraction. With respect to the Shipley verbal test, there was no support for mediation because both controlled attention and working memory shared equal variance with the Shipley verbal test.

General Conclusions

It has been theorised that working memory accounts for most of the variance in fluid intelligence. Fry and Hale (1996) postulated that it accounts for the relation between processing speed and intelligence. Kane and colleagues have also suggested that the executive properties of working memory explain the variance it shares with intelligence (Kane, et al. 2003). The results from the current study support the general finding that working memory is associated with fluid intelligence. However this association was found to vary based on the content of the measures (both working memory and fluid intelligence tests). The study further provided support for the view that working memory is not a unitary construct as has been proposed (Kane et al. 2005). Therefore assessing working memory as a unitary construct is narrow and does not provide an adequate explanation for observed individual differences. More importantly, a unitary construct provides a biased estimate that may not account for variance due to both the executive attention mechanism and task modality.

This also leads us to conclude that the Cascade model is only supported when the measures of the construct have shared content. In other words, it is only a reliable model within a specific modality where the measures are considerably correlated.

REFERENCES

Ackerman, P. L., Beir, M. E., & Boyle, M. D. (2002). Individual differences in working memory within a nomological network of cognitive and perceptual speed abilities. *Journal of Experimental Psychology: General,* 131(4), 567-589.

Ackerman, P. L., Beir, M. E., & Boyle, M. D. (2005). Working memory and intelligence: The same of different constructs? *Psychological Bulletin*, 131(1), 30-60.

Anderson, M. (1988). Inspection time, information processing and the development of intelligence. *British Journal of Developmental Psychology*, 6(1), 43-57.

Anum, A. & Sefa-Dedeh, A. (1996). A Normative Study of the Raven's Coloured Progressive Matrices Among school children in Ghana. An unpublished dissertation.

Baddeley, A. (1986). Working memory. Oxford psychology series, 11. New York, NY, US: Clarendon Press/Oxford University Press.

Baddeley, A. and Logie, R. H. (1999). Working memory: The multiple-component model. In Miyake, A. & Shah, Priti (Eds.). (1999). Models of working memory: Mechanisms of active maintenance and executive control. New York: Cambridge University Press.

Baddeley, A. and Hitch, G., J. (1974). Working memory. In G. H. Bower (Ed.) The psychology of learning and motivation: Advances in research and theory. New York: Academic Press.

Baddeley, A. and Hitch, G., J. (1994). Developments in the concept of working memory. *Neuropsychology*, 8(4), 485-493.

Belsky, J. K. (1990). The Psychology of Aging Theory, Research, and Interventions. Pacific Grove: Brooks/Cole Publishing Company.

Bjorkland, D. F. & Harnishfeger, K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Developmental Review,* 10, 48-71.

Bors, D. A. & Forrin, B. (1995). Age, speed of information processing, recall, and fluid intelligence. *Intelligence*, 20(3), 229-248.

Bowers, T. L. & Pantle, M. L. (1998). Shipley Institute for living scale and the Kaufman Brief Intelligence Test as screening instruments for intelligence. *Assessment*, 5(2) 187-195.

Brand, A. N. (1981). Word matching and lexical decisions: A visual half-field study. *Psychological Laboratory*, 27, 28

Buehner, M., Krumm, S., & Pick, M. (2005). Reasoning=working memory≠attention. *Intelligence*, 33(3), 251-272.

Buehner, M., Mangels, M., Krumm, S., & Ziegler, M.(2005). Are Working Memory and Attention Related Constructs? *Journal of Individual Differences*, 26(3), 121-131.

Cerella, J. and Hale (1994). The rise and fall in information-processing rates over the life span. *Acta Psychologica. Special Issue: Life span changes in human performance*, 86(2-3), 109-197.

Colom, R., Flores-Medoza, C., & Rebollo, I. (2003). Working memory and intelligence. *Personality and Individual Differences*, 34, 33-39.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, 30(2), 163-184.

Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, 7(12), 547-552.

Craik, F. I. M., & Jennings, J. M. (1992). Human memory. Craik, F. I. M; & Salthouse, Timothy A. (Eds.). (1992). The handbook of aging and cognition (51-110). Hillsdale, NJ, England: Lawrence Erlbaum Associates, Inc.

Dalton, J. E., Pederson, S. L., McEntyre, W. L. (1987). A comparison of the Shipley vs. WAIS--R subtests in predicting WAIS--R Full Scale IQ. *Journal of Clinical Psychology*, 43(2), 278-280.

Danthiir, V. Wilhelm, O., Schulze, R., Roberts, R. D. (2005). Factor structure and validity of paper-and-pencil measures of mental speed: Evidence for a higher-order model? *Intelligence*, 33(5), 491-514.

Das-Smaal, E. A., de Jong, P. F., & Koopmans, J. R. (1993). Working memory, attentional regulation and the Star Counting Test. *Personality & Individual Differences,* 14(6), 815-824.

Dempster, F. N. (1991). Inhibitory processes: a neglected dimension of intelligence. *Intelligence*, 15(2), 157-173.

Dempster, F. N., & Cooney, J. B. (1982). Individual differences in digit span, susceptibility to proactive interference, and aptitude/achievement test scores. *Intelligence*, 6(4), 399-416

Dugbartey, A. T., Sanchez, P. N., Rosenbaum, G. H., Mahurin, R. K., Davis, J. M., & Townes, B. D. (1999). WAIS--III Matrix Reasoning Test performance in a mixed clinical sample. *Clinical Neuropsychologist*, 13(4), 396-404.

Duncan, J. (1995). Attention, intelligence, and the frontal lobes. In Gazzaniga, Michael S. (Ed). The cognitive neurosciences (721-733). Cambridge, MA, US: The MIT Press.

Duncan, J. (2005). Frontal lobe function and general intelligence. Why it matters. *Cortex*, 41(2), 215-217.

Duncan, J., Burgess, P., & Emslie, H. (1995;) Fluid intelligence after frontal lobe lesions. *Neuropsychologia*, 33(3), 261-268.

Duncan, J., Seitz, R. J., Kolodny, J., Bor, D., Herzog, H., Ahmed, A., Newell, F. N., & Emslie, H. (2000). *Science*. 289(5478), 457.

Engle, R. W., Tuholski, S. W., Laughlin, J., E; & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, 128(3), 309-331.

Ferlisi, M.-C. and Segalowitz, S. (1999). Speed of perceptual processing, spatial ability and executive functions underlying fluid intelligence in childhood and adolescence. An unpublished thesis.

Fry, A. F. & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental Cascade. *Psychological Science*, 7(4), 237-241.

Fuster, J. M. (2000). Proceedings of the human cerebral cortex: From gene to structure and function. Prefrontal neurons in networks of executive memory. *Brain Research Bulletin*, 25(5) 331-336.

Fuster, J. M. (1991). The prefrontal cortex and its relation to behavior. In Holstege, Gerte (Ed). Role of the forebrain in sensation and behavior. Progress in brain research. New York, NY, US: Elsevier Science.

Gentner, D. & Toupin, C. (1986). Systematicity and surface similarity in the development of analogy. *Cognitive Science*, 10(3), 277-300.

Gottfredson, L. S (1997). Why g matters: The complexity of everyday life. *Intelligence*, 24(1), 79-132.

Haavisto, M.-L.; & Lehto, J. E. (2005). Fluid/spatial and crystallized intelligence in relation to domain-specific working memory: A latent-variable approach. *Learning and Individual Differences*, 15(1), 1-21.

Hale, S. & Fry, A. F. (2000). Relationships among processing speed, working memory and fluid intelligence in children. *Biological Psychology. Special Issue: Behavior, event-related potentials, and neuroimaging: A lifespan perspective*, 54(1-3), 1-34

Hale, S., Bronik, M. D., & Fry, A. F. (1997). Verbal and spatial working memory in school-age children: Developmental differences in susceptibility to interference. *Developmental Psychology*, 33(2), 364-371.

Hale, S. & Jansen, J. (1994). Global processing-time coefficients characterize individual and group differences in cognitive speed. *Psychological Science*, 5(6), 384-389.

Hale, S. (1990). A global developmental trend in cognitive processing speed. *Child Development,* 61(3), 653-663.

Hartman, M., & Potter, G. (1998). Sources of age differences on the Rey-Osterrieth Complex Figure Test. *The Clinical Psychologist*, 14(4) 513-524.

Hasher, L. & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In Gordon H. Bower (Ed). The psychology of learning and motivation: Advances in research and theory, 22 (193-225). San Diego, CA, US: Academic Press, Inc.

Hitch and Halliday (1983). Development of memory span for spoken words: The role of rehearsal and item identification processes. *British Journal of Developmental Psychology,* 11(2), 159-169.

Jenkins, L., Myerson, J., Hale, S. & Fry, A. F. (1999), Individual and developmental differences in working memory across the life span. *Psychonomic Bulletin & Review,* 6(1), 28-40.

Jensen, A. R. (1987). Psychometric g as a focus of concerted research effort. *Intelligence*, 11(3), 193-198.

Jensen. A. R. (1993). Why is reaction time correlated with psychometric g? *Current Directions in Psychological Science*, 2(2), 53-56.

Jensen, A. R. (1998). The g factor. The science of mental ability. Westport, CT, US: Praeger Publishers/Greenwood Publishing Group, Inc.

Johnson, W., Bouchard, T. J., Krueger, R. F., Mcgue, M., & Gottesman, I. I. (2004). Just one g: Consistent results from three test batteries. *Intelligence*, 32(1), 95-107.

Just, M., A. and Carpenter, P., A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, 99(1), 122-149.

Kail, R. (1991b). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin*, 109(3), 490-501.

Kail, R. (1991c). Processing time declines exponentially during childhood and adolescence. *Developmental Psychology*, 27(2), 259-266.

Kail, R. & Park, Y-S. (1994). Processing time, articulation time, and memory span. *Journal of Experimental Child Psychology,* 57(2), 281-291

Kail, R., & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica. Special Issue: Life span changes in human performance,* 86(2-3), 199-225.

Kane, M. J. (2003). The intelligent brain in conflict. *Trends in Cognitive Sciences*, 7(9), 375-377.

Kane, M., J., Beckley, M. K., Conway, A. R. A., Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, 130(2), 169-183.

Kane, M. J. & Engel, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, 132(1), 47-70.

Kane, M. J. & Engel, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*, 9(4), 637-671.

Kane, M. J., Hambrick, D. Z., & Conway, A. R. A. (2005). Working memory capacity and fluid intelligence are strongly constructs: Comment on Ackerman, Beier, and Boyle (2005). *Psychological Bulletin*, 131, No. 1, 66-71.

Kline, R. B. (2005). Principles and practice of structural equation modeling (2^{nd}). New York, NY, US: Guilford Press.

Kyllonen, P. C. & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?! *Intelligence*, 14(4), 389-433.

Lohman, D. F. (1993). Component scores as residual variation: or Why the intercept correlates best. *Intelligence*, 19(1), 1-11.

Matthews, T. D., Lassiter, K., & Habedank, H. (2001). Validity of two brief measures: The General Abilities Measure for Adults and the Shipley Institute of Living Scale. *Perceptual and Motor Skills*, 92(3,Pt1), 881-887.

McGivern, R. F., Andersen, J., Byrd, D., Mutter, K. L., & Reilly, J. (2003). Cognitive efficiency on a match to sample task decreases at the onset of puberty in children. *Brain & Cognition*, 50(1), 73-89.

Miyake, A., Friedman, N, P., Rettinger, D. A., Shah, P., & Hegarty, M (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of Experimental Psychology: General*, 130(4), 621-640.

Neubauer, A. & Bucik, V. (1996). The mental speed-IQ relationship: Unitary or modular? *Intelligence*, 22(1), 23-48.

Norman, D. A. & Shalice, T. (1986). Attention to action: willed an automatic processing of behaviour. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.) consciousness and self-regulation: Advances in research and theory. 4, 1-18. New York: Plenum press.

Oberauer, K., Süß, H -M; Schulze, R. W. O; Wittmann, W.W. (2000). Working memory capacity--facets of a cognitive ability construct. *Personality and Individual Differences,* 29(6), 1017-1045.

Phay, A. (1990). Shipley Institute of Living Scale: I. Moderator variables. *Medical Psychotherapy: An International Journal*, 3, 1-15.

Phillips, L. H., & Della S. S. (1998). Aging, intelligence, and anatomical segregation in the frontal lobes. *Learning and Individual Differences. Special Issue: Modularity and intelligence,* 10(3), 217-243.

Prabhakaran, V., Smith, J. A. L., Desmond, Glover, G. H. & Gabrieli, (1997). Neural substrates of fluid Reasoning: An fMRI study of neocortical activation during performance of the Raven's Progressive Matrices Test. *Cognitive Psychology*, 33(1), 43-63.

Raven, J. C. (1956). Standard Progressive Matrices. Oxford: Oxford Psychological Press.

Retzlaff, P., Slicner, N., & Gibertini, M. (1986). Predicting WAIS--R scores from the Shipley Institute of Living Scale in a homogeneous sample. *Journal of Clinical Psychology*, 42(2), 357-359.

Roberts, R., J., & Pennington, B. F. (1996). An interactive framework for examining prefrontal cognitive processes. *Developmental Neuropsychology. Special Issue: Executive functions in children*, 12(1), 105-126.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, 124(2), 207-231.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, 126(3), 211-227

Salthouse, T. A. (1994). How many causes are there of aging-related decrements in cognitive functioning? *Developmental Review*, 14(4), 413-437.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, 103(3), 403-428.

Salthouse, T. A. (2000). Aging and measures of processing speed. *Biological Psychology. Special Issue: Behavior, event-related potentials, and neuroimaging: A lifespan perspective,* 54(1-3), 35-54.

Salthouse, T. A.; Fristoe, N.; McGuthry, K. E.; & Hambrick, D. Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychology and Aging*, 13(3), 445-461.

Segalowitz, S., Cricenti, S., & San Cartier, N. (1998).The speed correlate of memory changes at adolescence. Unpublished manuscript.

Shah, P. & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General*, 125(1), 4-27.

Shah, P. & Miyake, A. (1999). Models of working memory. An introduction. In Models of working memory: Mechanisms of active maintenance and executive control. Miyake and Shah (Eds.). New York, NY, US: Cambridge University Press.

Shrout, P. E, & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods*, 7(4), 422-445.

Smith, E. E., & Jonides, J. (1997). Working memory: A view from neuroimaging. *Cognitive Psychology*, 33(1), 5-42.

Stelzl, I., Merz, F., Ehlers, T. & Remer, H. (1995).The effect of schooling on the development of fluid and crystallized intelligence: A quasi-experimental study. *Intelligence*, 21(3), 279-296.

Süß, H-M., Oberauer, K. & Wittmann, W. W. (2002). Working-memory capacity explains reasoning ability – and a little bit more. *Intelligence*, 30, 261-288.

Tabachnick, B. G. & Fidell, L. S. (2001). Using Multivariate Statistics. 4th Edition. Allyn and Bacon, Boston.

Van Veen, V. & Carter, C. S. (2002). The anterior cingulate AS a conflict monitor: fMRI and ERP studies. *Physiology & Behavior. Special Issue: The Pittsburgh special issue.* 77(4-5), 477-482.

Vernon, P. (1989). The generality of g. *Personality and individual differences*, 10(7), 803-804.

Vincent, K. R. & Cox , J. A. (1974). A re-evaluation of Raven's Standard Progressive Matrices. *Journal of Psychology: Interdisciplinary and Applied.* 88(2), 299-303.

Wager, T. D., Jonides, J., Smith, E. E, & Nichols, T. E. (2005). Toward a taxonomy of attention shifting: Individual differences in fMRI during multiple shift types. *Cognitive, Affective & Behavioral Neuroscience.* 5(2), 127-143.

Wechsler D. (1974). Intelligence defined and undefined: A relativistic appraisal. *American Psychologist*, 30(2), 135-139.

Weiss, J. L., & Schell, R. E. (1991). Estimating WAIS--R IQ from the Shipley Institute of Living Scale: A replication. *Journal of Clinical Psychology,* 47(4), 558-562.

Wilson, C., Nettelbeck, T., Turnbull, C., & Young, R. (1992). IT, IQ and age: A comparison of developmental functions. *British Journal of Developmental Psychology*, 10(2), 179-188.

Zachary, R. A. (1986). Shipley Institute of Living Scales – Revised Manual. Los Angeles: Western Psychological Services.

Zachary, R. A., Crumpton, E., & Spiegel, D. E. (1985). Estimating WAIS--R IQ from the Shipley Institute of Living Scale. *Journal of Clinical Psychology*, 41(4), 532-540.

Zook, N. A., Davalos, D. B., DeLosh, E. L., & Davis, H. P. (2004). Working memory, inhibition, and fluid intelligence as predictors of performance on Tower of Hanoi and

London tasks. *Brain and Cognition*, 56(3), 286-292.

APPENDICES

Appendix A: Tables

Table 1. Distribution of respondents by sex

Sex	Number	Percentage	Mean age [a]
Females	166	80.10	20.32
Males	40	19.50	19.33
Total	206		19.52

[a] Based on 197 cases.

Table 2. List of abbreviations of variables and order of presentation

Order	Abbreviation	Variables
1	MSKILL	Motor Speed
2	VIS_SCAN	Visual Scan
3	VIS_SCAN_CO	Coloured visual scan
4	SPAT_SCAN	Spatial scan
5	NUM_SCAN	Number scan
6	LET_SCAN	Letter scan
7	LET_WM 1	Letter working memory (1-back)
8	LET_WM 2	Letter working memory (2-back)
9	NUM_WM 1	Number working memory (1-back)
10	NUM_WM 2	Number working memory (2-back)
11	VIS_WM 1	Visual working memory (1-back)
12	VIS_WM 2	Visual working memory (2-back)
13	SPAT_WM	Spatial working memory measures
14	STROOP_CON 1	Stroop Congruent (25% targets)
15	STROOP_CON 2	Stroop Congruent (50% targets)
16	STROOP_INC 1	Stroop Incongruent (25% targets)
17	STROOP_INC 2	Stroop Incongruent (50% targets)
18	SET_SWIT 1	Set switching measures (50% targets)
19	SET_SWIT 2	Set switching measures (20% targets)
20	RPM	Raven's progressive matrices
21	SHIP_VERB	Shipley verbal test
22	SHIP_ABS	Shipley abstract test

Table 3. Descriptive Statistics for All Measures

Variables	M	SD	SE	Skewness	Kurtosis
Motor speed	24.80	6.12	.43	.20	-.22
Letter scan	20.35	2.74	.19	.88	1.37
Number scan	21.49	2.94	.21	.55	1.64
Visual scan	32.49	7.17	.50	-.02	-.77
Coloured visual scan	29.81	4.59	.32	-.87	.13
Spatial scan	16.17	3.29	.23	-.91	.03
Letter working memory 1	8.92	.45	.03	-2.21	11.97
Letter working memory 2	8.53	1.59	.11	-1.4	2.1
Number working memory 1	8.68	.74	.05	-3.12	13.61
Number working memory 2	8.41	1.64	.11	-1.5	4.1
Visual working memory 1	9.63	.68	.05	-1.76	2.78
Visual working memory 2	6.98	1.80	.13	-.85	.21
Spatial working memory	8.12	2.30	.16	-.45	-.02
Stroop (Congruent) 1	16.06	5.16	.36	.19	-.07
Stroop (Congruent) 2	31.26	8.40	.60	-.43	.75
Stroop (Incongruent) 1	17.68	4.18	.30	-.34	.55
Stroop (Incongruent) 2	23.31	5.27	.49	-.275	.45
Set switching 1	48.17	15.21	1.1	.25	.29
Set switching 2	67.95	21.32	1.5	-.04	-.56
Shipley Verbal	27.16	4.49	.32	.32	2.77
Shipley Number	13.95	3.83	.27	.25	.29
RPM	46.24	6.44	.45	-.84	.70

Table 4. Percentage of missing data by variable

Variables	N	Percent missing
Motor speed	198	3.90
Letter scan	205	.49
Number scan	202	1.90
Visual scan	204	.97
Coloured visual scan	203	1.50
Spatial scan	200	2.90
Letter working memory	204	.97
Letter working memory 2	193	4.40
Number working memory 1	202	1.90
Number working memory 2	197	4.30
Visual working memory 1	202	1.90
Visual working memory 2	198	3.90
Spatial working memory	206	0
Stroop (Congruent) 1	205	.49
Stroop (Congruent) 2	204	.97
Stroop (Incongruent) 1	202	1.90
Stroop (Incongruent) 2	203	1.50
Set switching	201	2.40
Set switching 2	202	1.90
Shipley (Verbal)	198	3.90
Shipley (Numerical)	198	3.90
RPM	206	0

Table 5. Correlation matrix for processing speed, working memory and fluid intelligence measures

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Motor speed															
	Verbal-numerical speed															
2	Number scan	.14*														
3	Letter scan	.15*	.64**													
	Visuo-spatial speed															
4	Visual scan	.28**	.16*	.11												
5	Col vis. Scan	.24**	.13	.07	.49**											
6	Spatial scan	.13	.28**	.23**	-.01	.10										
	Verbal-numerical WM															
7	Number WM 1	.13	.07	.10	.13	.27**	.25**									
8	Number WM 2	-.04	.05	.16*	-.04	.10	.20**	.38**								
9	Letter WM 1	.06	.12	.11	.14*	.16*	.11	.17*	.17*							
10	Letter WM 2	.00	.07	.12	.01	.06	.12	.26**	.44**	.15*						

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Visuo-spatial WM															
11	Vis. WM 1	.03	.10	.15*	.05	.13	-.04	-.02	.04	.10	.03					
12	Vis. WM 2	.01	.09	.14	.10	.05	.05	.18**	.25**	.10	.34**	.11				
13	Spatial WM	.06	.05	.14*	.06	.21**	.14*	.31**	.28**	.17*	.30**	.12	.15*			
	Fluid intelligence															
14	RPM	-.09	.08	-.04	.08	.14*	.24**	.25**	.28**	.15*	.32**	.02	.21**	.40**		
15	Shipley-verbal	.05	-.07	-.10	-.09	-.03	.03	.11	.21**	.05	.32**	.00	.05	.18**	.26**	
16	Shipley-abstraction	.00	-.07	-.02	-.02	-.09	.00	.19**	.27**	.12	.27**	.04	.13	.34**	.21**	.27**

Note: 1. * $p < .05$; ** $p < .001$. 2. Col vis = Coloured visual scan; Num. WM = Coloured Visual scan; Let. WM = Letter working memory; Vis. = Visual; RPM = Raven's Progressive Matrices. 3. N = 206

Table 6. Fit statistics for visuo-spatial and verbal-numerical CFA – Model 1

	df	χ^2	*p*	RMSEA	SRMR	CFI	GFI
CFA Speed							
VN Speed	0	.000	-		.000	1.000	1.000
VS Speed	0	.000	-		.000	1.000	1.000
CFA WM							
VN WM	2	1.70	.43	.000	.014	1.000	.996
VS WM	2	.260	.88	.000	.015	1.000	.999
Full Measurement model	55	76.324	.03	.043	.060	.944	.949

Note: VN = Verbal-numerical; VS = Visual-spatial; WM = Working memory. Dashes imply alpha values were not calculated.

Table 8. Multiple regression predicting RPM from processing speed.

Variables	B	SE	β	sr^2	p-value
Motor speed	-.165	.075	-.157	.02	.028
Number scan	.249	.195	.114	.00	.203
Letter scan	-.397	.206	-.169	.02	.055
Visual scan	.067	.071	.075	.00	.346
Coloured visual scan	.156	.109	.111	.01	.154
Spatial scan	.499	.138	.255	.06	.000

Table 9. Predicting RPM from working memory.

Variables	B	SE	β	sr^2	p-value
Number WM 1	.939	.616	.108	.01	.129
Number WM 2	.222	.291	.057	.00	.446
Letter WM 1	.681	.920	.048	.00	.460
Letter WM 2	.588	.296	.145	.02	.049
Visual WM 1	-.168	.607	-.018	.00	.782
Visual WM 2	.295	.241	.083	.01	.222
Spatial WM	.825	.191	.294	.07	.000

Table 10. Predicting RPM from processing speed and working memory

Variables	B	SE	β	sr^2	p-value
Spatial scan	.334	.122	.171	.03	.007
Letter WM 2	.822	.263	.203	.04	.002
Spatial WM	.893	.182	.319	.09	.001

Table 11. Predicting RPM from processing speed and working memory (All variables)

Variables	B	SE	β	sr^2	p-value
Motor speed	-.153	.067	-.146	.02	.023
Number scan	.398	.176	.182	.02	.025
Letter scan	-.665	.189	-.283	.04	.001
Visual scan	.079	.064	.088	.01	.218
Coloured visual scan	-.012	.102	-.008	.00	.908
Spatial scan	.329	.128	.168	.02	.011
Number WM 1	.904	.617	.104	.01	.145
Number WM 2	.240	.283	.061	.00	.397
Letter WM 1	.458	.891	.032	.00	.608
Letter WM 2	.569	.283	.140	.01	.046
Visual WM 1	.142	.593	.015	.00	.811
Visual WM 2	.309	.232	.087	.01	.185
Spatial WM	.856	.185	.305	.08	.001

Table 12. Predicting RPM from processing speed within the verbal-numerical modality

Variables	B	SE	β	sr^2	p-value
Motor speed	-.095	.074	-.091	.01	.197
Number scan	.423	.198	.193	.02	.034
Letter scan	-.365	.213	-.155	.01	.088

Table 13. Predicting RPM working memory within the verbal-numerical modality

Variables	B	SE	β	sr^2	p-value
Number WM 1	1.458	.617	.168	.02	.019
Number WM 2	.380	.300	.097	.01	.207
Letter WM 1	1.121	.950	.079	.01	.239
Letter WM 2	.907	.294	.224	.04	.002

Table 14. Predicting RPM from processing speed within the visuo-spatial modality

Variables	B	SE	B	sr^2	p-value
Visual scan	.034	.070	.038	.00	.630
Col Visual scan	.138	.110	.099	.00	.210
Spatial scan	.448	.134	.229	.05	.001

Table 15. Predicting RPM from working memory within the visuo-spatial modality

Variables	B	SE	β	sr^2	p-value
Visual WM 1	-.394	.605	-.042	.00	.516
Visual WM 2	.579	.230	.162	.03	.013
Spatial WM	1.075	.181	.384	.14	.000

Table 16. Predicting RPM from processing speed and working memory within the visuo-spatial modality

Variables	B	SE	β	sr^2	p-value
Processing speed					
Visual scan	.032	.065	.035	.00	.625
Col Visual scan	.039	.104	.028	.00	.710
Spatial scan	.349	.124	.179	.03	.005
Working memory					
Visual WM 1	-.319	.602	-.034	.00	.596
Visual WM 2	.541	.228	.151	.02	.019
Spatial WM	.986	.183	.352	.11	.000

Table 17. Predicting Shipley verbal test from processing speed

Variables	B	SE	Β	sr^2	p-value
Motor speed	.066	.056	.087	.01	.245
Number scan	-.008	.148	-.005	.00	.958
Letter scan	-.186	.156	-.109	.01	.235
Visual scan	-.069	.054	-.106	.01	.201
Col Visual scan	.008	.082	.008	.00	.922
Spatial scan	.066	.104	.047	.00	.526

Table 18. Predicting Shipley verbal test from working memory

Variables	B	SE	β	sr^2	p-value
Number WM 1	.013	.478	.002	.00	.979
Number WM 2	.217	.225	.077	.00	.337
Letter WM 1	-.131	.714	-.013	.00	.854
Letter WM 2	.833	.230	.285	.06	.000
Visual WM 1	-.054	.471	-.008	.00	.909
Visual WM 2	-.196	.187	-.076	.00	.296
Spatial WM	.178	.148	.088	.01	.233

Table 19. Predicting Shipley verbal test from processing speed within the verbal-numerical modality

Variables	B	SE	B	sr^2	*p*
Motor speed	.049	.054	.064	.00	.365
Number scan	-.014	.144	-.009	.00	.922
Letter scan	-.175	.155	-.103	.01	.260

Table 20. Predicting Shipley verbal test from working memory within the verbal-numerical modality

Variables	B	SE	β	sr^2	p-value
Number WM 1	.071	.459	.011	.00	.877
Number WM 2	.225	.223	.079	.00	.314
Letter WM 1	-.074	.707	-.007	.00	.917
Letter WM 2	.821	.219	.280	.06	.000

Table 21. Predicting Shipley verbal test from processing speed within the visuo-spatial modality

Variables	B	SE	B	sr^2	p-value
Speed					
Visual scan	-.065	.052	-.100	.01	.217
Col. Visual scan	.019	.082	.019	.00	.817
Spatial scan	.043	.100	.030	.00	.667

Table 22. Predicting Shipley verbal test from working memory within the visuo-spatial modality

Variables	B	SE	β	sr^2	p-value
Visual scan	-.062	.052	-.096	.014	.233
Col. Visual scan	-.020	.083	-.020	.00	.813
Spatial scan	.009	.100	.007	.00	.927
Visual WM 1	-.096	.482	-.014	.00	.842
Visual wm2	.093	.183	.036	.00	.610
Spatial WM	.376	.147	.186	.03	.011

Table 23. Predicting Shipley test of abstraction from processing speed

Variables	B	SE	Β	sr^2	p-value
Motor speed	-.005	.048	-.008	.00	.912
Number scan	-.144	.126	-.108	.01	.252
Letter scan	.068	.133	.047	.00	.610
Visual scan	-.014	.046	-.025	.00	.763
Col Visual scan	.096	.070	.112	.01	.172
Spatial scan	.014	.089	.011	.00	.879

Table 24. Predicting Shipley test of abstraction from working memory.

Variables	B	SE	β	sr^2	p-value
Number WM 1	.221	.393	.042	.00	.575
Number WM 2	.280	.185	.117	.01	.132
Letter WM 1	.138	.587	.016	.00	.814
Letter WM 2	.312	.189	.126	.01	.101
Visual WM 1	.030	.388	.005	.00	.938
Visual WM 2	.028	.154	.013	.00	.854
Spatial WM	.439	.122	.256	.05	.000

Table 25. Predicting Shipley test of abstraction from processing speed within the verbal-numerical modality

Variables	B	SE	B	sr^2	*p*
Motor speed	.007	.046	.011	.01	.876
Number scan	-.127	.122	-.095	.00	.302
Letter scan	.062	.132	.043	.00	.636

Table 26. Predicting Shipley test of abstraction from working memory within the verbal-numerical modality

Variables	B	SE	β	sr^2	p-value
Number WM 1	.448	.388	.084	.01	.249
Number WM 2	.356	.188	.148	.02	.060
Letter WM 1	.372	.597	.043	.00	.533
Letter WM 2	.443	.185	.179	.03	.017

Table 27. Predicting Shipley test of abstraction from processing speed within the visuo-spatial modality

Variables	B	SE	β	sr^2	p-value
Visual scan	-.021	.044	-.038	.00	.635
Col Visual scan	.092	.069	.108	.01	.184
Spatial scan	-.010	.084	-.009	.00	.903

Table 28. Predicting Shipley test of abstraction from working memory within the visuo-spatial modality

Variables	B	SE	β	sr^2	p-value
Visual WM 1	-.046	.383	-.008	.00	.904
Visual wm2	.186	.146	.085	.01	.204
Spatial WM	.569	.115	.333	.11	.000

Table 29. Correlations among working memory and controlled attention variables

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Working memory															
1	Num. WM 1															
2	Num. WM 2	.38**														
3	Let. WM 1	.27*	.21**													
4	Let WM 2	.29**	.44**	.15*												
5	Vis. WM 1	-.07	.05	.06	.03											
6	Vis. WM 2	.21**	.22**	.12	.34**	.11										
7	Spatial WM	.24*	.25**	.19**	.29**	.14	.11									
	Controlled attention															
8	Stroop (Congruent 1)	.22**	.35**	.12	.19**	.13	.09	.20**								
9	Stroop (Congruent 2)	.19**	.33**	.09	.20**	.15*	.10	.21**	.67**							
10	Stroop (Incong.1)	.23**	.31**	.09	.13	.13	.07	.11*	.60**	.62**						
11	Stroop (Incong. 2)	.26**	.36**	.15*	.13	.15*	.11	.14**	.55**	.40**	.62**					
12	Set Switch. 1	.31**	.25**	.03	.12	-.01	.18*	.32**	.32**	.25**	.32**	.43**				
13	Set Switch. 2	.37**	.30**	.13	.16*	.10	.12	.35**	.33**	.30**	.39*	.47**	.77**			

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Fluid intelligence															
14	RPM	.25**	.26**	.17*	.32**	.04	.21**	.39**	.21**	.18*	.12	.20	.37**	.32**		
15	Shipley-verbal	.09	.18*	.04	31.**	.00	.02	15*	29**	.21**	.17*	.20**	.15*	.15*	.25**	
16	Shipley-abstraction	.20**	.23**	.12	.26**	.04	.09	.31**	.09	.18*	.23**	.22**	.23**	.25**	.20**	.19*

Note: 1. * p <.05; ** p < .01; N = 203.
2. Num. = Number; Let. = Letter; Vis.= Visual; WM = Working memory; Incong. = Incongruent; RPM = Raven's Progressive Matrices.

Table 30. Fit statistics for controlled attention and working memory CFA - Model 2

		df	χ^2	*p*	RMSEA	SRMR	CFI	GFI
Controlled Attention	Baseline	9	181.55	.001	.308	.124	.705	.789
	Modified	7	15.487	.030	.077	.045	.986	.975
Working memory	Baseline	14	21.771	.083	.052	.050	.946	.972
	Modified	13	17.266	.187	.040	.041	.970	.977
Full measurement model	Baseline	61	101.019	.001	.057	.068	.950	.934
	Modified	57	74.940	.057	.039	.051	.977	.949

Table 31. Standardised parameter estimates for Confirmatory Factor Analysis – Model 2

	Measurement model		
	Controlled Attention	Working memory	Full Measurement Model
Controlled attention			
Set Switch. 1	.419		.418
Set Switch. 2	.475		.475
Stroop (Cong.1)	.765		.767
Stroop (Congr. 2)	.818		.814
Stroop (Incong.1)	.774		.774
Stroop (Incong.2)	.786		.786
Working memory			
Number WM 1		.518	.530
Number WM 2		.677	.689
Letter WM 1		.276	.339
Letter WM 2		.628	.578
Visual WM 1		.093	.157
Visual WM 2		.412	.370
Spatial WM		.470	.404

Table 32. Fit statistics for controlled attention, working memory and Fluid intelligence - Model 2

		df	χ^2	*p*	RMSEA	SRMR	CFI	GFI
RPM	Baseline	69	105.289	.003	.051	.063	.957	.934
	Modified	66	79.544	.122	.032	.050	.984	.949
Shipley verbal	Baseline	72	129.996	.001	.063	.060	.963	.922
	Modified	70	113.510	.001	.054	.050	.939	.932
Shipley Abstract	Baseline	72	132.437	.001	.064	.073	.915	.923
	Modified	68	105.392	.002	.052	.065	.947	.937

Table 33. Standardised parameter estimates for the Structural equation model – Model 2

	Structural model (Model 2b)				
	Controlled attention	Working memory	RPM	Shipley verbal	Shipley abstract
Controlled attention					
Set Switching (50%)	.417		.266		
Set Switching (20%)	.473				
Stroop (Cong.1)	.767				
Stroop (Congr. 2)	.814				
Stroop (Incong.1)	.774				
Stroop (Incong.2)	.786				
Working memory					
Number WM 1		.522			
Number WM 2		.677			
Letter WM 1		.342			
Letter WM 2		.596		.32	
Visual WM 1		.153			
Visual WM 2		.379			
Spatial WM		.406	.189		.21
Factors					
Contr. Attention			-.095	.28	.06
WM			.328	-.09	.37

Appendix B: Figures

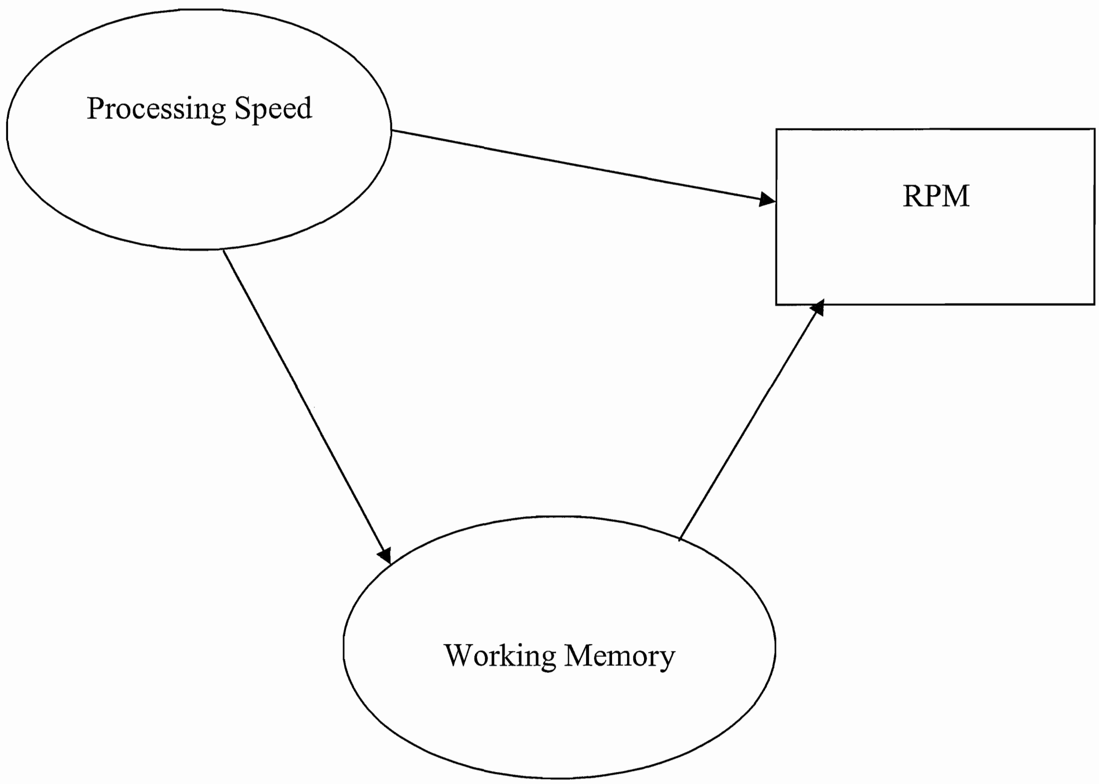


Figure 1. The Developmental Cascade Model (Fry and Hale, 1996)

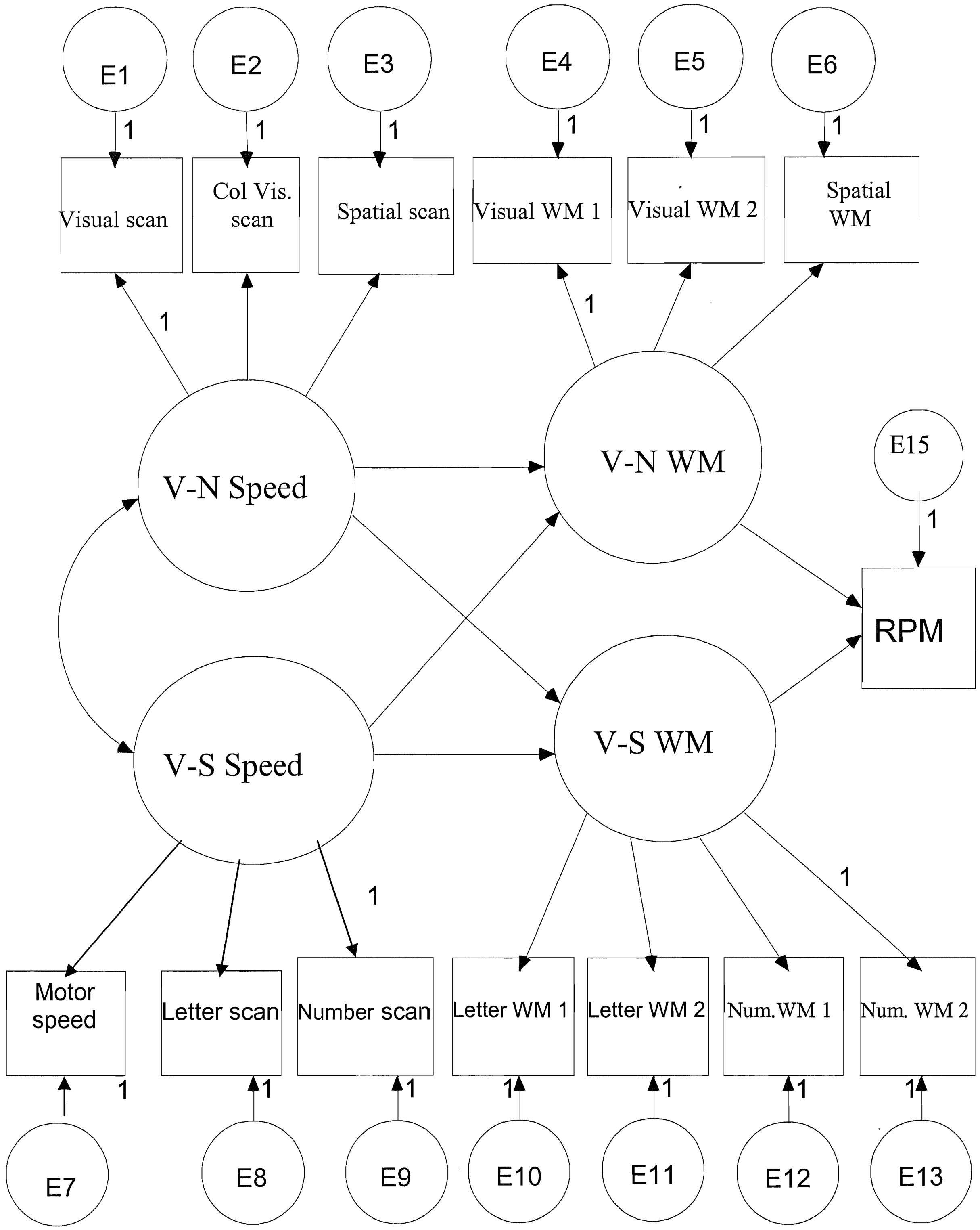


Figure 2. Model 1: The multiple factor Cascade model (RPM)

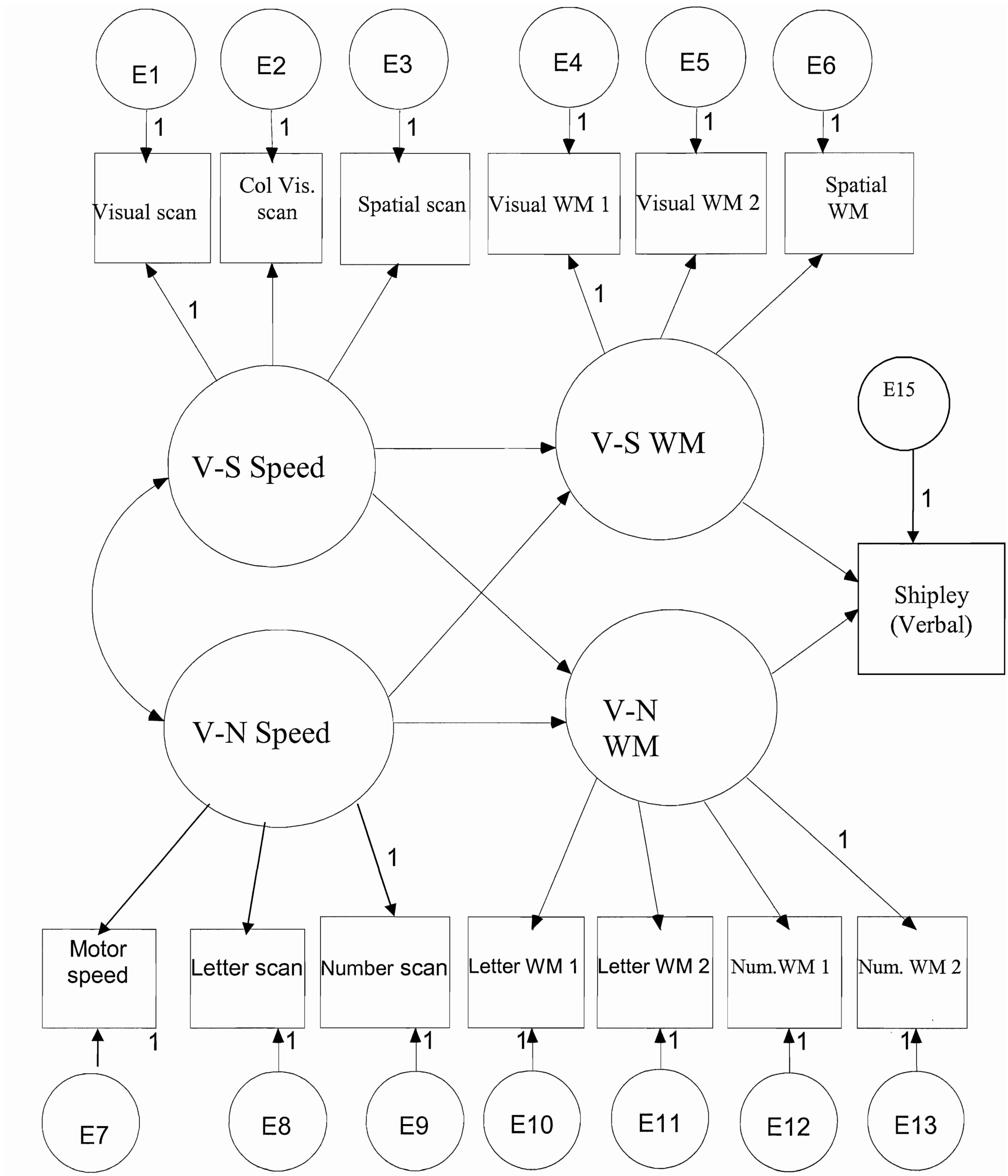


Figure 3. Model 1: The multiple factor Cascade model (Shipley verbal test)

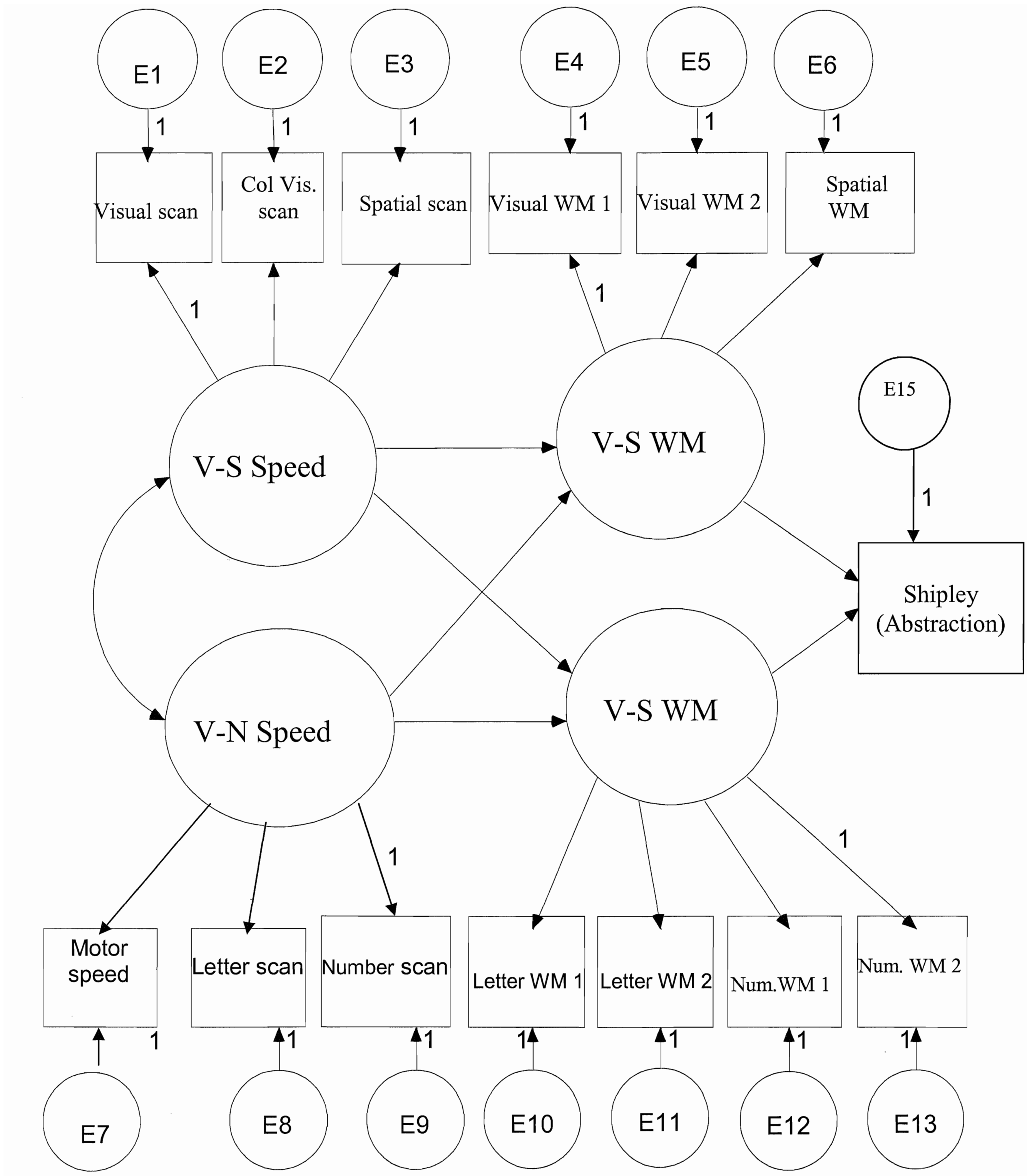


Figure 4. Model 1: The multiple factor Cascade model (Shipley Abstract Test)

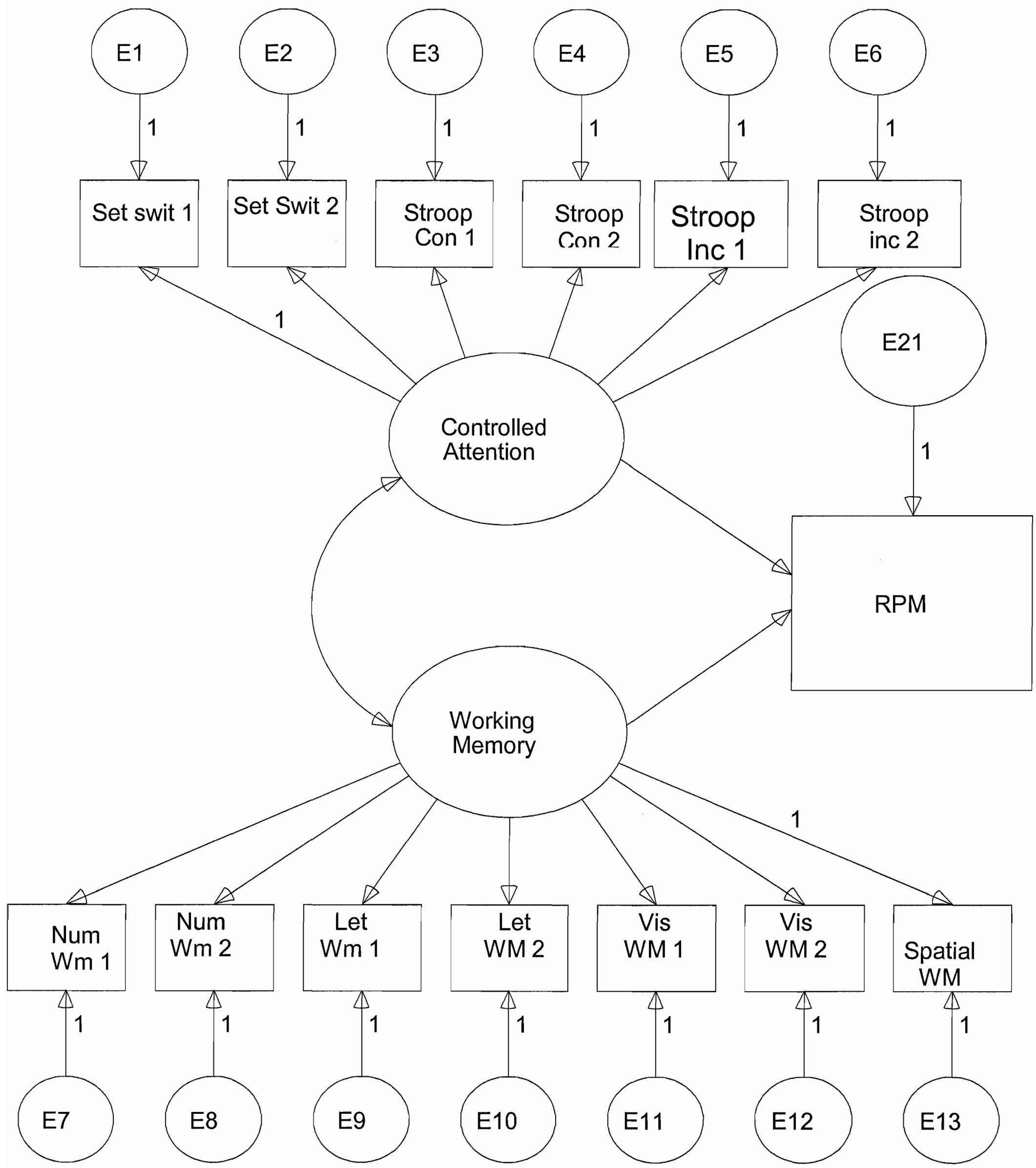


Figure 5. Model 2: The Controlled Attention-Working memory Model - RPM

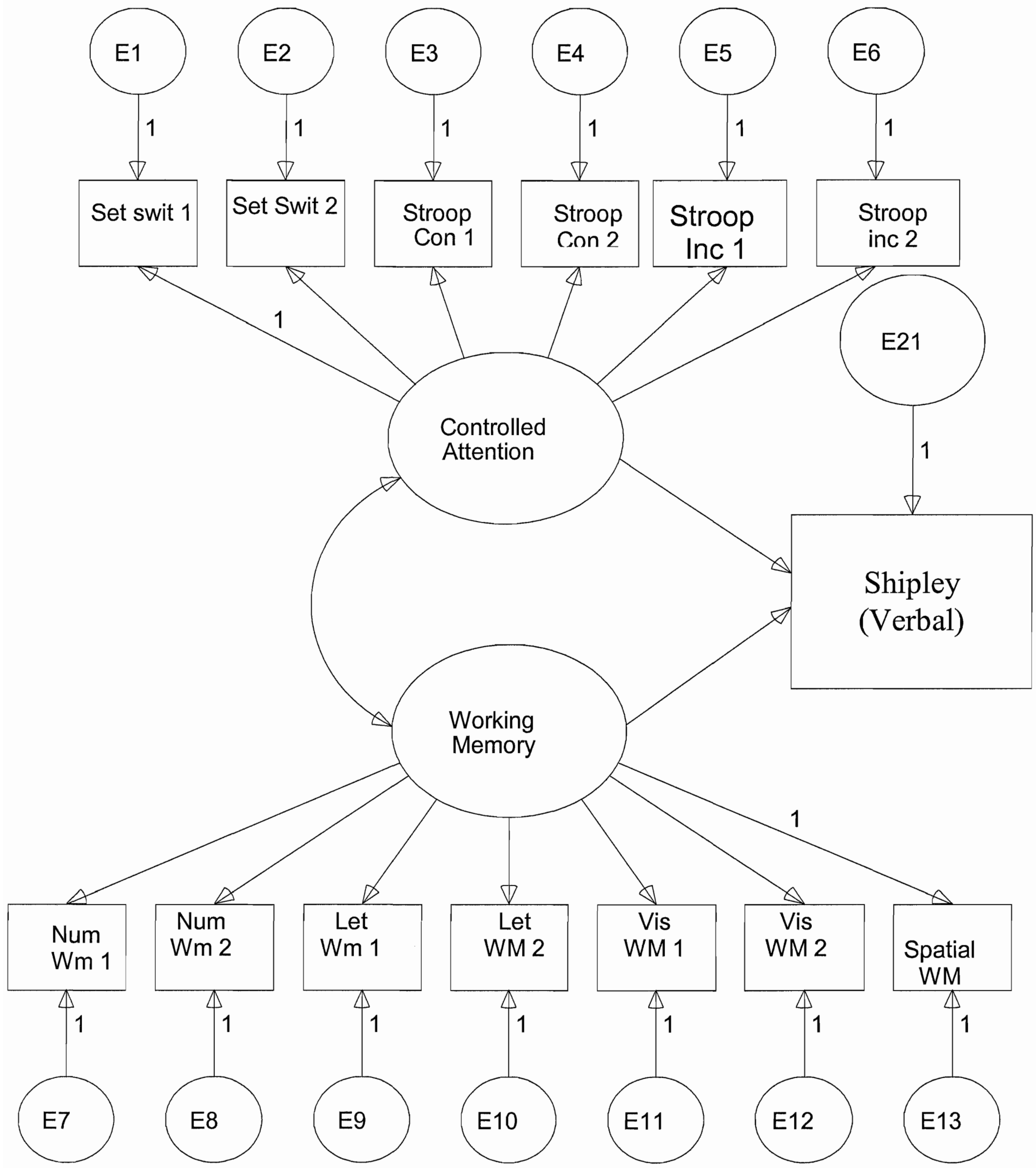


Figure 6. Model 2: The Controlled Attention-Working memory Model - Shipley Verbal Test

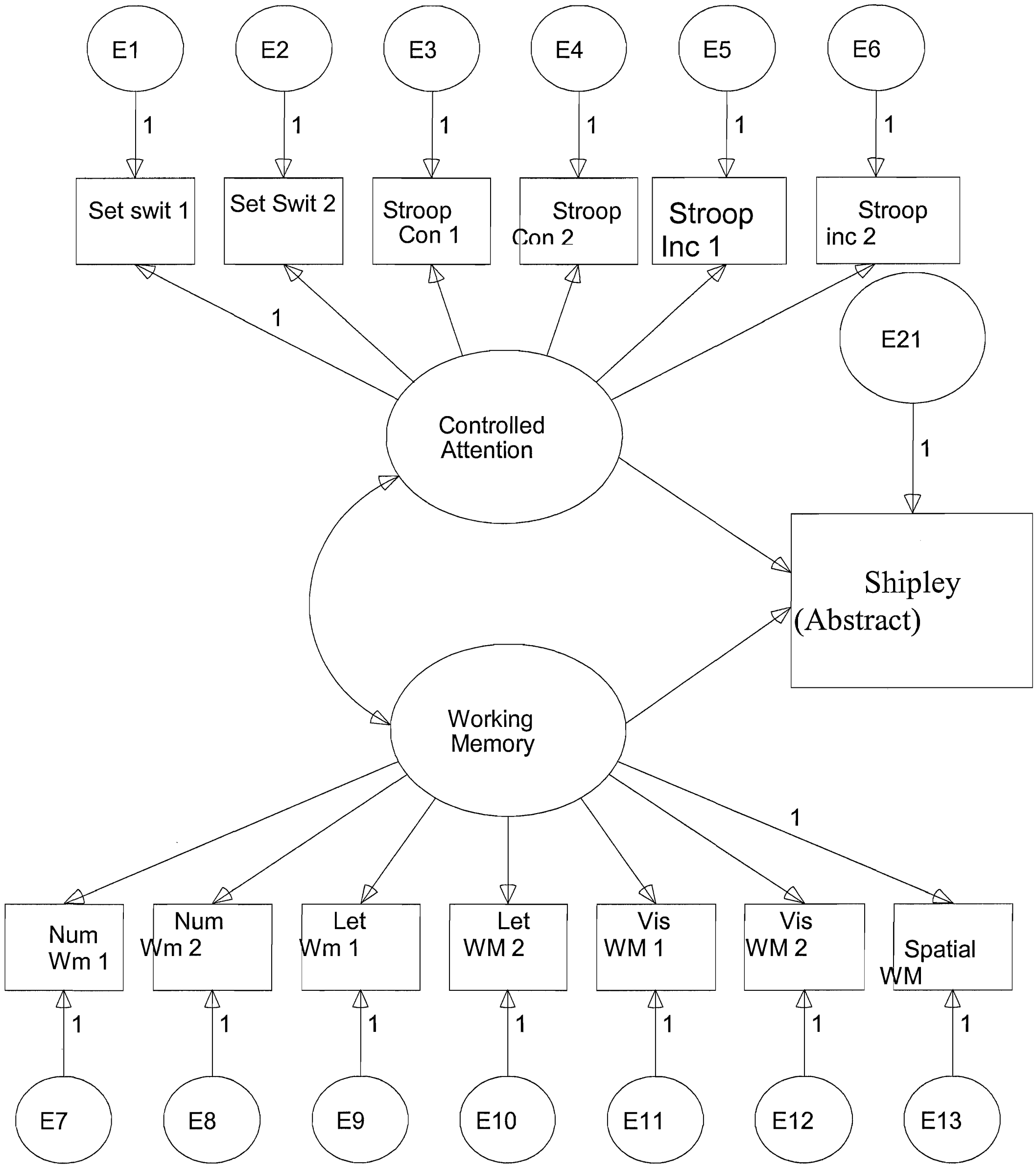


Figure 7. Model 2: The Controlled Attention-Working memory Model - Shipley Abstract Test

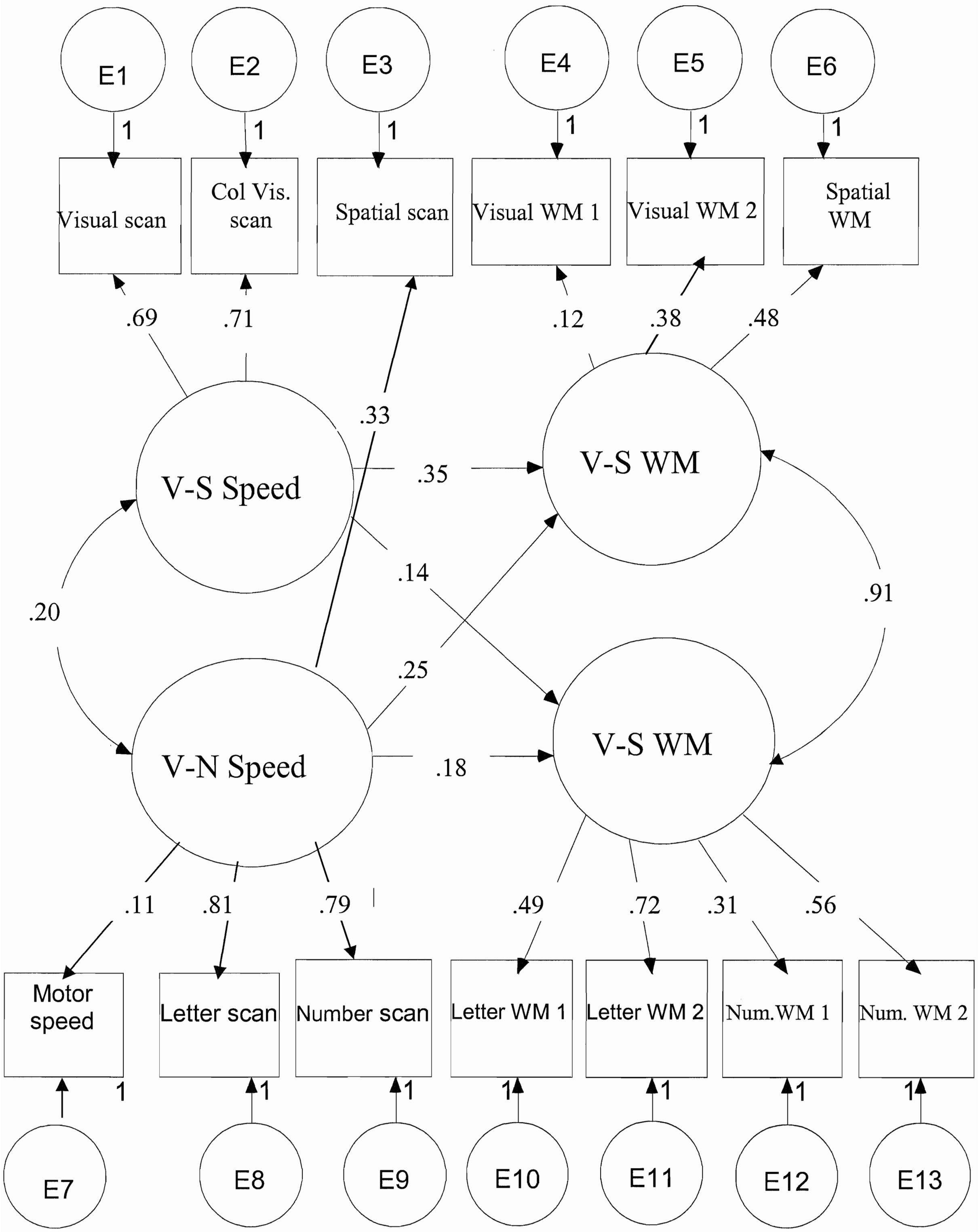


Figure 8: Model 1b: The multiple factor Cascade model – Revised Measurement model

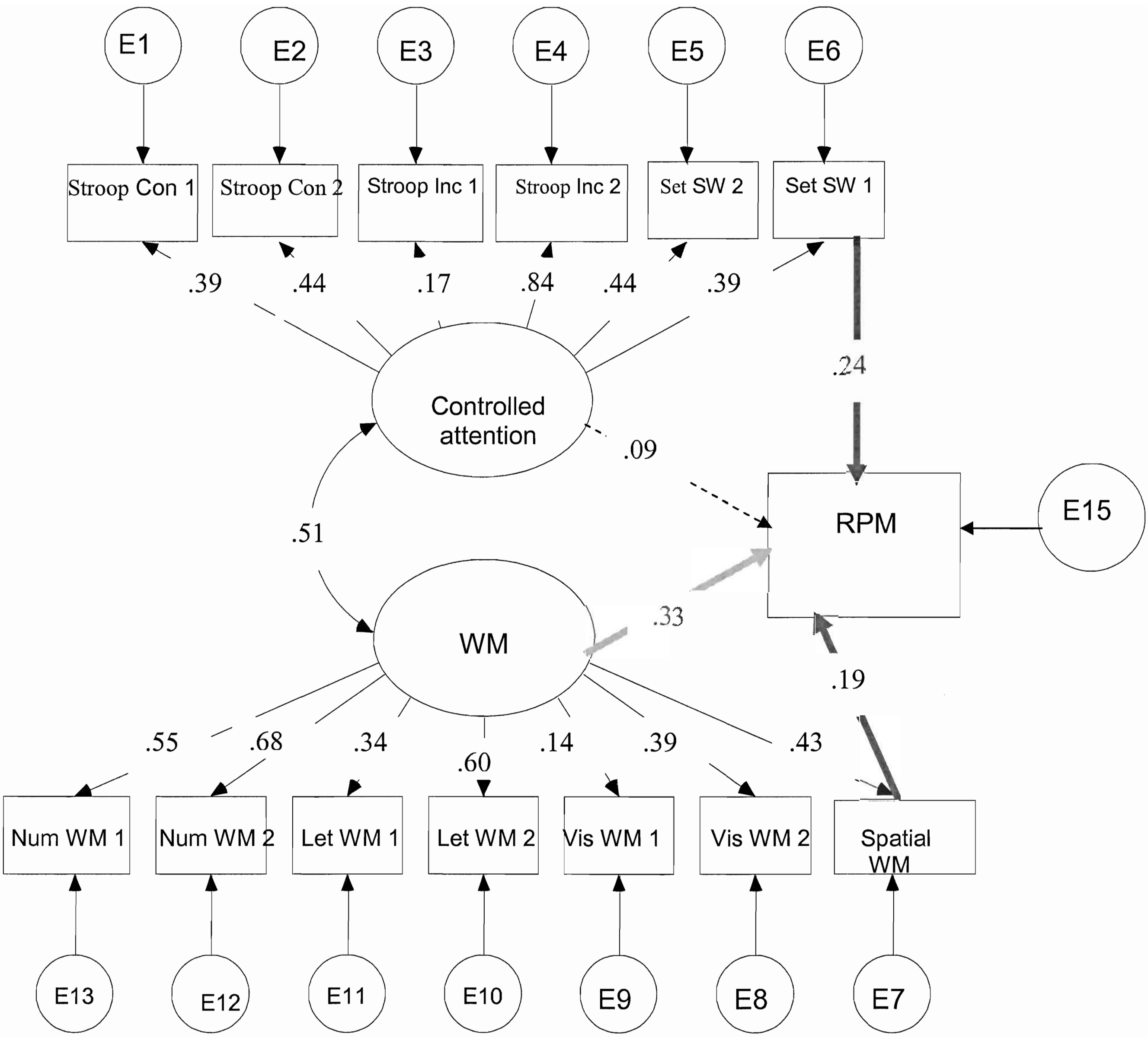


Figure 9. Model 2B: Controlled attention, working memory and RPM.

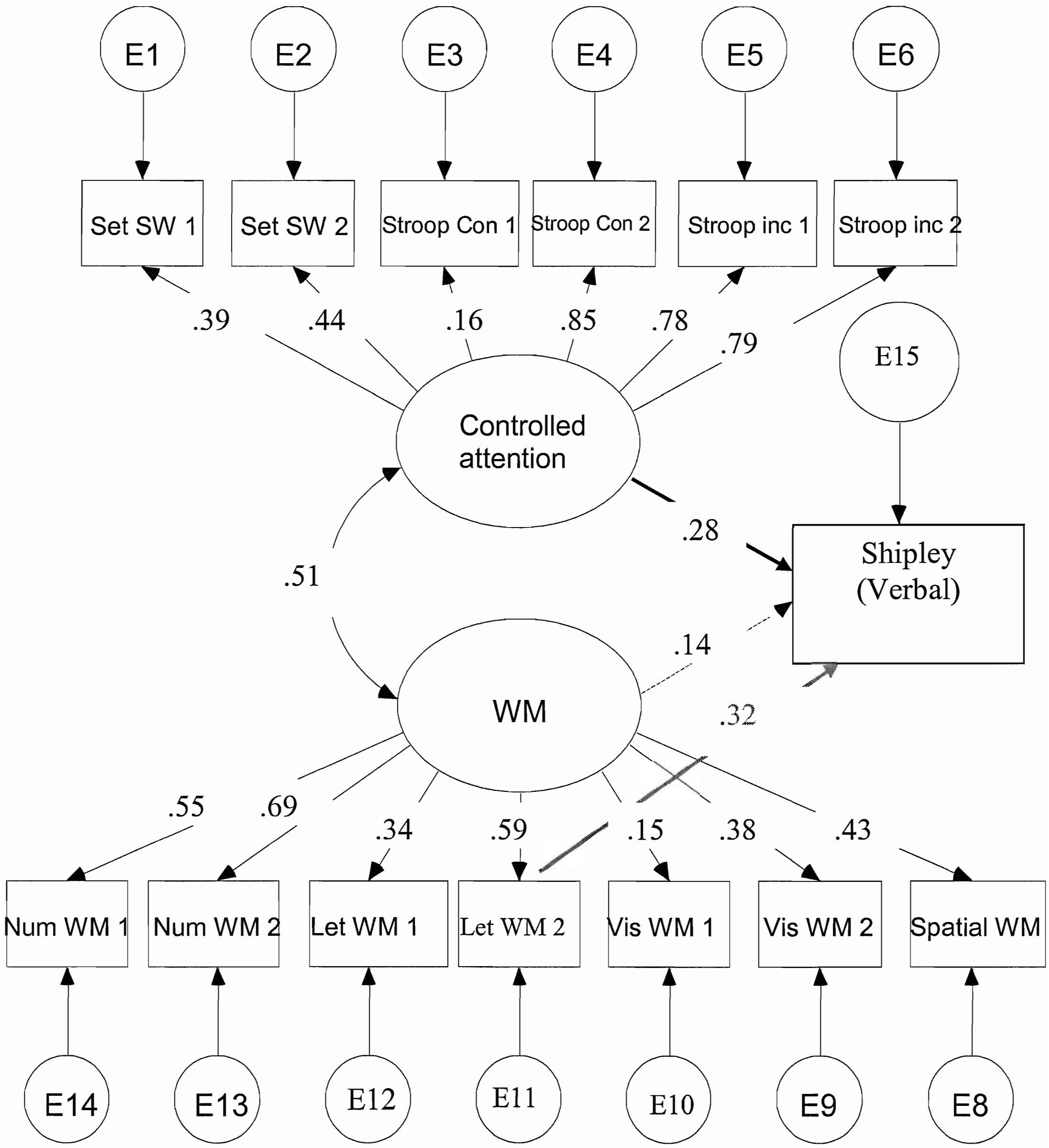


Figure 10. Model 2B: WM, controlled attention and Shipley verbal test

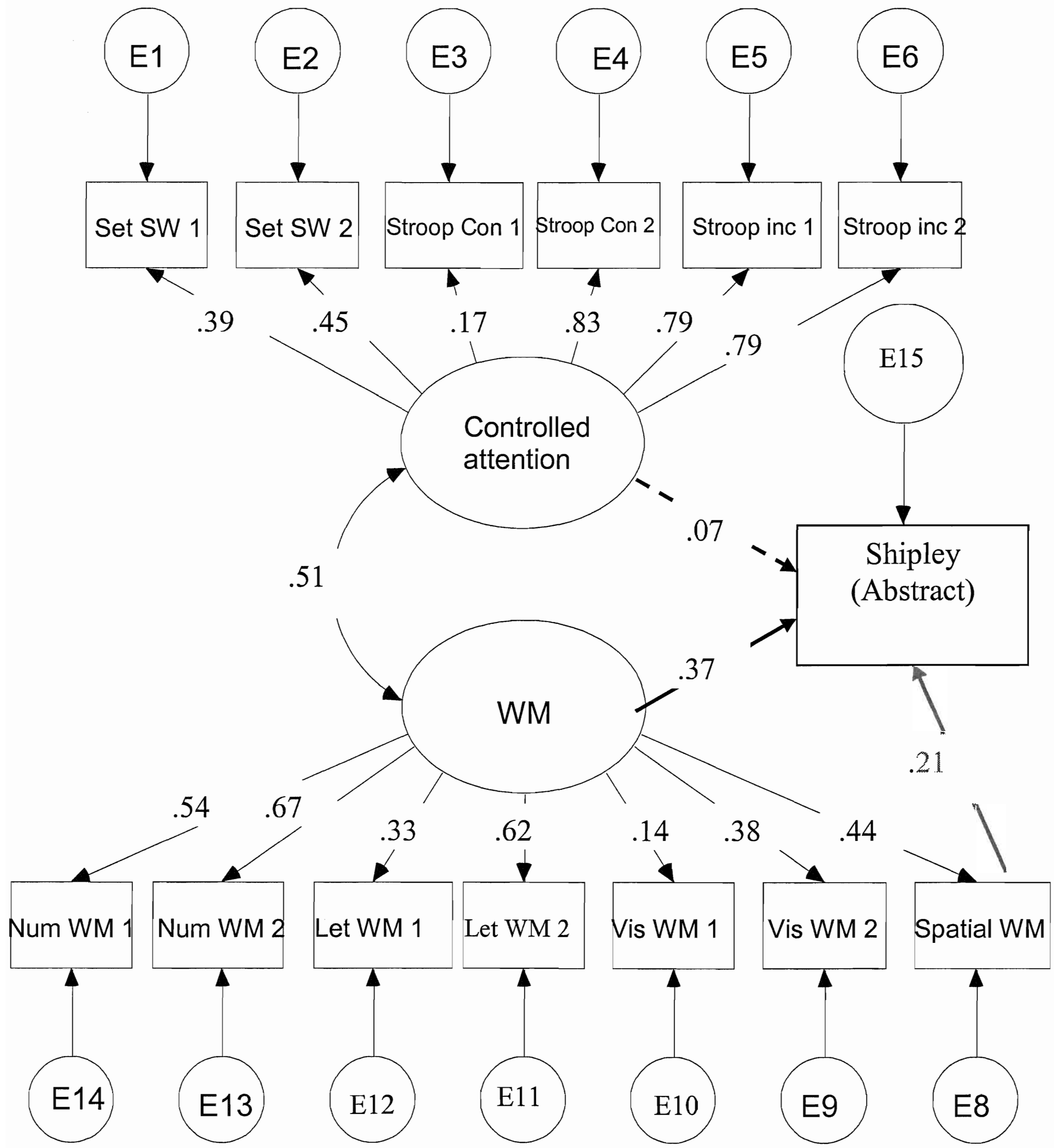


Figure 11. Model 2B. WM, controlled attention and Shipley Abstract Test

Appendix C: Measures

Serial Number ___________________________

SCREENING QUESTIONNAIRE

Name: ______________________________

Date of Testing: (YYYYMMDD)___________

Date of Birth: (YYYYMMDD)

____

Sex: Male Female

Handedness

Right ☐ Left ☐ Ambidextrous ☐

First Language:

English ☐ French ☐ Spanish ☐ Other ☐

Other Language (If applicable): ____________________________________

Do you have any difficulty with your sight? YES ☐ NO ☐

If YES, are you receiving treatment currently? YES ☐ NO ☐

Do you have problems with your hearing? YES ☐ NO ☐

If YES, are you receiving treatment currently? YES ☐ NO ☐

Are you aware if you are colorblind?

YES ☐ NO ☐ Don't know ☐

Do you have any learning disabilities?

YES, Reading ☐

YES, Math ☐

YES, Other ☐ (Please specify)____________________

NO ☐

Serial Number ___________________________

Have you ever suffered any injury to your head that resulted in a loss of consciousness?

YES ☐ NO ☐

If YES, How long ago? ______________

For how long were you unconscious?

Less than 5 minute ☐ Between 5 and 10 minutes ☐

Between 10 and 30 minutes ☐ More than 30 minutes ☐

Have you been diagnosed (currently or in the past) with any mood or mental disorder?

YES ☐ NO ☐

If YES, which type?

Anxiety ☐

Depression ☐

Panic Disorder ☐

Schizophrenia ☐

Other ☐

Are you currently receiving treatment for any of these disorders?

Yes ☐ NO ☐

Please list all medications you are currently taking (include both prescribed and unprescribed medications).

____

____

____

____

Serial Number ___________________________

MOTOR SKILL/SPEED TASK

There are numbers and letters in the table below. Quickly cross out all the numbers. Work as fast you can. I will tell you when to stop.

3	G	8	F	7	Q
4	R	9	G	8	X
5	E	5	W	4	D
6	D	4	Q	3	F
4	G	3	C	5	H
3	H	4	V	7	U
5	M	6	X	3	K
6	J	7	Z	2	N
4	K	9	P	6	F
2	L	3	G	8	D
4	O	1	I	9	E
6	P	4	D	5	R
7	T	7	S	4	Y
8	D	4	W	2	K
5	S	2	R	6	L
3	S	8	Y	8	O

Serial Number ___________________________

VISUAL SCAN TEST

PART I

INSTRUCTIONS: THERE ARE TWO TYPES OF LETTERS IN THE FOLLOWING TABLE, “Os” AND “Qs”. SEARCH AND CROSS OUT ALL THE “Qs” IN THE TABLE. WORK AS FAST AS YOU CAN.

O O O Q O O O O O O Q O Q O O O O O Q O O Q O O O O O O O

O O O Q O O O O O O O O O O O O O O O O O O O O O Q O O O

O O O O O O O O O O Q O Q O O O O O Q O O Q O O O O O O O

O Q O Q O O O O O O O O O O O O O O Q O O O O O O O Q O O

Q O O O O O O O O O Q O O O O O O O O O O Q O O O O O O O

O O O Q O O O O O O O O O O Q O O O O O O O O O O O Q O O

O O O O O O O O O O O O Q O O O O O Q O O Q O O O O O O O

O O O Q O O O O O O O O O O O O O O O O O O Q O O O Q O O

O O O O O O O O O O O O Q O O O O O Q O O O O O O O O O O

O O O Q O O O O O Q O O Q O O O O O O O O O O O O O Q O O

O O O O O O O Q O O O O O O O Q O O O O Q O O O O O O O O

O O O O O O O O O O O O O O O O O O O O O O O O O O O O O

O O O O O O Q O O O O O Q O O O O O O O O Q O O O O O O O

O O O Q O O O O O O O O O O O O O O O O O O Q O O O O O O

O O O O O O Q O O O Q O O O O O O O Q O O O O O O O O O O

O O O O O O Q O O O O O O O O O O O O O O O O O O O Q O O

O Q O O O O O O O O O O Q O O O O O O O O O O O O O O O O

O O O Q O O O O O Q O O O O O O O O O O O O Q O O O O O O

TURN TO THE NEXT PAGE

Serial Number ______________________________

COLOURED VISUAL SCAN TEST

INSTRUCTIONS: IN THIS SECTION, THE "Qs" ARE COLORED. SEARCH AND CROSS OUT ALL THE "Qs" IN THE TABLE THAT ARE COLORED GREEN. WORK AS FAST AS YOU CAN.

O O O Q O Q O O O Q O O Q O O O O O Q O O Q O O O O O O O

Q O O Q O O O O Q O O O O Q O O O O Q O O O O O O Q O O O

O O O O O Q Q O O O Q O Q O O O Q O Q O O Q O O O O O O O

O Q O Q O O O O Q O O O Q O O O Q O O O Q Q O O O O Q O O

Q O O O O Q O Q O O Q O O O O O O O Q O O Q O O O Q O O O

O O O Q O O O Q O O Q O O Q O Q O Q O Q O O O O O O Q O O

O Q O O Q O O Q O O O O Q O O O O O Q O O Q O O O O Q O O

O O O Q O O O O Q O O Q O O O O O O O O Q O Q O O O Q O O

O Q O O O O O Q O Q Q O Q O O Q O O Q O O O O O Q O O O O

O O O Q O O O O O O O O Q O O O O Q O O Q O O O O O Q O O

O Q O O O Q O Q O O O O Q O O Q O O O O Q O O O O O O O O

O O O O O O O Q O O Q O O O Q O O O Q O Q O O O Q O O O O

O Q O O O O Q O O O O O Q O O O Q O O O O Q O O Q O O O O

Q O O Q O O O O O O O O O Q O Q O Q O O O O Q O O O Q O Q

O O O O O O Q O O O Q O O O O O O O Q O O O O O Q O O O O

O O Q O O O Q O O Q O O O Q O O O O Q O Q O O O O O Q O O

O Q O Q O O O O O O O O Q O O O O Q O O O O O O O O Q O O

O O O Q O O O O O O Q Q O O O Q O O O O Q O Q O O O Q O O

TURN TO THE NEXT PAGE

Serial Number ____________________________

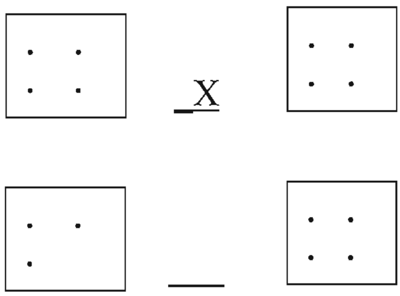
SPATIAL COMPARISON TEST

INSTRUCTION:

- ON THIS TEST, THERE ARE SQUARES WITH DOTS PLACED IN THEM.

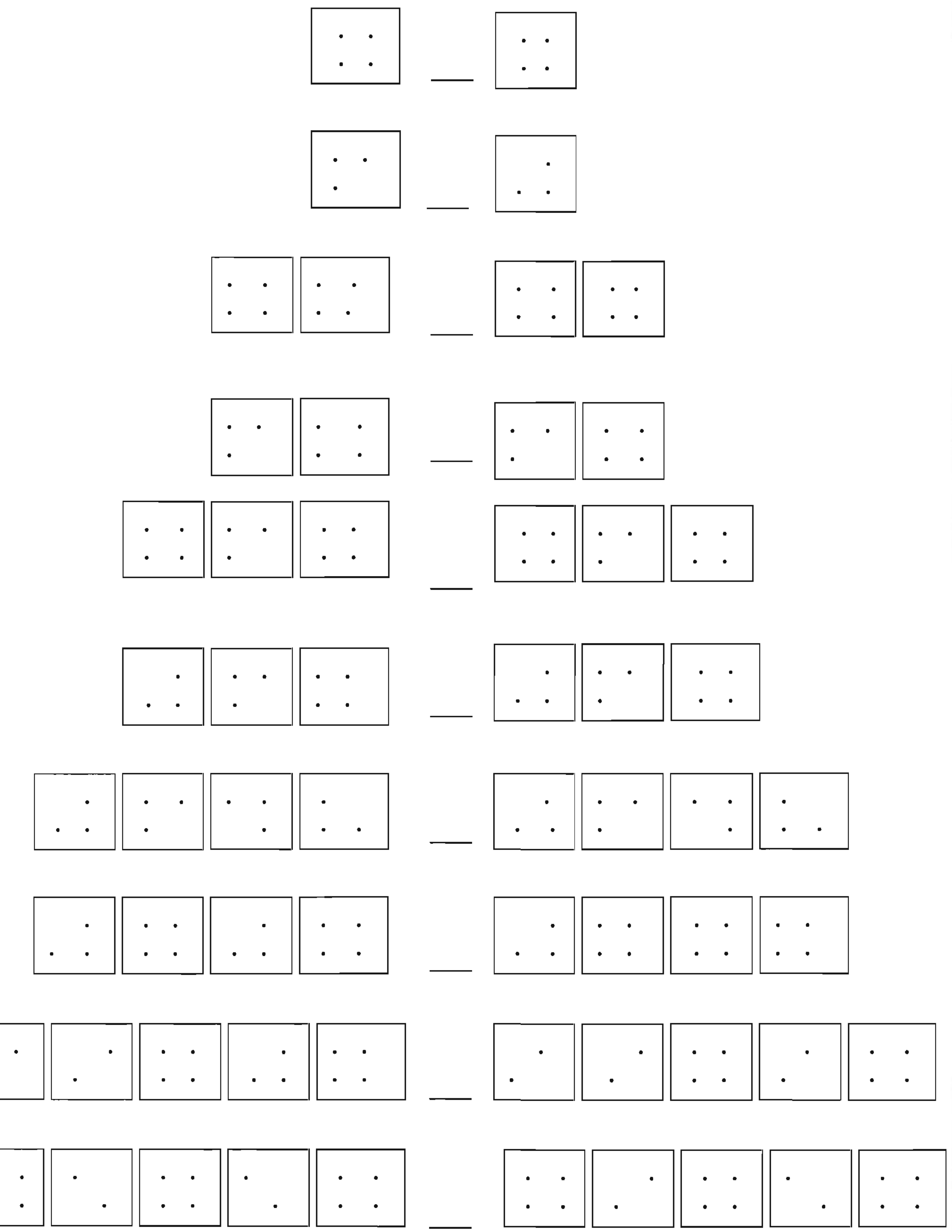
- GO THROUGH THE SQUARES BEGINNING FROM THE TOP OF THE PAGE AND PLACE AN "X" ON THE LINE BETWEEN THE SQUARES THAT HAVE IDENTICAL DOT PATTERNS.

FOR EXAMPLE:



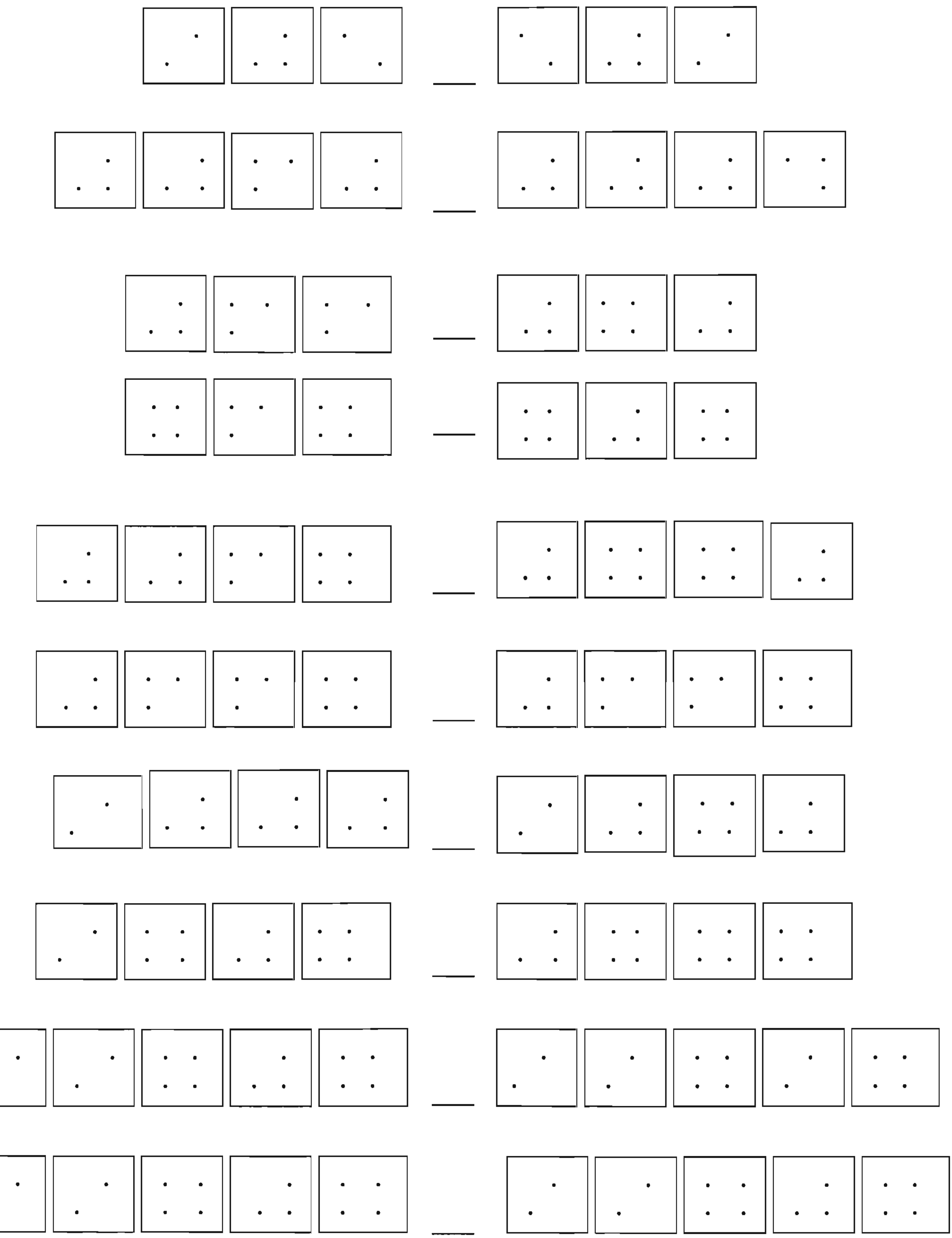
PLEASE DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO START

Serial Number ______________________________



PLEASE CONTINUE ON THE NEXT PAGE

Serial Number ______________________________



PLEASE DRAW A LINE UNDERNEATH THE LAST SET OF DOTS COMPARED

Serial Number ____________________________

NUMBER COMPARISON TEST

INSTRUCTIONS

- In the table below are two strings of digits.
- Some of the digit strings are identical.
- Go through the string of digits beginning from the top of the page and mark 'X' on the line between the pairs that are identical.
- Work as quickly as you can.
- When I asked you to stop, draw a line beneath the last string of digits you worked on.

For example:

2 5 6	_X__	2 5 6
1 7 4	___	1 4 7

Serial Number ___________________________

2 6	------	2 6
8 3	------	7 8
1 5 4	------	1 5 4
3 6 4	------	3 6 4
6 9 4 1	------	6 9 1 4
4 8 0 1	------	4 8 0 1
2 8 6 9 4	------	2 8 6 4 9
4 1 8 6 2	------	4 1 5 6 2
2 5 6 7 1 2	------	2 5 6 7 1 2
0 7 6 3 1 5	------	0 6 7 1 3 5
6 4 8 9 1 5 3	------	6 4 8 9 1 5 3
3 1 5 8 4 2 3	------	3 1 5 8 4 2 3
6 4 3 1 1 9 4 2	------	6 4 3 1 9 9 4 2
5 3 6 7 6 2 4 7	------	5 3 6 7 2 4 4 7
3 4 5 2 1 7 2 6 4	------	3 4 5 2 1 7 2 6 4
2 6 4 4 1 5 1 3 8 3	------	2 6 4 6 4 1 5 8 3

Serial Number ________________________

LETTER COMPARISON TEST

INSTRUCTIONS

- In the table below are two strings of letters.
- Some of the letter strings are identical.
- Go through the string of letters beginning from the top of the page and mark 'X' on the line between the strings that are identical.
- I will tell you when to start.
- Work as quickly as you can.
- When I asked you to stop, draw a line beneath the last string of digits you worked on.

EXAMPLE

g h j	__X__	g h j
s y j	____	s v j

Serial Number ______________________

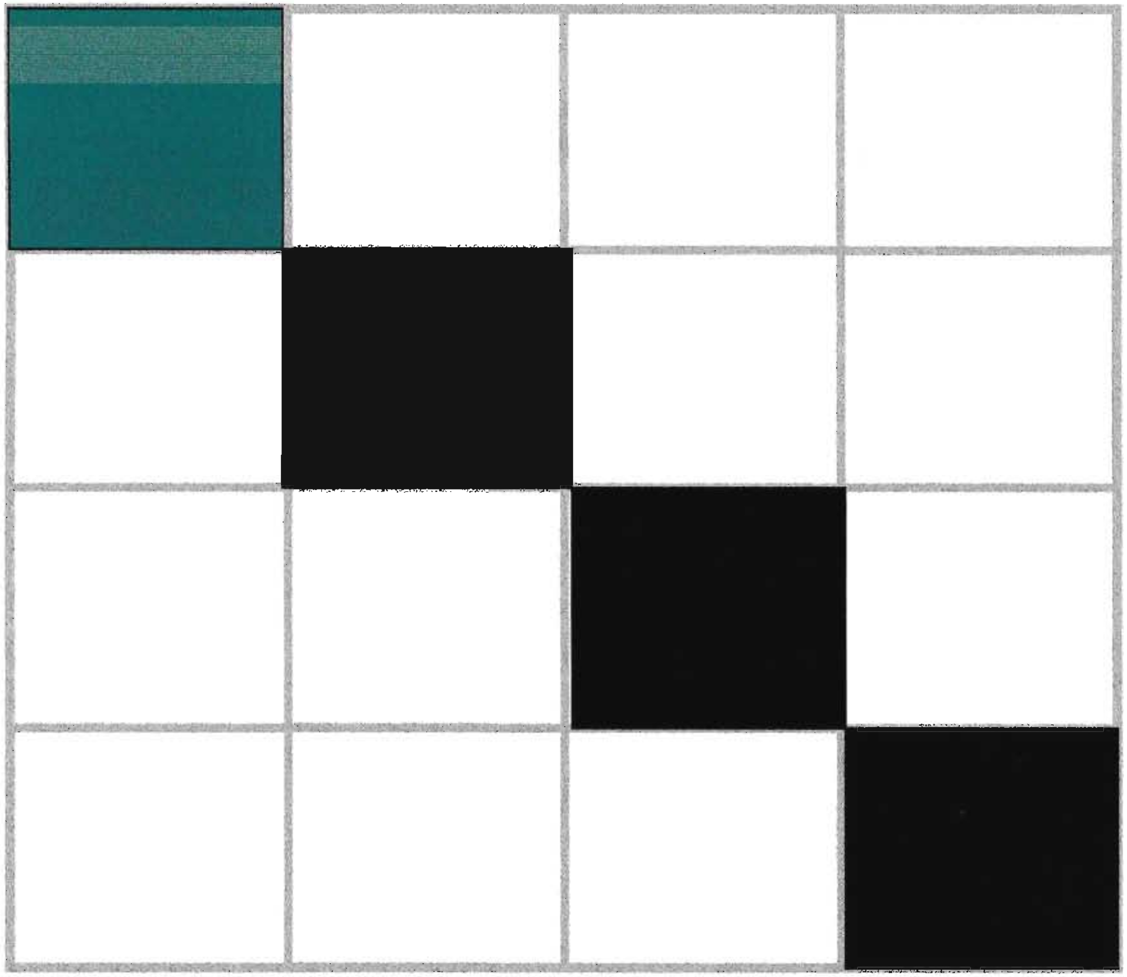
a c	------	a b
n u	------	n n
b c a	------	b c a
f b n	------	f b n
y e r i	------	g h r i
h q t b	------	h q b t
s w e r q	------	s w e r q
x r t h a	------	x r l h a
k f j v a j	------	f v a j k j
b c g x u m	------	b c g x u m
d v w p b n s	------	d v w p b n s
b o t e w s r h	------	b c t w r s r h
c v j k r e m l g	------	c v j k r e m l g
l y q p o x l f g	------	L y p q o x l f g

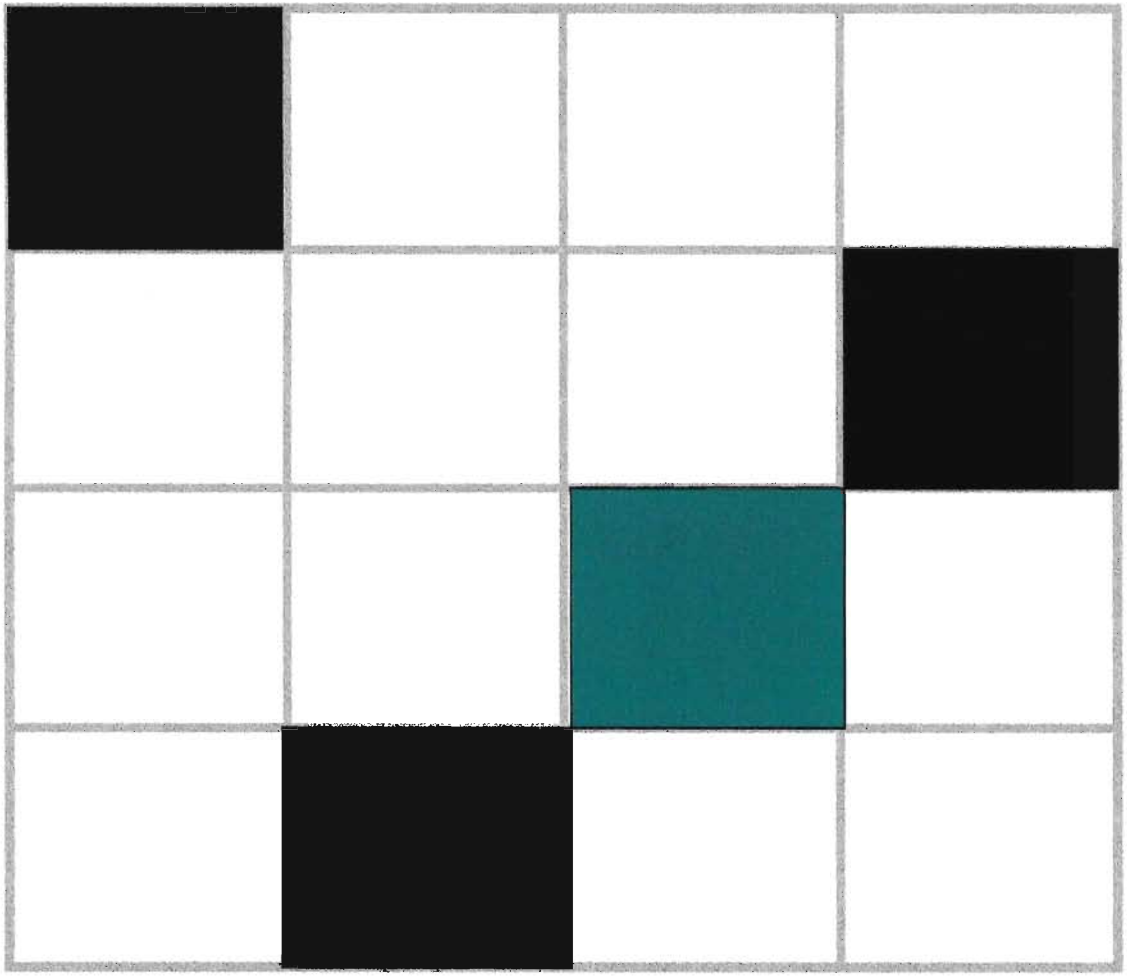
Serial Number ____________________________

SPATIAL WORKING MEMORY

- THERE WILL BE A SERIES OF TABLES FILLED WITH BOXES.
- EACH TABLE HAS SEVERAL BLACK BOXES AND ONE GREEN BOX.
- FOR EACH TABLE, YOUR TASK IS TO INDICATE EITHER "YES" OR "NO" WHETHER THE BOXES FORM A STRAIGHT LINE.
- AFTER THE SERIES OF TABLES IS PRESENTED YOU WILL HAVE TO INDICATE ON THE <u>NEXT PAGE</u> IN THE BOOKLET WHERE THE GREEN BOXES WERE LOCATED IN EACH OF THE TABLES.

PRACTICE





Serial Number ____________________________

VERBAL WORKING MEMORY

1 – Back Condition

- A series of letters will be presented on the screen, one at a time.
- Your task is to count the number of times you see the same letter twice in a row.
- Write your response in the answer booklet.
- In the following series of items,

C, V, G, G, R, T, T, W, A, W….

- There are 2 repeats: "**G**" and "**T**".
- However, "**W**" does not count as a repeat because something appeared in between.

Serial Number ____________________________

VERBAL WORKING MEMORY

2 – Back Condition

- This time you need to count the number of times a letter is repeated from 2 items earlier.
- An item is repeated <u>only</u> when it is the same as the one shown <u>TWO</u> items before it.
- In the following series of items,

C, V, G, R, G, P, T, A, T, W, W….

- There are 2 repeats: "**G**" and "**T**".
- However, "**W**" does not count as a repeat because it repeated immediately.

Serial Number ___________________________

NUMBER WORKING MEMORY

1 – Back Condition

- A series of numbers will be presented on the screen, one at a time.

- Your task is to count the number of times you see the same number twice in a row.

- Write your response in the answer booklet.

- In the following series of items,

7, 5, 8, 8, 4, 6, 6, 4, 2, 4, 5 …

- There are 2 repeats: "**8**" and "**6**".

- However, the "**4**" does not count as a repeat because something appeared in between.

NUMBER WORKING MEMORY

2 – Back Condition

- This time you need to count the number of times a number is repeated from 2 items earlier.

- An number is repeated only when it is the same as the one shown TWO items before it.

- In the following series of items,

7, 8, 5, 8, 4, 6, 2, 6, 4, 4, 5 …

- There are 2 repeats: "**8**" and "**6**".

- However, "**4**" does not count as a repeat because it repeated immediately.

Serial Number ____________________________

VISUAL WORKING MEMORY

1 – Back Condition

- A series of characters will be presented on the screen, one at a time.
- Your task is to count the number of times you see the same character twice in a row.
- Write your response in the answer booklet.
- In the following series of items,

س, ی, ی, ۴, چ, چ, ف, گ, ق,گ

- There are 2 repeats: "ی" and " چ".
- However, the "گ" does not count as a repeat because something appeared in between.

Serial Number ____________________________

VISUAL WORKING MEMORY

2 – Back Condition

- This time you need to count the number of times a character is repeated from 2 items earlier.
- An item is repeated <u>only</u> when it is the same as the one shown <u>TWO</u> items before it.
- IN THE FOLLOWING SERIES OF ITEMS,

س, ى, ۴, ى, ق, چ, ف, چ, گ, گ

- There are 2 repeats: "ى" and "چ".
- However, the "گ" does not count as a repeat because it repeated immediately.

all the names that have been printed in colours which **ARE CONSISTENT** with the names.
EXAMPLE: GREEN GREEN – *Version 2 (25%)*

GREEN	BLUE	RED	YELLOW
RED	GREEN	YELLOW	YELLOW
BLUE	YELLOW	RED	RED
RED	RED	BLUE	YELLOW
GREEN	YELLOW	GREEN	GREEN
GREEN	GREEN	YELLOW	BLUE
YELLOW	BLUE	RED	BLUE
RED	RED	RED	BLUE
YELLOW	GREEN	GREEN	GREEN
BLUE	GREEN	YELLOW	RED
GREEN	YELLOW	BLUE	RED
YELLOW	RED	GREEN	YELLOW
YELLOW	BLUE	BLUE	GREEN
BLUE	BLUE	GREEN	YELLOW
RED	YELLOW	RED	GREEN
YELLOW	RED	GREEN	YELLOW
BLUE	YELLOW	BLUE	BLUE
BLUE	BLUE	RED	GREEN
GREEN	GREEN	YELLOW	RED
RED	BLUE	RED	YELLOW
RED	BLUE	GREEN	BLUE

Instructions: The following are names of colours. Please go through quickly and **UNDERLINE** all the names that have been printed in colours which **ARE CONSISTENT** with the names.
EXAMPLE: GREEN GREEN (50%)

GREEN	RED	BLUE	RED
RED	BLUE	YELLOW	BLUE
BLUE	GREEN	RED	GREEN
RED	YELLOW	YELLOW	YELLOW
GREEN	RED	RED	RED
GREEN	YELLOW	BLUE	YELLOW
YELLOW	GREEN	GREEN	GREEN
RED	BLUE	YELLOW	BLUE
YELLOW	RED	BLUE	RED
BLUE	GREEN	RED	BLUE
GREEN	GREEN	GREEN	GREEN
YELLOW	YELLOW	RED	YELLOW
YELLOW	RED	YELLOW	RED
BLUE	BLUE	GREEN	BLUE
RED	BLUE	BLUE	GREEN
YELLOW	YELLOW	GREEN	YELLOW
BLUE	RED	GREEN	RED
BLUE	YELLOW	BLUE	YELLOW
GREEN	BLUE	RED	BLUE
RED	GREEN	YELLOW	GREEN

Instructions: The following are names of colours. Please go through quickly and UNDERLINE all the names that have been printed in colours which are **NOT CONSISTENT** with the names.
EXAMPLE: GREEN GREEN *Version 2 (25%)*

RED	**GREEN**	**BLUE**	**YELLOW**
BLUE	**RED**	**YELLOW**	**BLUE**
GREEN	**BLUE**	**RED**	**GREEN**
YELLOW	**RED**	**YELLOW**	**YELLOW**
RED	**GREEN**	**RED**	**RED**
YELLOW	**GREEN**	**BLUE**	**YELLOW**
GREEN	**YELLOW**	**GREEN**	**GREEN**
BLUE	**RED**	**YELLOW**	**BLUE**
RED	**YELLOW**	**BLUE**	**RED**
BLUE	**GREEN**	**RED**	**GREEN**
GREEN	**BLUE**	**GREEN**	**YELLOW**
YELLOW	**YELLOW**	**RED**	**GREEN**
RED	**RED**	**YELLOW**	**RED**
BLUE	**BLUE**	**GREEN**	**BLUE**
GREEN	**RED**	**BLUE**	**BLUE**
YELLOW	**YELLOW**	**GREEN**	**YELLOW**
RED	**BLUE**	**GREEN**	**RED**
YELLOW	**BLUE**	**BLUE**	**YELLOW**
BLUE	**GREEN**	**RED**	**BLUE**
GREEN	**RED**	**RED**	**GREEN**

structions: The following are names of colours. Please go through quickly and UNDERLINE the names that have been printed in colours which ARE **NOT CONSISTENT** with the mes. GREEN GREEN Version 1 (50%)

RED	GREEN	BLUE	RED
BLUE	RED	YELLOW	BLUE
GREEN	BLUE	RED	GREEN
YELLOW	RED	YELLOW	YELLOW
RED	GREEN	RED	RED
YELLOW	GREEN	BLUE	BLUE
GREEN	BLUE	GREEN	GREEN
BLUE	RED	GREEN	BLUE
RED	YELLOW	BLUE	RED
BLUE	BLUE	RED	GREEN
GREEN	GREEN	GREEN	GREEN
YELLOW	BLUE	RED	RED
RED	YELLOW	YELLOW	BLUE
BLUE	BLUE	GREEN	RED
GREEN	RED	BLUE	GREEN
RED	GREEN	RED	YELLOW
RED	BLUE	GREEN	RED
YELLOW	BLUE	BLUE	BLUE
BLUE	GREEN	RED	BLUE
GREEN	RED	YELLOW	GREEN

Serial Number ____________

SET SWITCHING TASK

There are numbers in provided in the Table below. Some numbers are underlined others are not. Use the instructions that follow to complete the task. Start when I ask you to do so and work as quickly as you can. I will tell you when it is time to stop.

For NUMBERS THAT ARE UNDERLINED: Please mark in the spaces provided below each number with a plus sign (+) if the number is greater than 5 and with a minus sign (-) if the number is less than 5.

FOR NUMBERS THAT ARE NOT UNDERLINED: Please mark in the spaces provided below each number with a plus sign (+) if the number is even and a minus sign (-) if the number is odd.

Start from the top of the table and work from Left to Right.

DO YOU HAVE ANY QUESTIONS?

Serial Number ______________________________

Set 1 (20% Switches)

<u>NOTE:</u> 1. Numbers underlined -"+" = Number is greater than 5
- "-" = Number is less than 5

2. Numbers not underlined "+" = Even Number
"-" = Odd Number

<u>4</u>	<u>3</u>	6	9	<u>7</u>	<u>4</u>	2	6	<u>2</u>	<u>6</u>
6	2	<u>6</u>	<u>9</u>	3	2	<u>8</u>	<u>3</u>	8	3
<u>3</u>	<u>6</u>	2	7	<u>9</u>	<u>2</u>	6	9	<u>3</u>	<u>7</u>
9	4	<u>3</u>	<u>9</u>	2	4	<u>8</u>	<u>2</u>	8	6
<u>4</u>	<u>8</u>	3	6	<u>2</u>	<u>7</u>	3	4	<u>8</u>	<u>3</u>
7	3	<u>4</u>	<u>9</u>	6	2	<u>4</u>	<u>8</u>	2	7
<u>2</u>	<u>8</u>	4	6	<u>9</u>	<u>2</u>	3	6	<u>7</u>	<u>8</u>
6	3	<u>7</u>	<u>2</u>	3	8	<u>2</u>	<u>4</u>	6	3
<u>2</u>	<u>8</u>	6	9	<u>4</u>	<u>3</u>	6	7	<u>9</u>	<u>4</u>
9	6	<u>7</u>	<u>3</u>	7	2	<u>3</u>	<u>2</u>	6	3

PLEASE TURN TO THE NEXT PAGE

Serial Number ______________________________

Set 2 (50% Switches)

NOTE: 1. Numbers underlined "+" = Number is greater than 5
"-" = Number is less than 5

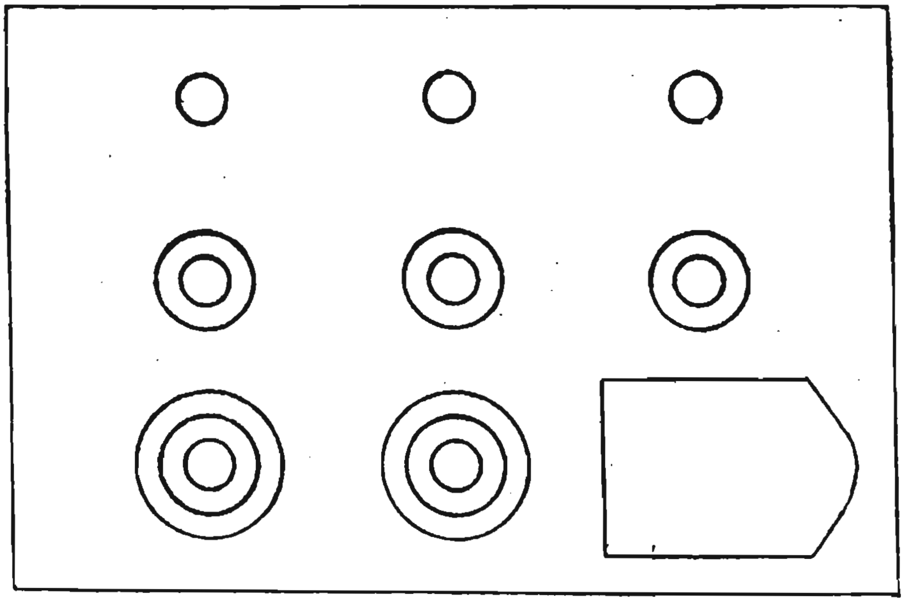
2. Numbers not underlined "+" = Even Number
"-" = Odd Number

4	3	6	9	8	<u>7</u>	<u>4</u>	<u>2</u>	<u>6</u>	<u>2</u>	6
6	2	6	9	<u>3</u>	<u>3</u>	<u>2</u>	<u>8</u>	<u>3</u>	8	3
3	6	2	<u>7</u>	<u>7</u>	<u>9</u>	<u>2</u>	<u>6</u>	9	3	7
9	4	<u>3</u>	<u>9</u>	<u>6</u>	<u>2</u>	<u>4</u>	8	2	8	6
4	<u>8</u>	<u>3</u>	<u>6</u>	<u>2</u>	<u>2</u>	7	3	4	8	3
<u>7</u>	<u>3</u>	<u>4</u>	<u>9</u>	<u>7</u>	6	2	4	8	2	<u>7</u>
<u>2</u>	<u>8</u>	<u>4</u>	<u>6</u>	4	9	2	3	6	<u>7</u>	<u>8</u>
<u>6</u>	<u>3</u>	<u>7</u>	2	8	3	8	2	<u>4</u>	<u>6</u>	<u>3</u>
<u>2</u>	<u>8</u>	6	9	3	4	3	<u>6</u>	<u>7</u>	<u>9</u>	<u>4</u>
<u>9</u>	6	7	3	4	7	<u>2</u>	<u>3</u>	<u>2</u>	<u>6</u>	<u>3</u>

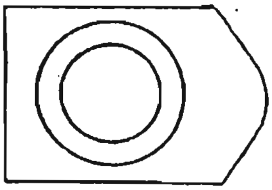
RAVEN PROGRESSIVE MATRICES

SET C

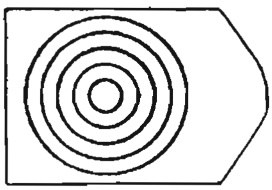
C 1



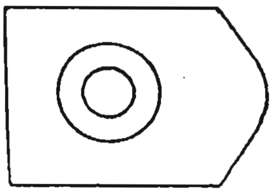
1



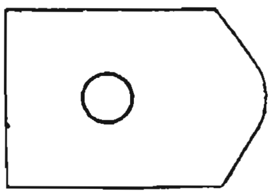
2



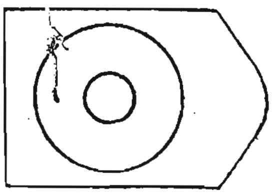
3



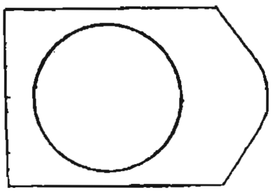
4



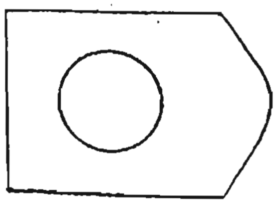
5



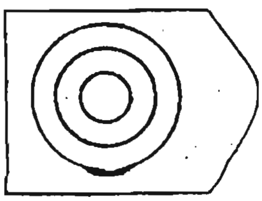
6



7



8



SHIPLEY VERBAL TEST

Instructions: In the test below, the first word in each line is printed in capital letters. Opposite it are four other words. Circle the ***one word*** which means the ***same thing***, or most the nearly the same thing, as the first word. If you don't know, guess. Be sure to circle the one word in each line that means the same thing as the first word.

EXAMPLE: LARGE red big silent wet

(1) TALK	draw	eat	speak	sleep
(2) PERMIT	allow	sew	cut	drive
(3) PARDON	forgive	pound	divide	tell
(4) COUCH	pin	eraser	sofa	glass
(5) REMEMBER	swim	recall	number	defy
(6) TUMBLE	drink	dress	fall	think
(7) HIDEOUS	silvery	tilted	young	dreadful
(8) CORDIAL	swift	muddy	leafy	hearty
(9) EVIDENT	green	obvious	sceptical	afraid
10) IMPOSTOR	conductor	officer	book	pretender
11) MERIT	deserve	distrust	fight	separate
12) FASCINATE	welcome	fix	stir	enchant
13) INDICATE	defy	excite	signify	bicker
14) IGNORANT	red	sharp	uninformed	precise
15) FORTIFY	submerge	strengthen	vent	deaden
16) RENOWN	length	head	fame	loyalty
17) NARRATE	yield	buy	associate	tell
18) MASSIVE	bright	large	speedy	low
19) HILARITY	laughter	speed	grace	malice
20) SMIRCHED	stolen	pointed	remade	soiled
21) SQUANDER	tease	belittle	cut	waste
22) CAPTION	drum	ballast	heading	ape
23) FACILITATE	help	turn	strip	bewilder
24) JOCOSE	humorous	paltry	fervid	plain
25) APPRISE	reduce	strew	inform	delight
26) RUE	eat	lament	dominate	cure
27) DENIZEN	senator	inhabitant	fish	atom
28) DIVEST	dispossess	intrude	rally	pledge
29) AMULET	charm	orphan	dingo	pond
30) INEXORABLE	untidy	involatile	rigid	sparse
31) SERRATED	dried	notched	armed	blunt
32) LISSOM	moldy	loose	supple	convex
33) MOLLIFY	mitigate	direct	pertain	abuse
34) PLAGIARIZE	appropriate	intend	revoke	maintain
35) ORIFICE	brush	hole	building	lute
36) QUERULOUS	maniacal	curious	devour	complaining
37) PARIAH	outcast	priest	lentil	locker
38) ABET	waken	ensue	incite	kindness
39) TEMERITY	rashness	timidity	desire	placate
40) PRISTINE	vain	sound	first	level

PLEASE DO NOT WRITE IN THE AREA TO THE RIGHT

SHIPLEY TEST OF ABSTRACTION

> **Instructions:** Complete the following by filling in either a number of a letter for each dash (___). Do the items in order but don't spend too much time on any one item.
> EXAMPLE: A B C D E

(1) 1 2 3 4 5 _____

(2) white black short long down _____

(3) AB BC CD D _____

(4) Z Y X W V U _____

(5) 1 2 3 2 1 2 3 4 3 2 3 4 5 4 5 4 5 6 _____ _____

(6) NE/SW SE/NW E/W N/ _____

(7) escape scape cape _____

(8) oh ho rat tar mood ___ ___ ___ ___

(9) A Z B Y C X D ___

10) tot tot bard drab 537 __ __ __

11) mist is wasp as pint in tone __ __

12) 5 7 3 2 6 7 3 2 6 5 3 2 6 5 7 2 6 5 7 3 __ __ __ __ __

13) knit in spud up both to stay ____ ____

14) Scotland landscape scapegoat ___ ___ ___ ___ e e

15) surgeon 1234567 snore 17653 rogue ___ ___ ___ ___ ___

16) tarn tan rib rid rat raw hip __ __ __

17) tar pitch throw saloon bar rod fee tip end plank ___ ___ ___ ___ ___ meals

18) 3124 82 73 154 46 13 ___

19) lag leg pen pin big bog rob ___ ___ ___

20) two w four r one o three ___

Appendix D: Research Ethics Approval

Brock University

Senate Research Ethics Board **Extensions 3943/3035, Room AS 302**

DATE: **April 6, 2004**

FROM: Joe Engemann, Chair

Senate Research Ethics Board (REB)

TO: Sid Segalowitz, Psychology

Adote Anum

FILE: ______**03-350 Anum**

TITLE: **Relationship Among Processing Speed, Working Memory and General Intelligence**

[redacted]

The Brock University Research Ethics Board has reviewed the above research proposal.

DECISION: Accepted as Clarified. However, please define "modality specificity" in lay terms on the consent form.

This project has been approved for the period of **April 6, 2004** to **August 31, 2005** subject to full REB ratification at the Research Ethics Board's next scheduled meeting. The approval may be extended upon request. ***The study may now proceed.***

Please note that the Research Ethics Board (REB) requires that you adhere to the protocol as last reviewed and approved by the REB. The Board must approve any modifications before they can be implemented. If you wish to modify your research project, please refer to www.BrockU.CA/researchservices/forms.html to complete the appropriate form ***REB-03 (2001) Request for Clearance of a Revision or Modification to an Ongoing Application.***

Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Principal Investigator, the safety of the participants and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-Council. Policy Statement requires that ongoing research be monitored. A Final Report is required for all projects, with the exception of undergraduate projects, upon completion of the project. Researchers with projects lasting more than one year are required to submit a Continuing Review Report annually. The Office of Research Services will contact you when this form ***REB-02 (2001) Continuing Review/Final Report*** is required.

Please quote your REB file number on all future correspondence.

Deborah VanOosten, Research Ethics Officer
Brock University
Office of Research Services
500 Glenridge Avenue
St. Catharines, Ontario, Canada L2S 3A1
phone: (905)688-5550, ext. 3035 **fax:** (905)688-0748
email: deborah.vanoosten@brocku.ca
http://www.brocku.ca/researchservices/humanethics.html

Appendix E: Consent Form

RELATIONSHIP BETWEEN PROCESSING SPEED, WORKING MEMORY AND GENERAL FLUID INTELLIGENCE

INFORMED CONSENT

Principal Investigator: Adote Anum, Tel. (905) 688 5550 Ext. 3034
aa01ar@brocku.ca

Supervisor: Dr. S. J. Segalowitz, Tel. (905) 688 5550 Ext. 3451
sid.segalowitz@brocku.ca

You are being asked to participate in a research project, part of which is related to a Ph.D dissertation. The primary objective of the study is to investigate the relationship between speed of information processing and working memory and how this relationship affects general fluid intelligence. Current models of general intelligence do not generally acknowledge or test the issue of modality specificity. In this study, we examine the notion that individual differences in specific abilities will influence this relationship. We expect that results from this study will help us better understand the issues relating to the measurement and conceptualization of general fluid intelligence. This is important because this definition of intelligence is used in most cross-cultural work on intelligence.

It is expected that the duration of your participation will be about 2.5 hours. Your participation will involve completing a series of tests and these will take place in one session. We do not foresee any short- or long-term risks involved for participants in this study.

When you decide to take part in this study, you will fill out a brief health questionnaire as part of the study. The testing session involves a total of 12 tests that most of which last between 30 seconds and 4 minutes. A few of the tests take a little longer.

The data from this study is for scientific purposes only and will be kept completely confidential. Your personal information will not be associated with the data nor with any written reports, presentations, or publications that may develop from this study. Any future use of the data will be for the same purposes and will be subjected to the same confidentiality guidelines. It is expected that the results from this study will be available by April 1, 2005. If you are interested in receiving information about the results please leave your permanent address and we will send you a copy.

This study has been reviewed and has received ethics approval from the office of Research Ethics Board, File Number 03 350. If you have any questions or concerns regarding your participation in this study please contact the Ethics Officer at (905) 688 5550 Ext. 3035.

I have read and understood the relevant information. I understand that I am free to ask any questions in the future and that I am free to leave at any time. By signing this consent form I indicate that I have given free consent to participate in this study. (Please don't forget to keep a copy of the consent form).

Date: ____________________
Name of Participant: ________________________________

Principal Researcher: ________________________________

I understand that the data collected at this time may be used for future studies and consent to the use of any data that I contribute under the direction of the faculty advisor.

Name of Participant: ________________________________

Appendix F: Feedback Letter

RELATIONSHIP BETWEEN PROCESSING SPEED, WORKING MEMORY AND GENERAL FLUID INTELLIGENCE

FEEDBACK LETTER

Principal Investigator: Adote Anum, Tel. (905) 688 5550 Ext. 3034
aa01ar@brocku.ca

Supervisor: Dr. S. J. Segalowitz, Tel. (905) 688 5550 Ext. 3451
sid.segalowitz@brocku.ca

The primary objective of the study is to investigate how the relationship between speed of information processing and working memory affects general intelligence. General intelligence, also known as 'g' is assumed by some psycho-educational researchers to reflect cognitive ability that is not based on education or cultural experience. One of the most important measures of general intelligence is the Raven's Progressive Matrices. Current theoretical models of general intelligence suggest that speed of information processing and working memory are both related to general intelligence because of the relation between speed and working memory, and the executive properties of the latter. However, these models have not explored the effects that individual differences in specific modalities (for example, numerical or spatial) have on this relation.

In the present study we are exploring how differences in domain will influence this relationship. More specifically, we will test a two-factor hypothesis, that a visual-spatial model will predict general intelligence better than a verbal-numerical model when general intelligence is measured by Raven's Progressive Matrices. We also explore if certain cognitive skills beyond the executive attention properties of working memory can predict general intelligence.

If you are interested in receiving information about the results please add your name to the list provided and we will send you a copy as soon as the preliminary results are made available.