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Role of Neurocognitive Factors in Academic Fluency for Children and Adults With Spina Bifida Myelomeningocele

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Abstract

Objectives: Fluency is a major problem for individuals with neurodevelopmental disorders, including fluency deficits for academic skills. The aim of this study was to determine neurocognitive predictors of academic fluency within and across domains of reading, writing, and math, in children and adults, with and without spina bifida. In addition to group differences, we expected some neurocognitive predictors (reaction time, inattention) to have similar effects for each academic fluency outcome, and others (dexterity, vocabulary, nonverbal reasoning) to have differential effects across outcomes. **Methods:** Neurocognitive predictors were reaction time, inattention, dexterity, vocabulary, and nonverbal reasoning; other factors included group (individuals with spina bifida, $n = 180$; and without, $n = 81$), age, and demographic and untimed academic content skill covariates. Univariate and multivariate regressions evaluated hypotheses. **Results:** Univariate regressions were significant and robust ($R^2 = .78$, .70, .73, for reading, writing, and math fluency, respectively), with consistent effects of covariates, age, reaction time, and vocabulary; group and group moderation showed small effect sizes (<2%). Multivariate contrasts showed differential prediction across academic fluency outcomes for reaction time and vocabulary. **Conclusions:** The novelty of the present work is determining neurocognitive predictors for an important outcome (academic fluency), within and across fluency domains, across population (spina bifida versus typical), over a large developmental span, in the context of well-known covariates. Results offer insight into similarities and differences regarding prediction of different domains of academic fluency, with implications for addressing academic weakness in spina bifida, and for evaluating similar questions in other neurodevelopmental disorders. (*JINS*, 2019, *25*, 249–265)

Keywords: Spina bifida, Academic fluency, Neurocognitive predictors, Neurodevelopment

INTRODUCTION

Spina bifida is the most common permanently disabling neurodevelopmental disorder in children (Williams, Rasmussen, Flores, Kirby, & Edmonds, 2005). Spina bifida myelomeningocele (SBM) is the most prevalent and severe form of this disorder, characterized by the herniated protrusion of the spinal cord and meninges from the vertebrae (Copp et al., 2015; Detrait et al., 2005). SBM has striking neurobiological variability. A key aspect is lesion level, with higher lesions indicating more severe neurological effects, including parietal thinning (Fletcher et al., 2005; Raimondi, 1994), Chiari II malformation and reduced infratentorial and cerebellar size, and corpus callosum malformations (Copp et al., 2015; Juranek & Salman, 2010). This neurobiological variability is recapitulated at physical, cognitive, and functional levels (Dennis, Salman, Juranek, & Fletcher, 2010; Wasserman & Holmbeck, 2016). Because spina bifida manifests quite early in development (2 to 4 weeks gestation; Van Allen et al., 1993), the entire developmental trajectory is impacted.

Academic Profile in Individuals with SBM

Dennis and colleagues (Dennis & Barnes, 2010; Dennis, Landry, Barnes, & Fletcher, 2006) proposed a model of SBM

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predicting relatively greater difficulties in assembled (active integration of information and relational reasoning) relative to associative (procedural or stimulus-response associative learning) processing. Performance differentiation occurs within neurocognitive domains, but also within academic domains. For example, children with SBM have more difficulties with math than with reading (Ayr, Yeates, & Enrile, 2005; Dennis & Barnes, 2002; Fletcher et al., 2005), but within reading, there is greater difficulty with reading comprehension than single word reading (Barnes, Dennis, & Hetherington, 2004; Barnes, Faulkner, & Dennis, 2001); within math, there is greater difficulty with computations and math applications than math fact retrieval (Dennis & Barnes, 2010; Raghubar et al., 2015). Written expression is difficult because of motor transcription demands, which in SBM are affected by the cerebellar impairment associated with the Chiari malformation (Fletcher, Ostermaier, Cirino, & Dennis, 2008), but may also be affected by difficulty in coordinating transcription skills with higher-level composition skills (Graham & Harris, 2000). However, little is known about the specific predictors of *academic fluency,* the efficient completion of basic academic tasks in reading, writing, and math. Data are particularly sparse for neurodevelopmental disorders, including SBM, including how it relates to the much wider literature on academic skills in typical development.

Academic Fluency in Typical Development

Academic fluency is important as a marker of basic skill mastery. For example, even though word reading can be accurate in older children and adults with an early diagnosis of reading disability, reading fluency remains weak (Cirino, Israelian, Morris, & Morris, 2005; Cirino, et al., 2013). For math disability, fact fluency is a consistent hallmark (Jordan, Hanich, & Kaplan, 2003). But, academic fluency is understudied relative to untimed academic content skills. Reading literature emphasizes single-word reading or comprehension rather than reading fluency (i.e., Catts, Fey, Tomblin, & Zhang, 2002; Wise et al., 2008); writing literature highlights spelling or composition rather than writing fluency; and math computation and problem solving are more studied than math fact fluency (Branum-Martin, Fletcher, & Stuebing, 2013; Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012).

There is evidence though that fluency is not simply a marker of academic mastery, but that fluency outcomes are important in their own right because they share bidirectional relationships with their untimed academic content skill counterparts. For example, reading individual words is necessary to read and write text fluently (McGrew, LaForte, & Schrank, 2014), which in turn promotes reading comprehension, presumably because word-level fluency permits processing resources to be devoted to comprehension (Perfetti, 2007; Pinnell et al., 1995). For writing, transcription fluency predicts composition quality for similar reasons (Berninger & Rutberg, 1992; Swanson & Berninger, 1996). Higher math fluency frees cognitive resources for complex math computations and problem solving (Fuchs, Geary, Fuchs, Compton, & Hamlett, 2016; Geary, Saults, Liu, & Hoard, 2000), and math calculation accuracy in turn relates to math fluency (McGrew et al., 2014).

Neurocognitive domains also support academic fluency. Processing speed (which can be operationalized along a continuum from simple reaction time [RT] measures to complex generative or decision-making tasks) is an important determinant of all three forms of academic fluency (Camarata & Woodcock, 2006; DeBono et al., 2012; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). Behavioral inattention is also related to academic fluency outcomes (Fuchs et al., 2011; Graham, Fishman, Reid, & Hebert, 2016) presumably because careless mistakes, lack of engagement, and distractibility can all reduce efficiency on such timed tasks. Such *shared* neurocognitive deficits across academic outcomes are consistent with multiple deficit models of childhood disorders (McGrath et al., 2011; Pennington, 2006; Shanahan, Pennington, & Willcutt, 2008).

Academic fluency outcomes may also *differ* in the extent to which they are impacted by neurocognitive domains. For example, reading and writing fluency in particular rely on language skills such as phonological awareness, rapid automatized naming, and vocabulary (Floyd, McGrew, & Evans, 2008; Kim, 2015; Landerl & Wimmer, 2008; Tobia & Marzocchi, 2014; Wolf & Bowers, 1999), with vocabulary as an indicator of semantic knowledge needed to judge sentence veridicality or generate meaningful sentences (required for reading and writing fluency, respectively).

Some recent evidence though suggests that language may relate to all three fluency outcomes, and also that predictors are similar across timed and untimed academic outcomes (e.g., Child, Cirino, Fletcher, Willcutt, & Fuchs, 2018; Cirino, Child, & Macdonald, 2018). Motor function is related to both writing fluency and math fluency; in particular dominant hand dexterity (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994) for writing fluency (given that writing is a dominant hand activity), and bilateral dexterity for math, due to links between finger representations and finger counting (using both hands) and early math skills (Penner-Wilger et al., 2007; Wasner, Nuerk, Martignon, Roesch, & Moeller, 2016). Math fluency could also be influenced by nonverbal reasoning, given that it has been implicated in more general math studies (e.g., Fuchs et al., 2006).

However, only a few studies (e.g., Child et al., 2018; Cirino et al., 2018; Korpipaa et al., 2017) compare the relative contributions of these neurocognitive predictors, particularly across academic fluency outcomes, that is, whether they differentially predict reading *versus* writing *versus* math fluency. Given that academic fluency outcomes are correlated with one another (Manolitsis, Georgiou, & Tziraki, 2013; Nelson, Benner, Neill, & Stage, 2006), and the evidence reviewed above, there is potentially both overlap and separation in the extent to which neurocognitive predictors influence academic fluency. There is a particular lack of data regarding whether such predictors would be similar and/or different in neurodevelopmental populations, such as SBM.

Academic Fluency in Individuals with SBM

Few studies address academic fluency in SBM, but doing so is relevant because timing, motor movement, and attention orienting are core deficits in spina bifida (Dennis et al., 2006). For example, key structures impacted in SBM (cerebellum, corpus callosum, longitudinal white matter pathways) (Barkovich, 2005; Dennis et al., 2004; Hasan et al., 2008) involve timing; these may affect all academic fluency outcomes *via* slowed RT. But motor deficits in SBM may differentially impact outcomes; for example, poor dexterity should impact math and writing fluency more than reading fluency. Attention orienting is impacted in SBM, but few studies relate any kind of attention directly to academic fluency, even though rates of inattention are high in SBM and more common than hyperactivity (Burmeister et al., 2005; Wasserman, Stoner, Stern, & Holmbeck, 2016).

Since academic fluency is considered an associative rather than assembled skill (Dennis & Barnes, 2010), relative preservation might be expected. However, this is juxtaposed against the fact that some studies find that children and adults with spina bifida have difficulty with academic fluency relative to typically developing (TD) individuals. For example, the speed with which children with SBM and TD peers read individual words or retrieve math facts does not differ (Barnes et al., 2001; Raghubar et al., 2015). In contrast, children with SBM are slower on academic fluency tasks involving reading sentences or solving single-digit arithmetic problems within a set amount of time (Barnes et al., 2004, 2014; Raghubar et al., 2015). Given what is known about SBM, it is plausible that academic fluency may manifest differently relative to TD peers. If group moderates the way that neurocognitive predictors relate to academic fluency outcomes, this could have implications for how these skills might be scaffolded for children with SBM.

Development of Academic Fluency in TD and SBM Individuals

Research into the development of academic fluency from childhood into adulthood in TD individuals is weak beyond the knowledge that academic fluency tasks are strongly correlated in both children and adults (r range = 0.64 to 0.74; McGrew et al., 2014). Within SBM, a few longitudinal studies have evaluated academic content and academic fluency skills development (Barnes et al., 2014; Pike, Swank, Taylor, Landry, & Barnes, 2013), but these studies evaluated different predictor sets, and did not control for academic content knowledge. Cross-sectional studies of academic skills are more common, but include a relatively narrow age range in children (Ayr et al., 2005; Barnes et al., 2006; Fletcher et al., 2005); very few studies consider academic fluency skills in adults with SBM (Barnes et al., 2004; Dennis & Barnes, 2002). Given the interrelations of academic fluency and untimed achievement skills, and given that untimed academic content skill tends to increase more at earlier ages and then increase to a lesser degree at later ages (Martens, Hurks, Meijs, Wassenberg, & Jolles, 2011; McGrew et al., 2014), the gap between individuals with and without SBM may either diminish or diverge over time.

Finally, an important question to ask is whether general deficits in RT are associated with academic fluency deficits *across* reading, writing, and math across development. Processing speed tasks are often used in studies of academic skills (Shanahan et al., 2006); there is evidence that RT and processing speed measures are significantly correlated with one another, and that more complex measures show stronger relations with academic achievement (Buckhalt, 1991; Catts, Gillispie, Leonard, Kail, & Miller, 2002). A recent cross-sectional study of RT (Dennis et al., 2016) used a wide age range (ages 8 to 40) and found that, despite slowed RTs relative to TD controls, individuals with SBM exhibited similar (complex quadratic) relations between RT and age, showing rapid decreases through childhood/adolescence, with slower rises through adulthood. What has not been studied is how other neurocognitive domains predict academic fluency outcomes when RT for non-academic stimuli is included in the models.

Summary

Academic fluency is understudied in terms of its neurocognitive predictors, as well as developmentally. Even less is known about how differential these predictors are across academic fluency outcomes. SBM is a relevant neurodevelopmental population in which to examine these factors and compare to typically developing children, given its relatively well-defined neurobiological and neurocognitive phenotype that may differentially impact academic fluency. Therefore, the novelty of the present study is that it was designed to evaluate the neurocognitive predictors for each academic fluency outcome, and their relative prediction across/between academic fluency outcomes, while including age, and evaluating group (TD *vs.* SBM) effects. Findings may be a step toward helping to identify and support such skills where they are weak, which may be similar or different across groups.

Hypotheses

Based on the literature review above, we propose two *types* of aims and related hypotheses. The first aim is to predict each academic fluency outcome (reading, writing, math separately), with age, group, and neurocognitive correlates (addressed with univariate multiple regression analyses). The second is to evaluate if a core set of common predictors *differentially predict* reading versus writing versus math academic fluency (addressed with *multivariate* multiple regression analyses).

Univariate hypotheses

We expect that group, quadratic age, RT, inattention, and vocabulary, controlling for covariates including single word reading, will each be uniquely predictive of reading fluency.

For writing fluency, we expect a similar pattern, but include dexterity as an additional unique predictor. For math fluency, we expect that group, age, RT, inattention, dexterity, and nonverbal reasoning, controlling for covariates including calculation skill will each be uniquely predictive. For group, we expect that participants with SBM will underperform relative to controls, and for age, we expect an asymptotic relationship (rapidly increasing before more slowly plateauing). It is unclear how group might moderate (interact with) the neurocognitive predictors, or with age, beyond the expectation that dexterity may be more predictive for individuals with SBM relative to their typically developing peers. Differential prediction across group would support population-specific approaches to scaffolding weaknesses in academic fluency.

Multivariate hypotheses

We expect that the *set* of common predictors (all those above) will be collectively stronger for reading and writing fluency relative to math fluency, given that determinants of reading are more clearly defined than those of math. We expect several neurocognitive predictors (RT and inattention) to exert similar significant effects across academic fluency measures. However, we expect language skills to be more predictive of reading and writing fluency relative to math fluency, and nonverbal reasoning to be more predictive of math fluency relative to reading and writing fluency. We expect dexterity to be more predictive of writing and math fluency relative to reading fluency. Finally, we expect group effects (weaker performance in SBM) to be largest for math fluency relative to reading and writing fluency, given disproportionate math difficulties in SBM.

METHODS

Participants

The initial sample comprised 186 children and adults with SBM and shunted hydrocephalus, and 97 TD individuals, from Houston and Toronto area hospitals. Participants were recruited from the second phase of a National Institutes of Health (NIH) project (2005–2010) on the neurobiological outcomes of spina bifida who received the achievement fluency measures and the core set of predictor variables. Diagnosis was confirmed from medical records. Participants with SBM were oversampled as part of the design of the parent study, given variability in this population. Prior studies from this project have not focused on achievement fluency. Inclusion criteria for this particular study included confirmed handedness (three individuals excluded), and verbal or nonverbal scores of at least 70 on subtests of the Stanford-Binet Intelligence Scale: Fourth Edition (SB:FE; Thorndike, Hagen, & Sattler, 1986; five excluded). Fourteen additional TD individuals were excluded because they were older than the oldest participant with SBM (so that age was group matched appropriately). Table 1 provides demographic and achievement data for each group ($n = 180$ SBM; $n = 81$ TD).

Table 1. Demographic and achievement characteristics of participants by group

	SBM ($n = 180$)	TD ($n = 81$)
Demographic characteristics		
Age, mean *(SD)***	19.38 (9.35)	23.29 (10.63)
Range (min – max)	7.87 – 48.63	8.17 – 48.24
Skewness, kurtosis	1.28, 1.04	0.62, –0.48
Socioeconomic status, mean *(SD)**	35.38 (13.74)	39.88 (14.86)
Skewness, kurtosis	–0.05, –0.81	–0.39, –0.87
Sex [*N* (% female)]***	79 (43.89)	54 (66.67)
Handedness [*N* (% right)]***	132 (73.33)	75 (92.59)
Ethnicity [*N* (% non-Hispanic)]*	134 (74.44)	71 (87.65)
Site [*N* (% Houston)]***	96 (53.33)	22 (27.84)
Abbreviated SB:FE IQ, mean *(SD)* ***	86.75 (13.18)	108.48 (11.57)
Achievement characteristics (standard scores)		
Letter Word Identification, mean *(SD)****	102.66 (19.69)	117.20 (15.66)
Calculations, mean *(SD)****	82.43 (17.74)	107.24 (17.50)
Reading fluency, mean *(SD)****	84.67 (12.69)	110.81 (14.98)
Writing fluency, mean *(SD)****	87.99 (14.83)	111.11 (14.24)
Math fluency, mean *(SD)****	80.73 (17.33)	102.91 (12.86)

Note. SB:FE = Stanford-Binet: Fourth Edition (Thorndike et al., 1986); a composite of the Pattern Analysis and Vocabulary subtests were used to estimate IQ. Socioeconomic data (from Hollingshead, 1975) are missing for five SBM participants and one control. Handedness ascertained from Edinburgh Handedness Inventory (Oldfield, 1971). In the SBM group, there were 103 children, 40 adolescents, and 37 adults; in the TD group, there were 31 children, 23 adolescents, and 27 adults.
*$p < .05$.
**$p < .01$.
***$p < .001$.

Overall, our SBM sample had proportionately more boys than girls, which is inconsistent with larger scales studies with regard to sex, where spina bifida and neural tube defects generally affect girls slightly more than boys (Deak et al., 2008; Poletta et al., 2018). However, we also found a higher proportion of Hispanics in the SBM group relative to typicals, which *is* consistent with prior literature (Agopian et al., 2012; Boulet, Gambrell, Shin, Honein, & Mathews, 2009; Shin et al., 2010). Table 2 presents medical characteristics for SBM. This study was conducted in compliance with Ethics Boards and approved at both sites.

Measures

Academic fluency outcomes

The fluency measures of the Woodcock-Johnson III Tests of Achievement (WJ III; Woodcock, McGrew, & Mather, 2001) were used to assess fluency in reading, writing, and math. Reading fluency required participants to read sentences and determine their veracity within 3-min. The dependent measures are the raw total (correct minus incorrect responses) for univariate hypotheses, and standard scores for the

Table 2. Medical characteristics for participants with SBM (n = 180)

	Frequency
Number of shunt revisions	
None	30
Fewer than 5	112
5 or more	28
Missing	10
Lesion level	
Above lumbar-1 (upper lesion)	46
Below thoracic-12 (lower lesion)	133
Missing	1
Chiari malformation	
None	6
Type I	2
Type II	170
Missing	2
Corpus callosum	
Normal	9
Hypoplastic	76
Dysgenetic	47
Missing	48
Seizure disorder	
No	135
Past	17
Present	8
Missing	20
Ambulatory status	
Normal	4
Independent	32
W/support	63
Unable	70
Missing	11

multivariate analyses (see Data Analysis section below). Writing fluency is timed for 7 min, and required participants to write a sentence from a prompt consisting of pictures and/or words, with dependent measures again raw total (number of reasonable sentences) and the standard score. Math fluency required participants to perform single digit arithmetic (addition, subtraction, and multiplication) within 3 min; dependent measures were again the raw total (correct) and standard score. All have strong reliability (reading fluency: .95; writing fluency: .83; math fluency: .98; McGrew & Woodcock, 2001).

Untimed academic content skill covariates

WJ-III Letter Word Identification and Calculations subtests have median reliabilities of .94 and .86, respectively (McGrew & Woodcock, 2001). Letter Word Identification was a predictor for reading and writing fluency models, and Calculations for the math fluency model. Standard scores were used as predictors.

RT

Participants were administered a computerized RT task requiring a decision rule. This task was a predictor in all three fluency models, and was chosen because it was more complex than simple (presence) RT, but did not use academic content. Participants press a colored button associated with a centered stimulus (blue for an up arrow; red for down arrow) with either hand. Further details are in Dennis et al. (2016). RT for correct trials (in milliseconds) was recorded by the computer as the interval between stimulus onset and button press.

Inattention

For children and adolescents (and some adults), the parent rated Swanson Nolan Achenbach Pelham-IV (SNAP-IV; Swanson, Nolan, & Pelham, 1992) was used. The SNAP-IV has 18 items (9 each for inattention and hyperactivity-impulsivity), corresponding to behavioral diagnostic criteria for inattention-deficit hyperactivity disorder (ADHD; American Psychiatric Association, 2000); for this study, only the inattention scale was used, given higher prevalence of this type of ADHD in SBM, and stronger relations with achievement (Rabiner & Coie, 2000). The measure corresponds with structured interviews (Bussing et al., 2008). Within-sample reliability for the inattention scale was high (alpha = .93). For adults, the Conners Adult ADHD Rating Scales – Observer: Long Version (CAARS-O:L; Conners, Erhardt, & Sparrow, 1998) was used. The CAARS-O:L also includes nine items of inattention based on DSM-IV.

Given that the instruments measure the same construct with highly similar items, we used a single score to represent inattention. Seventy unique participants had only CAARS data, 133 had only SNAP data, and 35 had both (23 were missing). Raw score totals were used in analyses. To evaluate relations with achievement, we regressed achievement on age, the test from which scores were obtained, the scores themselves, and their interactions. In all three cases (reading, writing, and math fluency) the interaction was not significant. Also for individuals who received both measure, they correlated highly, $r = .75$.

Dexterity

The Purdue Pegboard (Tiffin, 1968) was administered. Participants place small cylindrical pegs into a column of holes with their dominant, then nondominant, and then both hands together. This measure shows test–retest reliability of .60 to .76 (Tiffin & Asher, 1948). The normed Z-score for the dominant hand was a predictor for the writing fluency model (given that the same hand is used to produce writing), and the Z-score for both hands together was used as a predictor for the math fluency model (since both hands are used for finger counting).

Vocabulary and nonverbal reasoning

Two subtests of the Stanford-Binet: Fourth Edition (Thorndike et al., 1986) were included for both screening and predictor purposes: Vocabulary and Pattern Analysis. Median reliabilities for these subtests are .87 and .92, respectively (Thorndike et al., 1986). As a screener, the scores were only used as IQ inclusion criteria. For Vocabulary, participants progress through identifying pictures to supplying word definitions; this was a predictor variable for reading and writing fluency outcomes. Pattern Analysis is a measure of nonverbal reasoning requiring the manipulation of blocks to match a two-dimensional picture; this was a predictor variable for math fluency outcomes.

Data Analysis

To address univariate hypotheses, univariate multiple regressions were used to examine unique effects of group (SBM, TD), age (including its quadratic term), and neurocognitive predictors for each academic fluency outcome. Two-way interactions of group with neurocognitive predictors and age determined whether group moderated the relations of these predictors with academic fluency. Raw scores were used for univariate multiple regressions (in part to demonstrate age relations, which would be reduced/eliminated if standard scores were used). We built our model hierarchically by including first group (step 1), then adding demographics (step 2), then adding neurocognitive variables (step 3), and finally interaction terms of group with neurocognitive predictor variables.

Multivariate multiple regression analysis was advantageous to examine our second type of hypotheses (that compared how the suite of predictors *differentially* impacts reading *vs.* writing *vs.* math fluency). *A-priori* tests of the coefficients across fluency outcomes determined whether neurocognitive predictors are similarly or differently related to the outcomes. Standard scores were used in these multivariate multiple regression analysis (to prevent obvious "fluency" dependent variable effects solely due to scale). Statistical analyses were computed with SAS 9.4 software (SAS, Inc., 2015). Regression diagnostics preceded primary statistical analyses to ensure that our data met analytic assumptions so that obtained results are not misleading. Socioeconomic status, sex, handedness, ethnicity, and untimed academic content skills (single word reading accuracy and calculations) were included as covariates in all univariate and multivariate models. Continuous terms were grand mean centered to provide a meaningful interpretation of parameter estimates in the context of interaction terms.

RESULTS

Table 3 presents descriptive statistics and correlations for neurocognitive predictors and outcome measures for SBM and TD groups.

Univariate Models: Individual Prediction of Reading, Writing, and Math Fluency

Tables 4, 5, and 6 include standardized regression coefficients and squared semipartial omega effect sizes. The reading fluency analyses (Table 4) showed that group effects were significant at all four model stages. The final model (model 4), including all covariates, linear and quadratic functions of age, group (and its interaction with age), RT, inattention, vocabulary, and interactions of group with neurocognitive predictors, was statistically significant, $F(16,216) = 54.68$, $p < .001$, adjusted $R^2 = .79$. As hypothesized, there was a statistically significant interaction of group with the quadratic function of age, $\beta = -0.16$, $t(216) = -2.24$, $p = .026$; stronger age effects were noted for younger relative to older individuals, although with a flatter overall curve in SBM relative to TD individuals. RT, $\beta = -0.21$, $t(216) = -5.44$, $p < .001$, and vocabulary, $\beta = 0.16$, $t(216) = 3.23$, $p = .002$, were also statistically significant predictors of reading fluency. Individuals with faster RTs and higher vocabulary knowledge performed better on the reading fluency subtest. Among covariates, females, $\beta = 0.10$, $t(216) = 3.17$, $p = .002$, and individuals with better decoding skills, $\beta = 0.29$, $t(216) = 6.83$, $p < .001$, had higher reading fluency.

The writing fluency analyses (Table 5) showed that group effects were significant when they were entered first (model 1), and when demographic variables were included (model 2), but became non-significant with the inclusion of neurocognitive predictors in model 3 (and model 4). The full model (model 4) including covariates, linear, and quadratic functions of age, group (and its interaction with age), RT, inattention, dominant hand dexterity, vocabulary, interactions of group with neurocognitive predictors, and covariates, was significant, $F(18,213) = 31.07$, $p < .001$, adjusted $R^2 = .70$. Group was not a significant unique predictor, $p = .744$, considering all other predictors. As expected, there was a quadratic effect of age, $\beta = -0.30$, $t(213) = -4.52$, $p < .001$, suggesting stronger age effects for younger than older individuals.

RT, $\beta = -0.19$, $t(231) = -4.04$, $p < .001$, and vocabulary, $\beta = 0.22$, $t(213) = 3.56$, $p < .001$, were also significant; individuals with faster RTs, and higher vocabulary knowledge, had a higher writing fluency score. The group by inattention interaction was statistically significant, $\beta = -0.18$, $t(213) = -3.10$, $p = .002$. Follow-up analysis indicated higher inattention was related to poorer writing fluency in both groups, although moreso for the TD group, $r(71) = -0.44$, $p < .001$, than the SBM group, $r(166) = -0.16$, $p = .034$. Females, $\beta = 0.14$, $t(213) = 3.55$, $p < .001$, and individuals with better decoding skills, $\beta = 0.30$, $t(213) = 5.86$, $p < .001$, had higher writing fluency scores.

The math fluency analyses (Table 6) showed that group effects were significant when they were entered first (model 1), and when demographic variables were included (model 2), but became non-significant with the inclusion of neurocognitive predictors in model 3 (and model 4). The full model (model 4) including covariates, linear and quadratic functions

Table 3. Descriptive statistics and correlations for neurocognitive predictors and outcome measures by group

	1	2	3	4	5	6	7	8	9	10	Mean	*SD*	Skew	Kurtosis
1. Age		<0.01	–0.14	0.07	0.04	0.32**	–0.29**	0.49***	0.40***	0.57***	23.29	10.63	0.62	–0.48
2. Reaction time	–0.06		0.18	–0.18	–0.24*	0.23*	–0.03	–0.31**	–0.27*	–0.37***	409.75	68.7	0.97	1.42
3. Attention	–0.20	0.10		–0.02	0.02	–0.08	–0.10	–0.34**	–0.44***	–0.38**	4.61	4.39	1.16	1.29
4. DH dexterity	–0.05	–0.11	–0.02		0.85***	0.01	0.04	0.22*	0.25*	0.31**	–0.51	1.03	0.21	1.43
5. BH dexterity	–0.03	–0.15*	–0.02	0.90***		0.07	0.04	0.16	0.20	0.21	–0.64	0.86	0.59	1.01
6. Vocabulary	0.38***	–0.11	0.01	0.09	0.17*		0.26	0.41***	0.39***	0.24*	110.52	15.11	–0.06	–0.27
7. NV reasoning	–0.05	–0.22**	–0.07	0.25***	0.27***	0.23**		0.09	0.13	0.07	108.91	10.26	–1.3	2.26
8. Reading fluency	0.51***	–0.37***	–0.13	0.09	0.10	0.54***	0.20**		0.85***	0.77***	77.88	20.74	–0.99	–0.05
9. Writing fluency	0.43***	–0.38***	–0.16*	0.13	0.14	0.51***	0.30***	0.87***		0.76***	27.15	7.33	–0.67	–0.68
10. Math fluency	0.48***	–0.39***	–0.14	0.08	0.11	0.45***	0.19**	0.84***	0.84***		113.58	34.76	–0.47	–0.79
Mean	19.38	487.83	11.96	–3.02	–3.03	91.99	91.30	44.45	17.23	69.76				
SD	9.35	93.37	6.59	1.36	1.29	18.19	14.77	19.52	7.24	34.81				
Skew	1.28	0.34	0.25	0.86	0.99	–0.06	0.09	0.26	–0.16	0.39				
Kurtosis	1.04	–0.36	–0.47	2.32	2.97	–0.35	–0.45	–0.09	–0.26	–0.58				

Note. Correlations for SBM appear below the diagonal (with distributional statistics on the bottom); correlations for TD appear above the diagonal (with distributional statistics to the right).
DH = dominant hand; BH = both hands; NV = nonverbal.

*$p < .05$.

**$p < .01$.

***$p < .001$.

Table 4. Standardized regression results for univariate reading fluency model

	Model 1		Model 2		Model 3		Model 4	
	β	ω^2	β	ω^2	β	ω^2	β	ω^2
Step 1: Group								
Group	.62***	.38	.50***	.13	.22***	.03	.28***	.02
Step 2: Demographics								
SES			.02	$<-.01$	$<.01$	$<-.01$	.02	$<-.01$
Sex			.10*	$<.01$	.10**	$<.01$	.10**	$<.01$
Handedness			−.05	$<.01$	−.06	$<.01$	−.05	$<.01$
Ethnicity			−.17***	.02	−.10**	$<.01$	−.05	$<.01$
Age			.34***	.10	.28***	.06	.40***	.09
Step 3: Covariates/neurocognitive								
LWID					.26***	.04	.29***	.04
Reaction time					−.29***	.06	−.21***	.01
Attention					−.07	$<.01$	−.04	$<.01$
Vocabulary					.13**	$<.01$	.16**	$<.01$
Step 4: Interactions								
Age*Age							−.19***	.03
Group*Age							.13*	$<.01$
Group*Age*Age							−.16***	$<.01$
Group*Reaction Time							.03	$<-.01$
Group*Attention							−.08	$<.01$
Group*Vocabulary							−.03	$<.01$
	Adj. R_1^2	.38	*Adj.* R_2^2	.57	*Adj.* R_3^2	.75	*Adj.* R_4^2	.79

Note. All values in table (standardized regressions, effect sizes, significance) represent unique effects of a given predictor, net of other effects, for the model being tested. Group effects remain significant in model 2, even when achievement covariate (LWID) and quadratic age term (Age*Age) are entered at Step 2. ω^2 = semipartial squared omega effect size; *Adj.* R_x^2 = adjusted R^2 for a given model; LWID = Letter Word Identification subtest; SES = socioeconomic status.
*$p < .05$.
**$p < .01$.
***$p < .001$.

of age, group (and its interaction with age), response speed, inattention, overall dexterity, nonverbal reasoning, and interactions of group with neurocognitive predictors, was statistically significant, $F(18,213) = 30.14$, $p < .001$, adjusted $R^2 = .69$. Considering other predictors, there was no significant effect of group, $p = .441$.

As expected, there was a quadratic effect of age, β = −0.19, $t(213)$ = −2.79, $p = .006$, suggesting stronger age effects for younger than older individuals. There was a statistically significant interaction of group with linear function of age, $\beta = 0.14$, $t(213)$ = 2.01, $p = .045$, although the interaction was small (it was not visually discernable) and the correlations in the two groups were similar (TD $r(80) = 0.57$, $p < .001$; SBM $r(180)$ = 0.48, $p < .001$). Individuals with faster RTs, β = −0.23, $t(213)$ = −4.65, $p < .001$, and with better calculations skills, $\beta = 0.43$, $t(213) = 8.77$, $p < .001$, had higher math fluency scores.

Multivariate Models: Differential Prediction Across Fluency Outcomes

The multivariate model included all three academic fluency outcomes, with covariates, linear and quadratic functions of age, group (and its interaction with age), RT, inattention, overall dexterity, vocabulary, nonverbal reasoning, and interactions of group with neurocognitive predictors. This analysis, unlike the univariate models, allows for direct statistical comparisons across outcomes. Predictors accounted for large and similar proportions of variance in reading, writing, and math fluency (R^2 = .75, .68, and 65, respectively); these values are close to those of the univariate analyses, but are more comparable to one another given that the predictor set was identical in the multivariate case.

The relation between the three fluency outcomes and group was significant, *Pillais' Trace* = 0.05, $F(3,204) = 3.88$, $p = .009$. RT was also significant, *Pillais' Trace* = 0.05, $F(3,204) = 3.34$, $p = .020$. There was a significant effect of vocabulary, *Pillais' Trace* = 0.14, $F(3,204) = 9.64$, $p < .001$, and the group by vocabulary interaction was also significant, *Pillais' Trace* = 0.04, $F(3,204) = 2.85$, $p = .039$. Significant covariates included sex, *Pillais' Trace* = 0.09, $F(3,204) = 6.44$, $p < .001$, calculations, *Pillais' Trace* = 0.25, $F(3,204) = 22.85$, $p < .001$, and decoding, *Pillais' Trace* = 0.17, $F(3,204) = 11.62$, $p < .001$. Multivariate tests indicated no statistically significant effects for age (expected because standard scores were used for outcomes in these analyses), inattention, dexterity, nonverbal reasoning, and the remaining group by neurocognitive interactions (all $p > .05$).

Follow-up tests indicated that for group, regression coefficients differed when comparing reading in relation to writing, *Pillais' Trace* = 0.03, $F(1,206) = 6.12$, $p = .014$; SBM

Table 5. Standardized regression results for univariate writing fluency model

	Model 1		Model 2		Model 3		Model 4	
	β	ω^2	β	ω^2	β	ω^2	β	ω^2
Step 1: Group								
Group	.54***	.28	.42***	.15	.05	< −.01	−.03	< −.01
Step 2: Demographics								
SES			.05	< .01	.04	< −.01	.07	< .01
Sex			.13**	.01	.13**	.01	.14***	.02
Handedness			−.07	< .01	−.06	< .01	−.04	< .01
Ethnicity			−.09	< .02	−.02	< −.01	.05	< .01
Age			.32***	.08	.24***	.04	.44***	.07
Step 3: Covariates/neurocognitive								
LWID					.26***	.03	.30***	.04
Reaction time					−.28***	.06	−.19***	< .01
Attention					−.12*	.01	−.06	.02
DH dexterity					.07	< .01	.06	.01
Vocabulary					.17**	.01	.22***	< .01
Step 4: Interactions								
Age*Age							−.30***	.04
Group*Age							.03	< −.01
Group*Age*Age							−.03	< −.01
Group*Reaction Time							.04	< −.01
Group*Attention							−.18**	.01
Group*DH Dexterity							.07	< .01
Group*Vocabulary							−.07	< .01
	Adj. R_1^2	.28	*Adj.* R_2^2	.43	*Adj.* R_3^2	.64	*Adj.* R_4^2	.70

Note. All values in table (standardized regressions, effect sizes, significance) represent unique effects of a given predictor, net of other effects, for the model being tested. Group effects remain significant in model 2, even when achievement covariate (LWID) and quadratic age term (Age*Age) are entered at Step 2. ω^2 = semipartial squared omega effect size; *Adj.* R_x^2 = adjusted R^2 for a given model; LWID = Letter Word Identification subtest; DH = dominant hand; SES = socioeconomic status.

*$p < .05$.

**$p < .01$.

***$p < .001$.

weaknesses relative to TD were wider for reading than writing. Regression coefficients comparing math and reading fluency outcomes, or comparing math and writing fluency outcomes, did not differ ($p = .115$ and $p = .521$, respectively). For RT, regression coefficients differed when comparing math and writing fluency outcomes, *Pillais' Trace* = 0.03, $F(1{,}206) = 6.04$, $p = .015$; RT was more strongly predictive of math than writing fluency. Regression coefficients comparing reading and math fluency outcomes, or comparing reading and writing fluency outcomes, did not differ ($p = .278$ and $p = .125$, respectively). For vocabulary, regression coefficients differed when comparing reading or writing in relation to math (*Pillais' Trace* = 0.11, $F(1{,}206) = 23.12$, $p < .001$; *Pillais' Trace* = 0.07, $F(1{,}206) = 14.70$, $p < .001$, respectively), with larger effects for reading and writing fluency outcomes, which did not differ, $p = .300$.

The group by vocabulary interaction was stronger for math relative to reading fluency outcomes, *Pillais' Trace* = 0.04, $F(1{,}206) = 8.57$, $p = .004$. Vocabulary was more strongly correlated with math fluency in SBM relative to the TD group. Regression coefficients comparing writing and reading fluency outcomes, or comparing writing and math fluency outcomes, did not differ ($p = .204$ and $p = .080$, respectively).

For both the univariate and multivariate analyses, results were highly similar when analyses were repeated with only the SBM group.

DISCUSSION

This study evaluated neurocognitive predictors of academic fluency for SBM and TD individuals, across development, both univariately (each outcome individually) and multivariately (across outcomes). Univariately, each academic fluency outcome was strongly predicted by its set of hypothesized predictors (adjusted $R^2 = .67$ to .79), but unique effects of group (considering all other predictors) were small and significant only for reading fluency. Group also did not moderate the effects of the neurocognitive domains on academic fluency except in one case (inattention for writing fluency). Multivariately, analyses showed that group, RT,

Table 6. Standardized regression results for univariate math fluency model

	Model 1		Model 2		Model 3		Model 4	
	β	ω^2	β	ω^2	β	ω^2	β	ω^2
Step 1: Group								
Group	.51***	.38	.42***	.15	.09	< .01	.08	< −.01
Step 2: Demographics								
SES			−.02	< −.01	< −.01	< −.01	.03	< −.01
Sex			< .01	< −.01	.01	< −.01	< .01	< −.01
Handedness			< −.01	< −.01	< .01	< −.01	.02	< −.01
Ethnicity			−.11*	< .01	−.12**	< .01	−.07	< .01
Age			.41***	.14	.38***	.11	.48***	.12
Step 3: Covariates/neurocognitive								
Calculations					.39***	.08	.44***	.08
Reaction Time					−.31***	.07	−.23***	.02
Attention					−.03	< −.01	< −.01	< .01
BH dexterity					−.04	< −.01	−.01	< −.01
Nonverbal reasoning					.02	< −.01	< −.01	< −.01
Step 4: Interactions								
Age*Age							−.19**	.03
Group*Age							.14*	< .01
Group*Age*Age							−.14	< .01
Group*Reaction Time							< −.01	< −.01
Group*Attention							−.07	< .01
Group*BH Dexterity							.01	< .01
Group*Nonverbal Reasoning							.02	< −.01
	Adj. R_1^2	.25	*Adj.* R_2^2	.45	*Adj.* R_3^2	.66	*Adj.* R_4^2	.79

Note. All values in table (standardized regressions, effect sizes, significance) represent unique effects of a given predictor, net of other effects, for the model being tested. Group effects remain significant in model 2, even when achievement covariate (Calculations) and quadratic age term (Age*Age) are entered at Step 2.

ω^2 = semipartial squared omega effect size; *Adj.* R_x^2 = adjusted R^2 for a given model; BH = both hands; SES = socioeconomic status.

*$p < .05$,

**$p < .01$,

***$p < .001$;

vocabulary, and the interaction of group with vocabulary were significant, and differentially predictive of fluency outcomes.

Univariate Prediction Hypotheses

Vocabulary and RT (and covariates of word reading and sex) were important for reading and writing fluency, which is consistent with results in TD samples (e.g., Child et al., 2018; Cirino et al., 2018; Landerl & Wimmer, 2008; Wolf & Bowers, 1999). The development of reading and writing fluency skills were asymptotic (with a decreasing rate of skill development past adolescence), as expected, although individuals with SBM exhibited a flatter overall curve relative to TD individuals with regard to reading. Behavioral inattention was not uniquely related to reading fluency, and was more strongly related to writing fluency in the TD group relative to SBM. Dominant hand dexterity, an established correlate of transcription speed (Berninger & Rutberg, 1992), was unexpectedly not uniquely predictive of writing fluency. RT and math calculations were predictive of math fluency, consistent with TD samples (Bugden, Price, McLean, & Ansari, 2012; Fuchs et al., 2006; Jordan et al., 2013). Math fluency also plateaued with development, although moreso for individuals with SBM, who showed a flatter developmental curve. Somewhat surprisingly, inattention, bilateral dexterity, and nonverbal reasoning were not unique predictors of math fluency.

Inattention was not strongly related to academic fluency outcomes with the exception of writing fluency. It is possible that the reduced complexity of academic fluency outcomes (coupled with their brief duration) relative to untimed achievement did not overly stress attentional limits. Also, it is likely relevant that the measure of inattention was behavioral rather than cognitive in nature. Behavioral inattention is a known correlate of academic skills in general (Cirino, Fletcher, Ewing-Cobbs, Barnes, & Fuchs, 2007; Gaub & Carson, 1997; Massetti et al., 2008; Rabiner & Coie, 2000), but there are fewer data regarding its relation specifically to academic fluency. In this regard, it is interesting that the zero-order correlations of inattention, at least in the TD group (see Table 3), are of a similar magnitude as the aforementioned studies in academic content skills.

Correlation coefficients were much smaller in SBM, which is somewhat inconsistent with increased inattention symptomatology and academic fluency weaknesses, in SBM (Barnes et al., 2004, 2014; Burmeister et al., 2005; Raghubar et al., 2015; Wasserman et al., 2016). These smaller correlations are likely not due to restriction of range, as SBM showed *more* variability in terms of inattention relative to the TD group. Even for TD individuals, while inattention was related to academic fluency, it was less consequential relative to more dominant predictors of age, response time, and vocabulary.

The present results raise questions about the extent to which inattention impacts academic fluency skills in the context of other related predictors, and also suggest the need to better understand how inattention impacts academic fluency specifically within SBM. At any rate, the results do suggest that inattention is not driving the significant relations of slower RT to academic fluency, further supporting the fact that timing is a critical issue for SBM (Dennis et al., 2006).

We suggest several possibilities for why dexterity did not impact math and writing fluency. First, with respect to math fluency, the current sample included participants age 8 through adulthood, whereas studies exploring relations of motor skills and math often include younger samples, including preschoolers (Barnes et al., 2011; Penner-Wilger et al., 2009). As children develop, however, they transition from counting on their fingers to automatically retrieving math fact solutions (Geary, 2006), with many third-graders having automatized math facts (Ashcraft & Christy, 1995), in turn lessening the need for finger counting.

With respect to writing fluency, the writing requirements are minimal. It is known that speed of alphabet transcription is highly predictive of both writing quantity and quality (Christensen, 2005; Graham, Berninger, Abbot, Abbot, & Whitaker, 1997). However, the few studies to consider basic fine motor skills and writing have inconclusive results (Abbott & Berninger, 1993; Berninger et al., 1994 *vs.* DeBono et al., 2012), which meant that prior work was less directly informative for the current study. Also, the writing fluency task may be less sensitive to transcription problems since the task combines writing *per se* with a compositional element (sentences in response to word prompts). Finally, and more generally, results indicate that the collection of predictors in the model matters, which is relevant given that few studies evaluate academic fluency across groups while also considering untimed academic content, as well as RT and other neurocognitive predictors.

A major contribution of the present study is that it extended knowledge of the predictors of academic fluency to participants with SBM. A key finding was that these effects were not moderated by group (with the above-noted exception of group for writing fluency). This, of course, should not be taken to mean that individuals in each group performed at the same level (they clearly did not; see Table 1), but rather, if a neurocognitive predictor was related (or not) to a given academic fluency outcome, that this was true for both SBM and TD groups. The TD group only significantly outperformed SBM (in the context of other predictors) on reading fluency, with a small effect size (other group effects, alone or as interactions, also had small effect sizes).

Group differences in academic fluency outcomes for SBM have previously been found (Barnes et al., 2014; Dennis & Barnes, 2002; Raghubar et al., 2015), although at different ages and with different sets of predictors. However, in many of these and related studies, where group is evaluated as a moderator of relations for academic outcomes, its effect is rarely significant (Ayr et al., 2005; Barnes et al., 2011).

For math fluency outcomes in particular, the lack of group differences in the context of added predictors is not particularly surprising. Although math is known to be a weakness in general for individuals with SBM (Ayr et al., 2005; Dennis & Barnes, 2002), math fact retrieval is one area of relative preservation within this domain (Dennis & Barnes, 2010; Raghubar et al., 2015). On the other hand, timing and processing speed are also areas of weakness within SBM (Dennis et al., 2016, 2006). Recent studies in children with SBM show mixed effects. For example, Raghubar et al. (2015) found that the direct effect of group on math fluency was mediated by dexterity and visual-spatial working memory. However, Barnes et al. (2014) found that the group difference for both math fluency and reading fluency remained, although each was diminished by mediation effects of phonological awareness. It is not surprising that different unique effects are observed across studies, as the univariate results revealed that the unique contributions (see effect sizes in Table 4) of the individual predictors were small in general, highlighting the large degree of shared variance among predictors and the need to consider them in the context of one another rather than in isolation.

Multivariate Prediction Hypotheses

We expected that a set of common predictors would more strongly predict reading and writing than math, given that the former (particularly reading) have a much more mature literature base. This hypothesis was based in literature suggesting that relative to reading, known predictors of math skills are both more broad, for example, predictors range from working memory (Barnes et al., 2014; Peng, Namkung, Barnes, & Sun, 2016; Willcutt et al., 2013) to numerosity (Chen & Li, 2014; Halberda, Mazzocco, & Feigenson, 2008), and also predict less overall variance in outcomes (Cirino, Morris, & Morris, 2002; Fuchs et al., 2011) relative to reading. The results did not confirm our hypothesis. The set of common predictors were quite robust in predicting all academic fluency outcomes (66% to 75% variance). A small set of predictors (untimed academic content skill, RT and vocabulary) was consistently predictive of all academic fluency outcomes.

The diminished effect of age in the multivariate analyses relative to univariate analyses is likely a function of the use of standard scores in the multivariate analyses to control for scaling, and raw scores for the univariate analyses. Removing age effects by using standard scores likely also contributed to the significant group effect seen in the multivariate analyses moreso than the univariate analyses. The *differential* effect of group (largest for reading) may reflect that the TD group performed better than expected on reading relative to math (both in terms of fluency and untimed content skill, see Table 1). It would be helpful to follow up these results in comparison to a TD sample whose performances were more firmly average than above average in terms of academic skill. The overall robust prediction of academic fluency outcomes is not surprising given prior literature and the univariate results; the fact that each are timed also likely promoted similarities among their predictors.

We made specific multivariate contrast hypotheses regarding differential neurocognitive prediction across academic fluency outcomes, but these were only partially supported. We expected vocabulary to be more related to reading and writing fluency relative to math fluency, which we found in the multivariate effect of vocabulary (although this was more pertinent for the SBM group in relation to math fluency relative to reading fluency). We expected dexterity and nonverbal reasoning to differentially predict fluency outcomes, but this was not the case; in the context of other predictors, these variables did not have unique predictive power. We did not hypothesize that RT or inattention would differentially predict the three fluency outcomes, and this was the case for inattention. However, multivariate contrasts suggested that RT was more relevant for math than for writing fluency. Results are novel in that no prior comparisons of this type could be found in the literature, although behavioral genetic studies have shown math fluency to be separable from both computations as well as reading fluency (e.g., Petrill et al., 2012).

Summary and Implications

The set of predictors accounted for a substantial amount of variance in each of the academic fluency outcomes, and only one of eleven univariate group by neurocognitive interactions were significant. The similar results across groups have important implications for intervention because it suggests that the strong and influential corpus of results from TD populations might also apply to SBM, and this may be an area for future research. While there are empirically supported interventions that address either reading fluency (Chard, Vaughn, & Tyler, 2002; Wolf & Katzir-Cohen, 2001) or math fact fluency (Codding, Burns, & Lukito, 2011; Fuchs et al., 2010) in TD individuals, there are as yet very few data on the implementation of these programs for individuals with neurodevelopmental disorders such as SBM. For example, we know of only one small case study where an intervention that is efficacious for addressing weak academic skills in TD individuals (math) was shown to also be beneficial in SBM (Coughlin & Montague, 2011), although Barquero, Sefcik, Cutting, and Rimrodt (2015) did implement a reading intervention for individuals with reading difficulty with and without neurofibromatosis.

We are unaware of specific empirically supported interventions for RT or processing speed *per se*, but even if such interventions were available, it would important to tie their efficacy directly to functional outcomes (such as academic fluency) within SBM. If interventions are found to work similarly in TD as well as SBM populations, this could portend their benefit in other neurodevelopmental populations as well, although such hypotheses would of course need to be tested directly in future research.

Results address the extent to which academic fluency outcomes are a function of *speed/efficiency* versus achievement *content*. On the one hand, academic fluency measures were strongly related to one another, moreso than their untimed academic content skill counterparts were related to one another, and more strongly even than math and reading fluency related to their respective untimed academic skills. Also, in the multivariate analyses, even though RT and vocabulary differentially predicted fluency outcomes, these variables (along with untimed academic skill) significantly predicted all three academic fluency domains.

Other variables (inattention, dexterity, nonverbal reasoning) were not differentially predictive (and only inattention impacted writing fluency, even at a univariate level). The fact that group, vocabulary, and RT did show differential prediction across academic fluency outcomes suggests that content does play some role; however, the preponderance of evidence suggests that speed/efficiency plays a larger role. Finding that RT is a stronger determinant of performance than content is in line with the fact that processing speed (a more generalized version of RT) has been implicated as a shared cognitive risk factor across a range of comorbidities (e.g., McGrath et al., 2011; Slot, van Viersen, de Bree, & Kroesbergen, 2016), and given that comorbidity of reading, writing, and math disability is common (Badian, 1999; Berninger et al., 1992; Landerl & Moll, 2010).

Limitations

Several limitations are noted. First, a more complete set of achievement-specific predictors (e.g., phonological awareness and rapid naming for reading; numerosity and working memory for math) would have helped us more thoroughly characterize cognitive skills that contribute to academic fluency. However, the available predictors did strongly relate to fluency outcomes. A second limitation is that multiple measures of both fluency (academic and in terms of processing speed) as well as content (e.g., other untimed reading, writing, and math measures) would have allowed for better delineation of these processes from one another. Finally, there were demographic differences between SBM and TD groups, and our hypotheses particularly regarding group differences could have been strengthened (despite the statistical controlling that we used) if our TD group was selected to be similar to our SBM group on these variables.

CONCLUSIONS

The present study extends prior literature by evaluating multiple predictors of academic fluency across academic content (i.e., reading, writing, math), developmentally and in SBM as well as TD samples. Given the weak group moderation effects, it could mean that evidence from the much broader TD literature might be used to guide expectations regarding prediction of academic fluency skills in SBM. Vocabulary and RT were most strongly related to reading fluency and math fluency, respectively, suggesting differences in predictive strength across academic outcomes, although in general the impacts of these cognitive skills across fluencies were similar. This study provides a model to test hypotheses of differential prediction by group within a given outcome, and for evaluating differential effects of predictors across multiple outcomes. The present results pertain to SBM and TD populations, but might be extended to additional neurodevelopmental populations in future studies.

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