Published in final edited form as:

J Commun Disord. 2015 ; 53: 57–69. doi:10.1016/j.jcomdis.2014.11.002.

Information processing speed as a predictor of IQ in children with and without specific language impairment in grades 3 and 8

Jisook Park¹, Elina Mainela-Arnold², and Carol A. Miller¹

¹The Pennsylvania State University, Communication Sciences and Disorders

²The University of Toronto, Speech-Language Pathology

Keywords

processing speed; IQ; specific language impairment

1. Introduction

Specific language impairment (SLI) is a developmental disorder in which children exhibit low language abilities in the absence of any known cause. By definition, this language disorder is not explained by any clear neurological, emotional, auditory, speech-motor, physical, sensory, or intellectual deficits (Leonard, 2014; Tomblin et al., 1996). To ensure that children with SLI do not have intellectual disabilities, intelligence tests have been widely used. Thus, the definition of SLI implicitly relies on the belief that linguistic and intellectual development are independent of one another and that this relationship remains static over time. However, this view may be incorrect in two ways. First, both language and intellectual abilities may be influenced by limitations in general cognitive mechanisms, such as processing speed. Children with SLI have been found to show weaknesses in processing speed (Leonard et al., 2007; Miller et al., 2001, 2006). Modern theories of intelligence have proposed that processing speed is a component of intelligence (see Deary et al., 2010; Hunt, 2011 for review). Second, since children with typical development and those with SLI may have different developmental trajectories of processing speed (Kail, 1994), there may be different relationships between processing speed and IQ scores in the two groups over time. To test these hypotheses, this study investigated 1) whether nonlinguistic processing speed predicts nonverbal intelligence test scores in children with typical development and those with SLI and 2) whether the relationship between processing speed and intelligence test scores differs in typically developing (TD) and SLI groups at different time points.

© 2014 Elsevier Inc. All rights reserved.

Contact information: Jisook Park, Department of Communication Sciences and Disorders, The Pennsylvania State University, 308 Ford Building, University Park, PA 16802, USA, Phone: 1-814-867-1503, Fax: 1-814-863-3759, jzp151@psu.edu.

A preliminary report of these data was presented at the Symposium on Research in Child Language Disorders, Madison, Wisconsin, in June 2011 and at the American Speech, Language and Hearing Association Conference in San Diego, California, in November, 2011.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1.1. Issues concerning intelligence testing in diagnosing SLI

Spearman (1904) proposed that human intelligence consists of two factors. The specific factor, *s*, refers to the idiosyncratic abilities employed for particular cognitive tests. These specific abilities explain variations in one's performance on different tests. In contrast, the general factor, *general intelligence* or *g*, constitutes a unitary construct, which explains one's consistent performance on intelligence tests overall and, therefore, accounts for the high correlations among different subtests (Hunt, 2011; Mackintosh, 2011; Sternberg & Kaufman, 2011). A factor analysis of the Wechsler Intelligence Scale for Children–III (WISC-III, 1991), the most widely used intelligence test and also used in the current study, assessed the *g*-factor loading of the subtests. Block Design, a subtest with score bonuses for faster responses which was used in the current study, had the strongest *g*-factor loading (.71) among nonverbal subtests of WISC-III. Picture Completion, a subtest without speed bonuses, also used in the current study, had a fair *g*-factor loading (.60; Roid et al. 1993).

Nonverbal IQ is one of the criteria considered when diagnosing children with SLI. For a child to be considered as having SLI, the child must exhibit a language test score of 1 to 1.5 standard deviations (SD) below normative expectations (Leonard, 2014). Many researchers also require children with SLI also to have an IQ score within normative expectations (what this might mean is discussed below). Thus, SLI criteria rely on an assumption that language development is separable from IQ. However, there is an increasing consensus that children with SLI exhibit nonlinguistic deficits as well as language disabilities (see Leonard, 2014 for a review), challenging the usefulness of IQ criteria and the assumption that language development is separable from general intellectual ability.

The practice of applying an IQ criterion in identifying SLI is problematic for several reasons. After decades of SLI research, there is no clear consensus on a cut-off score that should constitute a normal IQ. In her review of IQ criteria, Plante (1998) noted that Stark and Tallal (1981) in their seminal work suggested twofold IQ criteria: nonverbal IQ score at 85 or above together with 70 or above on the full-scale IQ score (i.e., the composite of verbal and nonverbal IQ). Numerous studies have since adopted the IQ criterion of 85 for nonverbal intelligence only—which is not in line with its intended use. Furthermore, researchers have by no means adhered to this criterion; in fact, they have used various other IQ criteria (reviewed in Plante, 1998). Consequently, the appropriate cut-offs for the IQ criterion are highly debated.

The use of 85 as a cut-off score, i.e., one standard deviation below the mean for a standardized score with a mean of 100, requires children with SLI to have *average-range* IQ. A number of studies have found that children with language impairment whose nonverbal IQ scores fall below 85 (sometimes referred to as nonspecific language impairment, or NLI) do not differ from children with SLI in their response to intervention (Cole, Coggins, & Vanderstoep, 1999; Fey, Long, & Cleave, 1994) or in their language and cognitive profiles (Leonard, 2007; Tomblin & Zhang, 1999). In response to such evidence, a number of researchers use a lower cut-off score, seeking only to rule out intellectual disability (conventionally indicated by an IQ score below 70), and thus requiring *normal-range* IQ (see Gallinat & Spaulding, 2014 and Leonard, 2014 for reviews and discussion).

Whether a criterion of normal or average range IQ is applied to identify children with SLI, these children tend to exhibit significantly lower IQs than their TD peers. A recent meta-analysis by Gallinat and Spaulding (2014) found that, after accounting for variability within and across IQ tests, and differences in cut-off scores, participants' ages, and SES, children with SLI scored 0.69 standard deviation units lower than their TD peers. This suggests that the common research practice of matching SLI and control groups by IQ is likely to hamper our efforts to fully understand SLI, because it may result in a non-representative sample of children with SLI (Dennis et al., 2009).

Although children with SLI, on average, tend to have lower nonverbal IQ scores than TD peers, there is considerable individual variation, such that some children with SLI score above average. Partly for this reason, the current study used linear mixed model analyses to examine relationships between IQ and processing speed measures. Such analyses include the full range of variation within the sample.

Another issue with using nonverbal IQ in diagnosis of SLI is that different nonverbal IQ tests yield different scores within individuals. Swisher, Plante, and Lowell (1994) noted considerable differences in scores across the three tests that they used. Miller and Gilbert (2008) examined scores on two nonverbal IQ tests in children with and without language impairment. There were substantial differences across the tests in how many children with language impairment would meet an IQ cut-off of 85, and hence a classification of SLI vs. NLI. These studies indicate that the composition of research samples of children with SLI, as well as the eligibility of children for clinical services, will depend heavily on the nonverbal IQ test used.

The source of the differences between tests is not clear. Johnston (1982) found that children with language disorders scored better on items requiring only "recognition of physical resemblance" than items requiring that stimuli "be interpreted according to prior... knowledge" (p. 292) on a nonverbal IQ test, but the same was true of TD children. Kamhi, Minor, and Mauer (1990) obtained similar results with two other nonverbal IQ tests. Swisher et al. (1994) found larger effect sizes for differences between their language impaired and TD groups on items measuring spatial rotation, analogical reasoning, manual-sequential praxis, and matching across three tests, but effect sizes were substantial for almost all item types. Miller and Gilbert (2008) were not able to identify any obvious source for the differences in scores on the two tests they examined. In the current study, we investigated whether timed subtests might affect the performance of children with SLI.

Another problem with nonverbal IQ testing is that scores may fluctuate or even decline in children with SLI as they age (Botting, 2005; Mawhood et al., 2000; Tomblin et al., 1992). Tomblin et al. (1992) reported that a sample of 20 children with SLI showed a decline in their average nonverbal IQ scores (8.75 points) when tested as adults, in contrast with previous findings reported by Tomblin et al. (1992) indicating that TD individuals show stability of IQ scores. Also, a longitudinal study (Botting, 2005) found that 82 children who were diagnosed as having SLI showed a significant decline in their nonverbal IQ scores, 23 points on average, from age 7 years to 14 years. Although these studies spanned different

age ranges, and often used different tests at different times, the consistent finding of declining nonverbal IQ over time suggests that it may not be reliable as a criterion measure.

In summary, nonverbal IQ tests probably do not provide a valid, reliable estimate of intellectual capacity independent of language ability in children with language impairment. One reason for the lack of validity and reliability within and between tests, and over time, may be that both nonverbal IQ performance and language performance are affected by common factors. One of these factors may be processing speed.

1.2. The role of processing speed in IQ

In current theories of intelligence, processing speed has been proposed as one of the processes that subserves *g* (Hunt, 2011; Mackintosh, 2011; Sternberg & Kaufman, 2011). An information processing approach has been proposed as a basis for contemporary concepts of intelligence (Hunt, 2011). This approach investigates possible component processes in the way humans perceive, store, retrieve, and manipulate information (Hunt, 2011; Sternberg, 2000). One of the component processes contributing to *g* is processing capacity (Hunt, 2011). Processing capacity, including processing speed and working memory, is hypothesized to subserve intelligence (Hunt, 2011). Processing speed is of particular interest in this study.

Processing speed refers to information processing efficiency, the ability to process input before the input decays or before incoming information interferes with it (Jensen, 1993; Miller & Vernon, 1996). In relation to intelligence, processing speed has been considered to be a fundamental mechanism for intellectual functioning (Jensen, 1993). Empirically, processing speed at the early stages of development is known to influence the development of general intelligence (Rose et al., 2008). Individuals with high IQs show faster responses on simple reaction time tasks (Deary, 2000; Deary et al., 2010).

Processing speed can be regarded as a global construct that influences a variety of motor, perceptual, and cognitive tasks (Kail, 2000; Fry & Hale, 2000). Processing speed tasks have shown high correlations across different tasks of varying complexity (Vernon, 1983; Hale and Jansen, 1994). Processing speed as a global construct is also supported by findings that a consistent pattern of developmental differences in processing speed was observed across many different tasks (Hale, 1990; Kail 1991, 1993). In this approach, processing speed is not specific to a task; thus, in the current study, a variety of processing speed tasks were used and averaged to estimate general processing speed.

Processing speed is thought to be a fundamental element of *working memory*, the capacity “to maintain, update, and manipulate information in an active state, over short delays” (Kaufman et al., 2009, p. 375). Working memory capacity is found to be a strong predictor of IQ performance (Kaufman et al., 2009). Processing speed may constrain working memory capacity (Bayliss et al., 2005). Similarly, processing speed has been found to be involved with the development of working memory (Demetriou et al., 2002; Kail, 2007; Luna et al., 2004). Fry and Hale (1996) suggested that faster processing promotes the effective use of working memory, which advances general intelligence.

1.3. Processing speed in SLI

According to the generalized slowing hypothesis (Kail, 1994), processing speed limitations may account for language impairment in children with SLI. Kail (1994) showed that children with SLI exhibited slower performance than age-matched peers by approximately the same proportion on various nonlinguistic and linguistic tasks. His conclusion was that children with SLI have a general limitation in processing speed, which influences all mental operations across domains and modalities (Kail, 1994). In a comprehensive study, Miller et al. (2001) confirmed this view by demonstrating that children with SLI showed slower reaction times than did TD children on various reaction time tasks in both linguistic and nonlinguistic domains. Statistically significant group differences between children with and without SLI are not always found on simple speeded tasks, such as detecting an auditory signal (Kohnert & Windsor, 2004; but see Montgomery & Windsor, 2007). Furthermore, the degree of slowing is not the same across all types of tasks (Miller et al., 2006). However, a consistent pattern of slower processing speed averaged across different tasks is common in children with SLI.

Furthermore, speed of incoming linguistic information is associated with these children's language learning. Ellis Weismer and Hesketh (1996) found that difficulties in novel word learning exhibited by children with SLI increased as the rate at which the stimuli were presented increased. Also, Leonard et al. (2007) found that processing speed explained significant variance in language abilities in TD and SLI groups in a factor analysis. These studies indicate that slow processing speed may explain at least some of the language deficits seen in children with SLI.

1.4. Relationship between processing speed and IQ over time

Even in typical development, the strength of the correlation between processing speed and IQ is not fully understood (Fry & Hale, 2000). Fry and Hale (1996) found that processing speed improves working memory, and subsequently, working memory enhances intelligence. Further investigating this developmental cascade, Fry and Hale (2000) reported that they found no systematic developmental pattern of either decline or increase in the relationship between processing speed and intelligence in TD children. However, children with SLI appear to have deficits in processing speed (Kail, 1994; Miller et al., 2001, 2006); thus, the relationship between processing speed and IQ may strengthen over time in contrast to typically developing children. That is, slow processing speed places limits on working memory which in turn limits development of the cognitive skills needed for performance on IQ tests. This chain of effects would give processing speed more influence on IQ in children with SLI, because it is, in a sense, "holding them back".

1.5. Rationale and research aims

The growing evidence suggests that children with SLI exhibit nonlinguistic deficits even when they meet the traditional nonverbal IQ criterion (e.g., Finneran, Francis, & Leonard, 2009; Miller et al., 2001; Tomblin, Mainela-Arnold, & Zhang, 2007; Zelaznik & Goffman, 2010; for a review, see Leonard, 2014). Moreover, nonverbal IQ appears to decline or fluctuate over time in children with SLI (Botting, 2005; Mawhood et al., 2000; Tomblin et al., 1992). In an information processing approach, IQ may be decomposed into multiple

processes in the way humans perceive, store, retrieve, and manipulate information. One of the defining components of IQ may be processing speed (Kail, 2000). Children with SLI exhibit slow processing speed, which has been hypothesized to contribute to poor language learning in these children. However, this study is the first to directly examine relations between processing speed and nonverbal IQ scores in children with SLI, along with TD children.

Based on the prediction of the information processing approach that processing speed influences IQ, we hypothesized that nonverbal IQ scores are predicted by processing speed in all children, but particularly in children with SLI, for whom processing speed may be a particular weakness. One possibility is that processing speed predicts only those IQ subtests for which speed of response is factored into the score. However, if processing speed is essential to general intelligence, as some researchers suggest (Jensen, 1993; Kail, 2000), we would expect processing speed to predict even those subtests in which the score is not directly influenced by speed of response. Furthermore, since children with SLI may have delayed development of processing speed, we hypothesized that children with SLI may show different relationships between processing speed and IQ from TD children over time. If so, this would be a novel finding, and might suggest processing speed as a candidate factor in the observed changes in nonverbal IQ scores over time in individuals with SLI (Botting, 2005; Mawhood et al., 2000; Tomblin et al., 1992).

In the current study, we exploited the availability of an archival dataset in which a relatively large sample of children with and without SLI participated in a set of reaction time (RT) tasks that varied in the type of stimulus (linguistic or nonlinguistic) and in the complexity of the judgment required by the child (Miller et al., 2001). The children were also administered nonverbal IQ tests as part of a comprehensive diagnostic battery. Although the RT tasks were not selected specifically to address the role of processing speed in IQ, they were selected from published literature as representative of a wide range of cognitive functions, stimulus types, and complexity levels (see Miller et al., 2001).

The overall purpose of the current study was to better understand how processing speed is related to IQ among SLI and TD groups over time and what changes may be needed in the use of an IQ criterion for diagnosing children as having SLI. To achieve the purpose, two questions were addressed as follows.

1. Did nonlinguistic processing speed predict IQ scores on timed and untimed measures among two groups: TD children and children with SLI?
2. Did the relationship between processing speed and IQ among the two groups remain the same at two different time points: third grade and eighth grade?

2. Method

2.1. Participants

The participants were 110 children, 55 children with SLI and 55 children with typical development (37 males and 18 females per group) matched by grade, race and ethnicity, gender, and mother's education. The average age in grade 3 is 9;0 (age range: 8;3 – 10;00)

and the average age in grade 8 is 13;8 (age range: 13;1 – 15;00). The participants originated from the Midwest Collaboration on SLI, a longitudinal study of language impairment (see Tomblin et al., 1997; 2000 for review). That study excluded all children who met the following criteria: (1) home environment other than monolingual English speaking; (2) history of neurodevelopmental disorders such as autism, intellectual disability and frank neurological impairments; or (3) blind, used hearing devices, and/or had persistent bilateral hearing deficits. Initially, in second grade, there were 116 children with TD and 55 children with SLI who participated in processing speed tasks in grade 3 and 8. Fifty-five TD children were selected that matched the children with SLI according to race and ethnicity, gender, and mother's education.

The diagnostic test battery included nonverbal intelligence and language measures. For nonverbal IQ, all children (TD and SLI groups) received scores above 1SD below the mean on the performance scale of the Wechsler Intelligence Scale for Children-III (Wechsler, 1989). Participants were divided into SLI and TD groups according to five language composite scores: receptive; expressive; vocabulary; sentence; and narrative composite scores (see Table 1). These five composite scores were obtained from the following language tests: Peabody Picture Vocabulary Test – R (Dunn & Dunn, 1981), the Comprehensive Receptive and Expressive Vocabulary Test (Wallace & Hammill, 1994), and subtests of the Clinical Evaluation of Language Fundamentals 3 (Semel, Wiig, & Secord, 1995), and a narrative production task (Fey, Catts, & Proctor-Williams, 2001). Children were included in the SLI group if at least 2 of those composite scores were lower than -1.25 SD from the mean. For all language tests, local norms established for the entire study were used (Tomblin et al., 1997; Catts et al., 2002).

Table 1 shows the number of children, gender, age, race and ethnicity, mean years of mother's education, and the scores and standard deviations from the diagnostic battery in each group. All test scores in Table 1 were obtained from the diagnostic testing battery in the second grade. T-tests revealed that the two groups differed significantly on all of the language scores and the IQ scores. However, the groups did not differ significantly on the mean years of mother's education.

2.2. Tasks used in current analyses

2.2.1. Nonverbal intelligence—The first analysis, which examined the relationship between processing speed and IQ, included four Performance Scale subtests of the WISC-III: Picture Completion, Picture Arrangement, Object Assembly, and Block Design, administered in second grade. The Picture Completion subtest requires children to identify a missing piece in a picture. Picture Arrangement requires children to place scrambled pictures in a logically sequential order, which constitutes a story. Object Assembly requires children to correctly arrange puzzle pieces to create a common object as a whole. Block Design requires children to organize red-and-white blocks in a pattern that a given model demonstrates.

Out of the four WISC-III subtests, three subtests, Object Assembly, Picture Arrangement, and Block Design are timed and a higher score is applied to a quick and accurate response. One subtest, Picture Completion, has time limits, but fast responses are not assigned higher

scores. Therefore, we chose to examine the relationship between IQ and processing speed for the subtests with and without speed bonuses separately.

For the second analysis, which examined the relationship between IQ and processing speed over time, Block Design (IQ with speed bonuses) and Picture Completion (IQ without speed bonuses) were used for analysis since these two subtests were administered both in second grade and eighth grade.

2.2.2. Processing speed tasks—Children completed reaction time tasks in third grade, one year after the diagnostic testing, and eighth grade. The tasks were presented on a laptop computer. A detailed description of the tasks can be found in Miller et al. (2001; 2006). The tasks included four nonlinguistic tasks, (1) Tapping, (2) Strike-to-signal, (3) Visual Search, and (4) Mental Rotation.

The *Tapping* task, which primarily measures controlled motor function, required children to tap a key as rapidly as possible with the preferred hand for five seconds. The task started with a visual cue “Start” on the screen with a tone and ended with a visual signal “Stop” with a tone. In the *Strike-to-signal* task, children were asked to strike a key marked with a colored dot as quickly as they could when a visual response signal was displayed. The three asterisks of the response signal with a random delay variation of 1, 2, or 5 seconds appeared after the written word “Ready” in order to minimize any anticipatory artifact. In the *Visual Search* task, children were presented with a target figure on one side of the screen and scanned five figures from left to right on the other side. They pressed a key marked with a green dot when the target was present among the five figures and a key marked with a red dot when the target was not. The task required children to compare visual images in a systematic way. During the *Mental Rotation* task, children pressed a key marked with a green dot when a target figure on the left was the same as a figure on the right. The figure on the right varied by rotation degrees (e.g., 0°, 60°, or 120° clockwise from its original location). A mirror image of a target figure was considered to be different; therefore, the children were asked to press a key marked with a red dot when a mirror image was presented. This task required the most mental operations, as children had to compare an imagined figure to a visually present figure.

The Tapping and Strike-to-Signal tasks were chosen because their demands are relatively simple, requiring relatively few mental operations (Kail, 1994). In contrast, the Visual Search and Mental Rotation tasks require more mental operations. A composite reaction time combining these tasks was used in the analyses. Formation of a composite was supported by statistically significant correlations with magnitude $r > .24$ among all the processing speed tasks at both grade 3 and grade 8, with the exception of the Strike-to-Signal $\times$ Visual Search correlation at grade 3, which at $r = .17$, just missed significance.

Reaction times were excluded when the response was incorrect and outliers were identified and removed when reaction times were greater than twice the mean for each participant on each task based on methods used in previous RT studies (see Miller et al., 2001; 2006).

3. Results

The descriptive statistics for the IQ and processing speed measures are presented in Table 2.

3.1. Analysis approach

We conducted linear mixed model analyses to answer the questions: 1) whether nonlinguistic processing speed explains variance in timed and untimed measures of nonverbal IQ in children with SLI and TD peers and 2) whether the relationship between nonlinguistic processing speed and nonverbal IQ in the TD and SLI groups changes across different time points: third and eighth grades. Linear mixed models consider not only fixed effects but also random variation yielded by subjects and items, thus, these models are appropriate for studies with longitudinal or repeated measures (West et al., 2006). Since the dependent variables are repeated measures (IQ with/without bonuses) and longitudinal measures across grades, linear mixed models were used in the current analyses.

3.2. The relationship between processing speed and IQ

The first research question examined whether nonlinguistic processing speed predicts timed and untimed measures of nonverbal IQ in children with SLI and TD. To answer this question, linear mixed model analyses were conducted using nonverbal IQ with speed bonuses and nonverbal IQ without speed bonuses as dependent variables for grade 3. The reaction times on the processing speed measures were averaged and converted to z-scores to obtain standardized estimates. Estimates of Fixed Effects and tests of their significance were computed. The p values of the t-tests of the Estimates of Fixed Effects table were used to select significant predictors.

The nonverbal IQ was entered as a dependent variable. Main effects of group membership (TD/SLI), speed bonuses (with/without) and processing speed, two-way interactions (group $\times$ speed bonuses, group $\times$ processing speed, processing speed $\times$ speed bonuses), and the three-way interaction (group $\times$ speed bonuses $\times$ processing speed) were entered as fixed factors and participant was entered as a random factor. The two-way and three-way interactions were included in this analysis to determine if the degree to which processing speed predicting nonverbal IQ differed when IQ scores were rewarded with speed bonuses versus without speed bonuses differed for the two groups.

Table 3 shows that group membership, $\beta = 1.05$, $SE = .40$, $t = 2.60$, $p < .05$, explained nonverbal IQ, which indicates that children with SLI had significantly lower IQs than children with TD. However, speed bonuses $\beta = .17$, $SE = .37$, $t = .45$, $p > .05$ and processing speed, $\beta = -.40$, $SE = .29$, $t = -1.38$, $p > .05$, were not significant predictors of nonverbal IQ. The interaction between speed bonuses (with/without) and processing speed reached significance, $\beta = 1.04$, $SE = .38$, $t = 2.75$, $p < .05$. This interaction indicated that the relationship between processing speed and nonverbal IQ was significantly different depending on whether nonverbal IQ was measured with speed bonuses or without bonuses. To decompose this interaction, the data were split by speed bonus (with/without) and a linear mixed model analysis was run with processing speed as a predictor. When speed bonuses were given, processing speed, $\beta = -.60$, $SE = .19$, $t = -3.18$, $p < .05$, was significant.

When speed bonuses were not awarded, processing speed, $\beta = .25$, $SE = .22$, $t = 1.12$, $p > .05$ was not significant. The scatter plot in Figure 1 illustrates these relationships: higher nonverbal IQ scores on subtests requiring fast responses were associated with fast processing speed. However, nonverbal IQ measured by subtest not requiring fast responses was not associated with the direct measurements of processing speed.

None of the other interactions reached significance, group $\times$ speed bonuses, $\beta = -.31$, $SE = .52$, $t = -.58$, $p > .05$, group $\times$ processing speed, $\beta = -.21$, $SE = .40$, $t = -.51$, $p > .05$, and group $\times$ speed bonuses $\times$ processing speed, $\beta = -.43$, $SE = .53$, $t = -.81$, $p > .05$. This indicates that the relationship between nonverbal IQ and processing speed was not significantly different in the two groups and that the groups did not differ for the finding that only subtests with speed bonuses predicted nonverbal IQ.

3.3. The relationship between processing speed and IQ over time

Next we examined the second research question: Did the relationship of nonverbal IQ and nonlinguistic processing speed differ across two time points, third and eighth grades, in the TD and SLI groups? Since the analysis for the first question indicated that processing speed accounted for nonverbal IQ with speed bonuses only, we conducted a linear mixed model analysis for only nonverbal IQ with speed bonuses as a dependent variable for grades 3 and 8. Among the IQ subtests with speed bonuses, only Block Design was administered across grades, so we used the scores of Block Design in grades 3 and 8 as the dependent variable. After standardization, one participant's total RT in grade 8 was identified as an outlier, which was slower than 5 standard deviations above the mean. This averaged RT was excluded in this mixed model analysis.

For the second linear mixed model analysis, main effects of group membership (TD/SLI), grade (3/8) and processing speed, the two-way interactions (group $\times$ grade, group $\times$ processing speed, grade $\times$ processing speed), and the three-way interaction (group $\times$ grade $\times$ processing speed) were entered as fixed factors and participant was entered as a random factor. The two-way and three-way interactions were included in this analysis to determine if the degree to which processing speed explained nonverbal IQs changed across grades and changed differently for the two groups. Consistent with the first analysis, in the Estimates of Fixed Effects table, the p values in the t -tests were used to select significant factors.

Table 4 shows that nonverbal IQ with speed bonuses was explained by nonlinguistic processing speed, $\beta = -.101$, $SE = .35$, $t = -2.85$, $p < .05$, indicating that children who had higher nonverbal IQs with speed bonuses had faster nonlinguistic processing speed. Neither group membership (TD/SLI), $\beta = .21$, $SE = .50$, $t = .41$, $p > .05$, nor grade (3/8), $\beta = -.38$, $SE = .36$, $t = -1.04$, $p > .05$ were significant, which indicates that neither group membership nor grade explained nonverbal IQ with speed bonuses.

The estimate of fixed effects for the Group $\times$ Grade interaction, $\beta = .94$, $SE = .52$, $t = 1.81$, $p = .07$, approached significance. To further examine this interaction, a likelihood ratio test was used. A likelihood ratio test determines if a predictor can be included or excluded as a significant predictor of a dependent variable (Garson, 2013). The likelihood ratio was calculated by the difference of -2 log likelihoods and difference of degrees of freedom

between a simpler model (before adding a predictor) and a more complex model (after adding a predictor to the simpler model). Adding the grade $\times$ group interaction to a simpler model --which only contains main factors: processing speed, group, and grade-- reduced -2LL from 998.90 to 995.99, $\chi^2 = 2.91$ (df = 1), $p > .05$. This insignificant result indicates that nonverbal IQs for both children in the SLI and TD groups did not change to a different degree between grades 3 and 8.

Importantly, none of the other interactions reached significance, Group $\times$ Processing Speed, $\beta = .26$, $SE = .53$, $t = .48$, $p > .05$, Grade $\times$ Processing Speed, $\beta = .32$, $SE = .43$, $t = .73$, $p > .05$, Group $\times$ Grade $\times$ Processing Speed, $\beta = -.21$, $SE = .62$, $t = -.34$, $p > .05$. This indicates that the relationship between processing speed and nonverbal IQ with speed bonuses did not significantly differ across grades 3 and 8, nor did the relationship between nonverbal IQ and processing speed significantly differ across the two groups. These relationships are illustrated in Figure 2.

4. Discussion

The current study aimed to determine 1) whether processing speed predicts timed and untimed measures of nonverbal IQ in TD and SLI groups, and 2) whether the relationship between processing speed and nonverbal IQ changes over time in TD and SLI groups across grades 3 and 8. We examined these questions separately for nonverbal IQ subtests for which scoring was based on speed of response and subtests for which scoring was not based on response speed. We found that nonlinguistic processing speed did not predict nonverbal IQ performance without speed bonuses in grade 3. However, nonlinguistic processing speed predicted nonverbal IQ performance with speed bonuses and this relationship was similar in both groups in grade 3. For the second question, we found that while processing speed explained variance in nonverbal IQ performance with speed bonuses, the relationship between processing speed and nonverbal IQ with speed bonuses did not significantly differ across the grades nor across the two groups. Processing speed appears to explain significant variance in nonverbal IQ if it is measured by subtests that are scored based on fast, accurate performance. However, no significant developmental differences in the relationship between processing speed and IQ with speed bonuses were found across grades 3 and 8 and across the children with SLI and TD.

The finding that regardless of language group, faster processing speed explained higher IQ for the IQ subtests which fast responses were rewarded is not consistent with the theory that processing speed is an essential component of general intelligence (Anderson, 2005; Jensen, 1998). Rather, it suggests that processing speed is a specific ability that contributes more to some subtests, those in which fast responding is rewarded. It is worth noting that nonverbal IQ subtests with speed bonuses, such as Object Assembly, Picture Arrangement, and Block Design, have typically been considered as measures of general intelligence, not measures of processing speed per se. Therefore, the evidence presented here showing that processing speed is associated with performance only on nonverbal IQ subtests with speed bonuses suggests that for both theoretical and clinical purposes, timed subtests should be interpreted with caution when testing children with SLI, pending further research. One explanation for the association between processing speed and subtests with speed bonuses that readily

presents itself is that a child with slower processing speed is as accurate as speedier children but does not benefit from the speed bonuses to augment his or her score. However, it is also possible that accuracy is reduced in children with slower processing speed, due (at least in part) to the time pressure they experience. Research is needed that closely examines relations between processing speed and item-level performance on IQ subtests.

Current IQ criteria for SLI are problematic, because children with SLI tend to have slower processing speed (Kail, 1994; Kohnert et al., 2004; Leonard et al., 2007; Miller et al., 2001; 2006; Windsor et al., 1999; 2008). The well-established finding of slower processing speed, combined with the relationships between processing speed and timed tests found in our study, suggest that nonverbal IQ should be measured using untimed tests when diagnosing children as having SLI. Processing speed deficits may explain, in part, depressed IQ scores in children with SLI compared to their TD peers. The use of speeded IQ measures may also result in excluding some children from being diagnosed as having SLI, when in fact their depressed IQ scores as well as their language deficits may be a consequence of their underlying learning difficulties, such as slow processing speed.

Based on the previous literature indicating that children with SLI showed changes in IQ scores over time (Botting et al., 2005; Tomblin et al., 1992), and that increases in processing speed are delayed in children with SLI, we hypothesized that the degree to which processing speed accounts for IQ may change over time differentially for children with different language abilities. However, in contrast to our predictions, the children showed stable relationships between processing speed and IQ over time across different language groups. This result suggests that processing speed does not directly contribute to changes in IQ scores in children with SLI over time. However, the longitudinal analysis was based on only one IQ subtest, Block Design, and further research is needed to determine if a similar pattern holds for other time-constrained nonverbal IQ subtests.

If processing speed does not drive changes in the IQ scores of children with SLI, what does? One possibility is that language deficits are a more limiting factor. Many so-called nonverbal IQ tests use verbal instructions to the examinee (DeThorne & Schaefer, 2004). Even those that use nonverbal instructions cannot assure that the examinee will not use, or attempt to use, verbal mediation to complete the test. Lidstone, Meins, and Fernyhough (2012) suggested that the development of private and inner speech is delayed in children with SLI, and this may have a detrimental effect on their performance on nonlinguistic tasks. As children with SLI grow older, they may fall further behind their TD peers in the use of verbal mediation or verbal support in nonverbal tasks.

4.2. Limitations

An alternative explanation of why different developmental trajectories between the groups were not found in our study may be that we examined only two time points. Two time measurements implicitly focus on linear change, rather than nonlinear change (Wohlwill, 1980). Moffitt et al. (1993) noted that individual development patterns may not be sufficiently reflected by simple linearity of intellectual performance. Thus, relationship between processing speed and nonverbal IQ between TD and SLI may need multiple time points to explain more comprehensive developmental trajectories. Also, a longer time frame,

probably an earlier time frame, may be more appropriate to detect more significant developmental changes (Conti-Ramsden et al., 2012; Karmiloff-Smith, 1998).

4.3. Conclusions and clinical implications

The current study indicates that processing speed predicts nonverbal IQ measured by subtests that require fast responses in children with typical development and those with SLI. Since many nonverbal IQ subtests require timed responses, this underscores the need to refine the IQ criterion in SLI. IQ subtests that are not timed should be used to ensure the absence of intellectual disabilities in children with SLI. This step will not resolve all of the problems with the use of a nonverbal IQ criterion for SLI. Also, some children with SLI score at or above average on nonverbal IQ, as shown by the range of scores in our own data, as well as data reviewed in Gallinat and Spaulding (2014), and some children with SLI are not slower processors than their TD peers (Miller et al., 2006). Further, since we found evidence suggesting that one type of information processing significantly impacts children's nonverbal IQs, future work may investigate which other underlying mechanisms, such as working memory limitations, influence IQ in children with SLI. Future research should also investigate if the role of verbal mediation in IQ becomes more important over time.

The results of the current study have implications for clinical diagnosis. Instead of using nonverbal IQ scores, we may need to focus on criteria that are based on cognitive measures that may be directly involved with language impairment, in order to diagnose children as having SLI. In addition to processing speed measures, other candidate cognitive measures could include procedural memory (e.g., Tomblin, Mainela-Arnold, & Zhang, 2007) and attention tasks (e.g. Finneran, Francis, & Leonard, 2009). These are measures that present difficulties for many children with SLI and that are hypothesized to contribute to the language impairments in these children. These measures in addition to language measures show some promise of ultimately providing better assessment tools to diagnose children as having SLI than the current approach of using a combination of language and IQ measures.

Acknowledgments

The original study was supported by a clinical research center grant PO-DC-02748 from the National Institute on Deafness and Other Communication Disorders. We thank the Child Language Research Center at the University of Iowa and members of the Midwest Collaboration on SLI for the use of data.

References

- Anderson, M. Marrying intelligence and cognition: A developmental view. In: Sternberg, R.J.; Pretz, J.E., editors. *Cognition and intelligence: Identifying the mechanisms of the mind*. New York, NY: Cambridge University Press; 2005. p. 268-287.
- Bayliss DM, Jarrold C, Baddeley AD, Gunn DM, Leigh E. Mapping the developmental constraints on working memory span performance. *Developmental Psychology*. 2005; 41(4):579–597. [PubMed: 16060806]
- Botting N. Non-verbal cognitive development and language impairment. *Journal of Child Psychology and Psychiatry*. 2005; 46:317–326. [PubMed: 15755307]
- Catts H, Fey ME, Tomblin JB, Zhang Z. A longitudinal investigation of reading outcomes in children with language impairments. *Journal of Speech, Language, and Hearing Research*. 2002; 45:1142–1157.

- Cole KN, Coggins TE, Vanderstoep C. The influence of language/cognitive profile on discourse intervention outcome. *Language, Speech and Hearing Services in Schools*. 1999; 30(1):61–67.
- Conti-Ramsden G, St Clair MC, Pickles AP, Durkin K. Developmental trajectories of verbal and nonverbal skills in individuals with a history of specific language impairment: From childhood to adolescence. *Journal of Speech, Language, and Hearing Research*. 2012; 55(6):1716–1735.
- Deary, IJ. *Looking down on human intelligence: From psychometrics to the brain*. Oxford, U.K: Oxford University Press; 2000.
- Deary IJ, Penke L, Johnson W. The neuroscience of human intelligence differences. *Neuroscience*. 2010; 11:201–211. [PubMed: 20145623]
- Demetriou A, Christou C, Spanoudis G, Platsidou M. The development of mental processing: Efficiency, working memory, and thinking. *Monographs of the Society of Research in Child Development*. 2002; 67(1):1–155.
- Dennis M, Francis DJ, Cirino PT, Schachar R, Barnes MA, Fletcher JM. Why IQ is not a covariate in cognitive studies of neurodevelopmental disorders. *Journal of the International Neuropsychological Society*. 2009; 15:331–343. [PubMed: 19402919]
- DeThorne LS, Schaefer BA. A guide to child nonverbal IQ measures. *American Journal of Speech-Language Pathology*. 2004; 13:275–290. [PubMed: 15719895]
- Dunn, L.; Dunn, L. *The Peabody Picture Vocabulary Test-Revised*. Circle Pines, MN: American Guidance Service; 1981.
- Ellis Weismer S, Hesketh L. Lexical learning by children with specific language impairment: Effects of linguistic input presented at varying speaking rates. *Journal of Speech and Hearing Research*. 1996; 39:177–190. [PubMed: 8820709]
- Fey, ME.; Catts, HW.; Proctor-Williams, K. Narrative generation by school-age children with typical and impaired language; Poster presented at the annual conference of the American Speech-Language-Hearing Association; Washington, DC. 2001 Nov.
- Fey, ME.; Long, SH.; Cleave, P. Reconsideration of IQ criteria in the definition of specific language impairment. In: Watkins, RV.; Rice, M., editors. *Specific language impairments in children*. Vol. 4. Baltimore, MD: Brookes; 1994. p. 161–178.
- Finneran DA, Francis AL, Leonard LB. Sustained attention in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2009; 52:915–929.
- Fry AF, Hale S. Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science*. 1996; 7:237–241.
- Fry AF, Hale S. Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology*. 2000; 54:1–34. [PubMed: 11035218]
- Gallinat E, Spaulding TJ. Differences in the performance of children with specific language impairment and their typically developing peers on nonverbal cognitive tests: A meta-analysis. *Journal of Speech, Language, and Hearing Research*. 2014; 57:1363–1382.
- Garson, GD. *Hierarchical Linear Modeling: Guide and Applications*. Thousand Oaks, CA: SAGE Publications, Inc; 2013.
- Hale S. A global developmental trend in cognitive processing speed. *Child Development*. 1990; 61:653–663. [PubMed: 2364741]
- Hale S, Jansen J. Global processing-time coefficients characterize individual and group differences in cognitive speed. *Psychological Science*. 1994; 5:384–389.
- Hunt, E. *Human Intelligence*. New York, NY: Cambridge University Press; 2011.
- Jensen AR. Why is reaction time correlated with psychometric g? *Current Directions in Psychological Science*. 1993; 2(2):53–56.
- Jensen, AR. *The g factor: The science of mental ability*. New York, NY: Praeger; 1998.
- Johnston JR. Interpreting the Leiter IQ: Performance profiles of young normal & language-disordered children. *Journal of Speech, Language, and Hearing Research*. 1982; 42:744–760.
- Kail R. Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin*. 1991; 109:490–501. [PubMed: 2062981]
- Kail R. Processing time decreases globally at an exponential rate during childhood and adolescence. *Journal of Experimental Child Psychology*. 1993; 56:254–265. [PubMed: 8245769]

- Kail R. A method for studying the generalized slowing hypothesis in children with specific language impairment. *Journal of Speech and Hearing Research*. 1994; 37:418–421. [PubMed: 8028323]
- Kail R. Speed of information processing: Developmental change and links to intelligence. *Journal of School Psychology*. 2000; 38(1):51–61.
- Kail RV. Longitudinal evidence that increases in processing speed and working memory enhance children's reasoning. *Psychological Science*. 2007; 18:312–313. [PubMed: 17470254]
- Kamhi A, Minor J, Mauer D. Content analysis and intratest performance profiles on the Columbia and the TONI. *Journal of Speech and Hearing Research*. 1990; 33:375–379. [PubMed: 2359277]
- Karmiloff-Smith A. Development itself is the key to understanding developmental disorders. *Trends in Cognitive Sciences*. 1998; 2(10):389–398. [PubMed: 21227254]
- Kaufman SB, DeYoung CG, Gray JR, Brown J, Mackintosh N. Associative learning predicts intelligence above and beyond working memory and processing speed. *Intelligence*. 2009; 37:374–382.
- Kohnert K, Winsor J. The search of common ground- Part II: Non-linguistic performance by linguistically diverse learners. *Journal of Speech, Language, and Hearing Research*. 2004; 47:891–903.
- Leonard, LB. Processing limitations and the grammatical profile of children with specific language impairment. In: Kail, R., editor. *Advances in child development and behavior*. Vol. 35. 2007. p. 139–171.
- Leonard, LB. *Children with specific language impairment*. 2. Cambridge, MA: MIT Press; 2014.
- Leonard LB, Ellis Weismer S, Miller CA, Francis DJ, Tomblin JB, Kail RV. Speed of processing, working memory, and language impairment in children. *Journal of Speech, Language, and Hearing Research*. 2007; 50:408–428.
- Lidstone JS, Meins E, Fernyhough C. Verbal mediation of cognition in children with specific language impairment. *Development and Psychopathology*. 2012; 24:651–660. [PubMed: 22559137]
- Luna B, Garver KE, Urban TA, Lazar NA, Sweeney JA. Maturation of cognitive processes from late childhood to adulthood. *Child Development*. 2004; 75:1357–1372. [PubMed: 15369519]
- Mawhood L, Howlin P, Rutter M. Autism and developmental receptive language disorder—A comparative follow-up in early adult life. I: Cognitive and language outcomes. *Journal of Child Psychology and Psychiatry*. 2000; 41:547–559. [PubMed: 10946748]
- McKintosh, NJ. *IQ and Human intelligence*. 2. New York, NY: Oxford University Press; 2011.
- Miller CA, Gilbert E. Comparison of performance on two nonverbal intelligence tests by adolescents with and without language impairment. *Journal of Communication Disorders*. 2008; 41:358–371. [PubMed: 18395219]
- Miller CA, Kail R, Leonard LB, Tomblin JB. Speed of processing in children with specific language impairment. *Journal of Speech, Language and Hearing Research*. 2001; 44(2):416–433.
- Miller CA, Leonard LB, Kail RV, Zhang X, Tomblin JB, Francis DJ. Response time in 14-year-olds with language impairment. *Journal of Speech, Language, and Hearing Research*. 2006; 49(4):712–728.
- Miller LT, Vernon PA. Intelligence, reaction time and working memory in 4- to 6-year-old children. *Intelligence*. 1996; 22:155–190.
- Moffitt T. The natural history of change in intellectual performance: Who changes? how much? is it meaningful? *Journal of child psychology and psychiatry*. 1993; 34(4):455–506. [PubMed: 8509490]
- Montgomery J, Windsor J. Examining the language performances of children with and without specific language impairment: Contributions of phonological short-term memory and speed of processing. *Journal of Speech, Language, and Hearing Research*. 2007; 50:778–797.
- Plante E. Criteria for SLI: The Stark and Tallal legacy and beyond. *Journal of Speech, Language, and Hearing Research*. 1998; 41:951–957.
- Roid, GH.; Prifitera, A.; Weiss, LG. Replication of the WISC-III factor structure in an independent sample. In: Bracken, BA.; McCallum, RS., editors. *Journal of Psychoeducational Assessment Monograph series, advances in psychoeducational assessment: Wechsler Intelligence Scale for Children*. Third Edition. Germantown, TN: Psychoeducational Corporation; 1993. p. 6–21.

- Rose SA, Feldman JF, Jankowski JJ, Van Rossem R. A cognitive cascade in infancy: Pathways from prematurity to later mental development. *Intelligence*. 2008; 36:367–378. [PubMed: 19122757]
- Semel, E.; Wiig, E.; Secord, W. *Clinical Evaluation of Language Fundamentals*. Third Edition. San Antonio, TX: The Psychological Corporation; 1995.
- Stark RE, Tallal P. Selection of children with specific language deficits. *Journal of Speech and Hearing Disorders*. 1981; 46:114–180. [PubMed: 7253588]
- Spearman C. General Intelligence, Objectively Determined and Measured. *The American Journal of Psychology*. 1904; 15(2):201–292.
- Stark R, Tallal P. Selection of children with specific language deficits. *Journal of Speech and Hearing Disorders*. 1981; 46:114–122. [PubMed: 7253588]
- Sternberg, RJ. *Handbook of intelligence*. New York, NY: Cambridge University Press; 2000.
- Sternberg, RJ.; Kaufman, SB., editors. *The Cambridge handbook of intelligence*. New York, NY: Cambridge University Press; 2011.
- Swisher L, Plante E, Lowell S. Nonlinguistic deficits of language-impaired children complicate the interpretation of their nonverbal IQ scores. *Language, Speech, and Hearing Services in Schools*. 1994; 25:235–240.
- Tomblin JB, Freese P, Records N. Diagnosing specific language impairment in adults for the purpose of pedigree analysis. *Journal of Speech, Language, and Hearing Research*. 1992; 35(4):832–843.
- Tomblin JB, Mainela-Arnold E, Zhang X. Procedural learning in children with and without specific language impairment. *Language Learning and Development*. 2007; 3:269–293.
- Tomblin JB, Records NL, Buckwalter P, Zhang X, Smith E, O'Brien M. Prevalence of specific language impairment in kindergarten children. *Journal of Speech, Language and Hearing Research*. 1997; 40(6):1245–60.
- Tomblin JB, Records NL, Zhang X. A system for the diagnosis of specific language impairment in kindergarten children. *Journal of Speech and Hearing Research*. 1996; 39:1284–1294. [PubMed: 8959613]
- Tomblin, JB.; Zhang, X. Language patterns and etiology in children with specific language impairment. In: Tager-Flusberg, H., editor. *Neurodevelopmental disorders*. Cambridge, MA: MIT Press; 1999. p. 361-382.
- Vernon PA. Recent findings on the nature of g. *The Journal of Special Education*. 1983; 17:389–400.
- Wechsler, D. *Wechsler Intelligence Scale for Children*. 3. San Antonio, TX: The Psychological Corporation; 1989.
- Wallace, G.; Hammill, DD. *Comprehensive Receptive and Expressive Vocabulary Test*. Austin, TX: Pro-Ed; 1994.
- West, BT.; Welch, KB.; Galecki, AT. *Linear mixed models – A practical guide using statistical software*. Boca Raton, FL: Chapman & Hall / CRC Press; 2006.
- Windsor J, Hwang M. Testing the generalized slowing hypothesis in specific language impairment. *Journal of Speech, Language, and Hearing Research*. 1999; 42(5):1205–1218.
- Windsor J, Kohnert K, Loxtercamp AL, Kan PF. Performance on nonlinguistic visual tasks by children with language impairment. *Applied Psycholinguistics*. 2008; 29:237–268.
- Wohlwill, J. Cognitive development in childhood. In: Brim, OG., Jr; Kagan, J., editors. *Constancy and change in human development*. Cambridge, MA: Harvard University Press; 1980. p. 339-444.
- Zelaznik HN, Goffman L. Generalized motor abilities and timing behavior in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2010; 53:383–393.

Highlights

- We examined whether processing speed predicts IQ in children with SLI and TD.
- We examined whether this relationship between processing speed and IQ changes over time.
- Slower processing speed predicted a lower IQ across groups on a timed IQ measure.
- Relationship between processing speed and IQ stayed stable over time across groups.

Learning outcomes

The reader will be able to (1) describe the relationship between processing speed and nonverbal IQ in children with TD and SLI and (2) discuss problems using an IQ criterion to diagnose children as having SLI.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Figure 1.
Correlation between IQ with and without speed bonuses and processing speed in third grade.

Figure 2.
Correlation between IQ with speed bonuses and processing speed in third and eighth grade.

Table 1

Group characteristics in the diagnostic phase (second grade).

Measures	TD (n=55)	SLI (n=55)	t-test (<i>p</i> value)
¹ Nonverbal IQ SS	102 (11)	96 (8)	3.40*
² Receptive composite z	-.48 (.68)	-1.52 (.58)	8.70**
³ Expressive composite z	-.38 (.73)	-1.43 (.50)	8.81**
⁴ Vocabulary composite z	-.42 (.71)	-1.44 (.63)	8.03**
⁵ Sentence composite z	-.49 (.72)	-1.43 (.56)	7.57**
⁶ Narrative composite z	-.28 (.85)	-1.26 (.59)	7.10**
Sex (Male/Female)	37 / 18	37 / 18	
Race and Ethnicity (White/Black/Hispanic/Asian)	47 / 6 / 1 / 1	47 / 6 / 2 / 0	
Mother's education (mean years)	13.07	13.09	-.05

¹ Nonverbal IQ SS = a national standard score of the performance scale of The Wechsler Intelligence Scale for Children (WISC III).

² Receptive composite z = a composite z score of Peabody Picture Vocabulary Test-Revised (PPVT-R) and four subtests of Clinical Evaluation of Language Fundamentals-Third Edition (CELF-III): Sentence Structures, Concepts and Directions, Word Structure, Listening to Paragraphs

³ Expressive composite z = a composite z score of a subtest of Comprehensive Receptive and Expressive Vocabulary Test (CREVT): the expressive vocabulary, a subtest of CELF-III: Recalling Sentences, and a narrative production task (Fey, Catts, & Proctor-Williams, 2001)

⁴ Vocabulary composite z = a composite z score of PPVT-R and a subtest of CREVT: the Expressive Vocabulary

⁵ Sentence composite z = a composite z score of four subtests of CELF-III: the Sentence Structure, Concepts and Directions, Word Structure, and Recalling Sentences

⁶ Narrative composite z = a composite z score of a subtest of CELF-3: the Listening to Paragraphs and a narrative production task

* $p < .01$.

** $p < .001$.

Table 2

Means, standard deviations (SD) and ranges of standardized IQ scores in grade 2 and grade 8 and reaction time tasks for groups in third and eighth grade.

Grade	Measures	TD	SLI
Grade 2	IQ without speed bonuses ¹ Mean (SD)	10.3 (2.2)	9.7 (2.4)
	Min-Max	3.0 – 15.0	4.0 – 15.0
	IQ with speed bonuses ² Mean (SD)	10.5 (2.1)	9.3 (1.8)
	Min-Max	5.3 – 16.3	6.0 – 14.3
Grade 3	Nonlinguistic RT (SD)	1814 (392)	1941 (376)
	Min-Max	1047 – 3094	1264 – 2712
Grade 8	IQ without speed bonuses ⁴ Mean (SD)	9.5 (2.4)	9.1 (2.3)
	Min-Max	5.0 – 16.0	3.0 – 15.0
	IQ with speed bonuses ⁵ Mean (SD)	10.3 (2.1)	9.6 (2.8)
	Min-Max	6.0 – 15.0	3.0 – 19.0
Grade 8	Nonlinguistic RT (SD)	1160 (257)	1331 (285)
	Min-Max	763 – 2006	651 – 1970

¹ IQ without speed bonuses = Picture Completion

² IQ with speed bonuses = Block Design, Picture Arrangement, and Object Assembly

³ IQ without speed bonuses = Picture Completion

⁴ IQ with speed bonuses = Block Design

Table 3

Estimates of Fixed Effects for IQ with/without speed bonuses in Grade 3 when group, speed bonus, processing speed, two-way interactions and three-way interaction were entered in the model.

Parameter	Estimate	Std. Error	df	T	Sig.
Intercept	9.38	.29	214.90	32.91	.00
Group (TD/SLI)	1.05	.40	214.90	2.60	.01
Speed bonuses (with/without)	.17	.37	110.00	.45	.65
Processing Speed (PS)	-.40	.29	214.90	-1.38	.17
Group × Speed bonuses	-.31	.52	110.00	-.58	.56
Group × PS	-.21	.40	214.90	-.51	.61
Speed bonuses × PS	1.04	.38	110.00	2.75	.01
Group × Speed bonuses × PS	-.43	.53	110.00	-.81	.42

Note: Dependent Variables were IQ without speed bonuses (Picture Completion) and IQ with speed bonuses (Block Design, Picture Arrangement, Object Assembly).

Table 4

Estimates of Fixed Effects for IQ with speed bonuses (Block Design) when group, grade, processing speed, two-way interactions and three-way interaction were entered in the model.

Parameter	Estimate	Std. Error	df	T	Sig.
Intercept	9.84	.35	187.69	28.33	.00
Group (TD/SLI)	.21	.50	189.90	.41	.68
Grade (3/8)	-.38	.36	111.42	-1.04	.30
Processing Speed (PS)	-1.01	.35	193.32	-2.85	.01
Group × Grade	.94	.52	112.12	1.81	.07
Group × PS	.26	.53	198.93	.48	.63
Grade × PS	.32	.43	147.17	.73	.47
Group × Grade × PS	-.21	.62	142.79	-.34	.73