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The construct of cognitive processing and speed : test performance and information processing approaches

Lynette Silva

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LYNETTE M. SILVA

B.A., English, Stanford University, 1996

THESIS

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ABSTRACT

Speed of processing, theorized to be an important cognitive component of intelligence, is indexed by response speed on standardized cognitive ability tests. However, the term “processing speed” is also used to refer to “speed of information processing” during a cognitive task tapping early stages of processing, though these concepts arise from two different theoretical schools of thought. This study investigates the relationship between processing speed on higher-order cognitive tasks and information processing efficiency during early stages of processing. University of New Mexico undergraduate students (*n*=101) completed a widely used IQ test, the WAIS-III, and an information processing task, the visual backward masking task (VBM). The VBM consists of a computer presentation of a target and masking stimuli and is used to tap into the amount of time information is accurately processed in the sensory register. Two measures gathered during the VBM, detection accuracy, and a psychophysiological measure of mental effort, pupillary dilation response, were used to index information processing efficiency. Both VBM detection accuracy and the pupillary response to the

VBM masking stimulus, which represents resources allocated to the task irrelevant stimuli, have been associated with IQ scores. Consistent with previous studies, the VBM detection accuracy scores on the 83ms and 117ms stimulus onset asynchrony conditions were associated with various components of the WAIS-III; however, the VBM pupillary dilation response had stronger relationships to WAIS-III components appears to have a stronger underlying factor of *g*. In addition, the shorter VBM stimulus onset asynchrony conditions were associated with WAIS-III performance measures while the longer conditions were associated with verbal measures. These results suggest that, while processing speed and information processing efficiency are similar constructs with strong relationships to IQ, they are separate constructs with different underlying factors of those relationships. The VBM physiological measure of pupillary dilation response may be a more stable measure of cognitive ability than the VBM behavioral detection accuracy responses during this early information processing task.

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Introduction

Standardized cognitive ability tests rely heavily on response speed, theorized to index speed of processing, one of the more important cognitive components of intelligence (Deary & Stough, 1996; Bates & Stough, 1998; Helmbold, Troche, & Rammsayer, 2007; Sheppard & Vernon, 2008). However, standardized cognitive ability tests are not the only way to measure the construct of cognitive processing. In fact, information processing and psychophysiological measures can also inform on the relationships among and implications of response speed, mental effort, and processing efficiency. These measures can also help examine to what extent the relationships among these constructs are related to *g*, the general cognitive ability thought to underlie all cognitive tasks (Deary, Bell, Bell, Campbell, & Fazal, 2004). The terms “processing speed” and “speed of information processing” are often used interchangeably, yet they have been developed from differing theoretical backgrounds. Speed of information processing in the cognitive psychology literature is the time required for stimuli to be perceived, understood, and acted upon. One information processing model describes the sequence as input, integration, storage, and output (Silver, 1993). Processing speed as described in the psychometric literature is the time an individual completes a sequence of processing in a given cognitive task (Sternberg, 1969). The Weschler Adult Intelligence Scale, 3rd edition (WAIS-III; Weschler, 1997) Processing Speed Index (PSI) taps this concept and involves timed response to visual stimuli. However, this index and the subtests composing it are indirect measures of processing speed, and are subject to the condition of an individual’s visual working memory, as well as several noncognitive factors (Wolff & Gregory, 1991).

Speed is an integral component of the information processing approach in the forms of reaction time (RT) and inspection time (IT). RT is the amount of time it takes to respond to a stimulus (Smith, 1968). IT, a specific form of the backward masking paradigm, is the amount of time required to reliably pass information through the sensory register and accounts for approximately 20% of the variance in scores on standardized intelligence tests (Kranzler & Jensen, 1989; Deary & Stough, 1996). The visual backward masking task (VBM) has been used extensively in both the normal and abnormal cognitive literature to investigate the efficiency of the early stages of visual information processing including quickly and accurately attending to relevant stimuli as well as filtering out irrelevant stimuli (Granholm & Verney, 2004; Verney, Granholm, & Marshall, 2005; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005).

Overview

We will investigate the relationship between processing speed and information processing efficiency by studying performances on a widely used IQ test, the WAIS-III, an information processing task, the visual backward masking task, and a psychophysiological measure of mental effort, the pupillary dilation response. We will first provide an introduction to the relevant constructs of information processing and information processing efficiency, higher-order cognitive test processing speed, the backward masking paradigm and inspection time, and psychophysiological measurements. The speed at which a task is performed is usually the criterion used to measure the quality of that performance. Standardized cognitive ability tests, universally used to measure intelligence, rely heavily on processing speed (Neubauer & Fink, 2004). However, information processing and psychophysiological measures can also inform on the relationship(s) between and implications of response speed, mental effort, and processing efficiency. Information processing tasks tap into discrete stages of early processing, and psychophysiological measures can help quantify mental effort and processing efficiency. Inspection time, a specific form of the visual backward masking paradigm, has been shown to account for about 20% of the variance in IQ scores, suggesting that information processing efficiency underlies not only higher-order processing speed, but is also an underlying factor in the general cognitive ability, *g*. Finally, we will state the purpose of this study and our main hypotheses.

Information Processing

Information processing, the way environmental stimuli are perceived, understood, and acted upon, is a cornerstone of human functioning. The quantity and quality of information processed is used to determine an individual's level of cognitive functioning and ability, a determination that can generalize to evaluations of aptitude, skill, and intelligence.

The evolution of the computer brought new cognitive theories based on computer hardware and function. This so-called "cognitive revolution" shifted focus from theories of unitary ability to theories of information processing (Nietfield, et al., 2007), as well as excluded factors like personality and emotion. The concise and observable nature of input processed by a computer to yield output (Newell & Simon, 1956) led to comparisons to the human brain and its functions. The construct now known as information processing grew at least in part from Newell's and Simon's computer simulation program called The General Problem Solver (GPS) (Newell & Simon, 1995). The program was written to simulate the different steps involved in solving different kinds of problems; this method of dividing problem solving into several discrete steps led to the idea of a *process*. However, the explanation that processing creates output from input is an extreme oversimplification, particularly as it pertains to human cognition.

There are several accepted definitions of *information processing* that attempt to identify what exactly occurs between input and output. One such definition is "the sequence of mental operations and their products involved in performing a cognitive task" (Sternberg, 1981). Many different models have developed over the last sixty years to suggest what mental operations these might be, the most prominent of which are discussed below.

Theories & Models

Atkinson and Shriffin (1968) proposed the widely accepted "Stage Theory," which focuses on how information is processed to be stored into memory. This model contains three stages: sensory memory, short-term memory, and long-term memory. Under this model, information is serially processed and may or may not complete the journey through all three stages. Whiting (1972) had a tripartite theory as well, using mechanisms instead of stages: perceptual mechanisms handle sensory input, translator mechanisms run the decision process, and effector mechanisms cause action. These and the following models of cognition are based on similar stages and processes, and it is worth noting that non-cognitive factors like personality were not built into these models, thus the field of information processing evolved without them.

Craik and Lockhard (1972) veered away from the serial nature of the previous theories and proposed that information retention depends on the depth of processing. For example, new information will be processed more "deeply" if it relates to preexisting information, or if the new information is meaningful in some way. The deeper the processing, according to this model, the more enduring it will be in memory. Welford's model (1972) incorporated both the serial and the depth concepts as well as expanded the process: sensory input is temporarily stored while being evaluated; any information deemed relevant to the task at hand is stored in the short-term memory; a decision is reached by comparing the new information to preexisting information; action is taken based on information in the long-term memory; the results of the action are stored for future reference; the process starts over from the beginning.

Rumelhart and McClelland (1985) deviated entirely from serial models to a connectionistic model: the parallel-distributed processing model, which has become a more dominant model as brain imaging research advances (Cohen, Servan-Schreiber, & McClelland, 1992). This model theorizes that information is not stored in one central location but consists of a network which is distributed trans-cranially; meaning information is processed through different channels simultaneously. Like the levels-of-processing model, the parallel-distributed processing model posits that the more related new information is to preexisting information, the more likely the new information will be retained.

The WAIS-III incorporates a basic model of information processing composed of four stages: input, integration, storage, and output (Silver, 1993). The above models' components map on to or have equivalents of these stages. For example, the sensory memory, short-term memory, and long-term memory stages of the Stage Theory correspond to input, integration and storage, respectively. The final stage, output, incorporates the decision-making and evaluation of the "depth" models. Because this model is similar to all the previous models discussed, and because it is the model espoused by Weschler (1981), we will incorporate this four-stage model for the current study.

Components & Measures of Information Processing

Speed and efficiency are different aspects of information processing (Bates & Stough, 1998; Schweizer, 1998; Helmbold, Troche, & Rammsayer, 2007, Nietfeld, et al., 2007). Measuring these components can speak to the performance level and quality of the overall processing. Speed of information processing, as measured by the Hick reaction time task, visual inspection time (IT) tasks, and visual and auditory reaction time (RT) tasks, has been shown to correlate with psychometric intelligence as measured by tests like the Weschler Adult Intelligence Scale (WAIS), Raven's Progressive Matrices, and the Culture Fair Intelligence Test Scale 3 (Chaiken & Young, 1993; Clement & Kennedy, 2003; Helmbold, Troche, & Rammsayer, 2007; Luciano, et al., 2004; Lunneborg, 1978; Neubauer & Knorr, 1998; Sheppard & Vernon, 2008; Spiegel & Bryant, 1978), resulting in a mental-speed based model of intelligence (Bates & Stough, 1998). Indirect measures, like psychometric intelligence tests, attempt to tap this temporal correlate by using timed tasks: Assuming that speed of information processing is one of the more important cognitive components of intelligence (Neubauer & Fink, 2004), the faster an individual completes the sequence of processing in a given task, the higher the intelligence of that individual.

Scores on standardized IQ assessments rely on timed responses, the rationale being that faster responses are equivalent to faster task processing, involving several cognitive stages, which indicates more efficient processing. Speed of information processing is also used to infer higher processing efficiency; i.e. fewer mental resources are dedicated to the task, and responses will come more quickly and be more accurate. Following the aforementioned information processing sequence of input, integration, storage, and output, processing speed is how quickly an individual completes that sequence of processing in a given task (Silver, 1993). The shorter the time taken to complete a task, the higher the intelligence of the individual is predicted to be. The Weschler Adult Intelligence Scale, 3rd edition (WAIS-III) makes use of thirteen subtests categorized into four indexes: Verbal Comprehension Index (VCI), Working Memory Index (WMI), Perceptual Organization Index (POI), and Processing Speed Index (PSI). Most relevant to this study, the PSI is composed of two subtests, digit-symbol coding and symbol search; both subtests involve timed response to visual stimuli. The PSI has been shown to be most sensitive to traumatic brain injury, suggesting that it is an appropriate indicator of quality of overall cognitive functioning (Clement, & Kennedy, 2003; Kennedy, Clement, & Curtis, 2003).

Because psychometric intelligence tests are indirect measures of processing speed, they are subject to the condition of an individual's visual working memory, as well as several extraneous noncognitive factors like motivation, test anxiety, personality and mood (Deary, McCrimmon, & Bradshaw, 1997). Further, these tests were developed with the intent of measuring capacities as opposed to processes (Miller, 1999). The advancement of technology may provide a more direct measure of processing speed than traditional standardized cognitive assessments. Psychophysiological measures may expand our options for measurement while isolating the process we wish to examine (Small, Raney, & Knapp, 1987). The speed at which an individual completes items on a standardized cognitive ability test may indirectly inform on the speed of neural functioning; psychophysiological measures take a more direct route.

Reaction Time. Reaction time (RT) is the elapsed time between the presentation of a sensory stimulus and the subsequent behavioral response (Smith, 1968). Because this latency time is thought to be the time it takes for cognitive processes to turn input into output, RT is often used in experimental psychology to measure the duration of mental operations (Neubauer, et al., 1997) The behavioral response is often a button press but can also be an eye movement, a vocal response, or some other observable behavior.

There are three predominant types of RT, all measured slightly differently; simple, recognition, and choice reaction time (Smith, 1968). Simple reaction time is the time it takes an individual to detect a stimulus, which is usually measured by presenting a stimulus and requiring an act of acknowledgement, like a button press. Recognition reaction time is the time it takes to detect a target stimulus in the context of several different stimuli, and is measured by presenting target and non-target stimuli and requiring an act of acknowledgement only in response to the target. Choice reaction time (CRT) is the time it takes to detect and acknowledge a stimulus when different stimuli are paired with different responses; for example, pressing one button for one stimuli and a different button for another.

The pioneer reaction time study was that of Donders (1868), in which he showed that a simple reaction time is shorter than a recognition reaction time, and that the choice reaction time is longest of all. Laming (1968) concluded that simple reaction times averaged 220 milliseconds (ms) but recognition reaction times averaged 384 ms. This is consistent with many studies concluding that a complex stimulus (e.g., several letters in symbol recognition vs. one letter) elicits a slower reaction time (Teichner and Krebs, 1974; Brebner and Welford, 1980; Luce, 1986). Miller and Low (2001) determined that the time for motor preparation (e.g., tensing muscles) and motor response (in this case, pressing the spacebar) was the same in all three types of reaction time tests, implying that the differences in reaction time are due to cognitive processing time.

Reaction time has been shown to correlate negatively with intelligence: the shorter (and less variable) the time taken to respond, the higher the intelligence (Jensen & Vernon, 1984; Helmbold, Troche, & Rammsayer, 2007). Previous studies have found a negative correlation between -.26 and -.40 (Sheppard & Vernon, 2008). However, simple and recognition reaction times only measure neural speed, not other components associated with IQ (Bates, 1998). Standard deviations of reaction time has been shown to predict scores on IQ measures as well as mean reaction time, suggesting a relationship between consistency and intelligence (Jensen, 1992). There is some evidence that choice reaction time (CRT) is the more vital component to measure when gauging speed of information processing (Hamilton & Launay, 1976), and though using CRT is contrary to a unitary theory of intelligence, it is the RT that best predicts IQ (Luciano, et al., 2004).

The visual backward masking task (VBM). The VBM has been used extensively to investigate the efficiency of the early stages of visual information processing, as well as to quantify the amount of time required to ferry information through the sensory register. The VBM procedure consists of a rapidly presented target stimulus (i.e., two lines of different length), a varying duration of vacant time (interstimulus intervals typically range from 20 ms to 700 ms), and a masking stimulus that obscures the spatial presence of the target stimulus in its entirety (Saccuzzo, 1993). A no-mask condition, wherein only the target stimulus is presented, is often included to isolate the individual's ability to process the target stimulus without the interference of the masking stimulus The individual is usually asked to make a decision regarding the target stimulus, specifically, discriminating between the shorter and longer lines.

Because efficient cognitive processing requires the ability to identify and attend to relevant stimuli quickly and accurately, while simultaneously identifying and filtering out irrelevant stimuli (Granholm & Verney, 2004; Verney, Granholm, & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005), the VBM is a uniquely suited measure. The cognitive mechanisms underlying performance on the VBM include integration, interruption/inhibition, and attentional shifting/replacement (Michaels & Turvey, 1979).

In integration, representations of the target and the mask are fused into one mental image, an image that has been compared to a double-exposed photograph (Neisser, 1967). When the target and the mask are too physically close together, or shown with too little time in between (typically less than 20ms), it is more difficult to form a clear image of the target, and integration occurs. Interruption/inhibition results from the disruption of processing of the target by onset of processing of the mask, leaving the target only partially processed (Michaels & Turvey, 1979). The third cognitive mechanism, attentional shifting/replacement, occurs at approximately 100ms after the target stimulus presentation, and involves dividing attentional resources between the target and the mask (Michaels & Turvey, 1979; Phillips, 1974; Verney, Granholm, & Dionisio, 2001).

Where the psychometric approach to cognitive assessment focuses on the products of cognition, the information processing approach is concerned with the processes of cognition: instead of measuring an ability thought to represent a cognitive process, the information processing approach examines the basic processes underlying an ability (Miller, 1999). Speed is an integral component of the information processing approach and is assessed through reaction time (RT) and inspection time (IT), both of which correlate negatively with intelligence (Deary & Stough, 1996; Grudnik & Kranzier, 2001; Luciano, et al., 2004; McCrory & Cooper, 2007). These correlations become stronger as the complexity of the task increases. It has been theorized that increased complexity demands more of working memory, which might slow down information processing, making processing speed a more informative index of intelligence (Jensen & Vernon, 1984).

Inspection Time. Inspection time (IT) is a specific form of the backward masking paradigm and is similar to RT, but rather than the time it takes to emit behavior in response to stimuli, IT is the minimum amount of exposure time needed to reliably comprehend the stimuli (Kranzler & Jensen, 1989; Deary & Stough, 1996). The IT measure involves differential judgment of simple visual stimuli; usually two lines of different lengths. When asked to identify the longer line, participants with no visual impairment can do so accurately and reliably. However, accuracy decreases as the amount of time exposed to the stimulus decreases: the shorter the exposure time, the faster visual information must be integrated. After a stimulus is presented, visual information is held in the sensory register for a brief time as a precursor and aid to information processing. To ensure that participants are processing the stimulus itself and not information stored in the sensory register, a masking stimulus is usually used as interference, completely obscuring the target stimulus. The no-mask condition, wherein only the target stimulus of two lines of unequal length is presented, demands fewer cognitive resources than the masked conditions (Verney, Granholm, & Dionisio, 2001). The addition of the mask increases cognitive load, requiring the previously described process involving quick, accurate identification, attention, and filtering.

An important difference between IT and RT is that time is not measured between stimulus onset and response: exposure time of target stimuli is set, and only the accuracy of responding is measured. The measure of IT is the amount of time needed for a participant to achieve a specific level of accuracy; for example, it may require an individual an average of 17ms of exposure to the target stimulus to achieve 85% accuracy in discriminating between the longer and shorter line (Deary & Stough, 1996). In this example, 17ms is the stimulus onset asynchrony (SOA), or the time between the onset of the target presentation and the onset of the mask presentation. In IT experiments, the exposure time is set and used with all participants, only the average time required for a specific level of accuracy varies across individuals. This individual variation in inspection time required is thought to reflect differences in speed of information processing (Deary & Stough, 1996). IT has been shown to correlate negatively with intelligence (Nettlebeck & Lally, 1976; Deary & Stough, 1996; McCrory & Cooper, 2007), and to account for 20% of the variance of IQ scores (Kranzler & Jensen, 1989; Deary & Stough, 1996). In fact, there is some support for IT having the strongest correlation with IQ over any other cognitive assessment (Grudnik & Kranzier, 2001).

IT & choice reaction time (CRT) are moderately correlated (r=.23) with each other and each has a strong negative correlation with IQ (Luciano, et al., 2004). This suggests that each may be a valid measure of the construct of intelligence. Because IT is not measured by time of response, it is important to control the duration of stimulus exposure, and have the ability to assess whether comprehension of the stimulus has been achieved. To satisfy both these requirements, historically a tachistiscope-administered task (Dimmick, 1920; Saccuzzo, 1993) was the most commonly used instrument with which to measure IT. In order to utilize the eye tracking system to measure puillary responses we have modified the VBM for computerized administration. The general concepts of IT and CRT are considered to define processing speed, thus the VBM is used here as a measure of that construct.

Pupillary Dilation Response

Pupillary response has been shown to reflect the amount of resources allocated to the task, or mental effort expended during task performance (Beatty, 1982). Measurements of the variations of pupil diameter in response to stimuli can inform on cognitive load and information processing efficiency. Many mental operations result in pupil dilation, and as the demand of the task or number of stimuli is increased, the pupil diameter has been shown to increase (Beatty, 1982; Steinhauer, et al., 2004). For example, during a digit span recall task, pupil diameter increases with the presentation of each additional digit, and returns to baseline once the digits have been recalled (Granholm, Asarnow, Sarkin, & Dykes, 1996). In this way, pupillary responses to various cognitive tasks can index within-task variations of cognitive demand, as well as between-task variations when tasks are qualitatively dissimilar (Beatty, 1982). Likewise, differences between individuals' pupillary response on the same task can index differences in cognitive abilities across individuals (Beatty, 1982).

Previous research with the VBM and pupillary response has found greater pupil dilation following the peak response in later stimulus onset asynchrony (SOA) conditions: When there is enough time between the target and the mask (i.e. 300ms), they are perceived and processed separately (Verney, Granholm, & Dionisio, 2001). In these later conditions, pupillary response can index resources allocated to processing the target as well as the additional resources allocated to processing stimuli irrelevant to the task (the mask). The amount of resources inefficiently dedicated to the mask has been found to negatively correlate with SAT and IQ scores (Verney, Granholm, & Marshall, 2004; Verney, et al., 2005): i.e., the higher the cognitive ability, the more efficient the processing, and the fewer resources dedicated to the mask. Likewise, the lower the cognitive ability, the less efficient the processing, and the more resources dedicated to processing irrelevant stimuli.

In the present, study, pupillary dilation responses were collected during a VBM task as an index of mental effort. Larger pupil diameter in response to various stimulus onset asynchrony (SOAs) conditions of target and mask presentation would represent more resources allocated and thus, less efficient information processing. In concordance with previous research, we will use a principle components analysis (PCA) to identify which portions of the pupillary response waveform are associated with which specific stimuli. Previous analyses have revealed three time factors associated with the specific demands of target and mask processing: An early factor between 0 and 0.7 s, a middle factor between 0.7 and 1.5 s, and a late factor between 1.5 and 3.0 s (Granholm & Verney, 2004; Verney, Granholm & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). The difference between pupil dilation during the late factor of the longer SOAs and pupil dilation during the no-mask condition is thought to index the additional processing demands required due to the mask (Verney, 2001; Granholm & Verney, 2004; Verney, Granholm & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). This will help to quantify resources allocated to the mask, which is an irrelevant stimulus in this task, and inform on an individual's efficiency of processing. As with models of information processing, personality and emotion are not incorporated into this theory of mask processing. However, pupillary dilation response, as with other psychophysiological measures, focus on the difference between pupil dilation during two conditions, many trials are averaged to represent that condition (e.g., 20 trials per condition), and trials are counterbalanced throughout the task, which often lasts about 15 to 20 minutes. Thus, factors such as emotion and fatigue are assumed not to be major factors in the task in general and in mask processing as in this study. Further, motivation and strategy have been found to be insignificant in the inspection time task (Deary & Stough, 1996), thus top-down processing and other factors such as personality likely have minimal influence on task performance. Such resistance to extraneous factors for these information processing tasks cannot be said to exist definitively of paper and pencil cognitive ability assessments.

Summary

Psychometric processing speed and speed of information processing appear to be similar constructs although born out of different theoretical arenas. The speed and efficiency at which basic perceptual information is processed likely dictates the overall processing speed needed to complete a cognitive task that may incorporate many cognitive components. We will use an information processing task, the visual backward masking task (VBM), in conjunction with a psychophysiological measure, pupillary dilation response, to index efficiency of processing at early cognitive stages. We will compare the efficiency of processing to a processing speed index on the WAIS III, a standardized, widely used general cognitive ability test.

We conducted neurocognitive testing with an undergraduate student sample to investigate the associations between processing speed and efficiency of information processing. We administered a standardized cognitive ability test, the WAIS III, to assess processing speed and the VBM task to assess information processing efficiency. Pupillary responses were also recorded during the computerized VBM task to index the amount of processing resources allocated to the task (Beatty, 1982).

We expected that processing speed on a standardized cognitive ability test, the WAIS-III, would be strongly associated with performance on an information processing efficiency task, the visual backward masking task. Specifically, we expected to see a significant positive correlation between scores on the Processing Speed Index and VBM detection accuracy during the stimulus onset asynchrony conditions that appear most challenging, i.e., 83ms and 117ms conditions. We expected that processing speed on a standardized cognitive ability test, the WAIS-III, would be strongly associated with the pupillary responses indexing information processing efficiency during the VBM task. Specifically, we expected to see a significant negative correlation between test scores and VBM pupil dilation response due to mask processing. Additionally, we expected to be able to examine the extent to which both detection accuracy on the visual backward masking task and pupillary dilation are related to the underlying general cognitive ability, *g*, by using the method of correlated vectors (MCV) (Colm, Jung, & Haier, 2006). We hypothesized that that “processing speed” and “information processing speed” during higher-order cognitive tasks are overlapping but separate constructs.

Quickness and accuracy of responding are cornerstones of cognitive assessment. Information processing and psychophysiological measures may result in a greater understanding of the underlying cognitive mechanisms involved in such cognitive processing. These measures of early stages of information processing may assist in the development of more reliable and valid methods of cognitive assessment for populations from more diverse backgrounds. Information processing tasks and psychophysiological indices may be less influenced by cultural factors than higher-order cognitive tests (Fagan, 2000; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). In addition, understanding information processing efficiency may assist in greater understanding of various psychopathologies, and could aid in our conceptualization, prediction, and treatment of cognitive deficits associated with various disorders.

Methods

As part of a larger study, we conducted neurocognitive testing with an undergraduate student sample. To assess processing speed on cognitive ability tests, we administered a standardized and widely used cognitive ability test, the WAIS-III. To assess information processing speed, we administered the visual backward masking task (VBM), while simultaneously gathering pupillary dilation response information. By comparing scores on the WAIS-III to the percent correct on the VBM, we will examine the extent to which information processing speed compares with standardized cognitive test scores as an index of intelligence. Likewise, by comparing scores on the WAIS-III to the pupillary responses on the VBM, we will examine the extent to which physiological measurements compare to standardized intelligence tests as an index of information processing speed.

Sample and Setting

The sample consisted of 120 undergraduate students from the University of New Mexico (UNM). Data were collected between October 2004 and May 2007. Subjects were recruited as part of a larger study from psychology courses at UNM. Participants were offered class credit for their time and efforts and each participant provided informed consent. The human subject committees of UNM approved this study.

Of the 120 students, fifteen were excluded due to eyetracking technical difficulties, three were excluded due to incomplete WAIS-III scores. One participant was excluded due to a family history of schizophrenia; first-degree relatives of patients with schizophrenia also show information processing deficits (Snitz, Macdonald & Carter, 2006). The final sample of 101 students approximated the ethnic makeup of the UNM campus (for detailed demographic information, see Table 1).

Measures

Background Questionnaire

Participants were asked to fill out a self-report to obtain demographic information. The questions yielded answers regarding sex, age, ethnicity, parental education level and family income. For analysis, estimated socioeconomic status (SES) was calculated using parental education and family income level; parental education was assessed with six categories ranging from "below 8th grade education" and "completed graduate school," and family income was assessed with six categories ranging from "below $10,000 a year" to "above $50,000 a year." The SES score was calculated by averaging the index of these categorical variables. For example, a participant whose mother completed a college degree (an index of 6), and whose father completed high school (an index of 4), and their family income averaged $25,000 (an index of 2) his or her SES score would be 4.0.

WAIS-III

To estimate IQ, the Ward seven-subtest short form of the WAIS-III (Ward, 1990) was administered. This short form includes seven subtests of the WAIS-III: Picture Completion, Digit Symbol Coding, Similarities, Block Design, Arithmetic, Digit Span, and Information. Full scale and index score estimates obtained using the Ward seven-subtest short form have been shown to correlate highly with scores obtained using the complete WAIS-III: correlations for Performance IQ, Verbal IQ, and Full Scale IQ range from .95 to .98 (Ward, 1990; Callahan, et al., 1997; Pilgrim, et al., 1999).

The abbreviated version of the WAIS-III Processing Speed Index (PSI) consists of two subtests, Digit Symbol and Symbol Search, both of which require processing and responding to visual information under time pressure. For Digit Symbol, participants are instructed to copy symbols into blank boxes beneath their corresponding numbers based on a code key. In Symbol Search, participants are instructed to examine two symbols in one column and decide whether either of these symbols appears in a series of five symbols in the next column. Both subtests have a time limit of 120 seconds each. To calculate the PSI, we used the mean of the scores from Digit Symbol and Block Design, which substituted for Symbol Search. Like Symbol Search, Block Design requires processing and responding to visual information under time pressure. Additionally, Block Design has the most shared abilities with Digit Symbol: visual perception of abstract stimuli, comprehending verbal instructions, integration/storage, perceptual organization, model reproduction, speed of mental processing, and visual-motor coordination (Kaufman & Lichtenberger, 1999). Two abilities represented by Symbol Search but not Digit Symbol are figural organization and spatial visualization, two abilities which *are* represented by Block Design (Kaufman & Lichtenberger, 1999). Previous studies have used only Digit Symbol to estimate processing speed, while also drawing comparisons with Block Design (Deary, et al., 2004; Luciano, et al., 2004). Additionally, Block Design has been used in previous research as a lone measure of information processing (Royer, 1977).

The other three index scores were also estimated from the seven subtests and all are expressed in scaled score form, which has a mean of ten and a standard deviation of three. The Perceptual Organization Index measures non-verbal reasoning, ability to integrate visual stimuli, and visual motor coordination (Kaufman & Lichtenberger, 1999), and was estimated using the Picture Completion and Block Design subtests. The Working Memory Index, a measure attention, concentration, sequential processing, and executive processing (Kaufman & Lichtenberger, 1999) was estimated using the Arithmetic and Digit Span subtests. The Verbal Comprehension Index, a measure of verbal conceptualization, knowledge, expression, and factual knowledge (Kaufman & Lichtenberger, 1999), was estimated using the Similarities and Information subtests.

Visual Backward Masking (VBM) Task

A computerized VBM task consisted of a target stimulus, two vertical parallel lines of different length, 1.7cm apart, adjacent horizontally and offset vertically. This means either the shorter or the longer line could be higher. Participants were instructed to maximize accuracy and minimize response time when pressing either the left or right game controller button to indicate which line (left or right, respectively) was longer. The masking stimulus presented two lines of equal length that spatially replaced the target lines. The stimulus onset asynchronies (SOAs), or time between presentation of the target stimulus and presentation of mask, were 50, 83, 117, 300, and 700ms along with a no-mask condition that served as a control condition. These SOAs were chosen to represent a wide range of detection accuracy based on previous studies (Verney, Granholm, & Marshall, 2004) and to coincide with a 60-Hz computer screen refresh rate. Twenty trials were presented for each condition for a total of 120 test trials. Participants were given 30 practice trials with the first 12 trials providing accuracy and response time feedback. No feedback was provided during the test trials. Duration of presentation of target and mask was equal, 17ms (one screen at 60-Hz screen refresh rate). Between each trial, a plus sign was displayed in the center of the screen to keep the participant's gaze fixed on the screen, prepared for the next trial.

Pupillary Response Measures

A head-mounted infrared corneal-reflection-pupil-center eye-tracking system, EyeLink II (Copyright © SR Research Ltd. 2001-2008), was used to gather pupillometric data from both eyes during the VBM task performance. The left eye was analyzed for this study barring technical difficulties with left eye imaging, in which case right eye data was used. Difficulties with left eye imaging requiring use of right eye data occurred twice in our sample. Pupil diameter was sampled at 250 Hz, i.e., every 4 ms. Two PC computers were used in the eye-tracking setup: a task computer with a 17-inch monitor for participant task display and a computer to control and gather eye-tracking and pupillary response data. Participants were seated comfortably in front of the display monitor in a dimly lit room. The EyeLink II headband was placed and adjusted comfortably on the participant's head. A calibration routine ensured participant and instrument agreement of eye gaze coordinates and pupil images. The EyeLink II headband allows freedom of head movement during data collection; however, the average distance from the eyes to the screen is estimated to be 61 centimeters.

Raw pupil data was automatically processed according to a specialized computer program designed to smooth and filter, removing eyeblinks and other artifacts by linear interpolation. Post-processing was prepared using a MATLAB program (theMathWorks Inc., Sherborn, USA). The program then created a single pupillary response waveform for each participant's average of trials for each SOA condition.

Analytic Strategy

Data Preparation

Based on previous research, we will use a principle components analysis (PCA) to analyze the pupillary response waveform (Verney, Granholm & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). Because the pupil dilation response represents the total of all processing demands of a task, the PCA will help identify which processing demands are associated with which specific stimuli (e.g. target or mask). Previous studies have found three time factors associated with the specific demands of target and mask processing: An early factor between 0 and 0.7 s, a middle factor between 0.7 and 1.5 s, and a late factor between 1.5 and 3.0 s (Granholm & Verney, 2004; Verney, Granholm & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). The timeframe of the middle factor suggests this is the factor wherein resources are allocated to target/mask discrimination. Pupillary response during the late factor is thought to reflect mask processing: During the longer SOA conditions, the mask becomes a separate mental image from the target. Mask pupillary response is used in this study to quantify the attentional resources dedicated to identifying the masking stimulus. This is determined by the difference between the late PCA factor of the longer SOA conditions and the no-mask condition. The late factor pupil dilation during the longer SOA conditions has been found to be significantly greater than the no-mask condition, therefore the difference in pupil dilation between the two is thought to reflect the processing demands added to the task because of the mask (Verney, 2001; Granholm &

Verney, 2004; Verney, Granholm & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005).

Data Analysis

To evaluate the extent to which processing speed on a standardized cognitive ability test is associated with performance on an information processing efficiency task, we will use correlational analyses to investigate the relationship between WAIS-III processing speed and VBM detection accuracy scores for all SOA conditions. To evaluate the extent to which processing speed on a standardized cognitive ability test is associated with the pupillary responses indexing information processing efficiency during the visual backward masking task, we will use correlational analyses to investigate the relationship between WAIS-III processing speed and VBM pupillary responses. Specifically, we will use the mask processing index score derived from the late PCA factor scores of the longer SOA conditions and the no mask condition to investigate the efficiency of processing to the masking stimulus, an irrelevant stimulus to the task. Demographic factors such as age, sex, socioeconomic status (SES), and ethnicity, have been found to be associated with cognitive assessment; thus, these factors were included as covariates in regressions. When a covariate was found to be significant in the preliminary regression models, it was included in the final model presented.

We will also be using the method of correlated vectors (MCV) to investigate the extent to which *g*, the general factor thought to underlie all cognitive measures, is associated with VBM detection accuracy and pupillary response. Because the correlations between WAIS-III scores and VBM performance, for example, may or may not result directly from the underlying *g* component, simple correlation analyses would not be sufficient to conclude that *g* is responsible for the correlation. Using the MCV, the correlation between VBM detection accuracy and WAIS-III scores will yield a column vector. The correlation between this column vector and the vector of WAIS-III *g* loadings can show the extent to which *g* underlies the correlation between VBM detection accuracy and WAIS-III scores. The MCV will be analyzed for both VBM measures of information processing efficiency, detection accuracy and pupillary response, in association with the WAIS-III scores. This method provides an estimate of the extent to which *g* underlies a relationship. However, the variability and differential reliabilities of the different WAIS-III subtests confound unreliability with *g* loading. Thus, this methodology will only be used to estimate the relationship between VBM processing and WAIS-III performance.

Results

Descriptive Analyses

The sample of UNM undergraduate students used in this study was representative of the university population in ethnicity and age (see Table 1). The WAIS-III IQ scores were estimated based on the Ward seven-subtest short form and expressed in standard score form. The mean full-scale IQ (FSIQ) score of the sample was 103.7, which approximates the average standard score of 100 (±15). The WAIS-III index scores were calculated from the seven subtests administered as described and are expressed in scaled score form. Likewise, all subtest scaled score means fell within the average scaled score range of 10 (±3). All WAIS-III index score means also fell within the average range (see Table 2).

Table 1. ***Demographic Information of the Sample***

Variable	**M**	*SD (or %)*
N	*101*	
Age (in years)	21.6	7.5
Sex (female, %)	60.0	59.4
Primary Ethnicity (%)		
European American	45.0	44.6
Hispanic	40.0	39.6
Native American	6.0	5.9
African American	5.0	5.0
Asian American	4.0	4.0
Arab American	1.0	1.0
Mother's Education (years)	14.5	3.0
Father's Education (years)	14.9	3.4
Family Annual Income (thousands of dollars)	42.0	10.0
Socioeconomic Status [a]	16.2	3.8
English as a First Language (%)	86.0	85.1
Bilingual (%)	32.0	31.7

[a]Socioeconomic status was an average index of mother's and father's education level and family annual income categories.

Table 2. ***Mean WAIS-III Scores and g Loading***

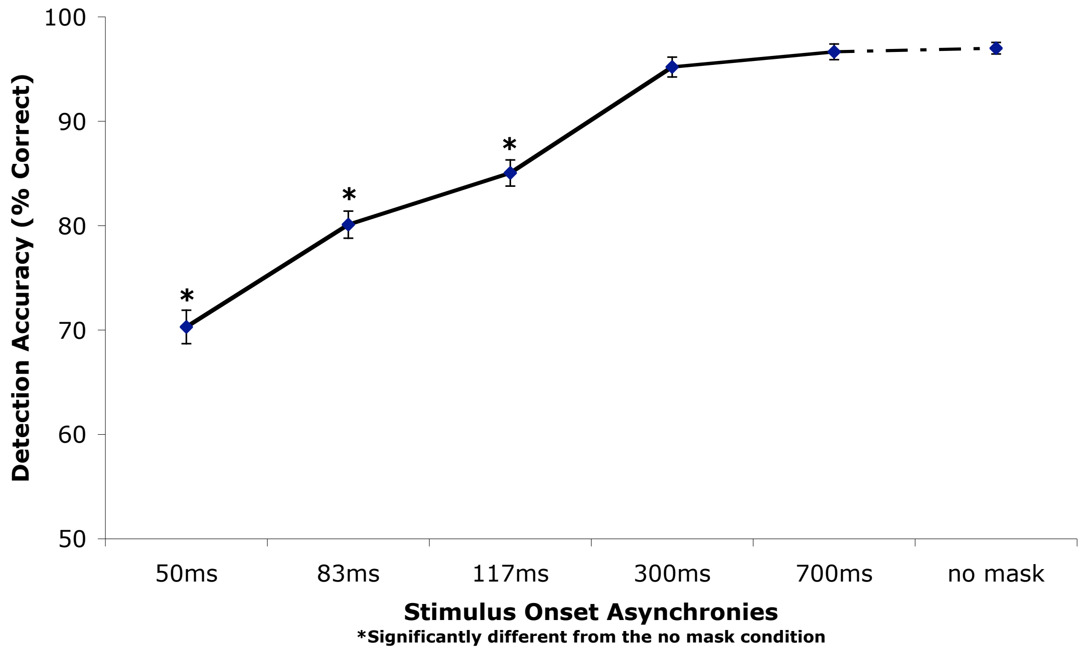
WAIS-III	*M*	*SD*	*g Loading*
Subtest Scores			
Picture Completion	10.8	2.5	.64
Digit Symbol	9.7	3.4	.59
Similarities	11.3	2.9	.79
Block Design	11.6	2.9	.72
Arithmetic	10.2	2.5	.75
Digit Span	9.9	2.5	.57
Information	11.6	2.8	.79
Index Scores			
PSI	10.6	2.4	
VCI	11.4	2.5	
POI	11.2	2.2	
WMI	10.0	2.1	
IQ Scores			
VIQ	103.6	9.6	
PIQ	103.7	9.9	
FSIQ	103.7	8.6	

Detection Accuracy

Visual backward masking detection accuracy for the five SOA conditions and the no mask condition is presented in Figure 1. Where target lines are presented alone, in the most discernable manner (i.e. the no mask condition), the rate of correct responses is highest, as expected (97%). In the shortest SOA condition, 53ms, the rate of correct responses falls to 70%. These findings are consistent with previous similar research and represent the expected pattern of detection accuracy on the VBM task (Verney, Granholm, & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). Paired samples T-tests showed that the two longest SOA conditions, 300ms and

700ms, were not significantly different from the no mask condition. The earlier SOA conditions, 50ms, 83ms, and 117ms, were significantly different from the no mask condition.

Figure 1. VBM Detection Accuracy in Six SOA Conditions

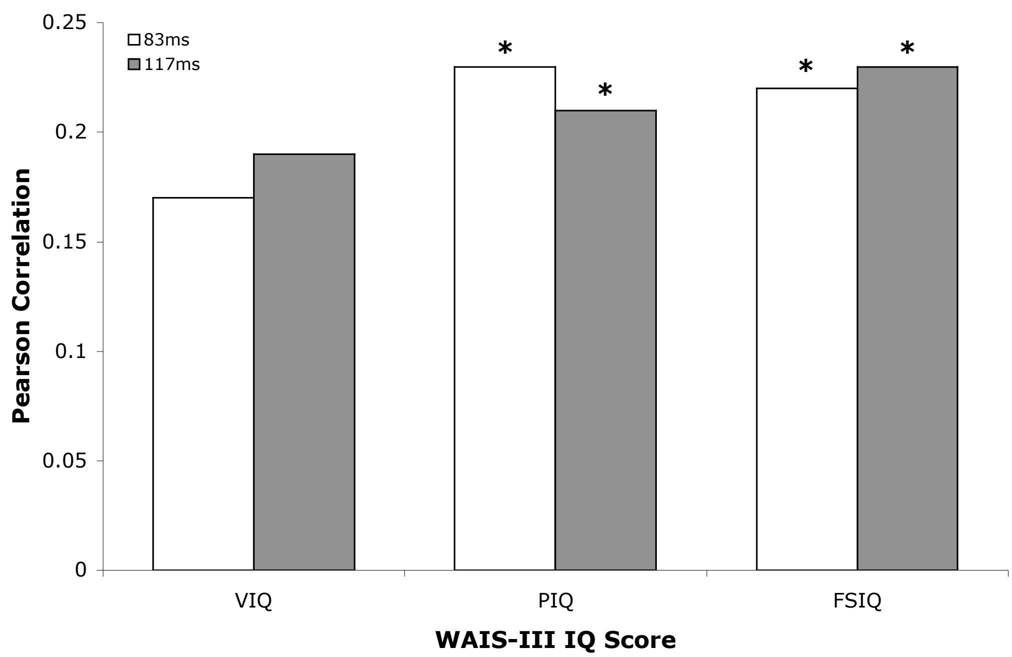


WAIS-III IQ Scores & Detection Accuracy

Figure 2 presents the associations between the relevant VBM detection accuracy scores, i.e., 83ms and 117ms conditions, and the WAIS-III scores. The WAIS-III IQ scores only had significant positive correlations with the VBM SOA conditions of 83ms and 117ms, the most challenging SOA conditions. These SOA conditions represent the highest processing demands, as the target and mask are not separate percepts and attention and short-term memory resources must be shared between both stimuli (Michaels & Turvey, 1979; Granholm & Verney, 2004). The 83ms condition correlated significantly with PIQ and FSIQ scores (r=0.23, p=0.03 and r=0.22, p=0.03 respectively);

the 117ms condition correlated significantly with PIQ and FSIQ scores (r=0.21, *p*=0.03 and r=0.23, p=0.03 respectively). The correlation between the 117ms condition and VIQ scores approached significance (r=0.19, *p*=0.07). However, with a sample of this size, the significant correlations between PIQ and detection accuracy and FSIQ and detection accuracy would both have to be r=0.44 to be significantly different.

Figure 2. Correlations Between WAIS-III IQ Scores and VBM Detection Accuracy During the 83ms & 117ms Conditions



*Correlation is significant at the 0.05 level (2 tailed)

Hierarchical regression analyses were used to covary other factors influencing the relationship between WAIS-III IQ scores and detection accuracy during the 83ms and 117ms conditions. Preliminary analysis showed sex and SES to influence VIQ and FSIQ scores, while only SES was significant in influencing PIQ in the 117ms condition. Thus these factors were used as covariates in the first step of the model. In predicting VIQ, the 83ms condition was not significant in either step 2 or the full model (see Table 3).

However, the 117ms condition was significant in predicting VIQ adding 4% of the variance accounted for in VIQ over and above that accounted for by sex and SES (see Table 4). In the full model, sex, SES, and the 117ms condition were significant factors predicting VIQ (sex: β=0.24, t(92)=2.51, p<0.05; SES: β=0.31, t(92)=3.36, p<0.01; 117ms: β=0.22, t(92)=2.25, *p*<0.05). In contrast to the correlations above, it appears that verbal processing has a stronger association with VBM task performance during the 117ms condition than the 83ms condition when sex and SES are taken into account.

Table 3. ***Regression Models of Predicting WAIS-III Scores from the VBM Detection Accuracy 83ms Condition and Significant Demographic Covariates***

WAIS-III IQ	*Step*	*R^2 Change*	*p*	*Model F*	*Df*	*p*
VIQ	1 (sex, ses)	0.17	<0.01	6.30	2,93	<0.01
	2 (83ms)	0.02	<0.05	5.89	3,92	<0.01
FSIQ	1 (sex, ses)	0.12	<0.01	9.65	2,93	<0.01
	2 (83ms)	0.04	<0.01	7.29	3,92	<0.01

Notes: Step 1 included significant demographic covariates in the hierarchical regression models with the WAIS-III Scores as the dependent variable. Step 2 added the VBM 83ms condition with R^2 change representing the amount of WAIS-III score variance over and above that accounted for by the Step 1 variables. Preliminary results revealed no demographic factors influencing the PIQ – 83ms condition; thus, these regressions were not analyzed. VIQ=Verbal IQ, FSIQ=Full Scale IQ.

In predicting PIQ, no demographic variables were significant in influencing PIQ in the 83ms condition; thus, these regressions were not analyzed and the PIQ – 83ms condition correlations above describe the relationship. The VBM 83ms condition accounted for 5.3% of the variance in PIQ. The 117ms condition was significant in predicting PIQ adding 7% of the variance accounted for in PIQ over and above that accounted for by SES (see Table 4). In the full model, only the 117ms condition was significant in predicting PIQ (117ms: β=0.27, t(92)=2.66, *p*<0.01). Both the VBM 83 and 117ms conditions were significantly associated with PIQ even when SES was taken into account.

In predicting FSIQ, the 83ms condition added a significant 4% of the variance accounted for in FSIQ (see Table 3). In the full model, sex, SES, and the 83ms condition were significant factors predicting FSIQ (sex: β=0.19, t(92)=1.97, p=0.05; SES: β=0.26, t(92)=2.73, p<0.01; 83ms: β=0.21, t(92)=2.14, *p*<0.05). The 117ms condition was also significant in predicting FSIQ adding 7% of the variance accounted for in FSIQ over and above that accounted for by sex and SES (see Table 4). In the full model, SES and the 117ms condition were significant factors predicting FSIQ (SES: β=0.28, t(92)=2.96, p<0.01; 117ms: β=0.26, t(92)=2.70, *p*<0.01). Both the VBM 83 and 117ms conditions were significantly associated with FSIQ even when sex and SES were taken into account.

As hypothesized, these regressions predicting VIQ, PIQ, and FSIQ suggest that "processing speed" and "information processing speed" are overlapping but separate constructs.

Table 4. ***Regression Models of Predicting WAIS-III Scores from the VBM Detection Accuracy 117ms Condition and Significant Demographic Covariates***

WAIS-III IQ	*Step*	*R^2 Change*	*p*	*Model F*	*Df*	*p*
VIQ	1 (sex, ses)	0.17	<0.01	9.65	2,93	<0.01
	2 (117ms)	0.04	<0.05	8.41	3,92	<0.01
PIQ	1 (ses)	0.02	>0.05	1.81	1,94	<0.01
	2 (117ms)	0.07	<0.01	4.49	2,93	<0.01
FSIQ	1 (sex, ses)	0.12	<0.01	6.30	2,93	<0.01
	2 (117ms)	0.07	<0.01	6.92	3,92	<0.01

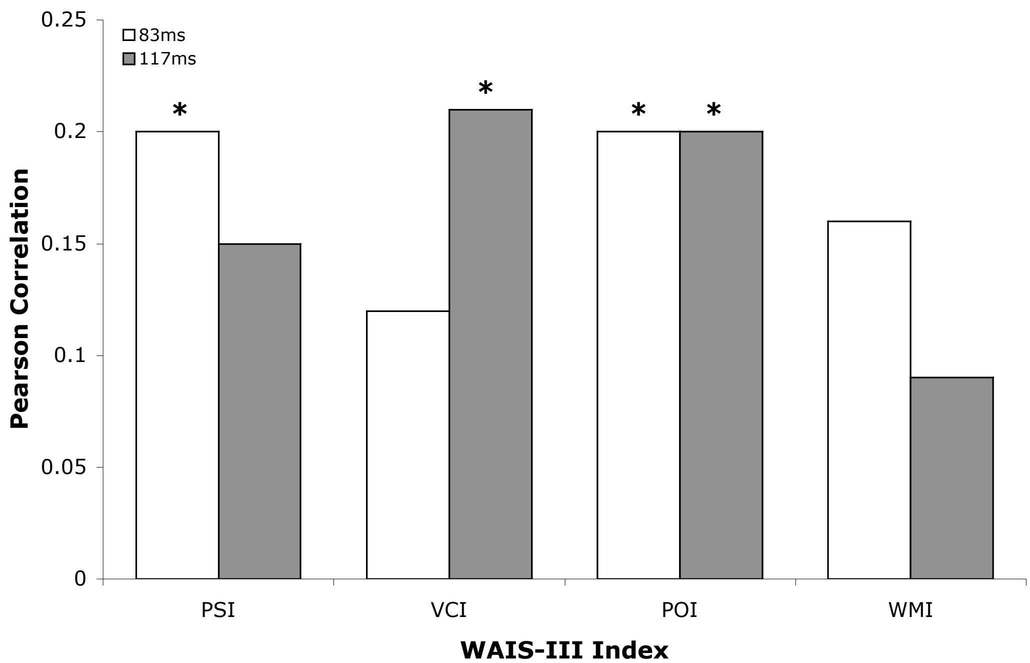
Notes: Step 1 included significant demographic covariates in the hierarchical regression models with the WAIS-III Scores as the dependent variable. Step 2 added the VBM 117ms condition with R^2 change representing the amount of WAIS-III score variance over and above that accounted for by the Step 1 variables. VIQ=Verbal IQ, PIQ=Performance IQ, FSIQ=Full Scale IQ.

WAIS-III Index Scores & Detection Accuracy

Figure 3 presents the associations between VBM detection accuracy and WAIS-III Index scores. The Processing Speed Index was only significantly correlated with the 83ms condition (r=0.20, *p*=0.04), while the Verbal Comprehension Index was only significantly correlated with the 117ms condition (r=0.21. *p*=0.02). However, with a sample of this size, the Processing Speed Index and 83ms condition correlation would need to be r=0.37 to be significantly different, and the Verbal Comprehension Index and 117ms condition correlation would need to be r=0.35 to be significantly different. The Perceptual Organization Index correlated significantly with both the 83ms and 117ms conditions (r=0.20, *p*=0.04 for both). While the relationship between the Working Memory Index and the 83ms and 117ms conditions showed a general positive trend, neither condition correlated significantly with scores on this index.

Hierarchical regression analyses were used to covary demographic factors influencing the relationship between WAIS-III index scores and detection accuracy during the 83ms and 117ms conditions. Preliminary analysis showed sex and SES to influence VCI and POI scores, while only SES was significant in influencing PSI scores in both the 83ms and 117ms conditions. These factors were used as covariates in the first step of the model. The 83ms condition was not significant in predicting VCI scores, but was significant in the full model (see Table 5). However, the 117ms condition was significant in predicting VCI scores, adding 5% of the variance accounted for in VCI scores over and above that accounted for by sex and SES (see Table 6). In the full model, sex, SES, and the 117ms condition were significant factors predicting VCI scores (sex: β=0.25, t(92)=2.71, p<0.01; SES: β=0.35, t(92)=3.83, p<0.01; 117ms: β=0.23, t(92)=2.41, $p<0.05$). As was suggested by the VIQ relationships mentioned above, it appears that verbal processing has a stronger association with VBM task performance during the 117ms condition than the 83ms condition when sex and SES are taken into account.

Figure 3. Correlations Between WAIS-III Indices and VBM Detection Accuracy During the 83ms & 117ms Conditions



*Correlation is significant at the 0.05 level (2 tailed)

PSI=Processing Speed Index, VCI=Verbal Comprehension Index, POI=Perceptual Organization Index, WMI=Working Memory Index

In predicting PSI scores, only SES was significant in influencing PSI scores in the 83ms condition, while SES and age were both significant in influencing PSI scores in the 117ms condition. The 83ms condition added a significant 5% of the variance accounted for in PSI scores (see Table 5). In the full model, SES and the 83ms condition were significant factors predicting PSI scores (SES: $\beta=0.20$, t(93)=2.01, $p<0.05$; 83ms:

$\beta=0.23$, $t(93)=2.28$, $p<0.05$). The 117ms condition was significant in predicting PSI scores adding 8% of the variance accounted for in PSI scores over and above that accounted for by age and SES (see Table 6). In the full model, SES, age, and the 117ms condition were significant in predicting PSI scores (SES: $\beta=0.25$, $t(92)=2.55$, $p<0.05$; age: $\beta=0.27$, $t(92)=2.60$, $p<0.05$; 117ms: $\beta=0.31$, $t(92)=2.97$, $p<0.01$). Both the VBM 83ms and 117ms conditions were significantly associated with PSI even when SES and age were taken into account.

Preliminary analysis showed sex and SES to influence POI scores in both the 83ms and 117ms conditions. Thus these factors were used as covariates in the first step of the model. In predicting POI scores, the 83ms condition was not significant in either step 2 or the full model (see Table 5). However, the 117ms condition was significant in predicting POI scores, adding 4% of the variance accounted for in POI scores over and above that accounted for by sex and SES (see Table 6). In the full model, sex and the 117ms condition were significant factors predicting POI scores (sex: $\beta=0.21$, $t(92)=2.11$, $p<0.05$; 117ms: $\beta=0.20$, $t(92)=2.01$, $p<0.05$). Only the VBM 117ms condition was significantly associated with POI scores when sex and SES were taken into account.

Table 5. ***Regression Models of Predicting WAIS-III Index Scores from the VBM Detection Accuracy 83ms Condition and Significant Demographic Covariates***

WAIS-III Index	*Step*	*R^2 Change*	*p*	*Model F*	*Df*	*p*
VCI	1 (sex, ses)	0.20	<0.01	11.85	2,93	<0.01
	2 (83ms)	0.01	>0.05	8.24	3,92	<0.01
PSI	1 (ses)	0.04	>0.05	3.36	1,94	>0.05
	2 (83ms)	0.05	<0.05	4.35	2,93	<0.05
POI	1 (sex, ses)	0.10	<0.01	4.87	2,93	<0.01
	2 (83ms)	0.03	>0.05	4.47	3,92	<0.01

Notes: Step 1 included significant demographic covariates in the hierarchical regression models with the WAIS-III Index Scores as the dependent variable. Step 2 added the VBM 83ms condition with R^2 change representing the amount of WAIS-III score variance over and above that accounted for by the Step 1 variables. VCI=Verbal Comprehension Index, PSI=Processing Speed Index, POI=Perceptual Organization Index.

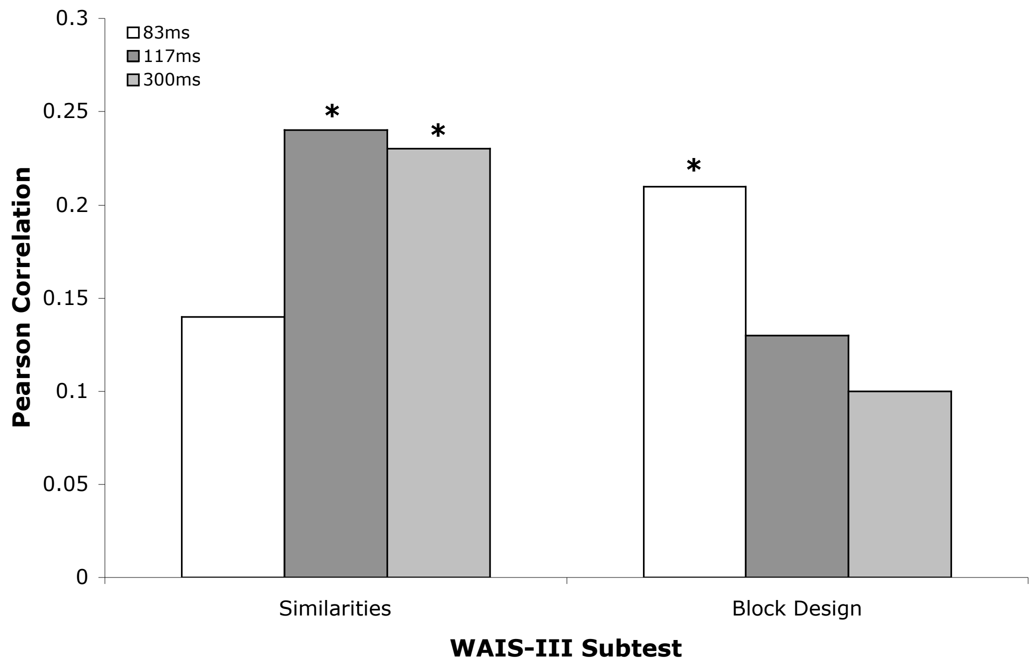
Table 6. ***Regression Models of Predicting WAIS-III Index Scores from the VBM Detection Accuracy 117ms Condition and Significant Demographic Covariates***

WAIS-III Index	*Step*	*R^2 Change*	*p*	*Model F*	*Df*	*p*
VCI	1 (sex, ses)	0.20	<0.01	11.85	2,93	<0.01
	2 (117ms)	0.05	<0.05	10.25	3,92	<0.01
PSI	1 (ses, age)	0.04	>0.05	1.68	2,93	>0.05
	2 (117ms)	0.05	<0.05	2.73	3,92	<0.05
POI	1 (sex, ses)	0.10	<0.01	4.87	2,93	<0.01
	2 (117ms)	0.04	<0.05	4.71	3,92	<0.01

Notes: Step 1 included significant demographic covariates in the hierarchical regression models with the WAIS-III Index Scores as the dependent variable. Step 2 added the VBM 117ms condition with R^2 change representing the amount of WAIS-III score variance over and above that accounted for by the Step 1 variables. VCI=Verbal Comprehension Index, PSI=Processing Speed Index, POI=Perceptual Organization Index.

In general, participants who performed with higher accuracy during the 83ms condition also did well on the WAIS-III nonverbal timed tasks, and those who performed with higher accuracy during the 117ms condition did well on the WAIS-III tasks that were more verbal in nature, and un-timed. The only significant relationships between WAIS-III subtests and VBM SOA conditions are presented in Figure 4. There was a significant correlation between Similarities and both the 117ms and 300ms conditions (r=0.24, *p*=0.02 and r=0.23, *p*=0.02, respectively). With this sample size, both correlations would need to be r=0.37 to be significantly different. There was also a significant correlation between Block Design and the 83ms condition (r=0.21, *p*=0.03). With this sample size, the correlation would need to be r=0.35 to be significantly different. Worth noting is that of all WAIS-III components, the only score to correlate significantly with performance on the 300ms condition was Similarities.

Figure 4. Significant Correlations Between WAIS-III Subtests and VBM Detection Accuracy During the 83ms, 117ms, & 300ms Conditions



*Correlation is significant at the 0.05 level (2 tailed)

Hierarchical regression analyses were used to covary other factors influencing the relationship between WAIS-III subtest scores and VBM detection accuracy during the 83ms, 117ms, and, where appropriate, 300ms conditions. As only Block Design and

Similarities had significant relationships with VBM detection accuracy, only those subtests were included in the hierarchical analysis. Preliminary analysis showed sex and SES to influence Block Design performance in both the 83ms and 117ms conditions. Thus these factors were used as covariates in the first step of the model. In predicting Block Design scores, the 83ms condition was significant in predicting Block Design scores, adding 4% of the variance accounted for in Block Design scores over and above that accounted for by sex and SES (See Table 7). In the full model, SES and the 83ms condition were significant factors predicting Block Design performance (SES: $\beta=0.26$, $t(92)=2.71$, $p<0.01$; 83ms: $\beta=0.21$, $t(92)=2.14$, $p<0.05$). However, in predicting Block Design scores, the 117ms condition was not significant in either step 2 or the full model (see Table 8).

Preliminary analysis showed sex and SES to influence Similarities scores in both the 83ms and 117ms conditions. In predicting Similarities scores, the 83ms condition was not significant in either step 2 or the full model (see Table 7). However, the 117ms condition added a significant 10% of the variance accounted for in Similarities scores (see Table 8). In the full model, SES and the 117ms condition were significant factors predicting Similarities scores (SES: $\beta=0.28$, $t(92)=2.85$, $p<0.01$; 117ms: $\beta=0.30$, $t(92)=3.14$, $p<0.01$). The 300ms condition was also significant in predicting Similarities scores, adding 6% of the variance accounted for in Similarities scores over and above that accounted for by SES (see Table 9). In the full model, SES and the 300ms condition were significant factors predicting Similarities scores (SES: $\beta=0.24$, $t(93)=2.51$, $p<0.05$; 300ms: $\beta=0.25$, $t(93)=2.55$, $p<0.05$). Both the VBM 117ms and 300ms conditions were significantly associated with Similarities scores even when SES was taken into account.

Similar to the VIQ and VCI score above, this verbally oriented subtest was more strongly associated with VBM detection accuracy only during the longer SOAs.

Table 7. ***Regression Models of Predicting WAIS-III Subtest Scores from the VBM Detection Accuracy 83ms Condition and Significant Demographic Covariates***

WAIS-III Subtest	*Step*	*R^2 Change*	*p*	*Model F*	*Df*	*p*
Block Design	1 (ses, sex)	0.12	<0.01	6.12	2,93	<0.01
	2 (83ms)	0.04	<0.05	5.77	3,92	<0.01
Similarities	1 (ses)	0.06	<0.05	5.63	1,94	<0.05
	2 (83ms)	0.03	>0.05	4.18	2,93	<0.05

Notes: Step 1 included significant demographic covariates in the hierarchical regression models with the subtest scores as the dependent variable. Step 2 added the VBM 83ms condition with R^2 change representing the amount of WAIS-III score variance beyond that accounted for by the Step 1 variables

Table 8. ***Regression Models of Predicting WAIS-III Subtest Scores from the VBM Detection Accuracy 117ms Condition and Significant Demographic Covariates***

WAIS-III Subtest	*Step*	*R^2 Change*	*p*	*Model F*	*Df*	*p*
Block Design	1 (ses, sex)	0.12	<0.01	6.12	2,93	<0.01
	2 (117ms)	0.03	>0.05	5.08	3,92	<0.01
Similarities	1 (ses)	0.06	<0.05	5.63	1,94	<0.05
	2 (117ms)	0.09	<0.01	8.00	2,93	<0.01

Notes: Step 1 included significant demographic covariates in the hierarchical regression models with the WAIS-III Subtest Scores as the dependent variable. Step 2 added the VBM 83ms condition with R^2 change representing the amount of WAIS-III score variance over and above that accounted for by the Step 1 variables

Table 9. ***Regression Models of Predicting WAIS-III Similarities Scores from the VBM Detection Accuracy 300ms Condition and Significant Demographic Covariates***

WAIS-III Subtest	*Step*	*R^2 Change*	*p*	*Model F*	*Df*	*p*
Similarities	1 (ses)	0.06	<0.05	5.63	1,94	<0.05
	2 (300ms)	0.06	<0.05	6.22	2,93	<0.01

Notes: Step 1 included significant demographic covariates in the hierarchical regression models with the WAIS-III Subtest Scores as the dependent variable. Step 2 added the VBM 300ms condition with R^2 change representing the amount of WAIS-III score variance over and above that accounted for by the Step 1 variables

Method of Correlated Vectors

The method of correlated vectors was utilized to determine the extent to which the general ability factor (*g*) underlies the relationship between VBM performance and WAIS-III subtest scores. This was accomplished by calculating the correlations between subtest scores and detection accuracy during the 83ms condition and the 117ms condition, and then correlating those results with published *g* loadings of the WAIS-III subtests. We chose not to calculate *g* loadings based on our sample, but to instead use the *g* loadings based on the WAIS-III standardization sample, which was larger and therefore a truer representation of *g* (Colom, Jung, & Haier, 2006), The Pearson correlation between the *g* loading and 83ms condition correlation vectors was 0.08 (p=0.86). The Pearson correlation between the *g* loading and 117ms condition correlation vectors was 0.11 (p=0.82). As the relationships between detection accuracy during both the 83ms and 117ms SOA conditions and WAIS-III subtest scores were not significant, they were found not to be dependent on *g* (see Figures 5 and 6).

Figure 5. *g* and the Relationship Between Detection Accuracy in the 83ms Condition and WAIS-III Subtests

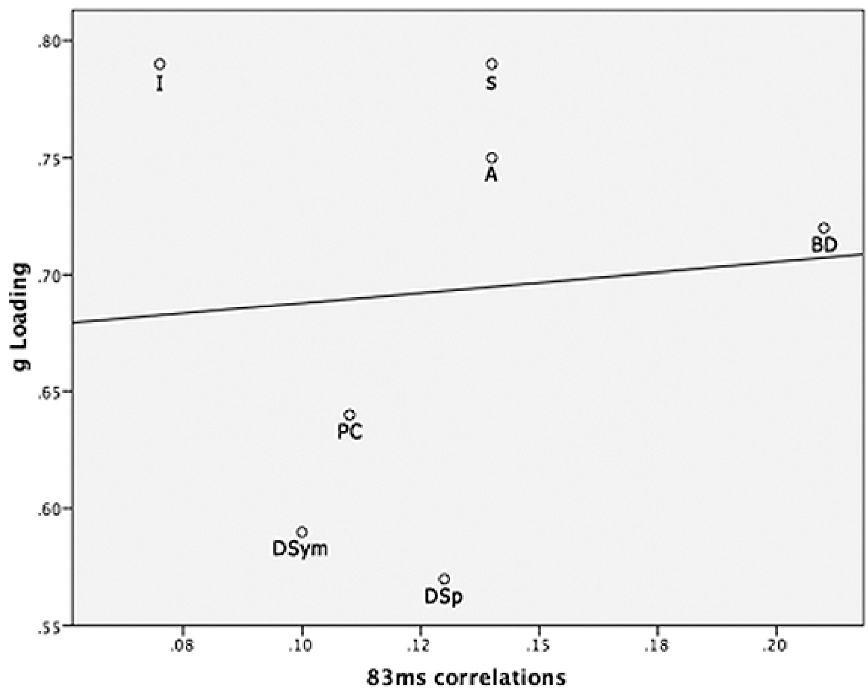
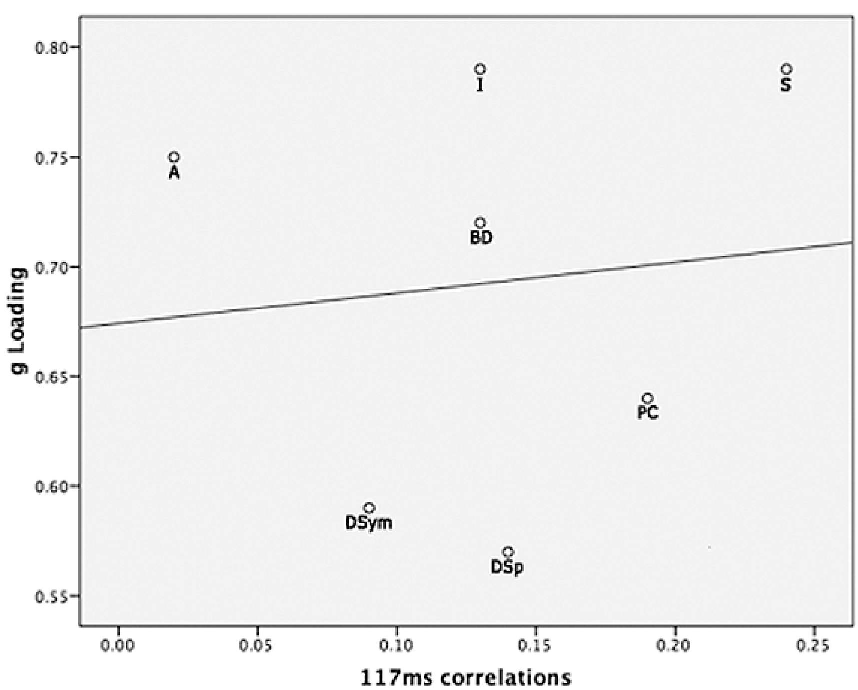


Figure 6. *g* and the Relationship Between Detection Accuracy in the 117ms Condition and WAIS-III Subtests



I=Information, S=Similarities, A=Arithmetic, BD=Block Design, PC=Picture Completion, DSym=Digit Symbol Coding, DSp=Digit Span

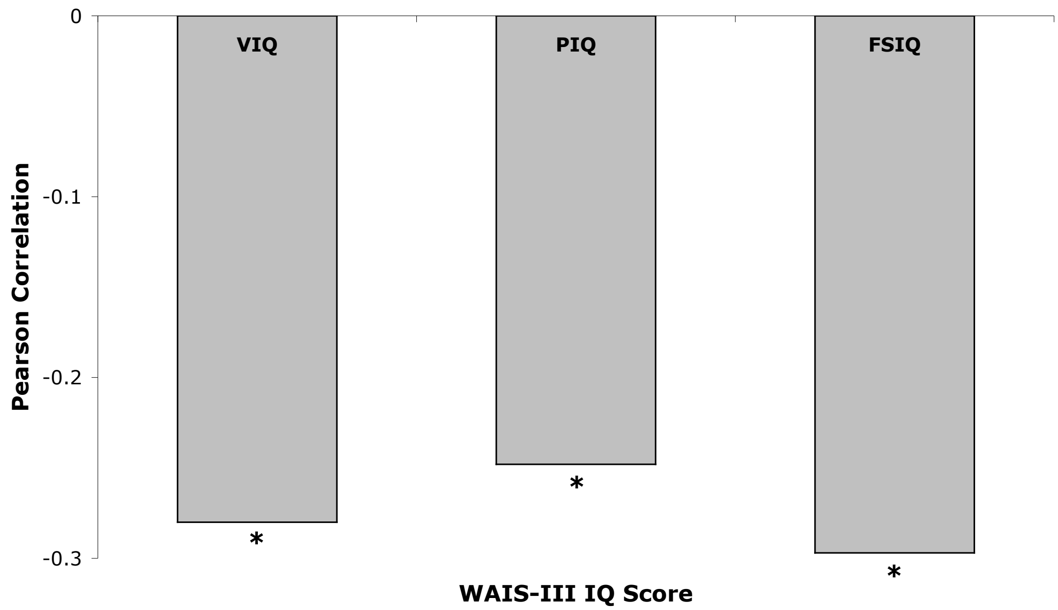
Pupillary Response

A principle components analysis (PCA) was conducted on the pupillary response waveform, but yielded no useful information, as only a single component emerged. Much variability was observed in the latency to peak, or the amount of time between the start of the measurement and the largest pupil dilation, diminishing the utility of the PCA. Based on previous research, we isolated the time span of interest by normalizing the curve. We then examined the time span between one quarter of a second and two seconds after peak dilation. This time span corresponds to the factor theorized to represent resources allocated to mask processing (Verney, Granholm, & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). Given the atypical pupillary response which we believe led to this increased variability, we excluded 39 subjects resulting in a sample of 62 for pupillary analysis. We compared the two groups to ensure this sample of 62 was representative of the total sample of 101; T-test and chi square results revealed the two groups to be no different on any demographic dimension, suggesting the sample of 62 was representative of not only the whole sample of 101, but also of the University of New Mexico undergraduate population.

The purpose of isolating this component was to investigate the relationship between resources allocated to processing the irrelevant stimulus (i.e., the mask) and WAIS-III performance. Because the mask stimulus becomes a separate percept from the target during SOA conditions longer than 100ms (Michaels & Turvey, 1979; Phillips, 1974; Verney, et al., 2005), the difference between the mean pupil dilation during the longer SOA conditions (i.e., 117 and 300ms conditions) and the mean of the no-mask condition is theorized to be an index of mask processing.

The WAIS-III FSIQ, VIQ, and PIQ scores were all significantly negatively correlated with mask processing (r=-0.30, *p*=0.02; r=-0.28, *p*=0.03; r=-0.25, *p*=0.05, respectively; see Figure 7), suggesting that individuals who allocated fewer resources to the mask scored higher on the IQ scores of the WAIS-III. Of the WAIS-III index scores, only the Verbal Comprehension Index and the Perceptual Organization Index showed significant correlations with mask processing (r=-0.28, *p*=0.03 and r=-0.34 *p*=0.01, respectively; see Figure 8). The Processing Speed Index correlated at a non-significant –0.16. As with the VBM detection accuracy results, these results suggest “processing speed” and “information processing speed” are overlapping but separate constructs. Again, interestingly, the Working Memory Index did not have a significant relationship with mask processing.

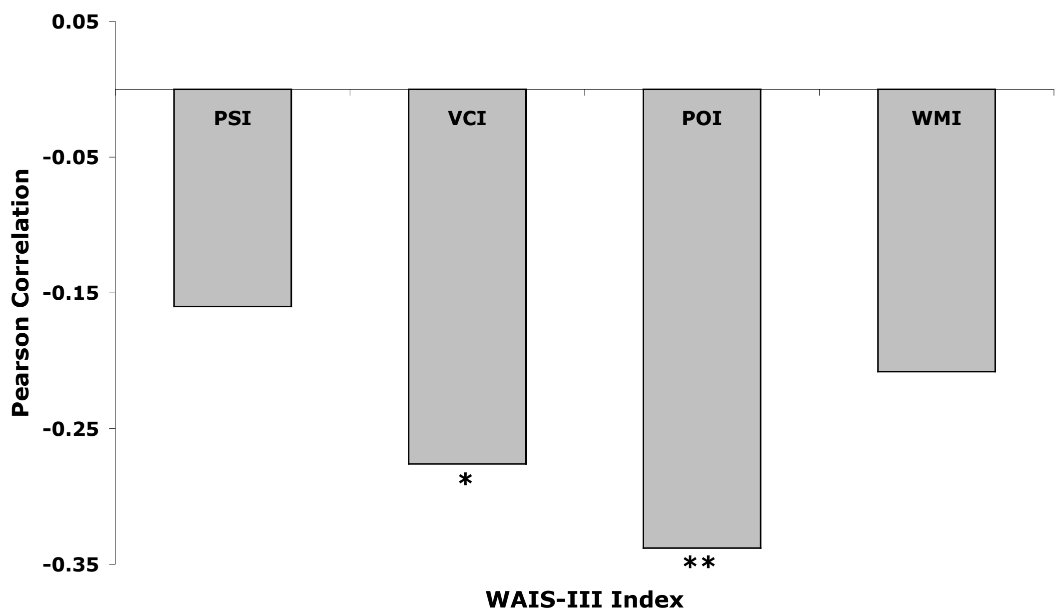
Figure 7. Correlations Between Mask Processing and WAIS-III IQ Scores



*Correlation is significant at the 0.05 level (2 tailed)

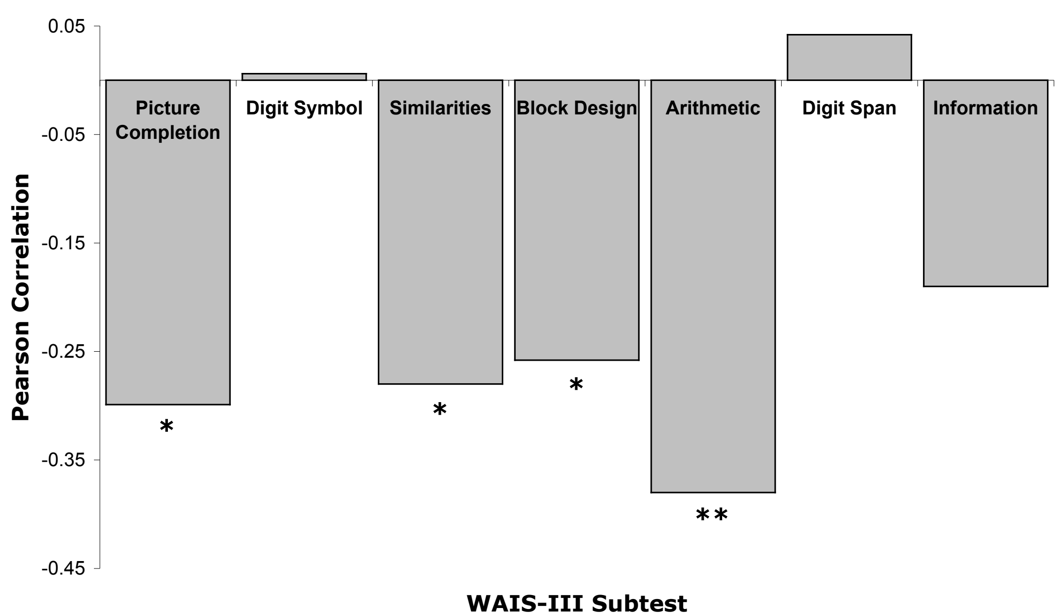
At the subtest level, scores on Picture Completion, Similarities, and Block Design had significant (p<.05) negative correlations with mask processing, (r=-0.30, p=0.02; r=-0.28, p=0.03; r=-0.26, p=0.05, respectively, see Figure 9). The strongest relationship with mask processing at the subtest level was with Arithmetic (r=-0.38, p=0.002). The other four subtests did not correlate significantly with mask processing.

Figure 8. Correlations Between Mask Processing and WAIS-III Indices



*Correlation is significant at the 0.05 level (2 tailed); **Correlation is significant at the 0.01 level (2 tailed). PSI=Processing Speed Index, VCI=Verbal Comprehension Index, POI=Perceptual Organization Index, WMI=Working Memory Index

Figure 9. Correlations Between Mask Processing and WAIS-III Subtests

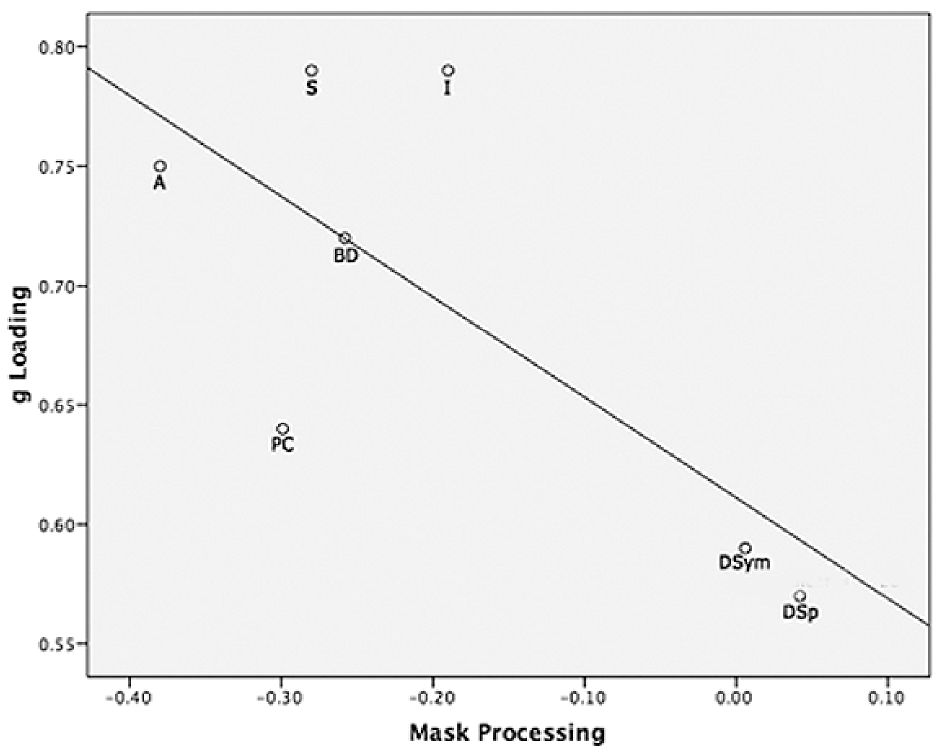


*Correlation is significant at the 0.05 level (2 tailed); **Correlation is significant at the 0.01 level (2 tailed)

Method of Correlated Vectors

The method of correlated vectors was utilized to determine the extent to which the general ability factor (*g*) underlies the relationship between mask processing and WAIS-III subtests (see Figure 10). The relationship approached significance, with a Pearson correlation of -.726 (p=0.06). While the relationship between mask processing and WAIS-III subtests appears not to be wholly dependant on *g*, these results suggest that *g* does play a role in that relationship.

Figure 10. *g* and the Relationship Between Mask Processing and WAIS-III Subtests



I=Information, S=Similarities, A=Arithmetic, BD=Block Design, PC=Picture Completion, DSym=Digit Symbol Coding, DSp=Digit Span

VBM Information Processing Efficiency and WAIS-III IQ

Hierarchical regression analyses were used to investigate the contributions of VBM detection accuracy for the 83ms and 117ms SOA condition and the pupillary response reflecting the VBM mask processing to WAIS-III IQ scores. Step 1 of the regression showed mask processing accounted for a significant amount of variance in FSIQ scores, R^2=0.09, F(1, 60)=5.82, p<0.05, Adjusted R^2=0.07. VBM mask processing accounted for a significant 8.8% of the variance in FSIQ scores. Step 2 added detection accuracy during the 83ms and 117ms conditions and resulted in a significant model, R^2=0.13, F(3, 58)=2.80, p<0.05, Adjusted R^2=0.08; however, the change in R^2 was not significant, R^2=0.04, F(2, 58)=1.27, ns. The addition of detection accuracy during the 83ms and 117ms conditions uniquely accounted for 3.8% of the variance in FSIQ scores above that of mask processing. In the full model of the regression predicting FSIQ, VBM mask pupil response had the only significant beta (β=-0.32, t-value of β=-2.55, p=0.01), while the 83ms and 117ms SOA conditions did not.

Regarding VIQ scores, Step 1 of the regression revealed mask processing to account for a significant amount of variance in scores, R^2=0.08, F(1, 60)=5.09, p<0.05, Adjusted R^2=0.06. Step 2 added detection accuracy during the 83ms and 117ms conditions and did not result in a significant model, R^2=0.10, F(3, 58)=2.23, ns, Adjusted R^2=0.06. The change in R^2 was also not significant, R^2=0.03, F(2, 58)=1.82, ns. The addition of detection accuracy during the 83ms and 117ms conditions uniquely but not significantly accounted for 2.5% of the variance in VIQ scores above that of mask processing. Mask processing accounted for a significant 7.8% of the variance in VIQ scores (β=-0.29, t-value of β=-2.31, p=0.02). This pattern was also observed in the PIQ scores: Step 1 of the regression showed mask processing accounted for a significant amount of variance in scores, R^2=0.06, $F(1, 60)$=3.94, p<0.05, Adjusted R^2=0.05. Step 2 added detection accuracy during the 83ms and 117ms conditions and did not result in a significant model, R^2=0.11, $F(3, 58)$=2.45, ns, Adjusted R^2=0.07; and the change in R^2 was not significant, R^2=0.05, $F(2, 58)$=1.66, ns. The addition of detection accuracy during the 83ms and 117ms conditions uniquely but not significantly accounted for 5.1% of the variance in PIQ scores above that of mask processing. Mask processing accounted for a significant 6.2% of the variance in PIQ scores (β=-0.27, t-value of β=-2.19, p=0.03).

Discussion

This study investigated the associations between processing speed and efficiency of information processing. We used performance on a standardized cognitive ability test, the WAIS III, to assess processing speed and performance on an information processing task, the visual backward masking (VBM) task, to assess information processing efficiency. A psychophysiological measure, pupillary dilation response during the VBM task, was also used to index efficiency of processing at early cognitive stages. The correlations between WAIS-III scores and these measures of information processing efficiency during the VBM further support the hypothesis that VBM processing underlies a general cognitive ability. Results of the method of correlated vectors (MCV) analysis with VBM detection accuracy, however, indicate that this underlying cognitive ability is not directly *g*. In general, the pupillary dilation in response to the irrelevant masking stimulus during the VBM task appeared to be a stronger and more reliable measure of general cognitive ability than VBM detection accuracy accounting for about 9% of WAIS-III Full Scale IQ, 8% of Verbal IQ, and 6% of Performance IQ. Processing speed during higher-order cognitive tasks and information processing efficiency appear to be separate but overlapping constructs.

Detection Accuracy & WAIS-III Components

Consistent with the literature on Inspection Time (IT) (Deary & Stough, 1996; Kranzler & Jensen, 1989), a specific form of the VBM, detection accuracy during the VBM task was associated with WAIS-III performance. The intermediate VBM stimulus onset asynchronies (SOA), i.e., the 83ms and 117ms conditions, accounted for the significant associations. These conditions also tended to be the most challenging conditions yielding the most variance between participants; shorter SOAs were too quick for most participants to reliably process, while the longer SOAs and the no mask condition were more easily and reliably processed by the participants. The correlation analyses appear to suggest a pattern of relationships between length of SOA and increasingly verbal processing: the 83ms SOA condition is significantly correlated with the WAIS-III Processing Speed Index, accounting for 4% of the variance in PSI scores. The longer 117ms SOA condition is significantly correlated with the Verbal Comprehension Index, accounting for 4% of the variance in VCI scores (see Figure 3). One possibility is the specific processing speed component of higher-order cognitive tests takes less time than verbal processing. It could be that verbal processing increases the cognitive load, resulting in slower processing. Another possibility is that those who rely on verbal processing, even in the absence of verbal stimuli, will perform better, though it may result in slower processing. Notably, the associations between these VBM conditions and IQ scores in this study were lower than has been found previously in a similar methodology and stimulus presentation, in which the intermediate VBM detection accuracy scores accounted for about 17% of IQ scores (Verney, Granholm, & Marshall, 2004; Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). Further research is needed to examine the underlying cognitive processes and determine the reasons for these differential associations between the 83ms and 117ms conditions and the WAIS-III Processing Speed and Verbal Comprehension indices.

The only significant relationship between a WAIS-III component and VBM detection accuracy for the 300ms SOA condition involved the subtest, Similarities (see Figure 4). Similarities is a verbal subtest that requires more than a basic, concrete sense of language. To perform well on this subtest, a deeper understanding of language, particularly the use of abstraction, is needed (Kaufman & Lichtenberger, 1999). One possible reason for these relationships between the longer SOA conditions of the VBM, i.e., the 117ms and 300ms conditions, and verbally driven scores is disembedding ability. Disembedding is the ability to restructure a problem both perceptually and verbally in order to discover a solution, and has also been called “field independence” (Longoni, 1981). Longoni found that a verbal task that required the breaking of a prominent semantic link as well as the creation of a new semantic relationship correlated significantly with performance on visual-perceptual disembedding tasks. In that same study, no significant relationship was found between disembedding ability and task involving simple vocabulary or semantic recognition, suggesting disembedding ability involves more complex verbal processing, perhaps like that of Similarities. Given this foundation, the relationship between the 300ms SOA condition and Similarities further supports a pattern of more complex verbal processing and accurate but slower processing.

Despite the strong relationship between inspection time (IT) and IQ (Deary & Stough, 1996; Kranzler & Jensen, 1989), throughout the literature in general and as demonstrated by these results specifically, the MCV analysis of the relationship between VBM detection accuracy and WAIS-III subtest scores suggests that what underlies this relationship are factors other than *g* (see Figures 5 and 6). One possibility is that the current study did not have enough power or enough variation within the sample to adequately detect this relationship. Another limitation that may explain this result is the use of an accepted but abbreviated version of the WAIS-III as an IQ assessment in this study, we used the Ward seven-subtest short form of the WAIS-III (Ward, 1990) instead of the full 13 subtests of the WAIS-III. The MCV is also a limiting factor itself, as the analyses of the associations between the WAIS-III subtest *g* loadings and the VBM detection accuracy of the 83ms and117ms SOA conditions contain so few data points from which to draw conclusions. However, the relationship between detection accuracy on a task using the VBM paradigm and IQ is a strong and consistent one, and the underlying factors of this relationship bear further investigation.

Pupillary Dilation & WAIS-III Components

Consistent with the literature on the pupillary dilation response reflecting the mask processing during the VBM task, the amount of effort invested in processing an irrelevant stimulus (Verney, Granholm, & Dionisio, 2001), VBM mask pupillary response in this study was associated with WAIS-III performance. In general, individuals who allocated fewer resources to the mask during the VBM task had higher WAIS-III IQ scores (see Figure 7). VBM mask pupillary response accounted for about 9% of the WAIS-III Full Scale IQ scores, 8% of the VIQ scores, and 6% of the PIQ scores. These associations are similar to those found in earlier studies using a similar methodology (Verney, et al., 2004; Verney, et al., 2005). These significant correlations support the hypothesis that this mask pupillary response, as an index of efficiency of processing, underlies a general cognitive ability. Also, these results appear to suggest a pattern of relationships between allocation of resources to irrelevant stimuli and complex processing: the WAIS-III subtests with the strongest relationships to mask processing are those that involve non-verbal reasoning as well as verbal conceptualization. Picture Completion, Similarities, and Block Design all had a significant relationship with mask processing (see Figure 9), but the subtest with the strongest relationship with mask processing was Arithmetic. While Arithmetic contributes to the Working Memory Index (WMI), its contribution was not enough to constitute a significant relationship between mask processing and the WMI. Similarities contributes to the Verbal Comprehension Index (VCI), which indexes verbal processing, and this index did have a significant relationship with mask processing. An even stronger relationship, however, was found between the Perceptual Organization Index (POI), which relies on Picture Completion and Block Design. While the POI is not entirely non-verbal, it relies more heavily on abstract processing and problem solving. Wastefully allocating resources to the irrelevant VBM masking stimulus may involve the cognitive mechanisms of distraction or lack of inhibition, or a combination of both. This study was not designed to delineate such cognitive processes for the masking stimulus, but adds to the literature on the VBM mask processing and cognitive ability relationship. The results of the MCV analysis suggest that the relationship between mask processing and IQ is at least partially reliant on *g* (see Figure 10).

VBM Efficiency of Processing & WAIS-III Performance

Based on previous research (Verney, et al., 2004; Verney, et al., 2005), the significant relationships between VBM detection accuracy and WAIS-III performance and VBM mask processing and WAIS-III performance were expected. However, an unexpected finding is that of the differential relationship these two response measures had with *g*. While the relationship between WAIS-III performance and detection accuracy during the VBM task cannot be said to rely on *g* based on the MCV results, the relationship between WAIS-III performance and mask processing showed a much stronger shared component of *g*. One possible limitation impacting this finding, however, is the number of participants in the VBM detection accuracy analysis with atypical pupil data that had to be excluded from the VBM mask pupillary response analysis.

To examine this differential relationship further, we employed hierarchical regression analysis, which showed VBM mask processing to account for more variance in IQ scores than VBM detection accuracy during the 83ms and 117ms conditions. Further, VBM detection accuracy became nonsignificant after the variance in IQ scores was accounted for by mask processing. However, detection accuracy did account for 4% of FSIQ scores, 3% of VIQ scores, and 5% of PIQ scores; while these additions were not a large amount of variance in scores, they did contribute to some variance in IQ scores. Consistent with the literature on demographic correlates of IQ performance (see Neisser, et al., 1996, for a review), we found that sex and SES were consistently related to IQ scores and subtest performance. Contrary to Verney, et al. (2005), we did not find a relationship with ethnicity and WAIS-III performance. That study used an IQ score comparable sample of Mexican American and Caucasian students to address the circular arguments of lower IQ scores of ethnic students. In addition, this study used a mixed ethnic sample and a categorical variable for the ethnic coding. This study did not focus on the ethnicity and did not use the appropriate methodology to investigate ethnic differences, and thus, the lack of an ethnic correlate is not surprising, nor inconsistent with previous findings.

These results support the previously hypothesized difference between psychometric processing speed and speed of information processing, which are similar constructs from different theoretical arenas. “Processing speed” is how quickly an individual completes a sequence of processing in a given task, while “information processing" is the time required for stimuli to be perceived, understood, and acted upon. While similar, overlapping constructs, previous literature and these results suggest they are different constructs with different relationships with the construct known as "intelligence." This difference could have implications for the intelligence assessment industry, as the construct measured may represent a different underlying mechanism of intelligence than previously assumed. The associations between the psychometric measure, the WAIS-III, and both the information processing measure, the VBM task, and the psychophysiological measure, pupillary dilation response for the irrelevant masking stimulus, suggest these two constructs do index intelligence, but do so differently. As the MCV analyses showed, while there are relationships between the psychometric measure and both the information processing measure and the psychophysiological measure, these two relationships rely differentially on *g*.

Limitations

Some possible limitations of this study include the population used, undergraduate students from the University of New Mexico, which may represent a restricted range of age and cognitive ability. Also, while the body of literature is encouraging, methodological differences exist between the earlier use of tachistoscope in administration of the VBM task and the computer-administered VBM task used in this study. The computerized version is bound by the screen refresh rage and stimulus persistence; thus, the millisecond display units of the tachistiscope version are not possible with the computerized version. The Ward seven-subtest version of the WAIS-III was used to measure the IQ and index scores, limiting our ability to tap into the cognitive ability constructs. The method of correlated vectors used to examine the extent to which *g* underlies the relationships between WAIS-III subtests and both detection accuracy and mask processing was limiting in that it was an estimate of the association due to the few number of data points used as well as confounding the differential reliabilities of the different WAIS-III subtests with *g* loading.

The size of our sample may have been another limiting factor in examining the relationships between WAIS-III factors and detection accuracy during the 83ms, 117ms, and 300ms SOA conditions. The difference between the significant and non-significant correlations may have been significant itself with a larger sample.

Finally, the exclusion of VBM trials and subjects due to artifact or atypical pupillary response was a limiting factor. Despite these limitations, interesting findings regarding the associations between early stages of information processing and higher-order processing and higher-order cognitive performance emerged.

Implications & Importance

One implication of this study is that information processing is a piece of more complex constructs like working memory and processing speed. While working memory has historically been shown to have a strong relationship with IQ, we found no significant relationships between working memory and either detection accuracy or mask processing. One possibility is that working memory, made up of cognitive processes like focusing attention, rehearsal, and transforming information (Colom, 2004), is more complex, and our investigation took place on a more basic cognitive level. Likewise with processing speed, which is described in the psychometric literature as the time required to complete a sequence of processing in a given cognitive task (Sternberg, 1969). This, too, is a more complex process than those we examined in this study. For example, one

WAIS-III subtest used to measure processing speed is Digit Symbol, which involves recognizing and remembering numbers and their corresponding symbols under time pressure. This subtest requires more cognitive steps than the VBM. As the VBM measures more basic processing, it is possible that these basic processes are a piece of the more complex whole that is processing speed.

Another implication is the utility of psychophysiological measures of intelligence. Two measures were used during the VBM task: detection accuracy, a behavioral response, and pupillary dilation response reflecting the irrelevant mask processing, a physiological response. Of the two, the stronger predictor of IQ and the one with the relationship most reliant on *g*, was the physiological response. This suggests that it may be possible to measure intelligence in the absence of overt behavior. While much has yet to be learned about the construct of human intelligence, how to define it as well as how to accurately and validly measure it, information processing and psychophysiological measures may be less influenced by cultural and educational factors like education level, quality of education, socio-economic status, and cultural bias (Verney, Granholm, Marshall, Malcarne, & Saccuzzo, 2005). More research is needed in this area to further examine the relationship between mask processing and assessments of IQ that the underling mechanisms might be understood, and accurate, valid, culture-fair assessments may evolve.

One implication of this study for the cognitive assessment industry is the need for consistent use of the terms “processing speed” and “information processing speed or efficiency,” because, while related, they appear to be separate cognitive constructs. More general implications of this study to the field include further supporting the theory that information processing and psychophysiological measures can inform on the relationships among response speed, mental effort, and processing efficiency.

Despite the growth and development of technology, standardized assessments have not changed very much over the last hundred years (Sternberg, 1997). The results of this study suggest that psychophysiological measures can help examine to what extent the relationships among these constructs are related to *g*, as well as to examine the nature of these constructs themselves. Examining the basic components of the overall process is useful on both theoretical and practical dimensions: These components can guide understanding not only of the underlying mechanisms of intelligence, but also of how the mind works; Practical uses include the ability to rule out noncognitive factors currently impacting psychometric assessments, and aid in creating more accurate, valid, and concise intelligence measures.

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