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Research Article

Bilingualism and Processing Speed in Typically Developing Children and Children With Developmental Language Disorder

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Purpose: The aim of the current study was to investigate whether dual language experience modulates processing speed in typically developing (TD) children and in children with developmental language disorder (DLD). We also examined whether processing speed predicted vocabulary and sentence-level abilities in receptive and expressive modalities.
Method: We examined processing speed in monolingual and bilingual school-age children (ages 8–12 years) with and without DLD. TD children (35 monolinguals, 24 bilinguals) and children with DLD (17 monolinguals, 10 bilinguals) completed a visual choice reaction time task. The Clinical Evaluation of Language Fundamentals, the Peabody Picture Vocabulary Test, and the Expressive Vocabulary Test were used as language measures.
Results: The children with DLD exhibited slower response times relative to TD children. Response time was not modified by bilingual experience, neither in children with typical development nor children with DLD. Also, we found that faster processing speed was related to higher language abilities, but this relationship was not significant when socioeconomic status was controlled for. The magnitude of the association did not differ between the monolingual and bilingual groups across the language measures.
Conclusions: Slower processing speed is related to lower language abilities in children. Processing speed is minimally influenced by dual language experience, at least within this age range.
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The purpose of this study is to examine whether processing speed differs between typically developing (TD) children and children with developmental language disorder (DLD), and if so, whether the group difference is modulated by bilingual experience. Processing speed refers to the ability to efficiently perceive and act upon a given stimulus (Kail & Salthouse, 1994), and this elementary cognitive function is associated with the integrity of white matter tracts (Penke et al., 2010). Processing limitation approaches to DLD suggest that slow processing speed may contribute to poor language abilities in children with DLD (see Leonard, 2014). Processing speed may be modulated by bilingual experience, as bilingual children may depend more on processing speed for efficient communication in a dual language environment; however, bilingual influence on processing speed, particularly in children with DLD, is largely unknown. If processing speed predicts children's language abilities but is not affected by bilingual experience, then processing speed tasks are potential tools for assessing language disorders in linguistically diverse populations. Our objectives were addressed by comparing processing speed in four groups: TD monolingual children (MO-TD), TD bilingual children (BI-TD), monolingual children with DLD (MO-DLD), and bilingual children with DLD (BI-DLD).

DLD (or specific language impairment) is a neurodevelopmental disorder in which language abilities fall significantly below age expectations in the absence of any known causes such as hearing impairment, intellectual disability, frank neurological disorder, or emotional or social dysfunction (Bishop, 1997; Leonard, 2014). Although a

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cause is unknown, weaknesses in nonlinguistic cognitive mechanisms are hypothesized to explain language difficulties in DLD (see Leonard, 2014; Leonard et al., 2007, for a review). One of the candidate mechanisms is processing speed. Slow processing speed is thought to impair oral language learning, given that oral language is ephemeral. Thus, if information is not processed fast enough, it is prone to loss or to disruption by new incoming information. Slow processing speed may therefore result in limited language processing and learning (Leonard, 2014). This hypothesis is consistent with empirical studies reporting that children with DLD exhibit slow processing speed across different domains, including nonlinguistic tasks (e.g., Miller et al., 2001, 2006), and that processing speed is associated with children's language abilities (Leonard et al., 2007). Moreover, developmental studies also suggest a causal link between processing speed and language abilities—early processing speed predicts children's later language abilities including vocabulary (Fernald & Marchman, 2012; Marchman & Fernald, 2008; Rose, Feldman, & Jankowski, 2009) and receptive language abilities (Newbury et al., 2016).

Bilingual Influence on Processing Speed

The proposed link between processing speed and language abilities may be modulated by individual differences in language experience, such as growing up in a bilingual environment. This circumstance may require faster processing speed as bilinguals need to efficiently manage their two languages. This rationale is based on research hypothesizing that, relative to monolinguals, bilingual children may depend more on nonlinguistic cognitive processes in their everyday language use. A considerable number of studies have focused on examining whether the bilingual environment is cognitively more demanding and thus provides exercise for executive function (EF). EF refers to a set of higher order or supervisory cognitive processes that regulate goal-directed thought and behavior (Diamond, 2013; Miyake & Friedman, 2012) and is associated with frontal and parietal cortices (Collette et al., 2006). To manage two languages, it is thought that bilingual language processing places more demands on EF (Blumenfeld & Marian, 2009; Poarch & Van Hell, 2018). Consistent with this assumption, several empirical studies found that bilinguals outperform monolinguals on EF tasks (e.g., Carlson & Meltzoff, 2008; Poarch & Van Hell, 2012; but see Antón et al., 2014).

Along these lines of reasoning, it can be hypothesized that not only the supervisory control (i.e., EF) but also the efficient basic operation (i.e., processing speed) is modulated by bilingual experience for efficient communication. Indeed, meta-analyses support a global reaction time (RT) advantage on EF tasks in bilingual children (Hilchey et al., 2015) and adults (Hilchey & Klein, 2011; Hilchey et al., 2015). However, it is unclear to what extent the observed bilingual advantages in global RT on EF tasks reflect advantages in EF or processing speed. Thus, we set out to examine effects of bilingualism on processing speed in a task that does not pose heavy demands on EF.

This question has previously been examined by Bonifacci et al. (2011). They used a visual choice RT task to measure processing speed. The visual choice RT task is considered a reliable measure of processing speed with minimal involvement of EF since the task involves simple discrimination of features (e.g., color) and response selection (Woods et al., 2015). The task has been widely used to measure processing speed in monolingual speakers (e.g., Albinet et al., 2012; Ballesteros et al., 2013; Brown et al., 2012; Deary & Der, 2005; Deary et al., 2010, 2011; Feeney et al., 2013). Bonifacci et al. (2011) found that both younger (6–12 years old) and older (14–22 years old) bilinguals did not significantly differ in RT relative to monolingual control groups on the visual choice RT task measuring processing speed. Thus, it raised the possibility that processing speed is not influenced by bilingual experience. However, given the limited research on processing speed in bilingual and monolingual children and the fact that Bonifacci et al. (2011) reported a null effect, it is timely to revisit whether processing speed is modulated by language experience studying a new sample of bilingual and monolingual children.

Moreover, the extent to which bilingualism influences processing speed in individuals with DLD is largely unknown. Given that children with DLD have deficits in nonlinguistic processing speed (Miller et al., 2001, 2006), it is important to consider what happens when children with DLD grow up in a bilingual environment. If bilingual experience does not influence processing speed, it may be possible to use a processing speed measure to identify DLD in linguistically diverse settings. Conversely, if growing up with two languages engenders faster processing speed, this may have unique consequences for children with inherently slower processing speed. To examine this question, we ask whether bilingual influence on processing speed differs between children with typical development and children with DLD. Our rationale for this question comes from two prior studies. Sorge et al. (2017) found that bilingual experience benefited children with poorer attentional skills to a greater extent relative to children with better attentional skills on an EF type task. On the other hand, Mor et al. (2014) found a bilingual disadvantage in an atypical group: Bilingual children with attention-deficit/hyperactivity disorder had poorer performance than TD bilinguals on an EF type task, whereas the monolingual group (TD vs. attention-deficit/hyperactivity disorder) exhibited comparable performance. Both studies indicate that bilingual influence, whether positive or negative, can be more prominent in children with a developmental disorder. Hence, it is important to determine how bilingual experience relates to variations in processing speed between TD and DLD groups.

To the best of our knowledge, no studies have examined this research question with a full 2 × 2 design, including monolingual and bilingual children with and without DLD. Kohnert and Windsor (2004) examined three of the four groups in 8- to 13-year-old children: MO-TD, BI-TD, and MO-DLD. Using a visual choice RT task similar to the one used by Bonifacci et al. (2011), children were asked to press a red or blue button as quickly and accurately as possible, corresponding to either a red or blue circle that appeared sequentially, in a randomized order, on a computer screen. The monolingual DLD group exhibited slower processing speed relative to both TD monolinguals and bilinguals who exhibited comparable performance on the same task, suggesting that processing speed on the visual choice RT task is affected in children with DLD but is not modulated by bilingual experience in TD children. However, Kohnert and Windsor's study did not include bilingual children with DLD. Therefore, we do not know whether bilingual experience modulates processing speed in children with DLD. As bilingual influences on cognitive processes may be greater at low levels of performance (Mor et al., 2014; Sorge et al., 2017), we set out to examine how bilingual experience influences processing speed in four groups: MO-TD, BI-TD, MO-DLD, and BI-DLD.

Current Study

Because there is limited evidence pertaining to bilingual influence on processing speed, particularly in DLD, we aimed to further inform this issue by examining four participant groups on the visual choice RT task. This design allowed us to replicate and extend Kohnert and Windsor's (2004) results by including the same three groups on the same task as they had tested, while adding a group of bilingual children with DLD. More specifically, we investigated whether the relationship between processing speed and language abilities differs between monolingual and bilingual children with and without DLD. If bilingual experience requires a greater degree of processing speed to be employed, we expected that bilingual children have faster processing speed than monolingual children, and the association between processing speed and language abilities to be stronger in bilinguals relative to monolinguals.

Method

Participants

Children were recruited via flyers in community locations and invitation letters distributed via schools in the Toronto District School Board. Both children with typical development and DLD were recruited in Toronto, Ontario, Canada. Only children with typical development were recruited in the community around State College, Pennsylvania. The study was approved by the research ethics board at the University of Toronto and the institutional review board at the Pennsylvania State University. We obtained consent from all parents for their child's participation, as well as verbal assent from all children.

A total of eighty-six 8- to 12-year-old children participated: 35 MO-TD, 24 BI-TD, 17 MO-DLD, and 10 BI-DLD. The four groups (MO-TD, BI-TD, MO-DLD, and BI-DLD) did not differ in age, $F(3, 82) = 0.82$, $p = .487$. The same group of children also participated in a study examining procedural learning (Park et al., 2018). See Table 1 for children's demographic information and performance on standardized tests.

All children were required to have a nonverbal IQ above 75 as measured by the Wechsler Abbreviated Scale of Intelligence–Second Edition (Wechsler, 2011) and within normal hearing on a hearing screen presented at 1, 2, and 4 kHz at 20 dB HL in each ear (American Speech-Language-Hearing Association, 1997). All children were required to have none of the following conditions according to parent report: intellectual disability, emotional or behavioral disturbances including autism, frank signs of neurological disorder, or seizure disorders or use of medication to control seizures.

Determining Monolingual and Bilingual Status

Monolingual children (MO-TD and MO-DLD) were required to use English both at home and school. Their minimal use of other languages (less than 15% of time listening and speaking per day) was assured by parental report.

Based on the parental report, bilingual status in the children included in the BI-TD and BI-DLD groups was confirmed using the following criteria: (a) minimum of 3 years of English exposure[1]; (b) use of home language with at least one member of the household and attendance of school and community events in English[2]; and (c) use of home language at least 20% of the time at home, a criterion also used in previous studies (Hoff et al., 2012; Place & Hoff, 2011). Requirement (a) was implemented to ensure that the bilingual children had sufficient exposure to English to be assessed in the English language. Requirements (b) and (c) were implemented to ensure that children had continued exposure to two languages on a daily basis. To ensure that English language assessment was appropriate, English dominance was examined. The parental report indicated that, out of 24 in the BI-TD group, the majority of children were English dominant (21 English dominant, one home language dominant, and two balanced children). All bilingual children with DLD were English dominant based on parental report. The bilingual children (BI-TD and BI-DLD) in this study had various language backgrounds in addition to English. In the BI-TD group, 10 children spoke Korean, nine children spoke Chinese, two children spoke German, one child spoke Bengali, one child spoke French, and one child spoke Spanish. In the BI-DLD group, three children spoke Korean, one child spoke Albanian, two children spoke Bengali, one child spoke Chinese, one child spoke Farsi/Dari, one child spoke Ojibwe, and one child spoke Spanish. Given there were no standardized measures for the bilingual children's various home language backgrounds, only English language measures were used in this study.

Determining TD and DLD Status

All children completed a battery of standardized English language tests: the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4; Semel et al.,

[1]One participant with DLD had 2.5 years of English exposure.
[2]One TD participant had English as home language and French as school language. One DLD participant had English as home language and Ojibwe as school language.

Table 1. Children's demographic information and performance on the standardized tests.

	MO-TD						BI-TD						MO-DLD		BI-DLD		
	Total		Pennsylvania		Ontario		Total		Pennsylvania		Ontario		Ontario		Ontario		
	(35)		(15)		(20)		(24)		(7)		(17)		(17)		(10)		
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	Group difference
Age	10.45	1.43	10.32	1.63	10.55	1.29	10.00	1.48	10.40	1.50	9.83	1.49	10.19	1.18	9.85	1.76	NO
SES[a]	16.71	2.37	17.47	2.20	16.15	2.39	17.00	3.01	19.14	2.73	16.12	2.71	14.88	1.90	12.80	1.93	BI-TD > BI-DLD
IQ[b]	110.94	13.96	115.73	13.55	107.35	13.48	115.38	13.81	114.57	13.07	115.71	14.47	89.76	11.94	98.10	12.96	TD > DLD
CLS[c]	111.43	12.82	116.33	10.57	107.75	13.35	110.75	12.20	111.86	10.11	110.29	13.23	72.71	15.58	74.90	7.65	TD > DLD
RLI[d]	111.89	13.67	117.27	10.51	107.85	14.59	113.92	12.18	113.57	12.58	114.06	12.40	76.82	10.16	83.30	8.41	TD > DLD
ELI[e]	112.97	14.44	118.67	13.40	108.70	14.00	111.12	13.21	111.29	7.93	111.06	15.07	76.88	15.39	70.60	5.56	TD > DLD
PPVT[f]	113.66	14.31	122.00	11.86	107.40	12.90	111.67	13.75	115.86	10.25	109.94	14.88	89.88	7.43	91.00	10.17	TD > DLD
EVT[g]	114.54	12.85	120.00	12.67	110.45	11.50	109.42	13.01	113.86	10.27	107.59	13.83	88.94	10.66	86.57	4.32	TD > DLD
Age of acquisition (English)[h]							3.33	2.35	5.00	1.73	2.65	2.26			2.70	2.60	NO
Daily exposure (hearing the other language)[i]							64.88	20.71	62.86	17.99	65.71	22.20			43.33	21.79	TD > DLD
Daily exposure (speaking the other language)[i]							51.88	29.07	51.43	25.45	52.06	31.18			29.00	23.31	TD > DLD

Note. MO-TD = typically developing monolingual children; BI-TD = typically developing bilingual children; MO-DLD = monolingual children with developmental language disorder; BI-DLD = bilingual children with developmental language disorder; NO = no differences.

[a]Socioeconomic status: quantified as maternal years of education. [b]Nonverbal Intelligence Quotient: The Perceptual Reasoning Index of the Wechsler Abbreviated Scale of Intelligence–Second Edition (Wechsler, 2011). [c]Core Language Score on English Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4; Semel et al., 2003). [d]Receptive Language Index on English CELF-4. [e]Expressive Language Index on English CELF-4. [f]Peabody Picture Vocabulary Test–Fourth Edition (Dunn & Dunn, 2007) [g]Expressive Vocabulary Test, Second Edition (Williams, 2007) [h]Age of Acquisition: Parental report of when child began hearing English. [i]Daily Exposure: Parental estimate of percentage of time the child is exposed to other language than English during typical weekdays.

2003), the Peabody Picture Vocabulary Test–Fourth Edition (Dunn & Dunn, 2007), and the Expressive Vocabulary Test, Second Edition (Williams, 2007). The children's language background and history were also obtained via parental report.

In the MO-TD group, children were required to attain standard scores at or above 82 (1.25 *SD*s below the mean) on the Receptive Language Index, Expressive Language Index, and Core Language Score on the CELF-4. In the BI-TD group, parental report was used to ensure children's typical development. Given that CELF-4 norms depend on a monolingual sample and therefore may not provide an appropriate reference point for bilingual children (Bedore & Peña, 2008; Kohnert, 2010), the same cutoff score (at or above 82) on CELF-4 was not used to indicate typical development in bilingual children. However, all children in the BI-TD group had language scores above 82 on the Receptive Language Index, Expressive Language Index, and Core Language Score on the CELF-4.

In the two DLD groups (MO-DLD and BI-DLD), children were required to be identified as having language learning difficulties by the Toronto District School Board or were advised to receive (or were already receiving) language services at their school. In addition, the parents were required to indicate concerns regarding their child's language development in any of the following four areas: comprehending, speaking, reading, or writing. All children with DLD obtained standard scores at or below 81 (1.25s *SD* below the mean) on one or more of the following on the CELF-4: the Receptive Language Index, Expressive Language Index, and Core Language Score.

With regard to overall language scores, socioeconomic status (SES), and IQ, the monolingual and bilingual groups within each language status group (TD vs. DLD) did not significantly differ. However, the TD and DLD groups within each bilingual status group (MO vs. BI) differed on those variables (see Table 1 for summary). Specifically, Sidak-corrected post hoc analyses revealed that there were significant differences in overall language abilities among the four groups, $F(3, 82) = 54.81$, $p < .001$. The DLD groups attained a significantly lower CELF-4 Core Language Score compared to the TD groups in both the monolingual (MO-TD vs. MO-DLD, $p < .001$) and bilingual (BI-TD vs. BI-DLD, $p < .001$) groups. However, CELF-4 Core Language scores differed in neither the TD (MO-TD vs. BI-TD, $p = 1.000$) nor the DLD (MO-DLD vs. BI-DLD, $p = .999$) groups. A main effect of SES, as estimated by maternal education in years, was significant, $F(3, 82) = 9.22$, $p < .001$, and was driven by significantly lower SES in the BI-DLD. Sidak-corrected post hoc analyses revealed that the BI-DLD group had lower SES relative to the BI-TD group ($p < .001$), but the MO-DLD group did not differ from the MO-TD group ($p = .061$). Also, SES did not differ by bilingual status in both the TD (BI-TD vs. MO-TD, $p = 1.000$) and the DLD (BI-DLD vs. MO-DLD, $p = .342$) groups. The children in the MO-DLD group did not differ from children in the MO-TD group ($p = .061$). Also, group differences were observed in IQ, $F(3, 82) = 14.86$, $p < .001$. Sidak-corrected post hoc analyses revealed that the DLD groups had lower IQ scores than the TD groups in both the monolingual (MO-DLD vs. MO-TD, $p < .001$) and the bilingual (BI-DLD vs. BI-TD, $p = .006$) groups. However, IQ differed in neither the TD (MO-TD vs. BI-TD, $p = .769$) nor the DLD (MO-DLD vs. BI-DLD, $p = .546$) groups.

Visual Choice RT task

Stimuli

Subjects were presented with a visual choice RT task modeled on the one used by Kohnert and Windsor (2004). Children were asked to look at a randomized presentation of a red or blue circle at the center of the computer screen and press corresponding buttons on an E-Prime response box as quickly and accurately as possible. Each visual stimulus remained on the screen until the child pressed a button. Prior to the start of the task, children were instructed to place their index and middle fingers on the two buttons, marked with blue and red stickers, and to press one of the buttons. To prevent the child from looking down at the buttons and to alleviate the memory demands associated with the location of the buttons, blue and red circle stickers were also attached to the top of the computer screen indicating the corresponding button locations. Button locations were counterbalanced across subjects to avoid any particular association between the colors and button presses. The visual choice RT included two conditions: preferred hand and nonpreferred hand conditions. On the preferred hand condition, the children were asked to press a button with their preferred hand, and on the nonpreferred hand condition, the children completed the task with their nonpreferred hand. Each condition consisted of six practice trials and 25 test trials.

Procedure

All instructions were given in English. Before test trials in each condition, practice trials with feedback were provided to ensure that all children understood the instructions and learned the association between the colors and buttons as well as how to perform the task. Each child was asked to complete the first block with the preferred hand (the preferred hand condition) and the second block with the nonpreferred hand (the nonpreferred hand condition). E-Prime software 2.0 (Schneider et al., 2012) was used to present the stimuli and record RT and accuracy.

Statistical Analyses

The children's RT performance for correct responses was our main variable of interest. We analyzed the data in R, Version 3.4.1 (R Core Team, 2017) using the lme4 package (Bates et al., 2015). Generalized linear mixed models (GLMMs) were used to examine whether processing speed differed between TD children and children with DLD, and if so, whether the group difference was modulated by bilingual experience. Generalized linear models (GLMs) were used to examine the relationship between processing speed and language abilities in monolingual and bilingual children.

Both models do not require a normal distribution or homoscedasticity of residuals (Lo & Andrews, 2015; Ng & Cribbie, 2017) and thus were able to analyze the nonnormally distributed raw data without data transformations. We obtained p values for both analyses using the lmerTest package (Kuznetsova et al., 2017).

To ensure that the groups did not differ in accuracy, a GLMM with a binomial distribution and a logit link function was conducted to fit binary responses (0 for an incorrect response, 1 for a correct response) on each trial. The results indicated no group differences in accuracy (see Supplemental Material S1). For both research questions, median RT with correct responses in each condition per child was used for statistical analysis. Given that median values are less affected by outliers, which may reflect random artifacts (Leys et al., 2013), we considered the median values to be more appropriate to measure processing speed. Since the median RT was used, we did not discard any data from the correct responses.

Our first objective aimed to examine whether processing speed differed by DLD status (TD vs. DLD) and/or by bilingual status (MO vs. BI) and whether these factors interacted. To address this objective, the median RTs for correct responses per child in each condition were modeled using a GLMM employing an inverse Gaussian distribution with an identity link to fit the positively skewed raw RT data (Lo & Andrews, 2015). A maximal random effects structure (Barr et al., 2013) was employed including the random intercepts for subjects as well as by-subjects random slopes for the effect of condition. In each model, condition (preferred vs. nonpreferred), DLD status (TD vs. DLD), bilingual status (monolinguals vs. bilinguals), the two-way interactions (Condition × DLD Status, Condition × Bilingual Status, DLD Status × Bilingual Status), and the three-way interaction (Condition × DLD Status × Bilingual Status) were entered as fixed effects.

Our second research question asked whether processing speed predicted sentence and lexical abilities in receptive and expressive modalities in monolinguals and bilinguals. Four different GLMs were run using English language measures: the Receptive Language Index and Expressive Language Index from the CELF-4, the Receptive Vocabulary scores from the Peabody Picture Vocabulary Test–Fourth Edition (Dunn & Dunn, 2007), and the Expressive Vocabulary scores from the Expressive Vocabulary Test, Second Edition (Williams, 2007) as dependent variables. In each model, processing speed (RT on the visual choice RT task), bilingual status (monolinguals vs. bilinguals), and the interaction between processing speed and bilingual status were entered as fixed effects. Maternal education (a proxy of SES) was entered as a control variable. The median RTs for each child across conditions were modeled using the GLM employing an inverse Gaussian distribution with an identity link to fit the positively skewed raw RT data (Lo & Andrews, 2015). Due to the restricted range of variability, the TD and DLD groups were combined to provide a more complete representation of variability in the language measures, which is suitable for linear analyses.

Note that matching or covarying IQ is undesirable for two reasons. First, processing speed was not correlated with IQ, both when SES was not controlled for, $r = -.18$, $p = .092$, and when SES was controlled for, $r = -.11$, $p = .321$. Second, as Dennis et al. (2009) suggest, either matching or covarying IQ in populations with developmental disorders is inappropriate given that this analysis often results in “overcorrected, anomalous, and counterintuitive” findings (p. 331). For these reasons, we think we should not adjust the (diagnosed) DLD and TD groups to match them on IQ, nor that IQ should be included as a covariate. Given that a small negative correlation, $r = -.22$ ($p = .043$), indicated that lower SES was associated with longer RT in the current study and is also found to be linked with language abilities (see Fernald et al., 2012, for a review), the results are presented with and without maternal education (a proxy of SES) as a control variable.

Given that the BI-TD and BI-DLD groups differed by the percentages of hearing and speaking the other language, $t(32) = 2.63$, $p = .013$ and $t(32) = 2.20$, $p = .035$, respectively, we further examined whether our findings were influenced by the variability of the children’s bilingual experience. Correlational analyses were conducted to examine whether either the percentages or the onset of the bilingual exposure were correlated with the child’s performance on the processing speed task. The results showed no significant correlations between processing speed and the percentages of bilingual exposure, that is, the percentage of hearing the other language (BI-TD: $r = -.16$, $p = .459$; BI-DLD: $r = .08$, $p = .824$) and the percentage of speaking the other language (BI-TD: $r = -.23$, $p = .271$; BI-DLD: $r = -.05$, $p = .883$). Furthermore, no significant correlations between processing speed and onset of second language exposure (BI-TD: $r = -.25$, $p = .235$; BI-DLD: $r = -.15$, $p = .670$) were found. Given that processing speed was not associated with the onset and the percentages of the second language exposures, we did not use these variables in the analyses.

Reliability of the processing speed task performance was checked by split-half reliability, adjusted using the Spearman–Brown prophecy formula to estimate internal consistency—the consistency of the children’s responses across the trials—in each condition. The trials were divided into even- and odd-numbered trials. The correlations between the even- and odd-numbered trials were $r = .90$ for the preferred hand condition and $r = .89$ for the nonpreferred hand condition, which yielded an internal consistency estimate of .95 and .94, respectively. These results demonstrate that the task was highly reliable (Webb et al., 2006).

Results

Our main objective was to determine whether processing speed differed by DLD status (TD vs. DLD) and whether processing speed was modulated by bilingual status (monolingual vs. bilingual). Thus, the effects of interest were main effects of DLD status and bilingual status as well as the two-way interaction between bilingual status and DLD status. See Table 2 for children’s accuracy and

Table 2. Children's performance on processing speed measured by the visual choice reaction time task.

		All		TD		MO-TD		BI-TD		DLD		MO-DLD		BI-DLD	
Performance	**Conditions**	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Accuracy (percent correct)	Preferred	88	32	90	30	88	32	92	27	85	35	86	35	85	36
	Nonpreferred	89	31	90	29	89	31	93	26	87	34	86	35	87	34
Reaction time (ms)	Preferred	485	128	463	99	453	92	477	109	534	166	539	133	524	220
	Nonpreferred	533	129	508	112	492	97	531	129	588	149	610	141	550	161
Accuracy (percent correct)	All	89	32	90	30	0.89	32	92	27	86	35	86	35	86	35
Reaction time (ms)	All	509	130	485	108	473	96	504	121	561	159	575	139	537	188

Note. TD = typically developing children; MO-TD = typically developing monolingual children; BI-TD = typically developing bilingual children; DLD = children with developmental language disorder; MO-DLD = monolingual children with developmental language disorder; BI-DLD = bilingual children with developmental language disorder.

RTs on the processing speed task. The results of GLMM analyses are presented in Table 3.

The GLMM analysis yielded a significant main effect of DLD status (TD vs. DLD), $t = 2.23$, $p = .026$, indicating that the TD groups were significantly faster at pressing the corresponding buttons than the DLD groups in both conditions. A significant main effect of condition was also found, $t = 6.71$, $p < .001$, indicating that children performed faster in the preferred hand condition than in the nonpreferred hand condition. No other predictors in the model were significant, including the main effect of bilingual status and the Bilingual Status × DLD Status interaction (see Figure 1).

Given that there was a group difference in SES, driven primarily by lower SES in the BI-DLD group relative to the BI-TD group, SES was included as a fixed effect in the model. The SES-related interaction terms (SES × DLD Status, SES × Bilingual Status, SES × DLD Status × Bilingual Status) were initially included but later removed from the models because they were nonsignificant (*p*s > .05). When SES was entered in the model alone, it was not a significant predictor, $t = -0.85$, $p = .397$; however, the significant main effect of DLD status (TD vs. DLD) became nonsignificant, $t = 1.51$, $p = .130$. The remaining results were unaffected when SES was entered in the model.

Table 3. Generalized linear mixed-effects models for processing speed.

Independent variable	Estimate	*SE*	*T*
Intercept	522.99	17.56	31.50*
Condition (preferred vs. nonpreferred)	51.60	7.69	6.71*
Bilingual status (MO vs. BI)	10.63	34.02	0.31
DLD Status (TD vs. DLD)	76.33	34.31	2.23*
Condition × Bilingual Status	–2.30	15.33	–0.15
Condition × DLD Status	27.52	15.33	1.80
Bilingual Status × DLD Status	–43.61	68.95	–0.63
Condition × Bilingual Status × DLD Status	–10.83	30.34	–0.36

Note. MO = monolingual; BI = bilingual; DLD = developmental language disorder; TD = typically developing.

*$p < .05$.

Our second question asked whether processing speed predicted language abilities in monolinguals and bilinguals and whether this association was stronger in bilinguals than monolinguals. Therefore, the effects of interest were a main effect of processing speed and the interaction between processing speed and bilingual status (monolinguals vs. bilinguals). The results of the analyses are presented in Table 4. As mentioned in the Method section, SES was entered into the models to dissociate the impact of SES and processing speed on the children's language performance. The SES-related interaction terms (SES × Processing Speed, SES × Bilingual Status, SES × Processing Speed × Bilingual Status) were first entered but subsequently removed from the models because they were nonsignificant (*p*s > .05). The results indicate that processing speed predicted the children's language abilities across the receptive and expressive modalities even after SES was controlled for.

For the Receptive Language Index, the main effect of processing speed was significant, $t = -3.05$, $p = .003$, indicating that faster processing speed was associated with higher receptive language abilities. None of the other predictors of interest were significant, including the Bilingual Status × Processing Speed interaction indicating that faster processing speed was not more strongly associated with higher receptive abilities in bilinguals than monolinguals.

For the Expressive Language Index, the main effect of processing speed was significant, $t = -2.61$, $p = .011$, indicating that faster processing speed was associated with higher expressive language abilities. None of the other predictors were significant, including the Bilingual Status × Processing Speed interaction (see Figures 2 and 3).

For receptive vocabulary, the main effect of processing speed was significant, $t = -2.29$, $p = .024$, indicating that children's faster processing speed was associated with children's higher receptive vocabulary. None of the other predictors was significant, including the Processing Speed × Bilingual Status interaction. The significant negative relationship between processing speed and lexical abilities in the receptive modality did not differ between the monolingual and bilingual groups (see Figure 4).

For expressive vocabulary, the main effect of processing speed was significant, $t = -3.15$, $p = .002$, indicating

Figure 1. Reaction time (RT) performance on Processing Speed. More values indicate slower reaction time. Error bars represent ± 1 standard errors of the means. TD = typically developing; DLD = developmental language disorder; MO = monolingual; BI = bilingual.

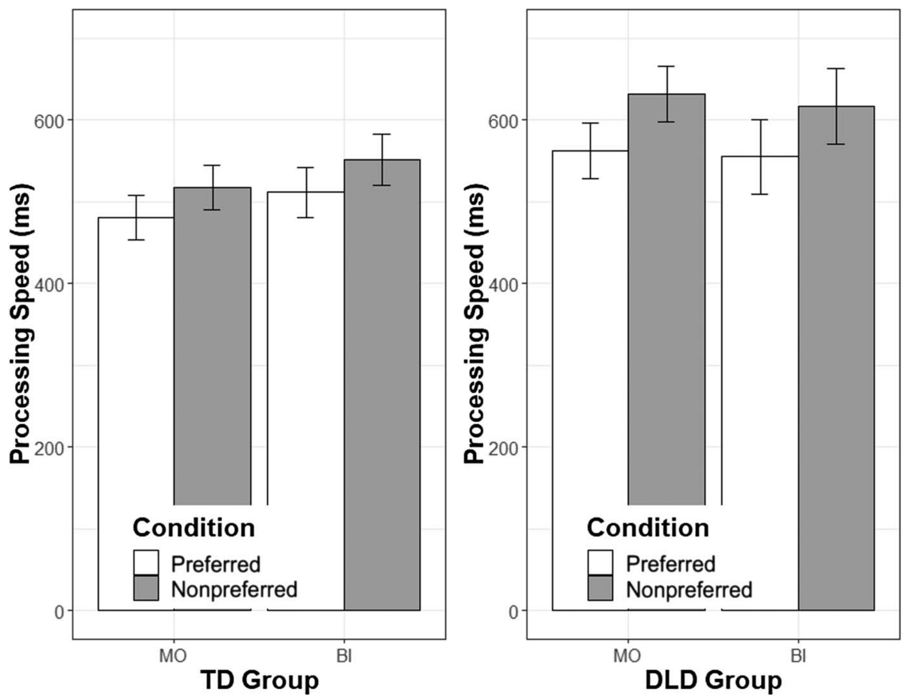


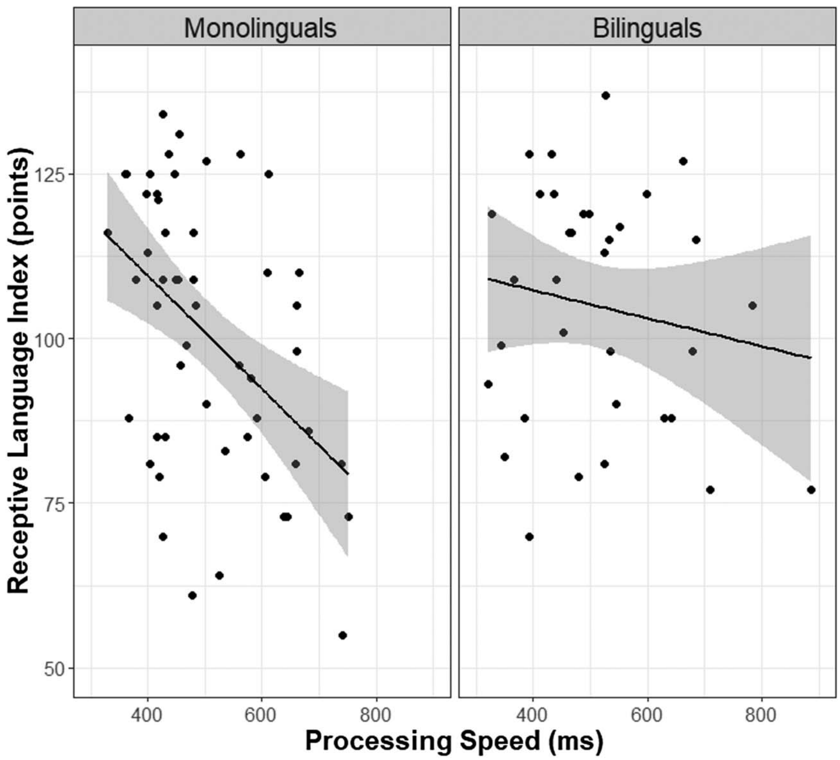
Table 4. Generalized linear model for the relationship between processing speed and lexical and sentence measures in receptive and expressive modalities.

Dependent variable	Independent variable	Estimate	*SE*	*T*
Receptive Language Index (CELF-4[a])	Intercept	76.39	17.96	4.25*
	SES[b]	3.33	0.74	4.48*
	Processing speed	−0.06	0.02	−3.05*
	Bilingual Status	−11.60	15.46	−0.75
	Processing Speed × Bilingual Status	0.04	0.03	1.28
Expressive Language Index (CELF-4[a])	Intercept	66.72	20.86	3.20*
	SES[b]	4.03	0.85	4.71*
	Processing speed	−0.06	0.02	−2.61*
	Bilingual status	−11.71	17.28	−0.68
	Processing Speed × Bilingual Status	0.02	0.03	0.76
Receptive Vocabulary (PPVT-4[c])	Intercept	83.89	15.51	5.41*
	SES[b]	2.63	0.63	4.19*
	Processing speed	−0.04	0.02	−2.29*
	Bilingual status	−13.00	13.36	−0.97
	Processing Speed × Bilingual Status	0.03	0.02	1.04
Expressive Vocabulary (EVT-2[d])	Intercept	88.41	15.09	5.86*
	SES[b]	2.82	0.60	4.67*
	Processing speed	−0.05	0.02	−3.15*
	Bilingual status	−27.20	12.90	−2.11*
	Processing Speed × Bilingual Status	0.05	0.02	1.95

[a]English Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel et al., 2003). [b]Socioeconomic status; quantified as maternal years of education. [c]Peabody Picture Vocabulary Test–Fourth Edition (Dunn & Dunn, 2007). [d]Expressive Vocabulary Test, Second Edition (Williams, 2007).

*$p < .05$.

Figure 2. The relationship between Processing Speed and Receptive Language Index on Clinical Evaluation of Language Fundamentals–Fourth Edition. More values indicate slower reaction time on *x*-axis and higher scores on *y*-axis. The shaded areas correspond to 1 standard error around the regression line.



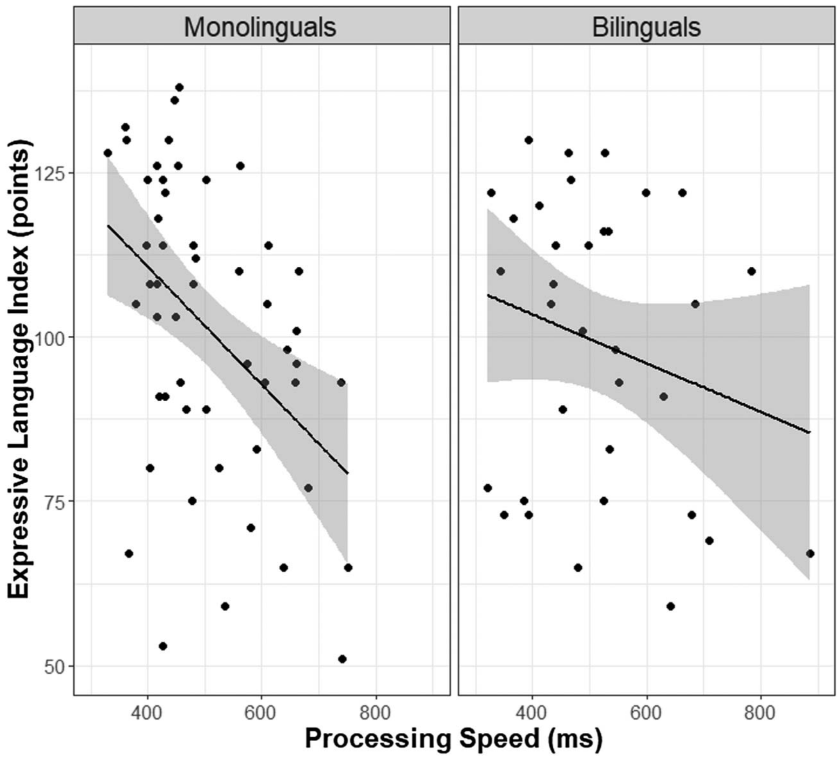
that children's faster processing speed was associated with higher expressive vocabulary scores. The main effect of bilingual status was also significant, $t = -2.11$, $p = .038$. The monolingual groups had higher expressive vocabulary scores than the bilingual groups. As can be seen in Figure 5, the association between processing speed and expressive vocabulary scores tended to be stronger in the monolingual group than the bilingual group, and the Group × Processing Speed interaction reached marginal significance, $t = 1.95$, $p = .054$. This marginally significant effect is opposite of our predictions that bilinguals would exhibit a stronger association between processing speed and language.

Discussion

In the current study, we examined whether children with DLD exhibit deficits in processing speed and whether processing speed can be modified by bilingual experience. Our study is the first to investigate bilingual influence on processing speed with four groups: MO-TD, BI-TD, MO-DLD, and BI-DLD. Consistent with prior findings (Kohnert & Windsor, 2004; Miller et al., 2001, 2006), we found that children with DLD showed slower processing speed than TD children. However, we found no evidence of group differences in processing speed between monolingual and bilingual children across the TD and DLD groups, at least not in this age range. When maternal education (SES) was controlled for, SES was a nonsignificant predictor, but the TD–DLD difference was no longer significant. Likewise, we found that faster processing speed was related to higher language abilities, and the magnitude of the association between processing speed and language abilities did not differ between the monolingual and bilingual groups across the language measures in both receptive and expressive modalities even after SES was controlled for.

Although children with DLD exhibited slower processing speed relative to the TD group, SES was to some extent confounded with DLD status and correlated with RT. When maternal education (a proxy of SES) was entered in the model, the group difference between the TD and DLD groups disappeared, presumably because SES accounted for some of the between-groups variance. It is largely unknown whether SES influences processing speed. Several studies suggest that there is an influence of SES on EF (e.g., Lawson et al., 2018; Noble et al., 2007). Consistent with this research, the correlation results in the current study indicate that low SES also has a negative association with processing speed. In interpreting the SES relationship with processing speed, and the absence of a processing speed difference between the TD and DLD groups after SES was controlled for, two factors should be considered. One is that SES is a

Figure 3. The relationship between Processing Speed and Expressive Language Index on Clinical Evaluation of Language Fundamentals–Fourth Edition. More values indicate slower reaction time on *x*-axis and higher scores on *y*-axis. The shaded areas correspond to 1 standard error around the regression line.



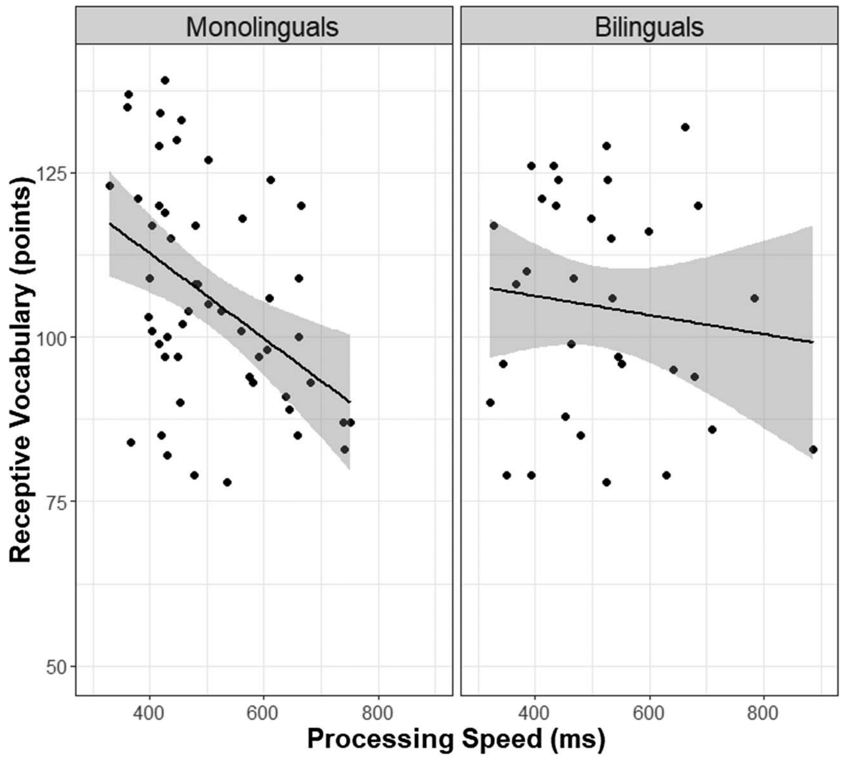
significant risk factor for DLD (Conti-Ramsden & Durkin, 2016; Tomblin et al., 1997; see Rudolph, 2017, for a review) and children with DLD tend to come from lower SES backgrounds (Conti-Ramsden & Durkin, 2016; Roy & Chiat, 2013; Toppelberg & Shapiro, 2000). The second is that, although SES was not a significant predictor of language abilities, processing speed remained a significant predictor of language abilities after SES was controlled for. Given this complex relationship, further research is needed to dissociate the influence of SES from DLD status on processing speed.

Nonetheless, our finding that the DLD group showed slower processing speed relative to the TD group is consistent with prior findings (Kohnert & Windsor, 2004; Miller et al., 2001, 2006). It is possible, since children with DLD are known to have problems with motor performance (Sanjeevan et al., 2015) and the visual choice RT task requires motor execution, that the TD-DLD difference resulted from difficulties in motor execution rather than difficulties in internally processing information. Future studies should include both the visual simple RT and choice RT tasks to confirm that the group difference was driven by internal processing speed rather than motor execution. Our study further found that monolingual and bilingual children in the DLD group performed comparably on the processing speed task; there was no interaction between bilingual status and DLD status. In other words, the magnitude of the difference in processing speed between monolingual and bilingual children in the DLD group was not larger or smaller than that of the difference between the monolingual and bilingual children in the TD group. The results do not support the notion that bilingual experience may partially alleviate or exacerbate the effects of language impairment with faster or poorer processing speed relative to monolingual children with DLD.

Although there are results in the literature indicating a bilingual advantage in overall RT on higher order cognitive tasks (Hilchey & Klein, 2011; Hilchey et al., 2015), we found a lack of bilingual advantage on the visual choice RT task, consistent with prior findings in TD children on similar measures (Bonifacci et al., 2011; Kohnert & Windsor, 2004). Choice RT tasks may tap into simpler cognitive processes, while overall RT performance on higher order tasks may tap into more complex, executive processes (Cepeda et al., 2013). A possible interpretation of these results is that bilingual and monolingual children do not differ in how fast they can process simple information, consistent with the speculation that bilingualism is more likely to exert influence on cognitively demanding tasks rather than on simple processing speed tasks (Bonifacci et al., 2011).

The minimal impact of bilingual experience on processing speed was also buttressed by the finding that the association between processing speed and language ability was not

Figure 4. The relationship between Processing Speed and Receptive Vocabulary on Peabody Picture Vocabulary Test–Fourth Edition. More values indicate slower reaction time on *x*-axis and higher scores on *y*-axis. The shaded areas correspond to 1 standard error around the regression line.

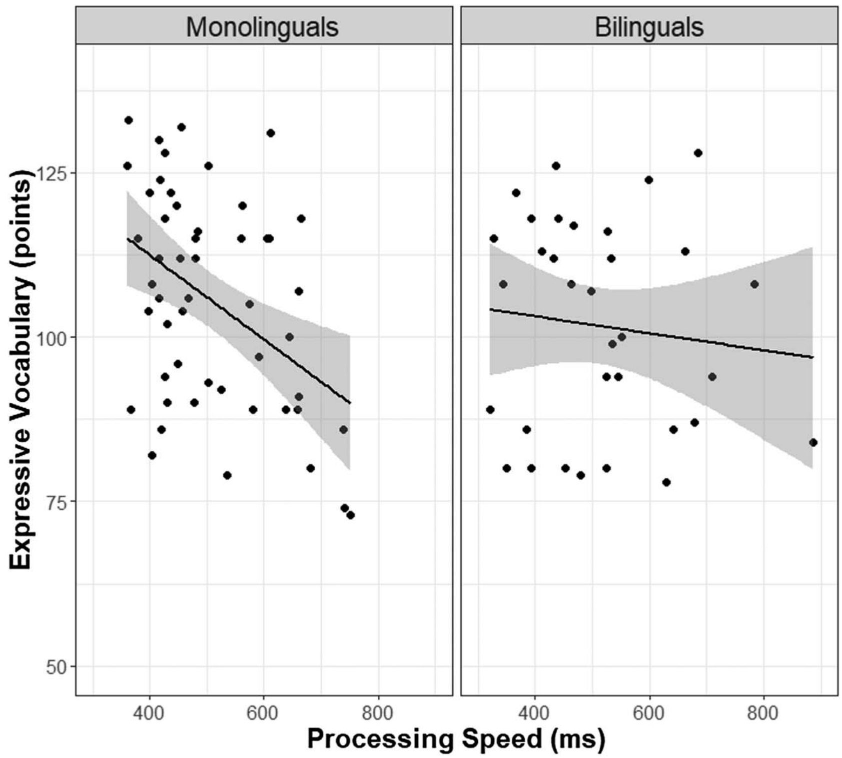


different between bilingual children and their monolingual peers. We found that, while associations between processing speed and language ability were present, consistent with Leonard et al. (2007), a stronger relationship was not observed between the two factors in the bilingual children relative to the monolingual children across different language measures in both receptive and expressive modalities. In addition to the lack of bilingual influence on processing speed at the group level, the results indicate bilingual influence on processing speed is not observed in the association between processing speed and language performance at an individual level. The reason that we found no bilingual advantage in processing speed may stem from the fact that most bilingual children in our study were English-dominant unbalanced bilinguals. Possibly, more balanced bilingual children would be more likely to exhibit processing speed differences, as some researchers have suggested is the case for EF (Yow & Li, 2015).

The lack of a bilingual advantage in processing speed could have also been a consequence of variability in the bilingual group, such as the children's different home language backgrounds. However, this seems unlikely given that bilingual advantages in cognitive functions have been reported in populations with various home language backgrounds (Bialystok, 1999; Bialystok et al., 2005; Bialystok & Martin, 2004; Poarch & Bialystok, 2015; Poarch & Van Hell, 2012, 2018; Scaltritti et al., 2015; Sorge et al., 2017). Second, given that bilingual effects may vary depending on to what extent dual language use is encouraged, future research should examine whether our results replicate in different bilingual environmental contexts (e.g., educational systems or communities). We also acknowledge that, since we only measured English language skills, we did not directly address the relationship between processing speed and bilingual children's home language skills. However, given that we found relationships of similar magnitude between monolingual language abilities and processing speed as well as bilingual second language abilities and processing speed, we argue that processing speed likely relates to language abilities similarly in different contexts of language learning. Finally, given the relatively small sample size of the bilingual groups (particularly, BI-DLD), the findings should be replicated with a larger sample size.

With regard to clinical implications, we propose that a nonlinguistic processing speed task would be a good candidate to identify risks of DLD in linguistically diverse settings, given that children with DLD exhibited slower processing speed compared to TD children and that processing speed was not modulated by bilingual influence. Future diagnostic accuracy studies should confirm whether a processing speed task would be a good clinical marker. Diagnostic accuracy studies will need to carefully consider

Figure 5. The relationship between Processing Speed and Expressive Vocabulary on Expressive Vocabulary Test, Second Edition. More values indicate slower reaction time on *x*-axis and higher scores on *y*-axis. The shaded areas correspond to one standard error around the regression line.



the shared and independent contributions of SES and processing speed in predicting risk of DLD, because the two were related to some extent in this study. In addition, given that children with DLD take longer than TD children to even process a simple visual task, we can infer how challenging a cascade of linguistic and nonlinguistic information would be. Consistent with this conjecture, presenting sentences at a slower rate seems to facilitate sentence comprehension of children with DLD (Montgomery, 2004). Our study poses a possible extension to this phenomenon by suggesting that children with DLD may have processing difficulties not only with linguistic information but also with nonlinguistic visual information. This raises an important consideration for clinicians and educators, as their interventions may become more effective if they present linguistic and nonlinguistic materials at a slower rate to children with DLD to provide sufficient time for encoding and processing.

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