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Visual Motor Integration Skills: Accuracy of Predicting Reading

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Abstract

Purpose.—This article investigated the contribution of visual motor integration to reading ability when known predictors of later reading outcomes were also present in the data analysis.

Methods.—Participants included 778 first and second grade students from a large diverse urban district in Texas. The data were analyzed using multiple regression models with a forced entry of predictors for each regression model and each model was run separately for each outcome.

Results.—The results indicate that visual motor integration drops out of the prediction models once more reading and language specific skills are introduced.

Conclusions.—While visual motor integration skills make a statistically significant contribution in some aspects of the regression model, the reduction in contribution reduces the predictive validity of visual motor integration skills. Therefore, a visual motor integration skill measure will not sufficiently determine if a child has a reading disability.

Keywords

visual motor integration; reading disabilities; reading predictors; early reading skills; reading ability

It is estimated that students with specific learning disabilities are most often (80–90% of students) identified as having difficulty with reading.^{1,2,3} Thus, a clear understanding of the factors associated with the early development of reading problems has never been more important for parents, teachers, and health professionals working with elementary school-aged children. The National Reading Panel⁴ reported the essential skills necessary for students to become proficient readers by the third grade. The report identified five areas of reading: phonemic awareness, phonics, vocabulary, fluency, and comprehension. Absent from this list are any skills relating to the visual processing of text, or the visual-motor processes involved in reading. It is noteworthy that studies involving measures of visual-motor processes were not excluded at the outset.

Since the publication of the report of the National Reading Panel, Hammill⁵ reviewed three meta-analyses of reading to determine which abilities most highly related to reading achievement. The ability measures from the meta-analyses were chunked into ten

superordinate ability clusters that included reading, writing conventions, letters, written language, rapid naming, phonological awareness, IQ, memory, spoken language, and perceptual and motor (including visual motor skills). The findings from these meta-analyses were consistent with the report of the National Reading Panel and other often cited syntheses of the research on the precursor skills necessary for the development of reading.

In this paper, we distinguish between reading, which is defined to be the process of extracting meaning from printed text, and the various skills that support reading. These supporting skills include phonological processes, the ability to decode words accurately and fluently, and knowledge of the meanings of words. It is important to make the distinction between reading related skills and reading comprehension because reading comprehension is the end product of many component skills being carried out in concert with one another. In prior work on the role of visual-motor skills in reading, studies have often failed to make this distinction. Some studies have focused exclusively on the component skills (e.g., decoding and fluency), whereas others have either ignored the component skills, or embedded them in general measures of reading. These approaches either ignore the role of the component skills in reading comprehension, or fail to specify the correct role of the component skills in comprehension, both of which lead to specification errors in the statistical models and potentially biased estimation of the role of visual-motor skills in reading. The present paper includes measures of reading comprehension as well as important reading related skills that play a role in the comprehension of text so as to obtain a clearer picture of the role of visual-motor skills in reading.

Research on visual-motor performance and reading ability has been present for over 50 years and has produced mixed results. For example, research comparing students with and without learning difficulties by Rosner et al.⁶ found a higher prevalence of visual-motor skill dysfunction among students with learning difficulties but the researchers did not specifically test any academic skills. Goldstein et al.⁷ sought to predict reading, mathematics, and writing achievement using three different visual motor test scores. The sample population was comprised of individuals referred for evaluation of a learning disability. The results indicated that while visual motor integration (VMI) was correlated with reading and other achievement scores, VMI was not independently related to reading over and above measure of intelligence. Kulp⁸ found a significant developmental trend of Berry VMI⁹ raw scores from kindergarten through second grade and that these scores were significantly related to teachers' ratings of children's reading ability, Stanford Reading test scores in first graders, and Otis-Lennon School Ability Test (OLSAT) scores for second graders. The variables in the study measured general reading ability along with teacher ratings. Missing from the study were measures of phonological abilities, alphabetic knowledge, or general language abilities such as vocabulary or listening comprehension that served as predictors of reading along with the measure of VMI. Also missing from the study as predictors of reading were any measures of decoding ability, indicating that the researchers were not operating from the most widely used theoretical model for reading, namely, the Simple View of Reading (SVR) of Gough and Tunmer.¹⁰ Feagans et al.¹¹ used the Gibson Task to measure visual-motor skills, the Peabody Individualized Achievement Test, the Woodcock Johnson, and the Wechsler Intelligence Scales for Children-Revised to determine that students with low performance on the Gibson Task also had low performance on all other measures, especially

reading. In a more recent study by Sortor et al.,¹² relations among Beery VMI, the Otis-Lennon School Ability Test, and the Stanford Achievement Test were examined and showed that visual-motor skills were significantly related to reading scores derived from the Stanford, a general reading ability test. Of the above mentioned studies^{8,11,12} none included measures of phonological abilities, alphabetic knowledge, decoding, or language skills as predictors of reading in their analysis examining the role of visual-motor skills. This omission suggests that the researchers were not considering the role of visual-motor abilities within the context of a comprehensive model for the development of reading and reading-related skills, such as decoding and fluency.

In contrast, Margolese et al.¹³ studied the impact of visual motor skills within the context of other language-based predictors of reading, including phonological skills and language comprehension. Results indicated that the strongest predictor of early reading was phonological skills. No effect of visual-motor skills was found when the phonological and language based measures were included as predictors. Busch¹⁴ found that the single best predictor of reading skills was the ability to recognize letters and sounds and the smallest contribution to the model was from VMI. This study was unlike other studies cited above in that phonological awareness was included as a predictor of reading. However, at the same time, the researchers did not articulate a comprehensive model for the development of reading, leaving open the possibility that results might differ if relationships were examined within a comprehensive, theoretically-motivated model. For example, including decoding and fluency along with VMI in a model of reading comprehension considers only the direct effect of visual-motor skills on reading. This direct effect may underestimate the role of visual-motor skill in reading if their influence on reading comprehension is fully mediated by word-level reading skills. Francis et al.¹⁵ found evidence that effects of visual motor skills on grade 5 reading were mediated by effects on grade 3 reading using latent variable models. However, that study failed to differentiate among decoding and comprehension skills and did not measure phonological processes involved in the development of decoding skills, which may have positively biased estimates of the effects of visual-motor skills.

A major factor contributing to variability across many of the studies has been the failure of some studies to take into account known predictors of early reading skills, particularly predictors in the language domain. Related to this criticism is the tendency for different studies to use different sets of measures, even if the same constructs, or domains of assessment have been included in different studies. Another factor influencing prior research has been the intermittent inclusion of measures of cognitive ability. Kavale¹⁶ found that there was a stronger relation for visual discrimination than visual-motor integration with reading, but Sortor et al.¹² argued that the results were due to the lack of control for IQ. Additionally, Kavale¹⁶ suggested that although visual perception, a term that encompasses visual discrimination and visual motor integration skills, correlates to reading achievement, other factors such as other reading variables should be considered to explain variance in reading skills. Finally, prior studies have varied in their focus on selected or unselected samples of students. Specifically, some studies have focused exclusively on students with disabilities, or students at-risk for the development of disabilities, while others have included relatively homogeneous samples of unselected students, such as participants who tended to be middle class and Caucasian,^{8,12} potentially limiting the generalizability of findings.

Variability across studies in the inclusion of constructs and in their measurement may reflect that researchers are operating from different theoretical models for the development of reading and do not agree on how best to measure all relevant constructs. In part this heterogeneity in theoretical orientations is not unexpected when the research base spans many disciplines with different histories and differences in shared assumptions. Similarly, variability across studies in the populations of interest are not unexpected given the variety of basic and applied scientific fields with a substantive interest in the development of reading. Given the significant correlation between visual-motor skills and reading achievement,^{8,12} a more comprehensive evaluation of the role of visual-motor skills in the development of children's reading seems warranted.

The goal of the present study was to investigate how visual-motor skills relate to reading achievement using a large and diverse sample of typically developing readers along with systematic measures of precursor and reading-related skills, word reading, vocabulary, and fluency, and norm-referenced achievement reading tests. Precursor and reading-related skills in this study refer to letter sound knowledge, rapid naming of letters, phonological awareness, vocabulary, decoding skills, and word reading fluency.

METHODS

Participants

The first and second grade students in the original study were participants in a larger longitudinal study that addressed the development of early reading skills¹⁷. The recruitment of students was from a large, diverse metropolitan area in Texas. A total of 778 students' data were analyzed (G1=617 and G2=550; n=383 students contributed data in both grades, whereas n=395 students contributed data in either grade 1 or grade 2, but not both grades). Exclusion factors for participation included failure to obtain parental consent, severe emotional problems, vision difficulties that prevented the child from being able to participate in testing (e.g., blindness), students identified at kindergarten for special education, and students who were non-English speakers. The students were not screened for undiagnosed vision problems, but were excluded if they had uncorrected visual problems that affected their ability to participate in the testing. Students who had difficulty viewing the test stimuli were excluded from participation. Because all students were tested individually and the tests employed in this study were similar to everyday school work, students with undiagnosed vision problems that would affect their ability to take part in testing would most likely have been identified by the school before the student's participation in the study, or would have been identified by the examiner at the time of testing. Boys and girls were almost equally represented (48% boys to 52% girls) in the final sample. Distribution across Socioeconomic status (SES) was reported at 8% low SES, 40% working, 46% middle-upper, and 6% not reporting. Ethnicity distribution was 50% Caucasian, 18% African-American, 16% Hispanic, 15% Asian, and 1% identified as other.

These data were collected as part of a longitudinal study of reading precursors focused on growth and development and the use of individual growth curve models to predict reading difficulties. Parents provided written informed consent each year that their son or daughter participated in the study and children provided verbal assent prior to each testing session.

Procedures for the original data collection were approved but the University of Houston's Institution Review Board (IRB). Examination of the already collected data for the sake of this post-hoc data analysis was also approved by the University of Houston's IRB.

Measures

To remain consistent with how the data were analyzed and presented in the tables, the measures have been classified according to the models presented in the analysis section of the paper. Each measure is listed by its full name and followed by the abbreviation used to reference that measure in the analysis section. For example, the Woodcock Johnson Revised is abbreviated WJ-R, but when a specific subtest is discussed the abbreviation is amended to include letters referencing the subtest name. For example, Woodcock Passage Comprehension is noted throughout the article as WJR:PC.

Outcomes

Woodcock Passage Comprehension (WJR:PC)—The Passage Comprehension subtest of the Woodcock Johnson-Revised¹⁸ was collected during the fifth wave of data collection. This subtest contains three item types and is a general measure of comprehension. The first item type has the student match a pictographic representation of the word with an actual picture of the object. The second type provides a multiple-choice format for which the student is asked to point to the picture represented by a phrase. Finally, the student reads a short passage and identifies a missing key word that fits within the context of the passage. While all WJ-R subtests were administered during the fifth data collection time point, three subtests were used in this data analysis. For an outcome measure the comprehension subtest, from the Broad Reading Cluster, was analyzed as the norm-referenced measure of general reading ability. Internal consistency is reported as 0.95 for six-year olds.¹⁸

The Formal Reading Inventory (FRI¹⁹)—The FRI requires that the student read passages silently and then respond to five comprehension questions at the end of each passage. There are a total of four forms containing 13 passages, which are graded from easiest to hardest. The child reads each passage silently and then answers five comprehension questions. Students typically do not perform as well on this measure of silent reading comprehension as they do on the general reading comprehension measure (WJR:PC). The FRI has internal consistency of 0.86 and shows good evidence of concurrent validity.²⁰

Predictors

Visual Motor Integration (VMI⁹)—This is the third edition of this test and it is individually administered to the students by a trained research assistant, requires students to copy 24 geometric line drawings, which increase in difficulty, with erasures not permitted. Testing begins at item 1 and continues until the student misses three consecutive items. Inter-rater reliability has been reported at 0.93 with a median split-half reliability of 0.79.⁹ The inter-rater reliability from the original data analysis with this data set is 0.80.²⁰

Intelligence (IQ)—The Wechsler Intelligence Scale for Children-R (WISC-R²¹) was standardized on a large sample of children, ages 6.0–16.5 years, stratified for age, gender, race, and SES according to 1970 U.S. census information. Test-retest reliabilities for all tasks ranged from 0.73–0.95. The study collected data on the WISC-R using the Hobby short form.²²

While the short form contains all subtests of the WISC-R, the administration is limited to every other item. The estimates of IQ scores with the full WISC-R to the Hobby are at and above 0.98.^{21,22}

WISC Performance IQ (WISCP²¹)—The performance portion of the assessment focuses on visual motor items - meaning they are less dependent on language. There are seven subtests that fall under the category of performance: picture completion, coding, picture arrangement, block design, object assembly, symbol search, and mazes.

WISC Verbal IQ (WISCV²¹)—The verbal portion of the WISC focuses on language-based skills and is comprised of six subtests: information, similarities, arithmetic, vocabulary, comprehension, and digit span.

Phonological Awareness (PA)—*The Comprehensive Test of Phonological Processing* (CTOPP²³) pre-publication version was administered and the total score was reported. The reported internal consistency estimates for the subtests²⁴ ranged from 0.71 to 0.87 over the subtests, while estimates calculated in studies from past reviews of the data ranged from 0.85 to 0.95.²⁰ There were seven tasks in the early version: blending onset and rime, blending phonemes into words, blending phonemes into non-words, first sound comparison, phoneme elision, sound categorization, and phoneme segmentation.

Rapid Naming (RAN²⁵): Rapid Automatized Naming Tests for Objects (RAN) was administered in kindergarten. The task requires children to name familiar objects within a set time. The stimuli consisted of five objects in a row, repeated 10 times in random sequences. The child was asked to name each object as quickly as possible. The correct number of responses within 60 seconds was recorded. Test-retest reliability was 0.57 for kindergarten and 0.77 for Grades 1 and 2.²⁶ The lower test-retest reliability in kindergarten in part reflects differential development of this skill across children over the retest interval in kindergarten. Test-retest correlations are reduced when there is heterogeneity in true change over time (Francis et al.²⁷). That is to say, when individuals are changing at different rates, test-retest correlations can be low even though reliability is high.

Decoding

Woodcock Letter Word ID (WJR:LW¹⁸)—This subtest requires students to first identify letters presented in large type and then pronounce presented words correctly.

Woodcock Word Attack (WJR:WA¹⁸)—This subtest starts with students providing sounds for single letters, followed by identification of letter combinations that follow English orthography but are either low-frequency or nonsense words.

Fluency

Word Reading Efficiency (WREA²⁸)—A list of 50 words presented on index cards were presented to students one at a time. The 50 items represented various types of word types, which were all real words. In particular, there were 36 single syllable words, 11 two-syllable words, and 3 three-syllable words. This item is common among reading research as a representative of word reading ability.^{29,30} As reported in previous studies^{31,20}, the internal consistency estimates were 0.90 and the concurrent and predictive validity had a 0.80 correlation with two subtests in the Woodcock Johnson Psychoeducational Battery-Revised, Letter Word and Word Attack.

Vocabulary

Woodcock Reading Vocab (WJR:V¹⁸)—In this subtest of the Woodcock Johnson students are asked to orally respond to a written analogy by filling in the last word (e.g., mouse : small :: elephant : ____) as well as reviewing printed words and providing synonyms and antonyms for each word presented.

Peabody Picture Vocabulary Test - Revised (PPVT-R³²)—For this measure of vocabulary recognition, the student is presented with a stimulus word and then shown a set of four pictures. The student then chooses one picture that represents the word.

Procedure

A battery of assessments was administered in five waves (October, December, February, April, and May). Waves one through four assessed the reading precursors and related skills (i.e., the measures used as independent variables in our models) using a battery of assessments. The same skills were assessed at each of the four waves. Reading and other achievement and intelligence measures were collected at wave five. Trained personnel administered the measures. While data were collected in five waves, only data from the fourth and fifth waves were used in the current analyses. The difference between the April and May data collection points was the type of assessment data collected; in May the achievement and intelligence measures were collected and in April the reading precursors and related skills measures were collected.

Analysis

The data were analyzed using multiple regression via PROC GLM in the SAS® 9.3 software package. We fit six regression models for each outcome using forced entry of the predictors. The models were structured similarly across outcomes to examine the contribution of VMI over and above the contributions of other predictors. The six models were organized to first enter more general skills (VMI and IQ) followed by more reading specific skills (PA, Decoding, Fluency, and Vocabulary). Separate analyses were conducted for each outcome and grade level using the same six regression models. The six specific models were as follows: (1) Model 1 – VMI only, (2) Model 2 – VMI and IQ, (3) Model 3 – VMI, IQ, and PA, (4) Model 4 - VMI, IQ, PA, and Decoding, (5) Model 5 - VMI, IQ, PA, Decoding, and Fluency, and (6) Model 6 – VMI, IQ, PA, Decoding, Fluency, and Vocabulary. It is also important to note that along with visual-skills we refer to the measures collectively as

“predictors” of reading in so far as they are being used in regression equations to predict students’ current status on measures of reading comprehension. This usage of the term predictor may seem unconventional because our models are based on concurrent measurement of the independent and dependent variables in the regression models. However, this usage is consistent with other uses in statistics in so far as the model results in an expected score on the outcome for each individual based on their standing on the set of independent variables in the model. These model-based expectations for individuals are often referred to as predictions, and the variables used to determine the expectations as predictors, regardless of any difference in time, or lack thereof, between the measurement of the independent and dependent variables.

Finally, we note that the data used in this study were not collected to test the specific models examined in this paper. The idea for this paper came about through examination of the literature in Optometry and noting some discrepancies with the reading literature. Knowing that we had available to us a database that could address the relevant issues, we laid out a set of models to examine the questions in a way that would elucidate the differences in the two literatures, and potentially inform the issues. In that sense the models were decided on after obtaining the data, because the idea for this particular paper came about after collecting the data. However, the models are not post-hoc in so far as we laid out the models and their ordering in accordance with current theories of reading, in advance of fitting any of the models.

RESULTS

Table 1 provides the descriptive statistics for each measure used in the multiple regression models. All measures, with the exception of PA and WREA, have a mean of 100 and a standard deviation of 15. The PA measure is standardized to have a mean of zero and standard deviation of one from the beginning of Kindergarten through the end of second grade. The WREA is a fluency measure with the words correct per minute reported. According to Hasbrouck and Tindal³³ first grade students should read at or above 53 words correct per minute (wcpm) while second grade students should be at or above 89 wcpm. However, these norms are for the reading of connected text and tend to exceed the expected words read correctly per minute for words read in isolation. The fluency measure in the present study is a predecessor of the Test of Word Reading Efficiency.²⁸ The descriptive statistics in Table 1 show the performance of the sample to be fairly typical of first and second grade students. The slightly elevated performance on the WISC subtests reflects norms obsolescence known as the Flynn Effect, which a recent meta-analysis by Trahan and colleagues indicates accounts for a growth in mean IQ of approximately 3 points per decade.^{34, 35}

The correlations among the measures are presented in Table 2. All correlations are statistically significant at the $p < .005$ with the exception of VMI with FRI at Grade 2, where $p = 0.053$. The correlations of VMI to the reading predictors in grade two drop in comparison to the grade one correlations. The smallest drop (0.02) is the correlation with WJR:WA (Woodcock Word Attack) and the largest drop (0.11) is the correlation with WISCV (WISC Verbal IQ). When reviewing the correlations it is instructive to square the

correlation to create a measure of shared variance. For example, VMI shares about 11% of the variance with Woodcock Johnson comprehension and 4% with FRI in grade one and 4% and 1%, respectively, with the two measures in grade two. The highest shared variance for VMI is with performance IQ (19% in grade one 18% in grade two).

Tables 3, 4, 5, and 6 present the results of the models for the different outcome measures. The models progress in complexity as each successive model includes one or more additional variables with no variables deleted. The rows in the tables represent the models, and each table includes results for Grade 1 in the upper half and results for Grade 2 in the lower half. Table 3 presents results for the passage comprehension measure (WJR:PC). Table 4 presents results for the silent reading comprehension measure (FRI). Table 5 presents results for decoding (WJR:LW) as an outcome measure, while Table 6 presents results for fluency (WREA) as an outcome measure. These last two analyses are included to examine the possibility that visual-motor skills are important in explaining the basic reading skills that enable students to extract information about language from printed text. If visual-motor skills are important to decoding and fluency, but not to reading comprehension once decoding and fluency are controlled, then it is possible that decoding and fluency mediate the role of visual-motor skills in reading.

The columns in each table present two types of information for the regression models. The first four columns of information pertain to the overall model, and provide the degrees of freedom for the model, the overall model R^2 , F , and p -value. The R^2 reports the percentage of variance in the outcome measure that is accounted for by the model, and the F and p -values test whether the variance accounted for by the model is statistically different from 0. The final three columns in each table provide results for the specific contribution of VMI to that model. The column labeled β_{vmi} provides the least squares estimate of the standardized relationship between VMI and the outcome variable, controlling for the other predictors in the model. This estimate shows how much scores on the outcome measure tend to differ (in standard deviation units) for students whose VMI scores differ by one standard deviation unit – all other things being equal. The column labeled t tests the hypothesis that the beta weight for VMI is equal to 0, and $(p(vmi))$ provides the p -value for this t statistic. Looking across all of the tables, one can quickly see that all models are statistically significant, accounting for a non-trivial portion of the variance in the outcome. More importantly, one can also quickly see that the significance of VMI drops off when reading specific variables are added to the model. Although the pattern varies slightly by grade, for the most part, the contribution of VMI is negligible once reading specific predictors like PA, decoding, and fluency are included in the model.

The strongest role for VMI is seen in grade one for passage comprehension. For passage comprehension (Table 3) VMI makes a contribution when it is the only measure in the model, and continues to contribute to the model when IQ is added, albeit to a somewhat lesser extent in grade 2 ($p = 0.0181$). However, once more reading specific measures of PA, decoding, and fluency are introduced into the model the contribution of VMI is substantially diminished. Specifically, the contribution of VMI to WJR:PC is neither practically (β) nor statistically significant (t , p) once decoding is added to the model in grade one ($t = 0.90$, $p = 0.3669$ for VMI in Model 4) or in grade two ($t = -1.12$, $p = 0.2614$). Although VMI

remained significant when only IQ and phonological awareness (PA) had been added to the model for WJR:PC in grade one ($t = 2.36$ and $p = 0.0089$ for VMI in Model 3), the contribution of VMI is negligible once PA has been added to the model in grade two ($t = 0.81$, $p = 0.4209$ for VMI in Model 3).

Examining the models for FRI (Table 4), VMI is not as strong on its own as in the models for passage comprehension. In grade one, VMI accounts for 3% of the variance in FRI when entered alone in the model ($p = 0.0004$ in Model 1) and 2% of the variance in FRI in grade two ($p = 0.0019$). Again, the contribution of VMI is negligible once reading specific language skills are added to the model. In fact, in the case of FRI, the contribution of VMI is negligible once IQ has been added to the model (Model 2) and remains non-significant as the reading specific language measures are added in Models 3 through 6.

To investigate the possibility that VMI plays a role in the development of basic reading skills, such as real word decoding, we ran regression models predicting decoding (Table 5) and fluency (Table 6). The models for decoding in Table 5 show a similar pattern to passage comprehension. VMI predicts decoding when it is the only variable in the model for both grades one and two ($p = 0.0001$), and continues to contribute to the model when PA is added. However, VMI does not contribute to the model for decoding once vocabulary has been added to the model ($p = 0.1158$ and $p = 0.1425$ in grades one and two, respectively).

The fluency results (Table 6) provide a slightly different look at the possible contribution of VMI to the development of reading, namely that the integration of visual motor skills is important to the automation of decoding skills, as opposed to the accurate recognition of words (i.e., decoding) or to comprehension. However, in both grades one and two, the results for VMI follow a similar pattern to the results for comprehension in that the contribution of VMI is not statistically significant beginning with Model 3, i.e., once PA has been entered into the model.

To examine the possibility that our partially overlapping sample reduced variability between the grade one and grade two outcomes, we also created a random sample of grade one and grade two students such that each student contributed only a single observation. That is, for students with data in grade one and grade two, we randomly selected one of the two observations. We repeated this sampling process 1000 times, creating 1000 bootstrap samples. For each of the 1000 samples we compare the variance of each measure in each grade for the non-overlapping bootstrap sample to the variance for the same measure and grade for the overlapping sample (i.e., the one used in the analysis). We compute this difference by subtracting the variance of the bootstrap sample from the variance in the overlapping sample. The difference is expressed as a percentage of the variance in the overlapping sample. Thus, a positive difference indicates greater variance in the analyzed data and a negative difference indicates greater variance in the samples without overlapping cases. Across 1000 repeated samples, the average difference in the variance ranged from -0.019% to $+0.054\%$ in grade 1 with 9 of 11 differences being positive, indicating greater variance in the analyzed data. In grade 2, the average difference ranged from -0.013% to $+0.054\%$, again with 9 of 11 differences being positive. The standard deviation of the percent difference ranged from $.027$ to $.048$ in grade 1 and from $.036$ to $.078$ in grade 2. Based on

these results, we find no evidence to suggest that allowing students to contribute to both the grade 1 and grade 2 analyses restricted the variance in either the grade 1 or grade 2 analyses.

DISCUSSION

This study contributes to the literature around visual motor integration and reading ability from the theoretical perspective of the simple view of reading. The present study lends to the literatures in Optometry and reading by attempting to rectify disparities between the two literatures and attempting to take into account which determinants of reading might reasonably be impacted by visual motor skills. Using a pre-existing, large longitudinal database, the potential role of visual motor skills in reading was examined in a way that would elucidate the differences in the two literatures by examining the role of visual motor integration in a series of increasingly complex models predicting reading performance at the ends of grade one and grade two. The sample size in the present study was also large and more diverse than many of the samples used in prior research conducted in this area.

The findings of this study are consistent with a few of the findings discussed in the literature review^{13, 14} in that visual motor integration skills are related to reading in both grades one and two. However, this simple relation fails to take into account the shared variance between VMI and other precursors of reading. Failure to account for this shared variance with other predictors of reading creates a biased view of the independent contribution of VMI to reading. In fact, when other known predictors of reading are included with VMI in the model, the contribution of VMI to reading over and above the other predictors is negligible, although the other predictors remain important. This diminution of importance in VMI as a predictor typically occurred with the introduction of phonological awareness (PA) and/or decoding skills to the model. As more language based measures were added to the models, the contribution of VMI to reading became progressively weaker. While all measures are imperfect indicators of the constructs they are designed to measure, and these errors of measurement can bias regression parameters as estimates of causal relations, all of the measures used in this study have strong reliability. Thus, it seems implausible to argue that the pattern of results seen across the two grades and multiple models can be explained on the basis of differential reliability across the VMI in comparison to the other predictors of reading. Consistent with the results from grades one and two, it is difficult to argue that visual motor integration contributes uniquely to the determination of reading scores, over and above the contributions of other known determinants of reading, such as phonological awareness, decoding, fluency, and vocabulary.

That is not to say that VMI is unrelated to reading, nor that, in the absence of information about these other determinants of reading, knowing a students' status on VMI would be unhelpful in predicting their reading performance. In the absence of knowledge about phonological awareness, decoding, fluency, and vocabulary, knowing something about a student's visual motor skills carries some information about reading performance. However, the more important take home message appears to be that visual motor skills play a small role in the acquisition of decoding skills along with phonological processes, as evidenced by the difference in the models for decoding as compared to the models for comprehension and fluency. However, relatively speaking, the contribution of visual motor skills is small

compared to phonological awareness, and the contribution does not extend to fluency once the role of decoding in fluency has been accounted for.

These findings are also consistent with neuroimaging research on reading acquisition, which shows a changing activation pattern from the earliest stages of reading to the point where reading becomes automatic.³⁶ This research also shows that when students struggle to acquire reading, brain activation patterns are more diffuse and include more bilateral, and right hemisphere activation. With successful intervention, brain activation normalizes and follows the pattern of activation seen in typically developing readers.^{37,38} The changes in activation going from unskilled to skilled reading reflect an automation of many of the component processes in reading, providing rapid recognition of familiar word forms and near instantaneous access to word meanings coupled with slower, more effortful processing of unfamiliar word forms.^{1,3,4,29} As decoding skills become automated, visual motor skills decrease in importance as evidenced by the fact that skilled readers can read texts that are highly visually degraded with minimal disruption in fluency or comprehension. At the same time, experimental studies have shown that readers pick up and use information about the shape and length of words that are outside the central area of fixation to aid the process of word recognition.³⁹ More recent research on neural changes following the acquisition of reading has led to speculation that specialization in the visual word form area for words may negatively affect the automatic processing of faces, as evidenced by decreased activation in this region when processing faces and checkerboards by individuals who differed in their degree of literacy skill.⁴⁰ These findings are also consistent with the notion that visual processes play a role early in the processing of words. Clearly, the foregoing should not be construed to suggest that vision is unimportant in sighted reading, only that individual differences in visual processing of stimuli account for a small percentage of the variability in reading both within individuals and between individuals.

One limitation of the present study is that vision screening by a qualified professional was not conducted as part of the battery of tests. As such, students with significant or mild undiagnosed vision problems (e.g., significant hyperopia, convergence insufficiency) may be represented in the sample and contribute to the results in unspecified ways. While it seems reasonable to expect that the inclusion of students with vision problems would increase the chances of finding a relationship between visual processing skills and learning to read, the specific contribution of such students to the present findings is impossible to assess with any degree of certainty.

There are several differences between the present study and those previously reported in the literature examining the effects of visual motor skills in reading. First, the present study included measures of key verbal and non-verbal skills that have been implicated in the development of early reading skills. Included in this battery was a highly regarded measure of visual motor skills, the Beery Test of Visual Motor Integration. Second, the models examined concurrent reading performance, focusing on the roles of visual motor skills and other measures in predicting students' current reading performance at the end of grade one and grade two. Although the sample of children was followed longitudinally, the present study did not focus on intra-individual change in reading performance. Rather, the current

focus was on assembling the largest possible dataset to examine the concurrent predictors of reading performance at the end of each grade.

Constructing the dataset in this manner and conducting the analyses as we did ensures that each individual only contributes one observation to each analysis, although some individuals contribute to both analyses whereas other individuals contribute only to one or the other analysis. This approach eliminates any concern about repeated assessments within each analysis, but raises the possibility that the sample would display less variability between grades than would fully independent (i.e., non-overlapping) samples. We attempted to examine this possibility by creating 1000 bootstrap samples where each child could contribute only a single observation to either the grade one or the grade two dataset, that is, 1000 grade one and grade two samples with no overlap. The average variance across these 1000 samples showed no evidence that the use of partially overlapping samples restricted the variance in samples. While these findings do not rule out the possibility that findings in grades one and two are more similar in our study than might have been expected if two fully independent samples had been used in the two grades, it is clearly not the case that the variability in the data has been unduly restricted by the partial overlap in the grade one and grade two samples in this study.

Future research on this topic may need to focus on more discrete measures of visual processing and visual motor skill, and measures of text processing that are capable of differentiating between readers in the speed with which they access and process information presented in written form. It is possible that the measures of visual motor, reading, and reading related skills used in the present study were simply too coarse to be sensitive to the subtle individual differences in visual processing that influence reading and the scale at which those differences are observed. For example, one might include measures of sensitivity to visual perceptual information outside the central fixation point and its effects on comprehension and processing speed.

At the same time, if the scale at which the effects of visual processes are measureable is too small to influence student performance on tests of reading achievement, what consequence do they have for teachers, practitioners, and readers? There is no doubt that reading is one of the most complex cognitive processes in which human beings engage and as such, it is the culmination of many cognitive and neural processes occurring simultaneously and sequentially within the individual, and these processes are under the influence of many contextual factors operating outside of the individual, and possibly beyond the specific reading task itself, such as when the reader's mind is distracted by other obligations, or interests. The precise roles played by visual and linguistic processes and the interactions between them will no doubt continue to occupy the interests of researchers, clinicians, and teachers for some time. For now, it seems clear that whatever the role played by individual differences in visual processes, these processes have exerted their influence largely prior to the completion of the decoding of individual words such that this influence can be accounted for by individuals' ability to decode. Moreover, even these influences on decoding are small in comparison to the linguistic factors of phonological awareness and vocabulary. Thus, practitioners faced with children struggling to learn to read would do well to concentrate on the linguistic factors known to strongly influence reading acquisition, provided that visual

acuity is correctible to within normal limits. Ignoring these important linguistic determinants of reading in search of subtle problems in visual processing cannot be justified based on what is presently known about the acquisition of reading and the factors most likely to make reading acquisition difficult for children and adults.

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Table 1.

Descriptive Statistics for Measures.

Measure	G1			Grade 2		
	N	Mean	SD	N	Mean	SD
Passage Comprehension ¹	615	107.5	16.3	546	109.6	15.4
Formal Reading Inventory	582	87.3	14.8	542	87.9	15.9
Visual Motor Integration	618	96.75	11.44	554	97.66	12.55
WISC ² Performance IQ	615	111.6	14.6	549	113.6	14.1
WISC ² Verbal IQ	616	104.3	14.2	549	106.5	14.7
Phonological Awareness	618	0.48	0.70	554	0.96	0.65
Letter Word Identification ¹	613	106.3	16.8	549	107.1	17.1
Word Attack ¹	615	103.7	15.5	550	103.3	16.0
Vocabulary ¹	614	101.7	14.5	549	103.7	14.9
Peabody Picture Vocabulary	618	79.6	14.0	554	91.6	13.6
Word Reading Efficiency ³	440	35.1	21.9	376	61.5	19.8

¹Subtest of the Woodcock-Johnson Revised Test of Achievement²Wechsler Intelligence Scale for Children-Revised³Words read correctly per minute

Table 2.

Correlations among measures in grades 1 (below diagonal) and 2 (above diagonal).

VARIABLE	1	2	3	4	5	6	7	8	9	10	11
1 Passage Comprehension ¹	-	0.46	0.21	0.43	0.60	0.52	0.81	0.70	0.78	0.83	0.44
2 Formal Reading Inventory	0.44	-	0.08	0.25	0.40	0.29	0.45	0.40	0.41	0.49	0.29
3 Visual Motor Integration	0.33	0.19	-	0.42	0.22	0.32	0.30	0.31	0.25	0.31	0.13
4 WISC ² Performance IQ	0.38	0.27	0.44	-	0.47	0.29	0.38	0.34	0.31	0.48	0.28
5 WISC ² Verbal IQ	0.49	0.34	0.33	0.47	-	0.42	0.55	0.45	0.49	0.67	0.62
6 Phonological Awareness	0.58	0.32	0.37	0.40	0.53	-	0.53	0.56	0.51	0.55	0.42
7 Letter Word Identification ¹	0.84	0.44	0.35	0.38	0.49	0.61	-	0.83	0.84	0.83	0.34
8 Word Attack ¹	0.75	0.42	0.33	0.35	0.47	0.63	0.86	-	0.76	0.72	0.24
9 Word Reading Efficiency ³	0.78	0.46	0.30	0.34	0.44	0.60	0.85	0.79	-	0.76	0.32
10 Vocabulary ¹	0.79	0.48	0.35	0.43	0.60	0.63	0.84	0.79	0.78	-	0.47
11 Peabody Picture Vocabulary	0.35	0.20	0.21	0.34	0.57	0.52	0.32	0.33	0.35	0.41	-

Note. Grade 1 correlations are presented below the diagonal; Grade 2 correlations are presented above the diagonal. Correlations of predictors with the two reading comprehension outcome measures are presented in bold text. All correlations are statistically significant at $p < .0015$ with the exception for the correlation between Visual Motor Integration and the Formal Reading Inventory in Grade 2, where $p = .059$.

¹ Subtest of the Woodcock-Johnson Revised Test of Achievement

² Wechsler Intelligence Scale for Children-Revised

³ Words read correctly per minute

Table 3.

Multiple Regression Results for Passage Comprehension.

Model for Grade 1		df_m	R^2	F_{model}	$p (model)$	β_{vmi}	t	$p (vmit)$
1: VMI		1	0.13	65.07	0.0001	0.36	8.07	0.0001
2: VMI + IQ		3	0.28	58.52	0.0001	0.18	13.87	0.0001
3: VMI + IQ + PA		4	0.38	68.19	0.0001	0.11	2.36	0.0089
4: VMI + IQ + PA +Decoding		6	0.69	163.90	0.0001	0.03	0.90	0.3669
5: VMI + IQ + PA +Decoding + Fluency		7	0.71	152.29	0.0001	0.04	1.31	0.1901
6: VMI + IQ + PA +Decoding + Fluency + Vocabulary		9	0.72	123.16	0.0001	0.04	1.23	0.2186
Model for Grade 2		df_m	R^2	F_{model}	$p (model)$	β_{vmi}	t	$p (vmit)$
1: VMI		1	0.09	36.50	0.0001	0.30	6.04	0.0001
2: VMI + IQ		3	0.42	92.17	0.0001	0.10	2.37	0.0181
3: VMI + IQ + PA		4	0.49	89.32	0.0001	0.03	0.81	0.4209
4: VMI + IQ + PA +Decoding		6	0.74	174.52	0.0001	-0.03	-1.12	0.2614
5: VMI + IQ + PA +Decoding + Fluency		7	0.76	166.83	0.0001	-0.02	-0.62	0.5335
6: VMI + IQ + PA +Decoding + Fluency + Vocabulary		9	0.79	151.55	0.0001	-0.00	-0.35	0.7271

Note: Adjusted R^2 is reported for the value of R^2 ; VMI = Visual Motor Integration; IQ – WISC-R Performance and Verbal IQ scores; PA – Phonological Awareness; Decoding – WJR Letter Word and Word Attack subscales; Fluency – Word Reading Efficiency; Vocabulary – Peabody Picture Vocabulary and WJR Vocabulary.

Table 4.

Multiple Regression Results for Formal Reading Inventory.

Model for Grade 1		df_m	R²	F_{model}	p (model)	β_{vmi}	t	p (vmi)
1: VMI		1	0.03	12.84	0.0004	0.17	3.58	0.0004
2: VMI + IQ		3	0.10	16.83	0.0001	0.06	1.09	0.2743
3: VMI + IQ + PA		4	0.14	17.20	0.0001	0.03	0.52	0.6020
4: VMI + IQ + PA +Decoding		6	0.22	20.85	0.0001	-0.02	-0.32	0.7513
5: VMI + IQ + PA +Decoding + Fluency		7	0.24	19.16	0.0001	-0.01	-0.13	0.8945
6: VMI + IQ + PA +Decoding + Fluency + Vocabulary		9	0.25	16.02	0.0001	-0.01	-0.16	0.8729
Model for Grade 2		df_m	R²	F_{model}	p (model)	β_{vmi}	t	p (vmi)
1: VMI		1	0.02	9.79	0.0019	0.16	10.22	0.0019
2: VMI + IQ		3	0.17	25.32	0.0001	0.06	1.16	0.2454
3: VMI + IQ + PA		4	0.18	20.69	0.0001	0.03	0.59	0.5568
4: VMI + IQ + PA +Decoding		6	0.26	21.97	0.0001	-0.01	-0.17	0.8682
5: VMI + IQ + PA +Decoding + Fluency		7	0.25	18.78	0.0001	-0.01	-0.16	0.8767
6: VMI + IQ + PA +Decoding + Fluency + Vocabulary		9	0.27	15.75	0.0001	-0.00	-0.04	0.9711

Note: Adjusted R^2 is reported for the value of R^2 ; VMI = Visual Motor Integration; IQ – WISC-R Performance and Verbal IQ scores; PA – Phonological Awareness; Decoding – WJR Letter Word and Word Attack subscales; Fluency – Word Reading Efficiency; Vocabulary – Peabody Picture Vocabulary and WJR Vocabulary.

Table 5.

Multiple Regression Results for Decoding.

Model for Grade 1		df_m	R^2	F_{model}	$p(model)$	β_{vmi}	t	$p(vmi)$
1: VMI		1	0.12	82.66	0.0001	0.35	9.09	0.0001
2: VMI + IQ		3	0.29	89.91	0.0001	0.16	4.23	0.0001
3: VMI + IQ + PA		4	0.42	112.01	0.0001	0.09	2.56	0.0108
4: VMI + IQ + PA + Vocabulary		6	0.71	250.98	0.0001	0.04	1.58	0.1158
Model for Grade 2		df_m	R^2	F_{model}	$p(model)$	β_{vmi}	t	$p(vmi)$
1: VMI		1	0.09	54.74	0.0001	0.30	7.40	0.0001
2: VMI + IQ		3	0.34	92.77	0.0001	0.16	4.25	0.0001
3: VMI + IQ + PA		4	0.42	98.04	0.0001	0.09	2.38	0.0179
4: VMI + IQ + PA + Vocabulary		6	0.70	215.11	0.0001	0.04	1.47	0.1425

Note: Adjusted R^2 is reported for the value of R^2 ; VMI = Visual Motor Integration; IQ – WISC-R Performance and Verbal IQ scores; PA – Phonological Awareness; Vocabulary – Peabody Picture Vocabulary and WJR Vocabulary.

Table 6.**Multiple Regression Results for Fluency.**

Model for Grade 1		df_m	R^2	F_{model}	$p(model)$	β_{vmi}	t	$p(vmi)$
1: VMI		1	0.09	43.83	0.0001	0.30	6.62	0.0001
2: VMI + IQ		3	0.22	42.99	0.0001	0.22	2.71	0.0071
3: VMI + IQ + PA		4	0.38	67.04	0.0001	0.05	1.14	0.2531
4: VMI + IQ + PA + Decoding		5	0.74	243.77	0.0001	-0.04	-1.37	0.1703
5: VMI + IQ + PA + Decoding + Vocabulary		7	0.75	185.65	0.0001	-0.04	-1.44	0.1493
Model for Grade 2		df_m	R^2	F_{model}	$p(model)$	β_{vmi}	t	$p(vmi)$
1: VMI		1	0.06	22.81	0.0001	0.24	4.78	0.0001
2: VMI + IQ		3	0.25	42.88	0.0001	0.11	2.16	0.0312
3: VMI + IQ + PA		4	0.35	50.40	0.0001	0.02	0.48	0.6293
4: VMI + IQ + PA + Decoding		5	0.70	178.09	0.0001	-0.06	-1.82	0.0692
5: VMI + IQ + PA + Decoding + Vocabulary		7	0.71	132.45	0.0001	-0.05	-1.66	0.0983

Note: Adjusted R^2 is reported for the value of R^2 ; VMI = Visual Motor Integration; IQ = WISC-R Performance and Verbal IQ scores; PA = Phonological Awareness; Decoding = WJR Letter Word and Word Attack subscales; Fluency = Word Reading Efficiency; Vocabulary = Peabody Picture Vocabulary and WJR Vocabulary