Is There a Relation Between Visual-Motor Integration and Academic Achievement in School-Aged Children with and without ADHD?

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Abstract

Objective: Visual-motor integration, motor coordination, and visual perception are associated with academic achievement in early school-aged children; however, our understanding of these associations in older school-aged children and children with neurodevelopmental disorders is limited.

Method: A well-characterized, clinically evaluated sample of 39 children with and without ADHD ages 8–13 (M=10.07, SD=1.56; 14 girls; 67.5% White/non-Hispanic) were administered standardized academic and visual-motor integration tests.

Results: Backward entry regression analyses that initially included age, sex, socioeconomic status, ADHD symptoms, comorbidities, and IQ revealed that better visual perception uniquely predicted better-developed reading (β=.38) and math skills (β=.21; both p<.03), whereas better motor coordination was associated with better reading (β=.25), writing (β=.50), and math skills (β=.21 all p<.05). The integration of visual perception and motor coordination processes was uniquely associated only with math skills (β=.28; p=.007). Children with ADHD exhibited significantly lower visual-motor integration (d=1.16) and potentially motor coordination (d=0.51), but did not differ from Non-ADHD children in terms of visual perception (d=0.03).

Conclusions: These findings extend prior evidence from younger, neurotypical samples, and indicate that underdeveloped visual-motor integration and/or its subcomponents (visual perception and motor coordination) reflect unique risk factors for academic underachievement in school-aged children's math, reading, and written language skills.

Keywords

ADHD; visual-motor integration; motor coordination; visual perception; academic achievement

The visual-motor system is responsible for the coordination of visual perception and motor coordination to successfully accomplish activities of daily living such as feeding,

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walking, and writing (Beery & Beery, 2006). *Visual perception* describes the ability to process information about one's surrounding environment that is obtained ocularly (Faao, 2011; Wade & Swanton, 2001). *Motor coordination* refers to the ability to control fine and gross motor components involved in body movement (Brannigan & Decker, 2003). Neurocognitive processes necessary for the completion of these activities use visual information to activate motor systems that initiate purposeful actions (Sortor & Kulp, 2003), and the fluidity of these coordinated processes is termed *visual-motor integration*. In some cases, deficits in individual subcomponents of the visual-motor integration system (i.e., visual perception and/or motor coordination) may prevent children from successfully integrating these processes. In other cases, even though children may have well-developed individual visual perception and motor coordination, other neurological impairments may limit their ability to effectively integrate/coordinate these processes (e.g., Brannigan & Decker, 2003). The efficiency of children's fine motor coordination, visual perception, and visual-motor integration is important for academic achievement (Barnhardt et al., 2001), with the available evidence suggesting that visual-motor integration and its subcomponents may differentially affect functioning across different academic domains (e.g., Sortor & Kulp, 2003; Willows, 1998). As such, the current study examined associations between visual-motor integration, its subcomponents, and all three primary academic domains (reading, math, writing), while controlling for known demographic, behavioral, and intellectual correlates of children's academic achievement in a small but carefully phenotyped sample of clinically evaluated children.

The Visual-Motor System and Academic Achievement

Motor coordination.—The relation between motor coordination and academic achievement has been given much attention in the developmental literature (Beery & Beery, 2006). For example, motor coordination has been consistently related to children's writing skills (Chagas et al., 2016; Clark, 2010). Furthermore, research indicates that preschool students who exhibit early deficits in writing skills continue to exhibit these deficits along with reading and math difficulties into their second grade year, as writing is a foundational ability required for most other academic skills (Dinehart & Manfra, 2013). In addition to predicting writing skills, motor coordination in preschoolers (Dinehart & Manfra, 2013) and kindergarteners (Grissmer et al., 2010; Son & Meisels, 2006) predicts later academic achievement in math. There is also evidence to suggest an association between motor coordination and reading skills. For example, motor coordination predicts passage comprehension, phonemic sound awareness, and letter identification skills in kindergarteners (Cameron et al., 2012) as well as reading achievement in first and second graders (Pagani et al., 2010; Roebers et al., 2014). However, one study failed to find an association between motor coordination skills and reading in five- and six-year-old children (Pitchford et al., 2016). In sum, there is evidence to suggest that motor coordination significantly influences math (Dinehart & Manfra, 2013; Grissmer et al., 2010; Son & Meisels, 2006) and writing (Chagas et al., 2016; Clark, 2010) skills, whereas the evidence base regarding motor coordination's influence on reading skills is mixed (Cameron et al., 2012; Pagani et al., 2010; Pitchford et al., 2016; Roebers et al., 2014).

Visual perception.—Evidence suggests that visual perception is related to reading achievement (Goldstand et al., 2005; Kavale, 1982). In particular, six- and seven-year-old children with deficits in visual perception exhibit worse performance in reading and overall academic achievement over the course of their elementary school years as compared to their peers with and without learning disabilities (Feagans & Merriwether, 1990). Notably, one study found that visual perception was a better predictor of reading and math achievement than motor coordination (Sortor & Kulp, 2003); however, this study failed to examine writing skills, which may contribute to the lack of significant associations between motor coordination and academic skills. Another study found that seven- and eight-year-old children who were labeled by teachers as ‘learners with learning-related problems’ experienced more visual perception difficulties compared to the ‘typical learner’ group (Coetzee & Gerber, 2018). Overall, the available evidence suggests that visual perception is related to reading, math, and overall academic achievement; however, research regarding the relations between visual perception and writing skills is limited (e.g., Goldstand et al., 2005; Sortor & Kulp, 2003).

Visual-motor integration.—Visual-motor integration is related to academic achievement (Keogh & Smith, 1967; Oberer et al., 2018) and learning readiness in neurotypical kindergarteners (Bart et al., 2007; Solan et al., 1985). In addition, longitudinal studies indicate that kindergarteners’ visual-motor integration predicts later elementary school achievement (Keogh & Smith, 1967). Positive correlations between visual-motor integration and academic achievement have also been found in neurotypical second graders (Banumathe et al., 2017). In particular, a large body of educational literature is devoted to the relation between visual-motor integration and writing skills. For example, positive relations have been found between visual-motor integration and letterform legibility in kindergarteners (Daly et al., 2003). Evidence also indicates a direct association between handwriting and visual-motor integration in first grade children (Capellini et al., 2017), and visual-motor integration difficulties are associated with difficulties in spatially organizing written material during both writing and math tasks (Barnhardt et al., 2001). In a sample of children ranging from kindergarten to third grade, teacher ratings of children’s performance in all academic domains (i.e., reading, math, and writing) were correlated with children’s performance on visual-motor integration tasks (Kulp, 1999). However, the conclusions for school-aged children in general remain preliminary as few studies have examined these associations in children in the third grade and older.

The Visual-Motor System in Clinical Child Populations

Interestingly, factor analysis indicates that attention difficulties as well as the subcomponents of the visual-motor integration system (i.e., visual perception and motor coordination) may underlie academic achievement for at least a subset of elementary school-age children diagnosed with learning disabilities (Leton et al., 1987). As such, the evidence supports three clusters of impairment in children with academic difficulties: (1) deficits in attention, (2) deficits in verbal association intelligence abilities, and (3) deficits in both visual perception and motor coordination (Leton et al., 1987), with the largest proportion of children grouped into the third cluster. This pattern indicates that deficits in individual components of the visual-motor integration system may underlie, at least in part, academic achievement difficulties for a large proportion of children diagnosed with a learning disability. Thus, examining the integration of these two subcomponents in children appears warranted to increase our understanding of how this integration (or lack thereof) leads to children's difficulties with academics. Because evidence suggests that most children with learning disabilities have impairments in both visual perception and motor coordination, interventions targeting these abilities in elementary school-aged children with learning disabilities have been given considerable attention (e.g., Pieters et al, 2012). Particularly, occupational therapy interventions have been successful in improving visual-motor skills and their integration in preschool children with developmental delays (Dankert et al., 2003). Additionally, occupational therapy interventions successfully improve visual-motor integration in children with learning disabilities (Sanghavi & Kelkar, 2005).

More recently, compromised visual-motor integration has been investigated in other neurodevelopmental disorders such as attention-deficit/hyperactivity disorder (ADHD). Relative to neurotypical children, children ages 8 to 16 with ADHD have more severe learning difficulties (Mayes et al., 2000), and researchers suspect that these difficulties may be related, in part, to deficits in visual perception and/or motor coordination (Fliers et al., 2007; Higashionna et al., 2017). As previously discussed, factor analytic evidence indicates that children with learning disabilities exhibit deficits in attention and both subcomponents of the visual-motor system; however, whether children with attentional deficits have a diagnosis of ADHD in addition to visual-motor impairments is not discernible from that study (Leton et al., 1987). Nonetheless, correlational evidence indicates an association between ADHD diagnosis and deficits in motor coordination (Fliers et al., 2007; Sutton et al., 2011). Despite evidence for associations between attention and academic achievement, and evidence indicating that children with ADHD exhibit impairments in subcomponents of the visual-motor system, research examining the influence of the visual-motor system on academic achievement in children with ADHD is limited (e.g., Mayes et al., 2018; Van et al., 2012).

Current Study

Taken together, there is substantial evidence to suggest a positive association between the subcomponents of the visual-motor system and academic achievement in preschoolers and kindergarteners (e.g., Banumathe et al., 2017; Feagans & Merriwether, 1990; Kavale, 1982; Keogh & Smith, 1967; Kulp, 1999), whereas our understanding of this association in elementary school children with and without ADHD is limited (e.g., Mayes et al., 2018; Van et al., 2012). Furthermore, in second to fourth grade children, studies have tended to investigate the association between visual-motor integration and overall academic achievement rather than its association with specific academic domains (Sortor & Kulp, 2003). Finally, emerging evidence suggests that children with elevated ADHD symptoms may be more likely to have visual-motor-related difficulties (Higashionna et al., 2017), but the extent to which ADHD symptoms and visual-motor integration difficulties reflect independent predictors of academic achievement remains unclear. Therefore, the current study included children aged 8 to 13 with and without ADHD and examined the relation between visual-motor integration, its subcomponents (motor coordination and visual

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perception), and three core academic achievement domains (reading, math, and written language).

Based on previous evidence in preschoolers and kindergarteners, we hypothesized that visual-motor integration, motor coordination, and visual perception would be positively correlated with measures of academic achievement in our sample of older children (Banumathe et al., 2017; Feagans & Merriwether, 1990; Kavale, 1982; Keogh & Smith, 1967). In particular, we expected to find associations between visual-motor integration and reading, math, and writing skills (Barnhardt et al., 2001; Chagas et al., 2016; Capellini et al., 2017; Daly et al., 2003; Kulp, 1999). In regard to motor coordination, we also expected positive associations with math and writing (Chagas et al., 2016; Dinehart & Manfra, 2013; Grissmer et al., 2010; Son & Meisels, 2006). In contrast, visual perception was expected to yield stronger associations with reading and math as compared to writing skills (Feagans & Merriwether, 1990). Further, we expected ADHD symptoms to be uniquely associated with academic achievement (Mayes et al., 2000). Finally, we hypothesized that children with ADHD would exhibit lower visual-motor integration and motor coordination compared to their Non-ADHD peers (Mayes et al., 2018; Van et al., 2012).

Method

Participants

The sample comprised 39 children aged 8 to 13 years ($M = 10.07$, $SD = 1.56$; 25 boys, 14 girls) from the Southeastern United States, recruited by or referred to a university-based children's learning clinic (CLC) through community resources (e.g., pediatricians, community mental health clinics, school system personnel, self-referral) from 2015 to 2019. The CLC is a research-practitioner training clinic known to the surrounding community for conducting developmental and clinical child research and providing *pro bono* comprehensive diagnostic and psychoeducational services. Its client base consists of children with suspected learning, behavioral, or emotional problems, as well as typically developing children (those without a suspected psychological disorder) whose parents agreed to have them participate in developmental/clinical research studies. All parents and children gave informed consent/assent, and Florida State University Institutional Review Board approval was obtained/maintained. Sample ethnicity was mixed with 26 White Non-Hispanic (67.5%), 6 Hispanic (14.6%), 6 Black children (14.6%), and 1 Multiracial child (2.4%). All children spoke English.

All children and caregivers completed a detailed, semi-structured clinical interview using the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Aged Children (K-SADS; Kaufman et al., 1997). The K-SADS (2013 Update) allows differential diagnosis according to symptom onset, course, duration, quantity, severity, and impairment in children and adolescents based on DSM-5 criteria. Its psychometric properties are well established, including inter-rater agreement of .93 to 1.00, test-retest reliability of .63 to 1.00, and concurrent (criterion) validity between the K-SADS and psychometrically established parent rating scales (Kaufman et al., 1997). K-SADS interviews were supplemented with parent and teacher rating scales from the Behavior Assessment System for Children (BASC-2/3;

Reynolds & Kamphaus, 2015) and ADHD Rating Scale (ADHD-RS-4/5; DuPaul et al., 2016). A psychoeducational report was provided to parents.

Of the 39 children included in the current study, 28 were diagnosed with ADHD based on the comprehensive, multi-informant psychoeducational evaluation (34.5% girls; 75% combined presentation, 21% inattentive presentation, 4% hyperactive/impulsive presentation). A subset of children with ADHD also presented with comorbid conditions including oppositional defiant disorder (21%)[1], depressive disorders (7%), and anxiety disorders (17%), and specific learning disorders (SLD) in reading (5.1%), math (12.8%), and written language (14.8%). The remaining 11 children did not meet ADHD criteria based on the comprehensive evaluation (36.4% girls; 55% neurotypical, 45% clinical disorders other than ADHD). Neurotypical children had normal developmental histories, nonclinical parent/teacher ratings, and completed the same evaluation as clinically-referred cases. Clinical diagnoses among children without ADHD included anxiety (36%), depression (9%), and written language learning disorder (9%). Positive screens for learning disorder were defined by score(s) >1.5 *SD* below age-norms on one or more subtest(s) in the Academic Skills Battery of the Kaufman Test of Educational Achievement, Third Edition (Kaufman, 2014). Children with vs. without ADHD did not differ in the proportion of children diagnosed with a clinical disorder other than ADHD (all $p > .11$).

Children were excluded from the larger study if they presented with (a) gross neurological, sensory, or motor impairment, (b) history of a seizure disorder, psychosis, or intellectual disability, or (c) non-stimulant medications that could not be withheld for research testing. Fourteen of the twenty-eight children with ADHD were currently prescribed psychostimulants.[2] Children prescribed psychostimulant medication received their usual dose on the psychoeducational testing day (i.e., when the tests described in the current study were administered).

Procedures

Children participated in a baseline psychoeducational assessment included in a larger research battery that spanned three sessions. Children were included in the current study if they received the Beery-Buktenica Developmental Test of Visual-Motor Integration Sixth Edition (Beery VMI) during the clinical evaluation. The Beery VMI was administered to a subset of participants based on clinical judgment that it may provide useful data for interpreting performance on the broader psychoeducational test battery or to support optometry/occupational therapy referrals (e.g., suspected fine motor or visual difficulties based on behavioral observations, developmental history, parent report).

[1]As recommended in the K-SADS, oppositional defiant disorder was diagnosed clinically only with evidence of multi-informant/multi-setting symptoms.

[2]Exploratory analyses added during the peer review process indicated that medication status was not significantly associated with any of the study's visual-motor or academic outcomes (Table 2, all p>.11), that medicated and unmedicated children with ADHD did not differ significantly on any of the study's visual-motor or academic outcomes (all p>.10), and that medication status did not significantly predict any of the academic outcomes (all p>.36) or change the pattern of significant predictors when added to the regression models.

Visual-Motor System

The Beery VMI was administered to assess visual-motor integration, visual perception, and motor coordination (1–2 week test-retest = .84–.88; α = .71–.89; Beery et al., 2010). The Beery VMI objective scoring system contains 3 subtests (Visual-Motor Integration, Visual Perception, Motor Coordination). The Visual-Motor Integration subtest is administered first and provides an overall index of visual-motor integration functioning. In this subtest, children are presented with a workbook that contains a series of increasingly complex line drawings that children are asked to copy. In addition, the Beery VMI provides supplemental measures of visual perception and motor coordination using the same geometric figures. The Visual Perception subtest asks children to identify the figure that matches the figure shown. The Motor Coordination subtest asks children to trace a geometric figure without drawing outside the boundaries. These timed supplemental subtests were designed to be conducted after the untimed Visual-Motor Integration subtest is administered, which allows for the comparison of the visual-motor integration score to relatively pure visual perception and motor coordination. Standard scores based on the national standardization sample (age norms) served as the primary indices for each of the three Beery VMI subcomponents (Beery et al., 2010). Higher scores reflect better developed visual-motor integration, visual perception, and motor coordination.

Academic Achievement

Academic achievement was assessed using the Kaufman Test of Educational Achievement, Third Edition, Academic Skills Battery (KTEA-3; 1–2 week test-retest = .80–.96; α = .92–.99; Kaufman & Kaufman, 2014). The KTEA-3 provides three domain-specific composite scores that served as the primary dependent variables in the current study, each based on the two subtests in parentheses: *Reading Composite* (reading comprehension, letter-word identification), *Math Composite* (math computation, math concepts and applications), and *Written Language Composite* (written expression, spelling). Standard Scores were obtained by comparing performance to the nationally representative standardization sample ($N = 3{,}000$) according to age. Higher scores reflect higher achievement.

ADHD Symptoms

The ADHD Rating Scale for DSM-IV or DSM-5 (ADHD-RS-4/5; DuPaul et al., 2016) teacher forms were used to assess the frequency and severity of ADHD symptoms based on DSM criteria in children and adolescents aged 5 to 17 (18 items; 4-point Likert scale). Psychometric support for the ADHD-RS-4/5 includes high internal consistency (α=0.94) and test-retest reliability ($r = 0.79$ to 0.85; DuPaul et al., 2016). Standardized scores (T-Scores) from the ADHD-RS-4/5 were used to assess the quantity and frequency of total ADHD symptoms (age and sex norms). Higher scores reflect greater quantity/severity of teacher reported ADHD symptoms.

Intellectual Functioning (IQ) and Socioeconomic Status (SES)

All children were administered the WISC-V Short Form (SFIQ; Sattler, 2016). Following Rapport et al. (2009), a residual IQ score was derived by covarying the Beery VMI variables described above out of IQ (R^2 = .40, p < .001). This residual IQ score represents cognitive functions important for IQ test performance but unrelated to lower-order visual-motor skills, and was computed to improve construct specificity because IQ test performance depends heavily on the visual-motor system (Ackerman et al., 2005; Dennis et al., 2009), even for IQ subtests without explicit motor demands (Breen et al., 1985). An expanded discussion of the rationale and support for this method is provided in Kofler et al. (2016). SES was estimated using the Hollingshead (1975) scoring based on caregiver(s)' education and occupation.

Data Analysis Overview

To assess the associations between visual-motor integration, its subcomponents, and academic achievement, our primary analyses involved a series of hierarchical, backward entry regression analyses. Age, sex, IQ, comorbidities, and SES were entered in the first step, followed by the three visual-motor subcomponents (Step 2), and teacher reported ADHD symptoms (Step 3). Hierarchical regression was selected to provide information regarding the extent to which each visual-motor subcomponent uniquely predicts academic achievement, and examine the extent to which any detected relations were robust to control for known demographic and behavioral correlates of academic achievement. Backward entry was used at each step to conserve power by removing non-significant predictors. Separate models were run for each of the three academic achievement outcome domains (reading, math, written language).

Power Analysis

An *a priori* power analysis was conducted using GPower v3.1 (Faul et al., 2007) to determine our sensitivity for detecting effects. For power = .80, α = .05, 3 predictors (visual-motor integration, motor coordination, visual perception), and our sample size of 39, we are sufficiently powered to detect R^2 = .24. In the event that all 8 potential predictors were retained in the final model (3 visual-motor subcomponent variables, age, sex, IQ, SES, ADHD symptoms), we would be sufficiently powered to detect R^2 = .33. A single predictor is expected to be significant if it explains at least 17.6% of the variance in an academic domain. As noted above, backward entry was used in all regression models to conserve power given our sample size; this process resulted in final n-to-k ratios of between 10:1 and 13:1 that fall at/above recommended guidelines for the number of cases per predictor in regression models (e.g., Austin & Steyerberg, 2015). Thus, the study is sufficiently powered to detect effects of the anticipated magnitude.

For between-group comparisons, the study is powered to detect ADHD group difficulties at d=0.80 or greater (i.e., large effects). In the current study, we refer to between-group differences of $p\leq.05$ as statistically significant, regardless of estimated effect size. In addition, we refer to non-significant (p>.05) between-group effect sizes of at least medium magnitude (i.e., $d\geq0.50$) as 'potentially significant' given Cohen's (1992) characterization of effects of this magnitude as 'visible to the naked eye of the careful observer' – i.e., these effects may be clinically or practically significant even if not statistically significant given our cell sizes.

Results

Preliminary Analyses

All independent and dependent variables were screened for univariate outliers, defined as values greater than 3 SD above or below the within-group mean. Outliers beyond 3.00 *SD* were winsorized relative to 3 SD above or below the within-group mean, with 0.9% of all data points being affected by this process. Task data from subsets of the current battery have been reported for subsets of the current sample to examine conceptually unrelated hypotheses in Kofler et al (2019). Data for the study's primary outcomes, Beery VMI subscale scores, have not been previously reported. Collinearity statistics were within range for all variables in all regression models (Tolerance =.74–.99, Variance Inflation Factors/ VIF=1.00–1.34), supporting the non-multicollinearity assumption. Intercorrelations among study variables are shown in Table 1. Inspection of Table 2 indicated that the ADHD group had higher parent- (d=0.74) and teacher-reported ADHD symptoms (d=1.13) as expected. The ADHD group also had significantly lower math (d=0.80), written language (d = 1.21), visual-motor integration (d=1.16), and potentially lower motor coordination (d=0.51) scores, but did not differ significantly from the Non-ADHD group in terms of reading or visual perception (p>.26). Levene's test was nonsignificant for all study variables, supporting the equality of variance assumption for ADHD/Non-ADHD between-group comparisons (all p>.14).

Primary Analyses: Visual-Motor Predictors of Academic Achievement

Reading skills.—Results of the final model indicated that children's visual perception (β = .38; p = .001), motor coordination (β = .25; p = .028), and IQ (β = .60; p < .001) significantly predicted their reading composite scores and accounted for a significant proportion of variance in the model (model R^2 = .63; p < .001). SES, sex, comorbidities, and age were excluded in Step 1 because they were not significant predictors of reading scores (all p > .48). Interestingly, teacher-reported ADHD symptoms did not significantly predict reading achievement (p = .36) when added to the model (Step 3). These results indicate that children with better visual perception, better motor coordination, and higher IQ exhibited better reading skills.

Math skills.—Results of the final model indicated that children's visual-motor integration (β = .28; p = .007), visual perception (β = .21; p = .034), motor coordination (β = .21; p = .049), IQ (β = .60; p < .001), and sex (β = .33; p < .001) significantly predicted their math composite scores and accounted for a significant proportion of variance in the model (model R^2 = .75; p < .001). SES, comorbidities, and age were not significant predictors and were therefore excluded in Step 1 (both p > .08). Similar to the previous model, teacher-rated ADHD symptoms did not significantly predict math scores (p = .12) when added to the model (Step 3). These results indicate that children with better visual-motor integration, visual perception, motor coordination, higher IQ, and male sex exhibited better math skills.

Written language skills.—Results of the final model indicated that children's motor coordination (β = .50; p = .003) and ADHD symptoms (β = −.44; p = .01) significantly predicted their written language composite scores and accounted for a significant proportion of variance in the model (model $R^2 = .48$; $p = .001$). SES, sex, comorbidities, and age were excluded in Step 1 (all $p > .20$). Interestingly, teacher-rated ADHD symptoms significantly predicted written language scores ($\beta = -.37$; $p = .027$) when added to the model (step 3). IQ was a significant predictor in Step 2 ($\beta = .39$; $p = .027$), but was no longer significant when accounting for ADHD symptoms ($p = .073$). These results indicate that children with better motor coordination and lower ADHD symptoms exhibited better written language skills.

Discussion

The current study examined the relations between visual-motor integration, its subcomponents, and academic achievement across three core academic domains in a clinically evaluated sample of school-aged children with and without ADHD (Sortor & Kulp, 2003). Results from the current study indicate that all three assessed visual-motor components significantly predicted children's academic achievement. Notably, the results indicated that different visual-motor components are important for different academic domains, such that children's visual perception and motor coordination are important for reading; their visual-motor integration, visual perception, and motor coordination are important for math; and their motor coordination is important for written language. As expected, the results were also consistent with previous evidence that higher IQ and lower ADHD symptoms significantly predict academic achievement, albeit with a more nuanced pattern than observed in some previous studies as discussed below (Freberg et al., 2008; Kofler et al., 2018; Mayes et al., 2000).

Of primary interest in the current study was the extent to which components of the visual-motor system differentially predict children's academic achievement across the three primary academic domains (reading, math, and written language). Overall, the current findings supported our hypothesis that children's visual-motor integration, motor coordination, and visual perception would be positively correlated with measures of academic achievement. The use of a series of backward entry regression analyses provided significant evidence that children with better visual perception, motor coordination, and visual-motor integration also exhibited higher levels of academic achievement, and that these associations were robust to consideration of a range of potential demographic, behavioral, and higher-level intellectual background confounders previously linked with academic achievement. The implications of these findings for each academic domain are described below.

The Visual-Motor System and Reading Skills

Results of the current study indicate that children with better developed visual perception, motor coordination, and IQ exhibit better reading skills. These findings are consistent with previous evidence supporting an association between visual perception and reading skills (Feagans & Merriwether, 1990; Kavale, 1982; Sortor & Kulp, 2003) as well as with evidence of an association between motor coordination and reading skills (Cameron et al., 2012; Pagani et al., 2010; Roebers et al., 2014). These results provide additional support for the importance of visual perception and motor coordination in children's reading achievement (Cameron et al., 2012; Feagans & Merriwether, 1990; Kavale, 1982; Pagani et al., 2010; Roebers et al., 2014), and extend prior work by replicating these associations in a clinically evaluated sample of children with and without ADHD. Whereas the association between visual perception and reading makes intuitive sense, the reading/motor coordination finding appears less face valid despite being consistent with prior work in this area (Cameron et al., 2012; Pagani et al., 2010; Roebers et al., 2014). In other words, a child must be able to see and visually discriminate printed letters and words to be able to convert them to phonological code (Baddeley, 2008), but it is less clear how motor coordination skills would aid in reading. Current theoretical models suggest that young students who exhibit early deficits in writing skills, which have an important motor component, continue to exhibit deficits in other academic areas, as writing is a foundational ability required for most other academic skills such as reading (Chagas et al., 2016). For example, kindergarteners who are better at writing letters and copying forms may grasp more advanced concepts like learning sentences and words faster than students who struggle with these early writing skills (Medwell, Strand, & Wray, 2007). Therefore, motor coordination may not directly impact reading skills, but children with better motor coordination skills may perform better in writing which in turn impacts reading skill development (Chagas et al., 2016; Medwell, Strand, & Wray, 2007). Alternatively, additional evidence suggests an association between fine motor skills and oral-motor skills (e.g., Belmonte et al., 2013) – the latter of which may be particularly important during early reading development as children read aloud and then continue to move their lips when reading silently before transitioning to silent reading (e.g., Kragler, 1995). Thus, an alternative explanation may be that the fine motor coordination/reading links detected in the current and previous studies reflect shared developmental factors and/or that fine motor skills serve as a proxy for oral-motor skills that may more directly impact early reading success.

In contrast, the current findings were inconsistent with previous literature that found an association between visual-motor integration and reading achievement (Kulp, 1999). A parsimonious explanation for this discrepancy may be that Kulp (1999) was unable to control for underlying visual perception and motor coordination processes, suggesting that previous findings may be attributable to difficulties with these lower-level processes rather than higher-level processes associated with integrating them. Alternatively, the previous study included children who were younger than our current sample, leaving open the possibility that different visual-motor subcomponents may be more/less important at different stages of development. It will be important for future work to determine whether different visual-motor subcomponents are more/less important during different developmental and academic periods (e.g., before vs. after the transition from learning-to-read to reading-to-learn; Kulp, 1999). Taken together, our results indicate that children with lower visual perception and motor coordination perform more poorly on measures of reading achievement, independent of IQ and ADHD symptoms.

The Visual-Motor System and Math Skills

Results of the current study indicate that children with better developed visual-motor integration, visual perception, motor coordination, and IQ exhibit better math skills. These findings are consistent with previous evidence of an association between visual-motor integration and math skills in preschoolers and kindergarteners (Barnhardt et al., 2001;

Chagas et al., 2016; Capellini et al., 2017; Daly et al., 2003; Kulp, 1999) and add support for this association in older school-aged children. The results were also consistent with prior evidence for an association between math achievement and both visual perception (Feagans & Merriwether, 1990; Sortor & Kulp, 2003) and motor coordination (e.g., Dinehart & Manfra, 2013; Chagas et al., 2016; Grissmer et al., 2010; Son & Meisels, 2006), and extend prior work by showing that all three visual-motor components independently predict math achievement, even when controlling for IQ, ADHD symptoms, and demographic factors. Taken together, these results suggest that children's math achievement is not only influenced independently by visual perception and motor coordination, but also by the integration of these processes. Stated differently, successful math performance requires children to visually perceive the printed math problem, engage motor coordination skills to work out the problem in writing, and integrate these visual and motor processes to achieve the desired outcome (e.g., lining up numbers in the correct columns, writing down the correct answer in the proper location on the page; Barnhardt et al., 2001; Chagas et al., 2016; Dinehart & Manfra, 2013; Feagans & Merriwether, 1990; Grissmer et al., 2010; Sortor & Kulp, 2003; Son & Meisels, 2006). This interpretation is consistent with previous evidence that visual-motor integration difficulties are also associated with difficulties in spatially organizing written material during both writing and math tasks (Barnhardt et al., 2001), and extends these findings by documenting them in a clinically evaluated sample of children.

The Visual-Motor System and Written Language Skills

Results of the current study indicate that children with better motor coordination and lower ADHD symptoms exhibit better writing skills. These findings are consistent with previous evidence of positive associations between motor coordination and writing (Chagas et al., 2016; Pitchford et al., 2016) and extend previous findings by examining differences in written language achievement and motor coordination in children with and without ADHD. The results are also consistent with previous evidence indicating that IQ scores significantly predict academic achievement in writing skills (Freberg et al., 2008). Further, the finding that visual perception was not predictive of writing scores was consistent with prior literature (Feagans & Merriwether, 1990; Kavale, 1982; Sortor & Kulp, 2003), and adds to the current research regarding visual perception and writing (Feagans & Merriwether, 1990; Kavale, 1982; Sortor & Kulp, 2003). In contrast, the current findings were at odds with previous literature reporting an association between visual-motor integration and writing achievement (Barnhardt et al., 2001; Daly et al., 2003). Similar to the results regarding visual-motor integration and reading skills, the previous literature did not control for the other two visual-motor subcomponents which may be why others have found an association whereas our study did not (Barnhardt et al., 2001; Daly et al., 2003). Taken together, results from the current study confirm that successful performance on tests intended to assess higher-level knowledge of grammatical rules, spelling, and written expression rely, to a significant extent, on lower-level motor coordination (Chagas et al., 2016; Pitchford et al., 2016).

Visual-Motor and Academic Functioning in Children with ADHD

Of secondary interest in the current study, children with ADHD performed significantly lower than their Non-ADHD peers on visual-motor integration, math, and written language measures. In addition, ADHD symptom severity uniquely predicted written language. These findings were generally consistent with previous evidence suggesting that children with ADHD exhibit lower levels of writing skills (Re et al., 2017; Rodriguez et al., 2015), higher rates of learning difficulties (Mayes et al., 2000), and more visual-motor integration difficulties compared to neurotypical children (Mayes et al., 2018; Van et al., 2012), and extend previous findings by being one of the few studies to examine writing skills and the integration of motor coordination and visual perception in the same sample. In contrast, children with ADHD do not appear to exhibit significant deficits in visual perception or reading skills, and ADHD symptom severity failed to uniquely predict reading or math achievement. Thus, the current study suggests that children with ADHD may have generally intact visual perception and potentially motor coordination, but their ability to integrate these two processes is impaired. These results stood in contrast with previous literature that found an association between ADHD symptoms and both reading (August & Garfinkel, 1990; Czamara et al., 2013; Ehm et al., 2016) and math (Czamara et al., 2013; Zentall & Ferkis, 1993), as well as potentially contrasted some evidence linking ADHD with motor coordination difficulties (Fliers et al., 2007; Higashionna et al., 2017). Some of the previous findings of an association between ADHD status and reading were from samples that included younger (7–9 year old) children than our sample (Ehm et al., 2016), older (15 years old) children than our sample (Zentall & Ferkis, 1993), or a larger age range (7–17 years old) than our sample (August & Garfinkel, 1990). Thus, it is possible that the difference in ages may have influenced the difference between our findings and prior work in this area (cf. Czamara et al., 2013).

At the same time, a more parsimonious explanation for this inconsistency may be that prior work was unable to control for effects of visual-motor integration's subcomponents when investigating links between ADHD symptoms and academic underachievement. That is, we speculate that the nonsignificant associations between ADHD status/symptom severity and reading achievement in the current study may suggest that visual-motor integration difficulties might be a mechanism by which ADHD results in academic underachievement. This hypothesis is generally consistent with our 'marginally nonsignificant' zero-order associations between ADHD symptoms and math achievement ($r = -.29$, $p = .07$; Table 2) before accounting for visual-motor system subcomponents, but should be considered speculative because the current study was not powered for testing mediation. Similarly, the pattern of results suggests that previous findings of motor coordination and/or visual perception difficulties in ADHD may be attributable to neurological factors specific to the integration of these processes rather than to difficulties in these underlying processes per se (Beery & Beery, 2006).

Limitations

The current study has several strengths, including measurement of not only visual-motor integration but the individual subcomponents being integrated, recruitment of a clinically heterogeneous and carefully phenotyped sample, and extension of the research on visual-motor/academic links to older school-aged children. Despite these methodological refinements, the following limitations must be considered when interpreting the results. First, due to sample size restrictions and disproportionate group sizes, we were unable to examine ADHD diagnostic status as a moderator of the associations between the visual-motor system and academic achievement. Thus, although we were able to examine the influence that dimensional ADHD symptomology has on these associations, future studies are needed that include larger samples, differentiate among ADHD symptom clusters, and employ more fine-grained assessment of specific academic skills to clarify the relations reported herein. Similarly, difficulties with motor coordination may have been detectable with a larger sample size despite Levene's test suggesting that its non-significance in the current study was not due to inequality of variances. In addition, including children with clinical disorders beyond ADHD (i.e., ODD, anxiety, depression) may limit the applicability of the results to understanding ADHD, just as including children with ADHD limits our ability to draw conclusions regarding neurotypical children. Notably, co-occurring conditions are common in ADHD (Wilens et al., 2002). Therefore, inclusion of children with these comorbidities was important to maximize external validity and generalizability of our findings. Although the ADHD and Non-ADHD groups were recruited with proportionate numbers of other psychiatric disorders to balance external and internal validity, future work is needed to compare more 'pure' (non-comorbid) ADHD and typically developing samples. In addition, although our models accounted for a large proportion of the variance in academic outcomes, a comprehensive model of academic functioning in ADHD would require, at minimum, several additional predictors that have been associated with both academic functioning and ADHD (e.g., working memory/executive functions; Kofler et al., 2018). Next, the Beery VMI was administered selectively to participants in the larger study based on clinical judgment. While this methodological decision may improve the generalizability of results to the population of interest (e.g., children suspected of visual-motor difficulties), it may have blunted our ability to detect relations via restricting the range of obtained Beery VMI scores (i.e., children with above average visual-motor integration may have been less likely to have been included). Future work that recruits for the full range of visual-motor integration is needed to examine the extent to which our recruitment strategy affected the pattern of results reported herein. Finally, children prescribed psychostimulant medication received their usual dose on the psychoeducational testing day. While this procedure has several benefits (e.g., reduced likelihood of adverse effects from participating in the study, as might occur if a child attends school without receiving their ADHD medication; reduced likelihood that interfering behaviors adversely affect test scores given that the psychoeducational report has implications for academic program eligibility), we were unable to investigate dosage, timing, or other potential confounds.

Clinical and Research Implications

Results from the current study provide further evidence for the significant influence that visual-motor integration, motor coordination, and visual perception have on school-aged children's academic achievement. That is, the current study found that children's motor coordination is important for success across all three core academic domains (reading, writing, math), and that better skill at integrating motor coordination and visual perception may provide incremental benefits for math achievement. Notably, occupational therapy services are associated with successful improvements in visual-motor integration in children (Sanghavi & Kelkar, 2005). Thus, these results provide further support for the potential benefits of routine occupational therapy screenings (and intervention as warranted by the screening results) for children exhibiting difficulties in mathematics or writing to support their future academic achievement (Sanghavi & Kelkar, 2005). Of course, these conclusions are speculative because the current study did not test intervention effects. Similarly, visual perception was independently associated with reading and math achievement. Given that visual acuity is a prerequisite for visual perception (e.g., Keane et al., 2015; Samaha & Postle, 2015), these findings highlight the importance of universal vision checks, and referrals to optometry as indicated – particularly for children identified as underachieving in reading and/or math (Goldstand et al., 2005).

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Table 1.

Zero-order correlations among study variables.

	Visual-Motor Integration	Visual Perception	Motor Coordination	Reading Achievement	Math Achievement	Written Language	IQ	ADHD Symptoms (Teacher)	Age	Sex	Meds N/Y
Visual-Motor Integration	—										
Visual Perception	.20	—									
Motor Coordination	.44**	.33*	—								
Reading Achievement	.32*	.47**	.38*	—							
Math Achievement	.41**	.32*	.38*	.78***	—						
Written Language	.34†	.34†	.46*	.70***	.73***	—					
IQ	.00	.00	.00	.60***	.62***	.33†	—				
ADHD Symptoms (Teacher)	−.07	−.02	−.05	−.19	−.29†	−.44*	−.13	—			
Age	−.25	−.32*	−.14	−.05	−.01	−.10	.05	−.29†	—		
Sex	−.01	−.03	−.06	.10	.35*	.08	.06	−.13	.14	—	
SES	−.16	−.11	−.11	.16	.01	−.21	.18	.22	−.03	−0.20	—
Medication Status (N/Y)	−.26	−.13	.07	.01	.04	.05	.09	−.04	.14	.44**	

† $p < .10$,

* $p < .05$,

** $p < .01$,

*** $p < .001$

Table 2.

Descriptive Statistics

Demographics	***ADHD (N =28)***	***Non-ADHD (N = 11)***	χ^2 ***(N=39)***	***p***	***Cohen's d***
Sex (Boys/Girls)	18/10	7/4	.001	.97	--
Ethnicity (Nonwhite/white)	7/21	6/5	3.10	.08	--
	M(SD)	***M(SD)***	***t(37)***	***p***	***Cohen's d***
Age	9.95 (1.52)	10.54 (1.62)	1.07	.29	0.38
SES	50.72 (11.37)	45.23 (10.18)	−1.39	.17	0.51
IQ	102.64 (13.70)	106.18 (18.54)	0.66	.52	0.22
ADHD 4/5 Total (Raw Scores)					
Teacher	9.88 (3.81)	5.45 (4.06)	−3.15	.003*	1.13
Parent	9.56 (3.56)	6.50 (4.63)	−2.11	.04*	0.74
KTEA-3 (T-Scores)					
Reading Composite	99.11 (13.53)	104.73 (14.70)	1.14	.26	0.40
Math Composite	95.21 (14.58)	105.45 (10.54)	2.12	.04*	0.80
Written Language Composite	90.83 (9.38)	105.22 (13.89)	3.20	.004*	1.21
Beery VMI (T-Scores)					
Visual-Motor Integration	85.11 (11.01)	96.36 (8.10)	3.07	.004*	1.16
Visual Perception	96.29 (11.96)	96.64 (12.60)	0.08	.94	0.03
Motor Coordination	79.36 (15.82)	86.55 (12.13)	1.36	.18	0.51

Note. ADHD = attention-deficit/hyperactivity disorder, IQ = WISC-V Short-Form IQ (based on Vocabulary, Similarities, Matrix Reasoning, and Figure Weights as recommended; Sattler, 2016), KTEA = Kaufman Test of Educational Achievement, SES = Social economic status, VMI = Beery-Buktenica Developmental Test of Visual-Motor Integration, 6th Edition.

* $p < .05$