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Can you spell dyslexia without SLI? Comparing the cognitive profiles of dyslexia and specific language impairment and their roles in learning

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ABSTRACT

The aim of the present study is to explore whether those with Specific Language Impairment (SLI) and dyslexia display distinct or overlapping cognitive profiles with respect to learning outcomes. In particular, we were interested in two key cognitive skills associated with academic performance – working memory and IQ. We recruited three groups of children – those with SLI, those with dyslexia, and a control group. All children were given standardized tests of working memory, IQ (vocabulary and matrix), spelling, and math. The pattern of results suggests that both children with dyslexia and SLI are characterized with poorer verbal working memory and IQ compared to controls, but preserved nonverbal cognitive skills. It appears that that these two disorder groups cannot be distinguished by the severity of their cognitive deficits. However, there was a differential pattern with respect to learning outcomes, where the children with dyslexia rely more on visual skills in spelling, while those with SLI use their relative strengths in vocabulary. These findings can have important implications for how intervention is tailored in the classroom, as disorder-specific support could yield important gains in learning.

Students with specific language impairment (SLI) and dyslexia (reading difficulties) are characterized by unique core deficits. SLI is characterized by a persistent deficit in language skills, including semantics, syntax, and expressive and/or receptive vocabulary (Leonard, 1998); while developmental dyslexia (or reading difficulties) is described as stemming from poor phonological awareness skills (Snowling, 2000). Despite these distinct language profiles, both groups manifest learning difficulties. How can we reconcile these learning deficits in spite of unique language profiles? One possibility may lie in the role of a key cognitive skill linked to learning: working memory.

Working memory, the ability to store and manipulate information, is a multidimensional system comprising of both verbal and visual aspects (Alloway & Alloway, 2013; Baddeley, 2003). Working memory is critical for a variety of activities at school, from complex subjects such as reading comprehension, mental arithmetic, and word problems to simple tasks like copying from the board and navigating around school (see Alloway & Copello, 2013, for a review). Working memory is also important from kindergarten (Alloway et al., 2005) to the tertiary level (Alloway & Gregory, 2013); and is an excellent predictor of academic success, longitudinally (Alloway & Alloway, 2010). IQ scores are also used to gauge academic ability (Duckworth, Quinn, & Tsukayama, 2012), however research has suggested that IQ and working memory represent distinct cognitive skills (Ackerman, Beier, & Boyle, 2005; Alloway, 2009, Conway, Kane, & Engle, 2003; though see Stauffer, Ree, & Carretta, 1996), and thus may have separable links to learning outcomes.

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1. SLI: working memory, IQ, and learning

Children with SLI manifest difficulties in learning vocabulary, grammar, and syntax in language development, specifically in slow rates of learning novel words and difficulties in the use of appropriate verbs in both oral and written language (Leonard, 1998). These language deficits disrupt their overall learning pattern across scholastic domains, including mathematics (Arvedson, 2002; Fazio, 1996) and literacy (Catts, Fey, Tomblin, & Zhang, 2002). To date, it is not clear whether working memory is linked to these learning problems, or whether the cumulative effects of working memory and language deficits are associated with their learning profile (see Montgomery, Magimairaj, & Finney, 2010, for a review). For example, longitudinal research has suggested that deficits in memory retrieval may affect mathematical ability (Fazio, 1996). Findings on literacy have found that reading comprehension is just as impaired as reading accuracy in children with SLI, suggesting an association not only with decoding text, but also with understanding the message in the text (Bishop & Snowling, 2004). It could be that a combination of verbal working memory deficits make reading accuracy difficult, yielding a slowed ability to learn novel words as well as difficulties in using contextual cues to help fill in the gaps in comprehension.

Children with SLI typically display verbal memory deficits, particularly in tasks using nonwords (Ellis Weismer, Evans, & Hesketh, 1999; Gathercole & Baddeley, 1990; Montgomery, 2003). This verbal memory deficit is thought to be linked to their difficulty in acquiring new words, often resulting in a limited vocabulary (Henry, 2012). In contrast, their visuo-spatial working memory skills are often reported to be at age-appropriate levels (Alloway & Archibald, 2008; Bavin, Wilson, Maruff, & Sleeman, 2005; though see Hick, Botting, & Conti-Ramsden, 2005). Interestingly, their verbal memory deficits persist even after general language abilities were taken into account, suggesting an additive effect of language impairments and verbal memory deficits that may underpin learning difficulties (Archibald & Gathercole, 2006).

The disruptive effect of language deficits is also evidenced in their IQ profile as they typically score at least one SD below the average for their age in standardized Verbal IQ tests, while their nonverbal IQ scores remain within age-appropriate limits (Bishop & Snowling, 2004; Catts, Adolf, Hogan, & Weismer, 2005). This pattern has traditionally been used as part of the diagnosis of SLI (WHO, 1993). However, there are concerns with this approach as longitudinal studies have found that some children with SLI exhibit fluctuations in nonverbal IQ scores, which suggests a complex interaction between language skills and nonverbal ability (Botting, 2005).

2. Dyslexia: working memory, IQ and learning

In terms of learning skills, children with dyslexia are characterized by impairments in word recognition, spelling, and decoding capabilities (Lyon, Shaywitz, & Shaywitz, 2003). These deficits tend to be expressed strongly in reading difficulties, particularly in reading fluency (though see de Oliveira, da Silva, Dias, Seabra, & Macedo, 2014). This can lead to decreased exposure to reading, causing a negative cycle of poor verbal ability and literacy (Stanovich, 1994). This decreased verbal ability has shown to be pervasive in other learning capacities, such as mathematics, particularly where tasks demands involve some verbal component. However, these observed comorbidities are not always prevalent in children with dyslexia; it is generally understood that the cognitive characteristics of dyslexia differ from specific deficits in mathematics (Lyon et al., 2003; also Gathercole, Alloway, Willis, & Adams, 2006).

Typically, dyslexic children display verbal working memory deficits and naming difficulties consistent with deficits in the verbal domain. For example, early studies by Shankweiler and colleagues found that poor readers made more memory errors when recalling a word list compared to superior readers (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). Meta-analyses by Swanson (2006), Swanson (2012) also reported high effect sizes in verbal working memory performance between those with dyslexia and typical readers. These verbal memory deficits predict difficulties in reading fluency and comprehension (Pham & Hasson, 2014). In contrast, individuals with dyslexia can display strengths in visuo-spatial working memory (Alloway & Copello, 2013; though see Smith-Spark & Fisk, 2007). These skills may be recruited for visual coding of written words (Miller & Kupfermann, 2009), and may also play a role in higher level reading processes, particularly in reading comprehension (Pham & Hasson, 2014). With respect to IQ, children with dyslexia show average or even above average standardized scores, while their reading ability is significantly lower (Snowling, Bishop, & Stothard, 2000).

3. Present study

The aim of the present study is to explore whether those with SLI and dyslexia display distinct or overlapping cognitive profiles (WM and IQ) with respect to links to learning outcomes. Learning outcomes were measured using standardized tests of spelling and arithmetic, as spelling appears to be a persistent difficulty in those with dyslexia (Lyon et al., 2003; Moats, 1996), as well as those with SLI (Cordewener, Bosman, & Verhoeven, 2012). Students with dyslexia also display overlapping arithmetic disabilities (Dirks, Spyer, & de Sonneville, 2008; Gathercole et al., 2006), and arithmetic (declarative knowledge of math) appears to be impaired in those with SLI (Fazio, 1996; also Alt, Arizmendi, & Beal, 2014). The issue of how to characterize cognitive deficits in those with dyslexia and SLI can be addressed in part by drawing from recent research on how to characterize the phonological deficits of those with dyslexia and SLI by Ramus, Marshall, Rosen, and Van der Lely (2013; see also Bishop, Bishop, & Leonard, 2000; Grzadzinski, Huerta, & Lord, 2013). One view according to the *severity model* is that both groups display phonological deficits and thus exist on a single dimension, distinguished only by the severity of their cognitive deficits (see Catts et al., 2005). An alternative view is that both dyslexia and SLI may represent qualitatively distinct disorders, and thus display unique cognitive deficits (see Ramus et al., 2013). Thus, the aim of the present study is to compare the cognitive deficits (working memory and IQ) in children with dyslexia and those with SLI to better understand whether to categorize them via severity or distinct deficits.

4. Method

4.1. Participants

A total of 114 British students were recruited for this study (*M* age: 9.9 years; *SD* = 11.98 months, 86% boys). There were 24 children diagnosed with dyslexia based on standardized reading assessments (*M* age: 11.28 years, *SD* = 2.69 months, range = 7.70–17). Diagnosis was made by the school psychologists using psychometric tests such as The British Ability Scales I and II (Elliott, Smith, & McCulloch, 1997) and the Wechsler Intelligence Scale for Children-IV (Wechsler, 2004), and measures of individual achievement skills, such as the Wechsler Individual Achievement Test-2nd (Wechsler, 2001), Dyslexia Screener (Turner & Smith, 2004), Nelson-Denny reading test (Brown, Fishco, & Hanna, 1993), and the Neale Analysis of Reading Ability (Neale, 1966). All children with dyslexia received standardized reading scores of 85 or less in their respective assessments.

There were 40 children with a diagnosis of SLI based on the Clinical Evaluation of Language Fundamentals (Semel & Secord, 2000), which includes standardized tests of expressive and receptive language (*M* age: 9.96 years, *SD* = 2.09 months, range = 7.04–15.09). All SLI children received standard scores of 85 or less in the composite language score (range 52–85; *M* = 71.55, *SD* = 7.59). None of the children with dyslexia or SLI were diagnosed with ADD/ADHD or hearing impairments.

There was also a control group of 50 typically developing children (*M* age: 9.87 years; SD = 0.10 months, range = 8.17–11.75). None were identified with a learning disorder or were receiving special support at school. Consent was obtained from all participating parents/guardians. Students from all three groups were attending public schools (free state education) and were in mainstream classrooms.

4.2. Materials

4.2.1. Working memory

Working memory was measured using a standardized memory assessment, the Automated Working Memory Assessment (AWMA; Alloway, 2007). All test trials began with two items, and increased by one item in each block, until the participant was unable to recall three correct trials at a particular block. There were four trials in each block and the number of correct trials was scored for each participant. The move-forward and discontinue rules, as well as the scoring, were automated by the program.

The Screener version was administered and this was comprised of one verbal and one visuo-spatial working memory test. In Processing Letter Recall (verbal working memory), the participant views a letter that stays on the computer screen for one second. Participants then hear an audio clip of a letter. They verify whether the letter heard was the same as the letter they saw on the screen by clicking on a green tick mark for “Yes” or a red “X” for “No” on the screen. They then click on the letters they saw in the correct sequence.

Visual working memory was tested using the Mr. X test. Participants are presented with a picture of two Mr. X figures. They identify whether the Mr. Blue figure is holding the ball in the same hand as the Mr. Red figure. The Mr. Blue figure may also be rotated. At the end of each trial, participants have to recall the location of each ball in Mr. Blue's hand in sequence by selecting the correct locations on a picture with eight compass points. The compass points stays on the computer screen until a response was provided. Test-reliability of the AWMA was established in a random selection of the normative sample tested on two separate occasions, four weeks apart. The reliability coefficient for the verbal working memory tests was .86 and for the visuo-spatial working memory test, it was .84 (Alloway, 2007). Raw scores were converted into standard scores based on a normative sample (*M* = 100; *SD* = 15).

4.2.2. IQ[1]

Verbal and non-verbal IQ were indexed with the vocabulary and matrix reasoning tests, respectively, from the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999). In the vocabulary test, the participant provides a definition of a given word. In the matrix reasoning test, the participant is shown a set of shapes and has to select the next shape in the sequence from an array. Raw scores were converted into standard *T*-scores based on a normative sample (*M* = 50; *SD* = 10).

4.2.3. Academic attainment

Academic performance was assessed with arithmetic and spelling tests from the Wechsler Individual Achievement Test-Revised (WIAT-II, Wechsler, 2001). In the spelling test, the words were presented out aloud by the research and students wrote out words. The arithmetic test was a paper and pencil test that included a combination of math problems that included addition, subtraction, multiplication, division, fractions, and algebraic equations. Raw scores were converted to standard scores based on test norms (*M* = 100; *SD* = 15). Children were tested individually by a trained researcher, in a quiet classroom at school.

[1] We use the term ‘IQ’ here as a shorthand, as we administered two of the four tests in the abbreviated version of this standardized test.

Table 1
Descriptive statistics for working memory and IQ tests as a function of group (standard scores, unless otherwise stated ($M = 100$, $SD = 15$).

Standardized tests	Dyslexia *M* (*SD*)	SLI *M* (*SD*)	Control *M* (*SD*)
Verbal Working Memory	92.75 (22.70)	87.65 (7.62)	102.76 (10.84)
Visuo-spatial Working Memory	95.38 (18.55)	95.93 (17.07)	102.86 (19.25)
Verbal IQ: Vocabulary	40.21[a] (8.93)	38.37[a] (8.78)	47.24[a] (10.92)
Non-verbal IQ: Matrix reasoning	46.08[a] (12.88)	46.10[a] (10.66)	47.50[a] (9.25)
Academic: Spelling	81.42 (13.76)	75.75 (8.99)	100.12 (12.41)
Academic: Arithmetic	88.88 (13.64)	82.83 (9.63)	95.62 (8.57)

[a] T scores ($M = 50$, $SD = 10$).

5. Results

5.1. Group comparisons

In order to compare the group performances on the working memory and IQ, two separate MANOVAs were conducted on the standardized scores. The overall group term associated with Hotelling's T-test is reported in all instances, with post hoc comparisons set at an alpha level of .05 (Table 1). The first MANOVA performed on the verbal and visual working memory tests indicated a significant group difference: $F = 7.39$, $p < .001$; $\eta_p^2 = .12$. Post hoc tests (Bonferroni adjusted, $p < .05$) indicated that in the verbal working memory tests, both the children with dyslexia and SLI scored significantly lower than the control children. However, there were no significant group differences in the visuo-spatial working memory test.

The next MANOVA performed on the two IQ tests also indicated a significant group difference: $F = 5.22$, $p < .001$; $\eta_p^2 = .16$. Post hoc tests (Bonferroni adjusted, $p < .05$) indicated that in vocabulary, both the children with dyslexia and SLI scored significantly lower than the control children. However, there were no significant group differences in matrix reasoning. In general, the pattern suggests that both the children with dyslexia and SLI performed significantly worse in verbal cognitive tests (working memory and IQ) compared to the controls, but there was no difference between them in the nonverbal cognitive tests.

5.2. Predictors of learning

In order to investigate predictors of spelling, stepwise regression analyses were conducted separately for children in the dyslexic group and SLI group (Table 2). Predictor variables were verbal working memory, visuo-spatial working memory, vocabulary (verbal IQ), and matrix reasoning (nonverbal IQ). For dyslexia, matrix reasoning (nonverbal IQ) was a significant predictor of spelling (31%). For the SLI group, vocabulary (verbal IQ; 14%) predicted spelling scores.

In order to investigate predictors of math, stepwise regression analyses was conducted for children in the dyslexic group, SLI group, and control group (Table 2). Predictor variables were verbal working memory, visuo-spatial working memory, vocabulary (verbal IQ), and matrix reasoning (nonverbal IQ). For dyslexia and SLI, matrix reasoning predicted math performance (47% and 20%, respectively).

6. Discussion

There are two main findings in the present study: first, both those with dyslexia and SLI exhibited similar working memory and IQ profiles; secondly, there were differential links between these cognitive skills and spelling, but not math, as a function of learning disability. Looking first at cognitive profile (WM and IQ) between those with dyslexia and SLI groups, there is evidence for an overlap in profiles between them in both working memory and IQ (verbal and nonverbal). In contrast, there was partial independence between the two learning disability groups and the control group with respect to verbal working memory, where both groups performed significantly worse than the controls. This latter finding is noteworthy because previous research has identified verbal

Table 2
Stepwise regression analyses predicting spelling scores, as a function of disability group (dyslexia vs. SLI).

	Spelling	R^2 change	F	β	t
Dyslexia	Matrix	.31	10.04*	.56	3.17*
SLI	Vocab	.14	6.17*	.37	2.49*
	Math	**R^2 change**	**F**	**β**	**t**
Dyslexia	Matrix	.47	19.68*	.69	4.44*
SLI	Matrix	.2	9.51	.45	3.08*

* $p < .05$.

working memory deficits in SLI children using words or nonwords where the working memory task mirrored their core language deficits. In the present study, there were observed deficits for the SLI group even in a test using letters, suggesting that their verbal working memory deficit is pervasive and not purely stemming from a receptive language difficulty.

It is interesting to note that there was no support for the SLI children demonstrating a greater severity of cognitive impairments compared to those with dyslexia in either verbal or visuo-spatial skills. This pattern suggests that although both these disorder groups have unique language-based deficits, their working memory and IQ profile may be similar. While it was beyond the scope of the present study to compare the relation between the language deficits and working memory in these groups, we did investigate whether there were differential links between these cognitive skills and learning outcomes.

The present findings indicated a differential pattern for spelling as a function of learning disorder: in those with dyslexia, visual IQ (matrix reasoning) predicted spelling performance, while in those with SLI, verbal IQ (vocabulary) predicted spelling scores. This pattern fits with previous research suggesting the use of visual coding in language (Miller & Kupfermann, 2009). In contrast, vocabulary scores predicted spelling in children with SLI. It is not entirely clear why vocabulary predicted spelling in this group as they typically start producing language at a later age and there is a wide range of individual differences in vocabulary development (see Hick, Joseph, Conti-Ramsden, Serratrice, & Faragher, 2002, for further discussion). However, the reliance on an area of weakness may account for their poor overall performance in spelling (group standard score almost 2SD from the mean).

In contrast, nonverbal IQ (matrix reasoning) scores predicted math performance in both the dyslexic and SLI groups. An interesting pattern trend was that working memory was not linked to math performance. One explanation may be due to the fact that the math problems used in this present study were arithmetic-based, which draws on fact retrieval. Studies that have reported the role of working memory in math performance typically use word problems, which are multi-step and require additional processing of information (Alloway & Passolunghi, 2011). Therefore when students with dyslexia or SLI completed math problems, working memory may not be necessary because they are drawing from a library of math facts to complete these problems (see Evans, Kochalka, Ngoon, Wu, Qin, & Battista, et al., 2015). Furthermore, previous research suggests that older children, such as those in the present study, no longer rely on working memory skills to solve these types of math problems, but rather solve them differently compared to younger children (Reuhkala, 2001).

One limitation of the present study is that was a difference in the chronological ages of the two learning needs groups, where the age group mean of children with SLI was approximately 13 months higher than the age group mean of children with dyslexia. Although the use of standard scores may go some way to address this age gap, it may have affected between-group comparisons. Future research can look at age-matched controls to address this issue.

In summary, the pattern of results suggests that both children with dyslexia and SLI are characterized with poorer verbal working memory and IQ compared to controls, but preserved nonverbal cognitive skills. It appears that that these two disorder groups cannot be distinguished by the severity of their cognitive deficits. However, there was a differential pattern with respect to learning outcomes, where the children with dyslexia rely more on visual skills in spelling, while those with SLI use their relative strengths in vocabulary. This finding can inform educational practices. If we conceptualize dyslexia as a reading disorder and SLI as a language disorder, we may need different teaching strategies tailored to each disorder. For example, children with dyslexia tend to rely more on visuo-spatial skills in language-based tasks so it may be beneficial to implement more visual learning aids in the classroom for them. For children with SLI, targeting vocabulary could also show improvements in spelling. The use of strategies that are tailored to their individual profiles relating to the cognitive skills that underpin learning can lead to more enduring learning.

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