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Merging the Wechsler Adult Intelligence Scale Picture Completion Subtest with fMRI in Adult Learners: a Pilot Study

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Abstract--With the emergence of functional magnetic resonance imaging (fMRI), standard intelligence tests can now be studied to assess neural activity during test performance. However, traditional assessments are given with paper/pencil or card based methods which are difficult to deliver while in an MRI. Here, we validate a computerized version of the Wechsler Adult Intelligence Scale (WAIS) Picture Completion subtest against the card based version in 20 adult learners. A preliminary fMRI series is included to investigate whether the blood oxygen level-dependent (BOLD) activity can be associated with the paradigm. Using sparse sampling fMRI techniques, a control condition is contrasted to when participants 'knew' what answer they were going to provide. In 8 task-novice individuals, significant activation was seen in right primary visual and left temporal cortex and is interpreted as task-specific activation related to visual search and naming the item missing from the scene. To our knowledge this is the first fMRI experiment of the WAIS picture completion subtest. Future imaging work can now use alternative control conditions to explore the different cognitive components used within the subtest.

Keywords – (WAIS), (BOLD), fMRI

I. INTRODUCTION

Over the past half century, educational and learning researchers have used various clinical instruments to describe characteristics related to the learning process that distinguish individual learners. Historically, most clinical and school psychologists have used intelligence tests to differentiate people by their mental abilities while educational and learning researchers have used other tests to describe learning style unique to individuals. Since the 1950's, both groups have proposed theories to conceptualize learning style as cognitive, affective, and physiological to indicate learners' interactions with the environment, but the theorists use few common definitions.

One such theoretical approach is the biological approach, or neuroscience approach, which focuses on the brain and physical events which are a part of the nervous system. In this approach, the study of the brain has been investigated in part through "brain mapping." With advanced technology this approach has become sophisticated enough to examine the living brain by non-invasive techniques, for instance fMRI, electroencephalography (EEG) and magnetoencephalography (MEG). By watching living brains interact with the sensory environment, the avenue through which individuals perceive the world can be monitored and evaluated as a medium for knowledge acquisition.

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Psychometric and physiological paradigms were once opponents of one another. Today, they are perceived as indispensable allies in our understanding of cognitive competencies. Brain-based assessments of intellect are now promoted as valid and useful methodologies. The correlation of neuroimaging to IQ has imperative and thought-provoking implications. Further research in the field of cognitive neuroscience is needed to more fully determine how different intelligence subtests are related to specific regions of the brain. Ultimately, this will provide a better understanding of the usefulness of test instruments to assess specific mental skills.

The Wechsler Adult Intelligence Scale (WAIS) is the most popular individual intelligence test for adults (Sattler, 1988). Wechsler (1958) explained the WAIS as a clinical tool that can yield more than just an overall IQ. The WAIS-R published in 1981, consists of 11 subtests, of which six are verbal and five are performance based. Generally, the subtests are administered in alternating order of verbal and performance subtests. The Full Scale IQ combines scaled scores from the subtests to yield a measure of global intelligence. Dozens of short forms have been reported in literature (for review, Kaufman, 1990). Specifically, three types of short forms can be distinguished: a reduced number of full subtests; split-half approaches, where most of the subtests are shortened in length; and criterion-based approaches that individualize the starting point within subtests for each subject. The most popular type of short form consists of administering two to five of the WAIS-R subtests and computing a prorated Full Scale IQ from these scaled scores. The selection of the short form is usually based on such criteria as acceptable reliability and validity, and the amount of time available for administrating the test (Sattler, 1988). There is an abundance or research on such forms pertaining to the WAIS-R (Silverstein, 1982b). The WAIS-III represents a revised and updated version of the WAIS-R and was published in 1997 (Wechsler, 1997).

Several groups have incorporated intelligence subtests or variations into fMRI experiments to identify neural correlates of cognitive ability (e.g., Langenecker et al. 2004, Phelps et al., 1997, and Sweet et al., 2005). The Symbol Search subtest was incorporated into a fMRI scan by Sweet and colleagues (Sweet et al., 2005). Using a visuospatial control task they illustrated higher activity in brain areas associated with executive and visual processing including occipital, parietal, and dorsolateral prefrontal cortex. Increased bilateral activation was associated with lower performance consistent with compensatory recruitment strategies as described by Cabeza and others (e.g., Cabeza et al., 1997).

However, it remains a challenge to adapt paper and pencil or card based tests to the scanner with the validity that traditional testing employs especially when considering the limited number of trials present in many of these subtests. For example, the Picture Completion subtest of the WAIS has 25 or fewer trials depending on the WAIS version (Wechsler, 1981 & 1997). Further this intelligence task presents a unique conversion challenge since it requires verbal responses that will require sparse-sampling MRI techniques (Nebel et al., 2005). Sparse sampling will collect brain scans intermittently during the session instead of continuous scanning. While this allows us to clearly hear verbal responses and remove motion artifacts in images that result from jaw movement, it drastically reduces the signal to noise ratio making BOLD (blood oxygen level dependent) signal even more difficult to detect.

From a psychometric perspective, the Picture Completion subtest has several commendable components. It takes relatively less time to administer and is particularly valuable in testing intelligence at lower levels of performance. Ostensibly, it measures abilities involved in the visual recognition and identification of familiar objects and forms (Wechsler, 1981). To be able to identify what is missing from any particular picture, the subject must first know what the picture represents. Also, he or she must be able to appreciate that the missing part is in some way essential either to the form or to the function of the object or picture. In a broad sense, the test measures the ability of the individual to differentiate essential from nonessential details. To begin to analyze neural involvement within the Picture Completion subtest, the paper/pencil or card based method for the Picture Completion subtest had to be modified and validated for delivery via computer in the MRI environment. Here, we report the methodology used to translate the Picture Completion task of the WAIS into the scanner environment and a preliminary data series evaluating the novel fMRI paradigm. To our knowledge this is the first conversion of this particular subtest to the MRI environment.

II. METHODS

For behavioral testing (experiment 1) to validate the computer-based version of the Picture Completion subtest, 20 subjects were recruited from Ball State University (Muncie, Indiana, USA) in accordance with their Institutional Review Board. All subjects were right-hand, -eye, -ear, and –foot dominant by self-report with an average age of 23 years (range 19 to 33). The sample had an education level of some college and contained 3 males and 17 females. For the fMRI experiment (experiment 2), 8 subjects were recruited from Wake Forest University Baptist Medical Center (Winston-Salem, North Carolina, USA) in accordance with their Institutional Review Board. All subjects were right-hand, -eye, -ear, and –foot dominant by self-report with an average age of 27 years (range 24 to 33). The sample had an education level of completed college (n=4) or post-graduate degrees (n=4) and contained 3 males and 5 females. All 8 subjects passed screening for counter MRI indications (i.e., foreign metallic objects) prior to entering the scanner.

A. Experiment 1: Behavior

The study required 1 session and took approximately 60 minutes to complete. To avoid the concerns associated with practice effect, the examiner employed a counterbalance administration format to remove carry-over effects between the two versions of the picture completion subtest. Half of the 20 subjects were randomized to receive either the computer version of WAIS-R picture completion subtest prior to the card-based version of WAIS-III Picture Completion subtest and the other half received the card-based WAIS-III first and the computer based WAIS-R second.

Each administration of the WAIS-R and WAIS-III began with some general statements concerning what the test subjects could expect during the examination process. They were informed that they would be required to complete a number of different tests, some which involved answering questions, while others did not involve words at all. Participants were informed that most subtests began with easy tasks and became harder as they progressed during the testing process. The examinee was also informed that they would find some of the questions or tasks very difficult to complete and that there would be no prompts provided during the administration of the subtests.

Behavioral results were compared using SPSS v17.0.

B.WAIS-III Card-based Picture Completion Subtest:

The WAIS-III card-based picture completion subtest presented the subject with a stimulus booklet containing 25 colored pictures on a white background. Subjects could view the item for up to 20 seconds. An item is failed if the subject responds incorrectly or does not respond within the allotted time. To provide distraction and a break between the two picture completion subtests, the verbal information and arithmetic subtests and the performance block design of WAIS-III were given between the two Picture Completion versions. This allowed an estimate of overall IQ to be calculated from WAIS-III performance. Based upon the recommendations of Wechsler (1981), the testing room was well lit, adequately ventilated, free from distractions, and quiet. All test materials remained out of sight of the examinee until they were necessary for administration for each of the selected subtests.

C. Computer-based WAIS-Picture Completion Subtest:

Reproduction of the WAIS-R picture completion subtest for this computer-version was approved by The Psychological Corporation and all testing occurred within the approved temporary license agreement between 2009 and 2010. The WAIS-R and III versions of the subtest were used due to contractual licensing from the publisher. E-prime software (Psychology Software Tools, Pittsburgh, PA) was used to present stimuli and record the time of response generation. Subjects were seated at the same level and face-to-face with the computer screen. The WAIS-R picture completion subtest consisted of 20 black and white pictures on a white background. The computer task (see Figure 1) was designed for use in a sparse sampling fMRI experiment and added fixed waits of 6 seconds following a participant's signal that they were ready to provide a verbal answer and baseline trials to isolate task associated brain activity. Briefly, participants were allowed to view each trial picture for up to 20 seconds. When they were ready to provide their answer, they pushed the space bar and spoke their response which was recorded by the researcher.

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When the space bar is engaged, a 6 second pause began while the picture continued to be shown. After the 6 seconds, a grey cross would appear for a random duration between 250 and 500 msec and then the next trial would begin. Should the 20 seconds elapse prior to the participant responding a magenta cross would appear for 6 seconds prior to the grey cross. In addition to the 20 pictures of the test, 6 randomly inserted baseline trials occurred after the 3rd, 8th, 9th, 13th, 15th, and 19th picture. The baseline trial consisted of a green cross and participants were instructed to push the space bar when the green cross appeared. Following a 6 second delay, the green cross switched to grey for the inter-trial interval.

D. Experiment 2: fMRI

Following completion of the consent form, participants completed a short demographic questionnaire and then were taken to the MRI suite for scanning.

MRI Scans were performed on a 1.5-T General Electric twin-speed LX scanner with a birdcage head coil (GE Medical Systems, Milwaukee, WI). Visual stimuli were delivered via MR-compatible display goggles (Resonance Technology, Inc., Northridge, CA). The task was the same computer-based version tested in experiment 1.

MRI parameters used for the scans presented in this manuscript are as follows:

3DSPGR: TE (3.4-13.0s); Prep time (450); Bandwidth (15.63); Flip angle (25°); FOV (24); Acquisition matrix (256x256); Number of Slices (128); Slice Thickness (1.5mm); Slice gap (0mm); NEX (0.75); Time (6:15)

Sparse-Sample fMRI of the computer-based picture completion subtest: TR(2s); flip angle (75°); FOV (24); acquisition matrix (64x46); Number of slices (35); Slice thickness (4mm); Slice gap (0mm), TE (32); Bandwidth (62.50)

DataProcessing.Verbal responses were collected by the researcher during the 6 second delay between participant's button-press and the scanner turning on for acquisition. The participant's button press triggered the MRI scanner to take a volume of data. Since the hemodynamic response is delayed on average by 6 seconds, the image captured the BOLD activity of the brain at the time of the button-press. Images were preprocessed using SPM5. All images were realigned and normalized to the MNI template placing individual brains into a common space for analysis. Functional images were smoothed with an $8mm^3$ FWHM Gaussian kernel. Random effects analyses were performed for all imaging comparisons in SPM5 and results corrected for multiple comparisons. Behavioral results from the scanned task were compared using SPSS v17.0.

III. RESULTS

A. Experiment 1

Participants were found to have similar results on either version of the picture completion subtest.Pearson product coefficient showed a 0.61 correlation between the WAIS-III card-based version and the WAIS-R computer version. This is similar to the correlation reported in the WAIS-III instructional material for the correlation between the WAIS-R and –III card based versions of the picture completion subtest (Wechsler, 1997). Participants ranged in intelligence between 95 and 113 indicating that all subjects were performing within one standard deviation of the mean for intellectual functioning (i.e., 85-115).

B. Experiment 2

Scanned fMRI participants had a mean scaled performance score of 10.25 (range 9-14) on the computerized Picture Completion sub-test and performed similarly to participants in Experiment 1. When experimental trials were compared to baseline trial activity, significant areas of activation were found in left middle temporal gyrus and right primary visual cortex. These areas survived correction for multiple comparisons by FWE $p<0.05$.

IV. DISCUSSION

Though this series is limited by a small n, a number of significant findings were seen and indicate that the WAIS Picture Completion subtest can be adequately administered within the MRI scanner to ascertain BOLD signal activity using a sparse-sampling fMRI technique. Assessment of the computerized WAIS-R subtest compared to the card-based WAIS-III showed equivalent correlation to that reported in the WAIS-III manual for comparison between the card-based versions. The fMRI study found significant task-associated BOLD activity in right primary visual cortex and left middle temporal gyrus (see Figure 2). One could interpret these activations as the result of the visual processing associated with the subtest and preparing to name the missing item, respectively; however due to the simplicity of the control condition this is a generous interpretation (see Shen et al., 1999). Future testing will need to explore whether more complex control conditions (e.g. visual scene with no missing item) may result in reliable fMRI signal to elucidate other components of the task including frontal cortices not evident here.

As we continue to merge the fields of neuroscience with education, understanding the implications of test findings specific to each discipline will continue to be important to place educators and neuroscientists on the same theoretical page. Frequently intelligence tests have been the gold standard for cognitive ability and have been used within the neuroscience community as a means to assess specific cognitive domains in research subjects. Test scores are assessed in relation to biomarkers or treatment conditions to illustrate differences between groups. Within the classroom, these tests and subsequent findings on cognitive domains provide structure for individual development plans to improve skill deficits on an individual basis. Crossing from group comparisons to individual applications presents a unique opportunity to translate knowledge about neuroscience into educational methods to aid in knowledge acquisition in children and adult learners.

In 2009, Gottfredson and Saklofske pondered the quintessential questions of the measure and assessment of intelligence. One question proposed was "[C]ould intelligence tests be better grounded in knowledge of how the mind and brain work together?" They contended that

[D]ifferences in *g* are so pervasively and consistently enmeshed in all aspects of brain function and cognitive performance that *g* may not be ability but a property of the brain, such as overall processing efficiency. *g*is clearly not unitary at the physiological level, but likely a function of many metabolic, electrical, and other elemental processes" (p. 193).

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Geake and Cooper (2003) observed adaptive plasticity at the neurophysiological level in the brain's ability to react to changes in the cognitive environment. This concept of adaptive plasticity has implications for pedagogical elements related to learning and the design of curriculum.

Mason (2009) stated that "neuroscience research should be taken into account together with other relevant areas of scientific research that contribute to our understanding of school learning processes, products, and context" (p.548) and that educational psychologists must become "bilingual scholars" (p.549). The pathway between neuroscience and education will become more highly developed as neuroscientific findings are applied to educational practices (Ansari, 2005). Specific learning tasks which should be investigated using neuroimaging techniques have been suggested by educational researchers (Koch, Peiffer &Laurienti in-press). If neuroimaging is intended to provide region-specific information for localizing specific brain functions, and if the purpose of psychological assessment is to provide information pertaining to cognitive discrepancies and capabilities, it is logical that these two areas complement one another when assessing the validity of intelligence tests. In this study, the WAIS Picture Completion Subtest was adapted for use within the MRI scanner and significant fMRI activations were associated with performance of the WAIS-R Picture Completion subtest in adult learners.

Intelligence has long been a highly debated construct as to how it is defined and measured. The lack of agreement on a specific theory and structure of intelligence may be one major reason there are so many intelligence tests available today. As neuroimaging techniques have evolved, so has our ability to identify selected components of intelligence which are believed to be linked to specific locations in the brain. If the brain is the mainstay of intelligence, it would seem logical for school psychologists to seek an understanding of those factors that influence the central nervous system. No matter what the origin of intelligence might be, IQ scores can have serious, if not sometimes harmful, implications to the examinee. High IQ scores can assist in the admission to a prestigious institution, while a low IQ score may imply the existence of an intellectual disability. Measuring this highly contested construct will remain the most important pursuit to the psychological profession until this debate is resolved.

Initial findings from our study indicated significant activation was observed in the right primary visual and left temporal cortex. The temporal lobe is located laterally on both cerebral hemispheres, directly under the parietal lobe. This region of the brain is responsible for auditory processing as well as semantics in speech, language and vision. In a 1993 study by Andreasen, Flaum, Swayze and O'Leary, it was determined that Full Scale IQ was significantly correlated with left (0.33) and right (0.46) temporal lobes, Performance IQ with the right (0.30) temporal lobe, and Verbal IQ with left (0.34) and right (0.50) temporal lobes in normal populations. Voxel-based studies have also indicated that the temporal lobes play a significant role pertaining to intelligence. In a 2004 study, Haier, Jung, Yeo, Head and Alkire reported that temporal lobe gray matter was significantly correlated with Full Scale IQ. Also that same year, Gray and Thompson (2004) determined that test subjects who measured higher in fluid intelligence (Gf) displayed greater neural activity in the temporal lobe. Both the Block Design and Vocabulary subtests of the WAIS and WAIS-R are highly *g* –loaded subtests. The temporal lobe was found to be one of the most relevant gray matter correlations (Colom, Jung and Haier, 2006).

Though this series is limited by a small n, a number of significant findings were seen and indicate that the WAIS Picture Completion subtest can be adequately administered within the MRI scanner to ascertain BOLD signal activity using a sparse-sampling fMRI technique. Assessment of the computerized WAIS-R subtest compared to the card-based WAIS-III showed equivalent correlation to that reported in the WAIS-III manual for comparison between the card-based versions. The fMRI study found significant task-associated BOLD activity in right primary visual cortex and left middle temporal gyrus. One could interpret these activations as the result of the visual processing associated with the subtest and preparing to name the missing item, respectively; however due to the simplicity of the control condition this is a generous interpretation (see Shen et al., 1999). Future testing will need to explore whether more complex control conditions (e.g. visual scene with no missing item) may result in reliable fMRI signal to elucidate other components of the task including frontal cortices not evident here.

In conclusion, the WAIS Picture Completion Subtest could be adapted for use within the MRI scanner and significant fMRI activations were associated with performance of the WAIS-R Picture Completion subtest in adult learners.

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Table I: Scaled Score Results of Experiment 1

	WAIS-III					WAIS-R
	Verbal		Performance			
	Information	Arithmetic	Picture Completion	Block Design	IQ	Picture Completion (computer)
Mean	12.30	11.20	9.75[a]	10.85	104.70	10.45[a]
Range	11-15	8-15	5-15	9-14	95-113	7-18

[a]No significant difference in performance was seen between the card-based WAIS-III and computer-based WAIS-R Picture Completion subtest (paired t-test, n.s.).

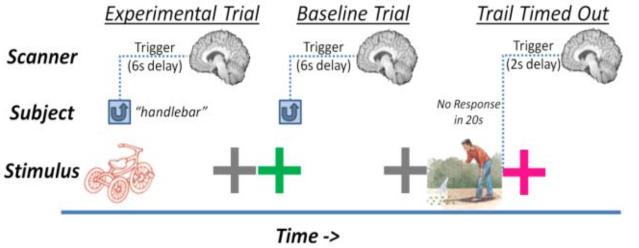

Fig. 1Schematic of Computerized Picture Completion Trial Conditions:

Three trial types are represented for the computer-based picture completion subtest. Participants push the response key when ready to provide their answer to what is missing in the picture. During the fMRI task a trigger will turn the MR scanner "on" to collect a brain volume 6 seconds after the key press. The delay, based on the time lag of the hemodynamic response, allows the participant to provide a verbal answer without motion interfering in the acquisition of brain activity associated with knowing the missing item. During baseline trials, participants respond to a green cross with the same key press to remove basic motor responses from the fMRI signal. Should a participant fail to respond during the allotted 20 seconds, a magenta cross will appear and trigger the scanner to collect a brain volume without startling the participant.

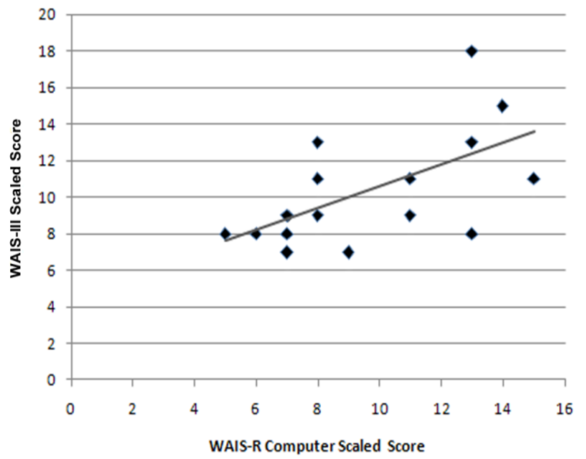

Fig. 2:Relation between computer and card versions of the WAIS Picture Completion subtest. A significant correlation (p<0.01) existed between the two versions of the subtest. The Pearson-product coefficient equaled 0.61 between the two versions similar to the card-based versions of the WAIS-R and WAIS-III presented in Wechsler, 1997.

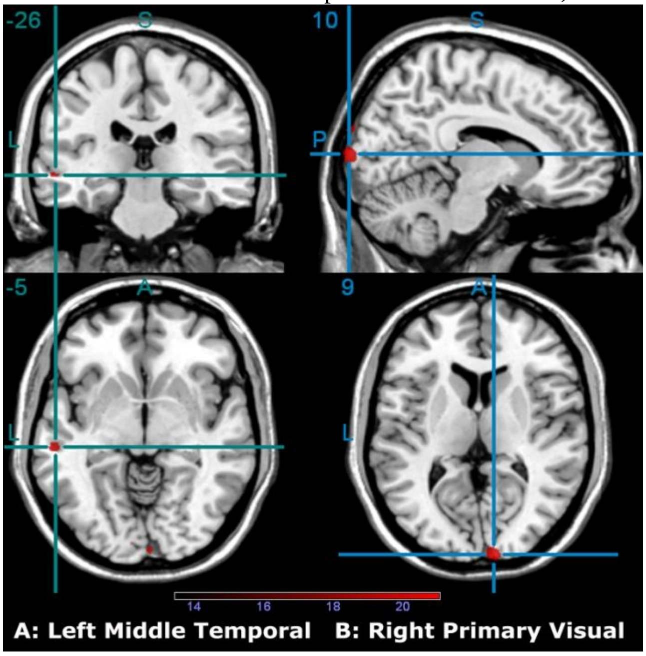

Fig. 3: fMRI Results for the Computerized Picture Completion Subtest corrected for multiple comparisons with FWE p<0.05. Significant areas with higher BOLD signal on experimental trials relative to baseline trials were seen in left middle temporal gyrus (number of voxels = 4) and right primary visual cortex (number of voxels = 9). Baseline trials removed activity associated with the button-press leaving activity evident of visual processing and item naming preparation.

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