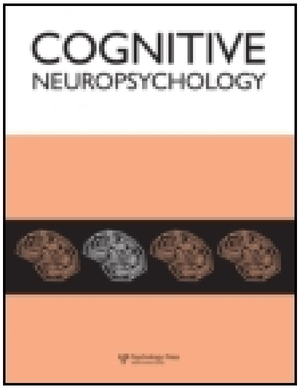

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Do children with dyslexia and/or specific language impairment compensate for place assimilation? Insight into phonological grammar and representations

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Do children with dyslexia and/or specific language impairment compensate for place assimilation? Insight into phonological grammar and representations

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English speakers have to recognize, for example, that *te[m]* in *te[m] pens* is a form of *ten*, despite place assimilation of the nasal consonant. Children with dyslexia and specific language impairment (SLI) are commonly proposed to have a phonological deficit, and we investigate whether that deficit extends to place assimilation, as a way of probing phonological representations and phonological grammar. Children with SLI plus dyslexia, SLI only, and dyslexia only listened to sentences containing a target word in different assimilatory contexts—viable, unviable, and no change—and pressed a button to report hearing the target. The dyslexia-only group did not differ from age-matched controls, but the SLI groups showed more limited ability to accurately identify words within sentences. Once this factor was taken into account, the groups did not differ in their ability to compensate for assimilation. The results add to a growing body of evidence that phonological representations are not necessarily impaired in dyslexia. SLI children's results suggest that they too are sensitive to this aspect of phonological grammar, but are more liberal in their acceptance of alternative phonological forms of words. Furthermore, these children's ability to reject alternative phonological forms seems to be primarily limited by their vocabulary size and phonological awareness abilities.

Keywords: Phonological representations; Place assimilation; Dyslexia; Specific language impairment.

Significant aetiological overlap has been reported between many developmental disorders, and the comorbidity of two in particular, dyslexia and specific language impairment (SLI), is receiving

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much attention in the current literature (Bishop & Snowling, 2004; Catts, Adlof, Hogan, & Weismer, 2005; Pennington & Bishop, 2009; van der Lely & Marshall 2010; inter alia).

Developmental dyslexia is defined as an impairment in acquiring literacy skills despite normal sensory abilities and nonverbal IQ and adequate exposure to written language (Snowling, 2000). SLI is defined as an impairment in acquiring language despite, again, normal sensory abilities and nonverbal IQ and adequate exposure[1] (Leonard, 1998). The overlap between the two disorders is substantial, with over half of dyslexic children having SLI and vice versa (McArthur, Hogben, Edwards, Heath, & Mengler, 2000). Several theories of dyslexia and SLI claim that phonological deficits of various types underlie both disorders and therefore play a key role in this overlap (Joanisse, Manis, Keating, & Seidenberg, 2000; Kamhi & Catts, 1986; Messaoud-Galusi & Marshall, 2010; Tallal, 2003).

There is considerable evidence for a phonological deficit in dyslexia (for some early work, see Bradley & Bryant, 1983; Lundberg & Høien, 1989; Wagner & Torgesen, 1987), although it has been argued that a phonological deficit is neither necessary nor sufficient to cause dyslexia and that the deficit might be much broader. Alternative theories of dyslexia include theories that ascribe the reading disability directly to purely visual or visual attention deficits (Stein & Fowler, 1981; Valdois, Bosse, & Tainturier, 2004; Vidyasagar & Pammer, 2010). Other hypotheses focus on underlying cognitive and/or neural causes of either the phonological deficit (such as auditory theories, Tallal, Merzenich, Miller, & Jenkins, 1998), or of broader manifestations including phonological, visual, and learning/memory deficits (such as the magnocellular theory, Stein & Walsh, 1997; the automaticity/cerebellar/procedural learning theory, Nicolson & Fawcett, 2007; the sluggish attentional shifting theory, Hari & Renvall, 2001). Recent theoretical proposals include a noise exclusion deficit (Sperling, Lu, Manis, & Seidenberg, 2005), a perceptual-centres perception deficit (Goswami et al., 2002), an anchoring deficit (Ahissar, 2007), and abnormal temporal sampling (Goswami, 2011).

Nonetheless, researchers generally agree that a phonological deficit is one of the most prominent symptoms of dyslexia and attempt to explain it one way or another. While it is widely acknowledged that there is a reciprocal relationship between reading and phonological skills so that the phonological deficit theory is partly circular (Castles & Coltheart, 2004), there is nevertheless ample longitudinal evidence for the precedence of phonological and more general language-related deficits in children at risk of becoming dyslexic (Guttorm, Leppänen, Richardson, & Lyytinen, 2001; Lyytinen et al., 2004; Molfese, 2000; Scarborough, 1990). Investigating the nature and the cause of the phonological deficit of dyslexic children thus remains a major research goal.

The phonological deficit in dyslexia makes itself manifest in three main areas: manipulating phonological representations (e.g., phoneme deletion tasks), holding verbal material in short-term memory (e.g., nonword repetition and digit span tasks), and accessing phonological representations (rapid naming tasks). What underlies this phonological deficit is less clear—degraded (i.e., fuzzier, noisier, or underspecified) or, conversely, overspecified phonological representations, limited working memory capacity, and speech perception problems have all been proposed and might be interrelated (Adlard & Hazan, 1998; Mody, Studdert-Kennedy, & Brady, 1997; Serniclaes, Van Heghe, Mousty, Carre, & Sprenger-Charolles, 2004; Snowling, 2000). A major current research question concerns whether the phonological deficit consists of an actual degradation of phonological representations themselves, or whether it is a deficit in accessing and manipulating those representations (Blomert, Mitterer, & Paffen, 2004; Dickie, 2008; Ramus & Szenkovits, 2008; Soroli, Szenkovits, & Ramus, 2010).

[1]SLI also occurs in signed languages, among deaf children who are acquiring a signed language as their native language (Mason et al., 2010).

The picture with regard to SLI is even more muddled. Although children with SLI are reported to have difficulties with phonological representations, phonological working memory, and speech perception (Bortolini & Leonard, 2000; Gallon, Harris, & van der Lely, 2007; Leonard, McGregor, & Allen, 1992; Tallal & Piercy, 1974), previous studies have rarely distinguished between SLI children with and without dyslexia (McArthur et al., 2000). Of those that have, some studies report similar deficits—for example, a deficit affecting the perception of rhythmic timing in both children with SLI only and those with dyslexia only (Corriveau, Pasquini, & Goswami, 2007; Goswami et al., 2002), while others report differences; for example, children with dyslexia only but not those with SLI only have a disadvantage for repeating consonant clusters in unstressed compared to stressed syllables (Marshall & van der Lely, 2009).

In this study, we focus our attention on a hitherto relatively neglected aspect of phonology in children with dyslexia and SLI—namely, place assimilation. We argue that this approach allows us to investigate not only the quality of children's phonological representations, but also their phonological grammar (which we define in due course). Furthermore, we address the issue of the overlap between the two disorders by comparing three groups: SLI + dyslexia, SLI only, and dyslexia only. In the remainder of this introduction we discuss the phonological phenomenon of place assimilation and why investigating assimilation promises to shed further light on our understanding of dyslexia and SLI.

Knowing a word involves knowing the phonological form of that word, a form that is idiosyncratic in that it differs between languages. Moreover, "the phonetic interpretation of a sentence makes reference not only to the phonological shape of individual words but also to the phonological effects that result from combining these words in sequence" (Harris, 1994, p. 1). Importantly, a word's phonological form can change when it is produced next to other words. Such phonological changes are not idiosyncratic: They display regular patterning, in that they are characteristic of particular sound sequences rather than particular words. One such pattern involves a process where a particular type of sound is systematically altered when it is juxtaposed with another particular type of sound. For example, in English this situation arises when a word-final coronal nasal or coronal stop is followed by a word-initial stop consonant with a different place of articulation, for example:

ten pens–te[m] pens, ten coins–te[ŋ] coins
good boy–goo[b] boy, good girl–goo[g] girl

This process is termed regressive place assimilation and is optional but widespread in connected speech (Barry, 1985).

In cases such as these, it is not enough to know that the phonological shape of the word ten is /ten/, but that this phonological shape can be altered in a systematic way in connected speech. Despite the fact that these phonological changes can potentially disrupt lexical recognition, since they can neutralize contrasts between phonemes, they seem to matter little in everyday continuous speech. Native listeners are able to "compensate" for assimilation—that is, undo the change and thereby access the correct lexical form, due to their implicit knowledge of which sound changes are or are not allowed at word junctures in their language. For example, English has place assimilation but not voicing assimilation, whereas French has voicing assimilation but not place assimilation. Hence *football* is often realized as *foo[p]ball* in English but as *foo[d]ball* in French.

One explanatory model of place assimilation is "phonological inference", first proposed by Marslen-Wilson and colleagues (Marslen-Wilson, Nix, & Gaskell, 1995). Phonological inference is a language-specific mechanism that undoes the effect of assimilation rules that apply during phonological planning prior to production. This mechanism is variously proposed to operate on the basis of some kind of rule-based "reverse" phonology (Gaskell & Marslen-Wilson, 1996) or through a statistically based recurrent connectionist model (Gaskell, Hare, & Marslen-Wilson, 1995).

More recently, Darcy and her colleagues have proposed a model whereby compensation for assimilation is driven by multiple cues: universal phonetic compensation for some coarticulation cues, inverse phonological rules that are specific to the particular language in question, and lexical influences (Darcy, Ramus, Christophe, Kinzler, & Dupoux, 2009). Darcy et al. ran a word detection task, where participants pressed a button as soon as they detected a particular target word—for example, *brown*. Participants were presented with an assimilated form of the word, either in a context in which assimilation was possible in English or French—for example, *fa[p] puppy* (place assimilation—possible in English), *bla[g] glove* (voicing assimilation—possible in French)—or a context in which it was impossible—for example, *fa[p] squirrel*, *bla[g] rug*. Darcy et al. found that American English adults compensated more for place than for voicing assimilation, while French adults showed the opposite pattern and compensated more for voicing assimilation. However, they also found that the non-native assimilation rule (i.e., voicing assimilation for English and place assimilation for French) induced a small but significant compensation effect, suggesting that both language-specific and language-independent mechanisms are at play.

Lexical phonological representations must be abstract enough to encompass variability due to voice, intonation, and linguistic context, but must also include enough phonetically relevant detail to discriminate near lexical neighbours and to permit the child to learn about the various systematic sources of variability in the sounds of words. Therefore, phonological learning mechanisms must be able to both abstract over and incorporate phonetic details and information about words' surrounding context (Fisher & Church, 2001). Assimilatory processes are part of the listener's phonological grammar, where by "grammar" we mean the set of abstract rules or constraints that explain the mapping between the underlying form of a word and the surface form (i.e., the form that is actually uttered; Chomsky & Halle, 1968; Prince & Smolensky, 2004). Investigating assimilation therefore provides a novel test of the accuracy of phonological representations at the segmental level in children with dyslexia and SLI: If phonological units are poorly represented, then phonological grammar—that is, the mapping process between a word's underlying and surface form, in this case at word junctures—would plausibly be affected. To our knowledge, assimilation has not been studied in children with SLI, but there have been at least a couple of studies in individuals with dyslexia.

The effect of assimilatory context has been tested in Dutch children with dyslexia aged 7–9 years (Blomert et al., 2004). In a two-alternative forced-choice task, children were asked to report whether they heard /m/ or /n/ in compound words whose context for assimilation varied. They heard unassimilated and assimilated forms of *tuin* in an appropriate context[2] (*tui[n]bank* and *tui[m]bank*, "garden bench"), an inappropriate context (*tui[n]stoel* and *tui[m]stoel*, "garden chair"), or no context (*tui[n]* and *tui[m]*). The dyslexic children showed the same pattern of results as their controls: Identification of the nasal was more difficult in the appropriate context than in the inappropriate or no context conditions, and there was a bias towards the canonical form *tui[n]bank* for both groups. However, the results of this study are not easily generalizable as they were obtained on a single pair of words.

French adults with dyslexia were tested on Darcy et al.'s experimental stimuli (Szenkovits, Darma, Darcy, & Ramus, 2011). Adults with dyslexia compensated for voicing assimilations in viable contexts to the same extent as did controls and, again like the controls, rarely compensated for place assimilation. Furthermore, in a production experiment, the dyslexic group produced voicing assimilation around 40% of the time in

[2]Here and in the rest of this paper, we use the terms "appropriate" or "viable" for a phonological context in which the target assimilation may occur, according to the phonology of the particular language under consideration (for example, here, in Dutch, a bilabial stop is an appropriate context for regressive place assimilation). Conversely, an inappropriate or unviable context is a context where such assimilation does not normally occur (here, a fricative is not an appropriate context for place assimilation in Dutch).

viable contexts but not in unviable contexts, as did the controls.

In summary then, it would appear that children with dyslexia are able to acquire the phonological assimilation and compensation processes of their native language. That they are able to acquire this aspect of their phonological grammar suggests, contrary to the received wisdom, that their phonological representations are detailed enough to represent the relevant phonological contexts and the various forms of the segments undergoing assimilation. However, the experiments of Szenkovits et al. (2011) were only carried out with well-compensated dyslexic adults and so need to be run on children. Furthermore, assimilation has never been tested in English-speaking children with dyslexia, nor has it been tested in children with SLI. Therefore we set out to investigate whether English-speaking children with dyslexia and/or SLI are impaired in their use of the place assimilation rule, as compared with typically developing children matched for age and different aspects of reading and language ability.

Method

Background

In order to investigate participants' implicit knowledge of assimilation, we consider context effects: Occurrences of assimilation in the stimuli are either viable (i.e., surface in an appropriate context for assimilation) or unviable (the context is not normally a trigger for the modification). There is a third condition ("no change") in which the target word surfaces without any change, in order to provide baseline performance for the ability to report the word within a sentence. These conditions are illustrated in Table 1.

We based our task on the English word-reporting task of Darcy et al. (2009), but adapted it for children, making the sentences simpler and the procedure more child orientated. In their task and ours, target words are presented auditorily and are followed by a sentence containing the target, and participants are asked to report when they hear the target word correctly pronounced. In the sentences, the target word surfaces either with a change of the final place feature or without any change (baseline). The change occurs either in a viable context or in an unviable context. Participants press a button when they think that the sentence contains the target word correctly pronounced. A *yes* response (button press) indicates that the word in the sentence is being treated as a token of the target, and a *no* response (no button press) indicates that the change altering the word blocks its interpretation as a token of the target.

This design therefore permits us to obtain a measure of the degree of tolerance for modifications altering word forms and the degree to which this tolerance depends on phonological context in the way defined by the language's phonological grammar. If a participant reports the changed word as canonical more often in viable than in unviable contexts, then that indicates that he or she has acquired sensitivity to English place assimilation rules. For example, recognizing *goo[b]* as a good instance of "good" when it is followed by "boy" but not when it is followed by "friend" implies some knowledge of both the phonological features that may be assimilated in English (place but not voicing) and of the contexts in which they may be assimilated (plosives, but not fricatives). Thus such an effect can be explained neither by solely attending to the acoustic/phonetic details of the target word, nor by general compensation for coarticulation processes.

Table 1. *Experimental conditions*

Condition	*Example*	*With carrier sentence*
no change	*brow[n] roof*	*My neighbour has an ugly brow[n] roof*
viable context	*brow[m] bell*	*My neighbour has an ugly brow[m] bell*
unviable context	*brow[m] lamp*	*My neighbour has an ugly brow[m] lamp*

Participants

Three clinical groups (SLI + dyslexia, SLI only, and dyslexia only) and three control groups also participated in the study (two younger groups matched for different aspects of language and literacy abilities (LA1 and LA2, where "LA" stands for "language/literacy ability"), and one group matched for chronological age (CA). The children in the clinical groups were recruited two years prior to the current study, to take part in a comprehensive investigation of phonological abilities in SLI and/or dyslexia (Marshall, Harcourt-Brown, Ramus, & van der Lely, 2009; Marshall & van der Lely, 2009). Note that all participants continued to be in special education during this time and were tested every six months as part of that investigation. The children in the clinical groups were between the ages of 8;00 and 12;11 years at the time of recruitment and between 10;00 and 15;00 years at the time of this particular study. The following criteria were used to select children for the clinical groups:

A minimum standard score of 80 on two tests of nonverbal cognition (Raven's Standard Progressive Matrices, RPM, Raven, 1998; and the Block Design subtest from British Ability Scales−2, BAS, Elliott, 1996) and an average combined minimum score of 85 (i.e., −1 *SD* below the mean or higher); no additional diagnoses of attention-deficit/hyperactivity disorder (ADHD), autistic spectrum disorder (ASD) or dyspraxia; a statement of special educational need and attendance at a special school or unit for children with SLI or dyslexia.

In addition, selection for SLI was based on the following criteria:

A standard score of 78 or below (i.e., 7th percentile, z score of −1.5) on at least one of the following: Test for Reception of Grammar−2 (TROG; Bishop, 2003); British Picture Vocabulary Scales−2 (BPVS; Dunn, Dunn, Whetton, & Burley, 1997); Sentence Repetition subtest of Clinical Evaluation of Language Fundamentals−3 (CELF; Semel, Wiig, & Secord, 1995); Test of Word-Finding−2 (TWF; German, 2000).

Selection for the dyslexia group used the following criteria:

A standard score of 78 or below (i.e., 7th percentile, z score of −1.5) on the Single Word Reading subtest of the Wechsler Objective Reading Dimensions (WORD; Wechsler, 1990), which comprises phonologically regular and irregular words.

In order to obtain a detailed profile of our participants' language, literacy, and phonological abilities, we carried out some additional tests. We administered two nonstandardized language tests: the Test of Active and Passive Sentences (TAPS; van der Lely, 1996)—a test of reversible active and passive sentence comprehension—and the Verb Agreement and Tense Test (VATT; van der Lely, 2000)—a test of third-person agreement and past-tense marking on regular and irregular verbs. These two tests target language structures that are particularly impaired in SLI: passive sentences and finite verb morphology. We calculated age-corrected z scores for the TAPS and the VATT on the basis of the control data. In addition, we administered the Single Word Spelling and Comprehension subtests of the WORD and the Nonword Reading subtest of the Phonological Assessment Battery (PhAB; Frederickson, Frith, & Reason, 1997). To gain a picture of participants' phonological abilities, we used three other subtests of the Phonological Assessment Battery—Rhyme, Spoonerisms, Rapid Naming (digits)—and also the Digit Span subtest (forwards and backwards) of the Wechsler Intelligence Scales for Children (WISC; Wechsler, 1992). These tests tap a range of different abilities that traditionally fall under the rubric of "phonology" in dyslexia research; the rhyme and spoonerisms tasks test phonological awareness and also require phonological representations to be held in phonological working memory whilst they are being compared/manipulated; the rapid naming task requires rapid access to lexical phonological representations; and the digit span task requires phonological working memory.

In order to test children's phonological representations using a task that was unspeeded and that had minimal working memory and metaphonological demands, we created a picture−word matching task. This task allowed us to investigate whether children are able to distinguish between two familiar phonological representations that differ only minimally. Stimuli were restricted to monosyllabic CVC, CV, or VC words (where C is consonant, V is vowel), presented in minimal pairs (see Appendix A for a full list). The pairs differed in either initial or final consonant, and half were presented with multitalker babble as background noise (with a signal-to-noise ratio of 0 dB) in order to stress the child's perceptual system. The experiment was run on a laptop computer that had a touch screen to record the participants' responses. In each trial, participants saw two pictures whose names differed only by one consonant sound, and they heard the name of one of those pictures. They had to touch the picture that corresponded to the word that they heard.

The results of all these tests are set out in Tables 2 and 3.

We found a substantial overlap between the SLI and dyslexia groups even though many of the children had an official diagnosis of only a single deficit. Thus, many children fulfilled our criteria for both SLI and dyslexia and so were assigned to the SLI + dyslexia group. For this round of testing, the numbers in each group were as follows: 28 SLI + dyslexia, 10 SLI only, and 18 dyslexia only.

Children in the control groups had to have a standard score of 85 or above on every language and literacy task along with no history of speech or language delay or special educational needs. They were between 5;00 and 12;11 years of age at the time of recruitment and 7;01−14;11 years in this current round of testing. They were divided into three age bands: LA1 ($N = 15$), 7;01−8;06, mean 7;11; LA2 ($N = 16$), 8;07−10;00, mean 9;03; CA ($N = 30$), 10;01−14;11, mean = 11;10. The oldest group was a chronological age-matched control group for the SLI and dyslexic groups and therefore allowed us to investigate whether the phonological skills of

Table 2. *Number of participants in each group, age of participants at time of experimental testing, and results of nonverbal and language tests*

		SLI + dyslexia (N = 28)		*SLI only (N = 10)*		*Dyslexia only (N = 18)*		*LA1 controls (N = 15)*		*LA2 controls (N = 16)*		*CA controls (N = 30)*	
Test	*Score*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age†		12.75	1.15	12.44	1.74	12.32	1.23	7.92	0.50	9.23	0.50	11.84	1.26
RPM	raw	33.71	4.76	37.9	4.09	38.11	5.90	18.87	4.14	27.88	7.73	39.00	8.47
	z	−0.55	0.37	0.20	0.74	0.19	0.94	0.48	0.40	0.80	0.77	0.63	0.90
BAS‡	*z*	−0.44	0.46	−0.18	0.57	0.22	0.77	0.77	1.23	0.47	1.03	0.70	0.96
TROG	raw	10.75_{a}	3.30	$13.80_{b,c}$	2.30	$16.22_{c,d}$	2.10	$12.00_{a,b}$	3.66	$14.81_{c,d}$	2.20	16.93_{d}	1.91
	z	−1.64	0.91	−0.78	0.71	0.05	0.72	0.75	0.92	0.60	0.70	0.39	0.54
BPVS	raw	78.14_{b}	16.68	$87.30_{b,c}$	14.60	$98.89_{c,d}$	13.18	64.73_{a}	10.63	85.19_{b}	7.74	102.07_{d}	13.12
	z	−1.28	0.76	−0.65	0.76	0.08	0.67	0.44	0.76	0.86	0.56	0.50	0.64
CELF	raw	19.20_{a}	8.96	$23.95_{a,b}$	5.82	45.11_{c}	12.65	30.47_{b}	8.88	$37.75_{b,c}$	9.27	52.50_{c}	9.65
	z	−2.17	0.25	−2.00	0.42	−0.43	0.78	0.57	0.50	0.42	0.76	0.32	0.69
TWF	raw	39.04_{a}	10.24	50.90_{b}	8.17	$60.83_{b,c}$	7.98	39.80_{a}	12.35	$58.63_{b,c}$	6.28	64.73_{c}	7.39
	z	−2.26	0.61	−1.25	0.61	−0.30	0.76	0.14	0.61	0.55	0.78	0.39	0.79
TAPS	raw	26.14_{a}	5.90	26.30_{a}	5.52	32.83_{b}	2.31	27.13_{a}	5.77	$30.06_{a,b}$	3.07	31.90_{b}	3.60
	z	−1.37	1.28	−1.29	1.31	0.16	0.53	−0.12	1.19	0.21	0.65	0.05	0.78
VATT	raw	17.18_{a}	10.44	27.50_{b}	6.87	$34.28_{b,c}$	4.24	29.13_{b}	6.72	$33.81_{b,c}$	3.37	37.37_{c}	2.22
	z	−4.09	1.95	−2.10	1.09	−0.67	0.81	−0.28	1.23	0.22	0.61	0.07	0.52

Note: For each test, raw scores that share a subscript do not differ significantly at the $p = .05$ level on post hoc testing with Bonferroni correction. SLI = specific language impairment. LA = language/literacy ability. CA = chronological age. *Key to tests:* RPM: Raven's Progressive Matrices (Raven, 1998). BAS: British Ability Scales, Block Design subtest (Elliott, 1996). TROG: Test of Reception of Grammar (Bishop, 2003). BPVS: British Picture Vocabulary Scales (Dunn, Dunn, Whetton, & Burley, 1997). CELF: Clinical Evaluation of Language Fundamentals, Sentence Repetition subtest (Semel, Wiig, & Secord, 1995). TWF: Test of Word Finding (German, 2000). TAPS: Test of Active and Passive Sentences (van der Lely, 1996). VATT: Verb Agreement and Tense Test (van der Lely, 2000).

†Children were an average of 24 months younger than this at the time that the standardized language and literacy tests were administered. ‡We do not report raw scores for the BAS, because, depending on their age, children attempt a different number of items—the raw scores therefore vary in ways that do not reflect performance on this task.

Table 3. *Results of literacy and phonological tests*

			SLI + dyslexia (N = 28)		*SLI only (N = 10)*		*Dyslexia only (N = 18)*		*LA1 controls (N = 15)*		*LA2 controls (N = 16)*		*CA controls (N = 30)*	
Test		*Score*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
WORD	Reading	raw	18.39_{a}	7.05	36.90_{b}	9.55	20.00_{a}	5.52	18.60_{a}	9.66	34.63_{b}	4.67	44.57_{c}	5.86
		z	−2.07	0.46	−0.18	0.81	−1.83	0.33	1.20	0.95	1.39	0.88	0.96	0.73
	Spelling	raw	16.57_{a}	4.32	27.40_{b}	7.31	17.28_{a}	3.04	15.20_{a}	4.97	24.38_{b}	4.83	33.17_{c}	5.48
		z	−1.95	0.41	−0.43	0.54	−1.78	0.45	1.01	0.62	1.09	0.93	0.58	0.76
	Comprehension	raw	6.79_{a}	4.86	$16.30_{b,c}$	5.83	$10.89_{a,b}$	6.35	8.40_{a}	7.14	18.75_{c}	3.87	27.30_{d}	3.75
		z	−2.58	0.55	−1.10	0.72	−1.88	0.65	0.80	0.94	0.91	0.69	1.06	0.89
PhAB	Nonword reading	raw	6.12_{a}	4.47	$14.00_{b,c}$	4.88	$9.39_{a,b}$	3.63	10.53_{b}	4.87	14.75_{c}	2.98	17.90_{c}	2.92
		z	−1.03	0.55	−0.03	0.53	−0.56	0.49	0.77	0.34	0.67	0.34	1.06	0.75
	Rhyme	raw	8.21_{a}	4.25	17.00_{c}	3.77	12.28_{b}	5.72	13.20_{b}	5.02	17.50_{c}	3.27	18.63_{c}	1.69
		z	−1.56	0.49	−0.09	0.50	−0.82	1.15	0.82	0.33	0.88	0.57	0.48	0.60
	Spoonerisms	raw	6.89_{a}	5.41	15.40_{b}	7.43	$11.11_{a,b}$	6.52	7.67_{a}	2.58	15.00_{b}	6.13	22.97_{c}	4.78
		z	−1.18	0.54	−0.23	0.77	−0.63	0.60	0.38	0.15	0.78	0.59	0.97	0.65
	Rapid naming	raw	$73.86_{a,b}$	23.67	$54.80_{b,c}$	12.70	$76.44_{a,b}$	23.74	94.07_{a}	24.66	$65.63_{b,c}$	15.87	47.37_{c}	15.11
		z	−1.12	0.71	−0.19	0.69	−1.05	0.76	−0.24	0.43	0.53	0.79	0.78	0.95
WISC	Digit span	raw	9.43_{a}	1.81	10.30_{a}	2.21	10.94_{a}	2.07	14.40_{b}	3.81	13.69_{b}	2.55	15.83_{b}	3.01
		z	−1.57	0.48	−1.27	0.78	−1.04	0.50	1.13	1.15	0.58	0.85	0.49	0.91
Picture−word matching		raw	$91.46_{a,b}$	5.29	$92.95_{a,b,c}$	3.85	$94.94_{b,c}$	3.40	87.39_{a}	9.36	$91.54_{a,b,c}$	6.34	95.33_{c}	5.07

Note: For each test, raw scores that share a subscript do not differ significantly at the $p = .05$ level on post hoc testing with Bonferroni correction. SLI = specific language impairment. LA = language/literacy ability. CA = chronological age. *Key to tests:* WORD: Wechsler Objective Reading Dimensions (Wechsler, 1990). PhAB: Phonological Assessment Battery (Frederickson, Frith, & Reason, 1997). WISC: Wechsler Intelligence Scales for Children (Wechsler, 1992).

children with SLI and dyslexia fall below age expectations. However, as described in the next section, the two younger control groups allowed us to investigate more closely the relationship between phonology, literacy, and language abilities such as word and sentence comprehension.

There were significant group differences on all the language, literacy, and phonology tests, as measured by a series of one-way analyses of variance (ANOVAs) on raw scores ($p < .001$ for each). Differing subscripts in Tables 2 and 3 indicate significant differences on post hoc testing with Bonferroni correction. At this point in the text, we highlight the results for the measures that were not used as admission criteria to the different clinical groups. For the two nonstandardized tests, tapping syntax and morphosyntax—the TAPS and the VATT—the two SLI groups, but not the dyslexia-only group, score significantly below chronological age expectations (see Table 2). For the PhAB nonword reading task, this pattern is, not surprisingly, reversed—this time it is the two dyslexia groups, but not the SLI group, that fall below chronological age expectations. For the phonological tasks—namely, the other three subtests of the PhAB (Rhyme, Spoonerisms, and Rapid Naming) and the WISC Digit Span—the two dyslexia groups also fall below chronological age expectations, as would be expected from many previous studies of dyslexia. The SLI-only group also shows weaknesses in phonology, but only falls below chronological age expectations for two tasks: Spoonerisms and Digit Span.

Characteristics of control groups

Younger controls with comparable linguistic and literacy abilities are widely used in research with children who have dyslexia and/or SLI. If performance on a particular task falls below chronological age expectations, this method of matching allows researchers to determine whether the lower performance is still in line with general language and literacy abilities, or whether it falls below even those expectations. Typically in research with children who have dyslexia and SLI, performance on phonological tasks is at or below that expected from general language and literacy abilities (e.g., Corriveau et al., 2007; Gallon et al., 2007; Joanisse et al., 2000).

In line with a previous study (Marshall et al., 2009), we carried out post hoc analyses to determine which control groups provided the best matches for each clinical group for language and literacy abilities—namely, for the comprehension of a mixed range of sentences (TROG), single word comprehension (BPVS), and reading abilities (WORD reading). These analyses reveal that the LA1 group provides the best match to the SLI + dyslexia group for sentence comprehension and to both the dyslexia groups for single word reading. The LA2 group provides the best match to the SLI + dyslexia group for vocabulary comprehension and to the SLI-only group for all three tasks. In contrast, the CA group provides the best match to the dyslexia-only group with respect to sentence and vocabulary comprehension. These matches are set out in Table 4 for clarity.

Table 4. *Group matches*

Language/literacy measure	*LA1 controls*	*LA2 controls*	*CA controls*
Sentence comprehension: TROG	SLI + dyslexia	SLI only	Dyslexia only
Receptive vocabulary: BPVS		SLI + dyslexia SLI only	Dyslexia only
Single word reading: WORD	SLI + dyslexia Dyslexia only	SLI only	

Note: SLI = specific language impairment. LA = language/literacy ability. CA = chronological age. *Key to tests:* TROG: Test of Reception of Grammar (Bishop, 2003). BPVS: British Picture Vocabulary Scales (Dunn, Dunn, Whetton, & Burley, 1997). WORD: Wechsler Objective Reading Dimensions (Wechsler, 1990).

Stimuli

A total of 16 target adjectives were chosen, 8 ending in /n/, 4 in /d/, and 4 in /t/ (see Appendix B for a full list). Each of the target adjectives was associated with a triplet of context nouns. Each adjective in a triplet corresponded to one of the experimental conditions—no change, viable change, and unviable change. For the viable-change condition, the noun's initial consonant was a stop consonant that could trigger place assimilation of the adjective-final consonant (e.g., *brown bell–brow[m] bell*; *fat puppy–fa[p] puppy*). For the unviable-change and no-change conditions, the noun's initial consonant was a nonstop consonant and could not trigger place assimilation of the adjective-final consonant. However, in the stimuli that participants heard, adjectives in the viable and unviable change conditions had undergone assimilation (incorrectly, of course, in the case of the unviable change condition; e.g., *brown lamp–brow[m] lamp*; *fat squirrel–fa[p] squirrel*).

Three sentence frames were constructed for each of the target items. A sentence frame consisted of a sentence beginning and sentence ending, where each of the three adjective–noun combinations could be inserted to create a plausible sentence (e.g., *My neighbour put a brow[n] roof above his door*; *My neighbour put a brow[m] bell above his door*; *My neighbour put a brow[m] lamp above his door*).

For the purposes of counterbalancing, we made three experimental lists. In each list, all three conditions were present for each item, but in different sentence frames. The sentence frames were rotated across the three lists, so that across the experimental lists all three conditions appeared in all three sentence frames.

Participants first participated in a training trial with 18 training sentences using a different set of adjectives, where they received feedback as to whether their answer was correct or incorrect. Modifications involved voicing, manner, and place contrasts at the ends of words, or deletion of a word-final syllable or alteration of a rime, in order to drive the participants' attention to the precise form of words (e.g., target *cheap*, sentence containing *chea[b] rooms*; target *fine*, sentence containing *final score*). Crucially, these training sentences did not contain any cases of place assimilation in either viable or unviable contexts, so the feedback could not affect responses on test sentences.

Sentences were recorded by a female speaker (the first author), and the target words by a male speaker, both with standard southern British English accents. Post hoc, and as part of the experiment on adult participants described below, we verified that the target words had indeed been produced as intended.

Procedure

The experiment was programmed in Visual Basic. A wizard appeared on the left hand side of the screen and said the target word; 500 ms later a girl appeared on the right-hand side of the screen and said a sentence. Participants were requested to press a button when they thought they heard the girl say the wizard's (i.e., target) word in her sentence exactly as he had said it and to refrain from pressing the button otherwise. This instruction—together with the specific training—was given so that they paid attention to the actual form of the words. Participants were told to respond as quickly as possible, without waiting until the end of the sentence. They had up to one second following the end of the sentence to make their reply if they needed it.

Presentation of each trial was controlled by the experimenter. Instructions were presented orally. During the training phase, feedback was provided in the shape of a green smiley face for a correct response and a red sad face for an incorrect response. There was no feedback in the test phase. Each of the three lists was pseudorandomized, and, within each list, each participant received items in the same order. The entire procedure lasted approximately 12 minutes.

Predictions

Correct understanding of this task should be reflected by the participants' ability to report target words in the no-change condition and to reject them in the unviable-context condition. The performance of these two conditions serves as a baseline to evaluate the responses in the viable-context condition. If participants fully compensate for the phonological rule, they should (erroneously) report the target word to the same extent as in the no-change condition, despite the fact that the target underwent the same featural change as in the unviable condition. If there is no compensation for the phonological rule, participants should respond as in the unviable-context condition—that is, reject (correctly) the changed word as a target. Given previous studies, we did not predict full compensation for assimilation. In the study by Darcy et al. (2009), adult American English listeners compensated for place assimilation 46% of the time in viable contexts. Therefore, the difference in acceptance of the changed word between the viable and unviable conditions can be seen as an index of language-specific phonological compensation.

We predict a developmental progression within control children, whereby the magnitude of the difference between acceptance in the viable and unviable conditions increases with age. Given previous results for voicing assimilation in French and place assimilation in Dutch, we might expect the dyslexia-only group to show the same pattern as the controls. However, for all three clinical groups (SLI + dyslexia, SLI only, and dyslexia only), there are several possible predictions depending on one's hypothesis about the nature of their deficit, and the predictions need not be the same for the three groups.

- "*Degraded phonological representations*" *hypothesis:* If children with dyslexia and/or SLI have degraded phonological representations at the segmental level (which is predicted in particular by auditory theories; Tallal et al., 1998; Tomblin & Pandich, 1999), then one would predict that they would show fewer consistent responses overall (because of less precise representation of target phonemes) and less sensitivity to phonological context—that is, less difference between viable and unviable context conditions (because of less precise representations of phonological contexts).
- "*Impaired acquisition of phonological rules*" *hypothesis:* Alternatively, they might have a more specific deficit in the acquisition of phonological rules, possibly as a particular manifestation of their grammatical impairment in the phonological domain. This would predict again that they would be less sensitive to the phonological context. Two opposite predictions might follow: They might have an overall tendency not to compensate for assimilation, and so would not report target words in either viable nor unviable contexts, or they might have a tendency to overcompensate, reporting target words in both viable and unviable contexts.
- "*Intact phonological representations*" *hypothesis:* Yet another hypothesis would be that they do not have degraded phonological representations (Ramus & Szenkovits, 2008; Soroli et al., 2010), or at least not at the segmental level (van der Lely & Marshall, 2011). This would predict no difference with the control children.
- "*General task difficulties*" *hypothesis:* Finally, they might have more general difficulties performing the task. Indeed the word-reporting task is quite complex, so its performance could be affected by various cognitive limitations, including: (a) underspecification of phonological lexical forms; (b) poor metalinguistic abilities; (c) poor vocabulary (inducing less familiarity with target words); (d) poor verbal short-term memory (recognizing words within sentences requires verbal short-term memory; Jacquemot, Dupoux, Decouche, & Bachoud-Levi, 2006); (e) poor inhibition (word reporting needs to be inhibited in the unviable context). All these task performance factors would predict less difference between the two baseline conditions (no change and unviable context). Note that this hypothesis is not incompatible with any of the previous three, so that the results might reflect a superimposition of several of the predictions proposed here. We specifically test whether our measures of vocabulary size, verbal short-term memory, metaphonological abilities, and simple (CVC) phonological

representations at the word level predict performance on the assimilation task.

Checking the adequacy of the stimuli

Before we ran the experiment with children, we tested the materials on adults in two ways. First, we ran a replication of Darcy et al.'s (2009) word-reporting study, using the procedures outlined previously. The aim was to check that the stimuli to be used with the children produced the same pattern of results with adults as Darcy et al.'s stimuli had. We then ran a control task, whereby participants were asked to categorize the target words that had been extracted from their carrier sentences. Here the aim was to check that the stimuli used in the viable and unviable conditions were acoustically comparable.

A group of 11 adults participated. All were speakers of British English recruited from University College London and were between the ages of 18 and 38 years. Their word-reporting data are presented in Table 5.

A repeated measures ANOVA by subjects revealed a significant difference between the adults' performance in the different conditions of the word-reporting task (i.e., the no change, viable, and unviable), $F_1(2, 20) = 100.83$, $p < .001$. Paired-sample t tests showed that the differences between all conditions were highly significant: viable versus unviable, $t(10) = -7.692$, $p < .001$; no change versus unviable, $t(10) = 15.539$, $p < .001$; and no change versus viable, $t(10) = 6.145$, $p < .001$. A one-way ANOVA by items also showed highly significant differences between conditions, $F_2(2, 47) = 50.441$, $p < .001$. Paired-sample t tests again showed that the differences between all conditions were highly significant: viable versus unviable, $t(15) = -5.500$, $p < .001$; no change versus unviable, $t(15) = 10.829$, $p < .001$; and no change versus viable, $t(15) = 6.483$, $p < .001$. Although detection rates in the viable and unviable conditions were about 10% higher than those reported by Darcy et al. (2009; they found approximately 50% detection for the viable and 15% detection for the unviable conditions), the basic pattern of results was the same.

To assess whether the critical items' final consonants had been produced as prescribed by the experimental conditions, after adults had completed the word-reporting task they undertook a control task. All target words were extracted from their carrier sentences and were presented in isolation in a forced-choice categorization task. The motivation for this task was to check that the difference we observed between the viable and unviable conditions in the main task was not simply due to differences in the target words: Rather, it was due to differences in the context in which those words were presented. Words were presented auditorily and were followed by a 3,000-ms silence, during which participants had to circle the consonant they heard on the response sheet. Participants were always given the choice between the original consonant and the assimilated one. For example, for the word "brown" the choice was between "n" and "m". However, they also had a free cell in which to place an alternative consonant if that is what

Table 5. *Responses: Percentage reporting of target word*

	Adult		*SLI + dyslexia*		*SLI only*		*Dyslexia only*		*LA1*		*LA2*		*CA*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No change	97.16	4.30	93.95	8.05	94.33	4.62	88.54	15.79	91.52	9.37	92.97	7.53	93.07	6.35
Viable	61.93	18.64	87.45	12.47	80.63	23.28	81.94	12.84	77.17	16.12	76.17	20.44	72.20	20.63
Unviable	25.00	13.11	80.62	16.64	73.75	22.20	58.68	23.59	66.07	20.02	55.86	24.53	43.68	21.63

Note: Illustrative example. SLI = specific language impairment. LA = language/literacy ability. CA = chronological age. Target word to be reported: *brown* No-change condition: *brow[n] roof* Viable condition: *brow[m] bell* Unviable condition: *brow[m] lamp*

Table 6. *Results for the forced-choice categorization of extracted words*

	% final consonants perceived as changed	
Condition	*M*	*SD*
No change (e.g., *brow[n]*)	2.86	2.17
Viable change (e.g., *brow[m]*)	92.38	6.23
Unviable change (e.g., *brow[m]*)	87.86	7.65

Note: Adult group only.

they heard. The entire procedure lasted about 15 minutes. The results are shown in Table 6.

The rates of perception of the final consonant as "changed" are more accurate than those reported in Darcy et al's (2009) experiment (which were 23%, 74%, and 78% for the no-change, viable, and unviable conditions, respectively). A Wilcoxon signed ranks t test revealed that the difference between the viable and unviable conditions just missed significance, $Z(9) = -1.834$, $p = .067$. Therefore, there was a trend for target words from viable contexts to be pronounced more assimilated than words from unviable contexts. This difference could only have reduced the likelihood of reporting the target words in viable contexts in the main experiment and therefore makes our estimation of compensation for assimilation rather conservative.

Results

Two children with SLI + dyslexia refused to complete the task, and a technical failure resulted in data from one child in the LA1 control group not being saved. We removed responses where the reaction time was negative or below 150 ms. This amounted to 2.84% of the data from the three clinical groups and 2.41% of the data from the three control groups. Results are shown in Table 5.

A 3 (condition: no change, viable, unviable) × 6 (group) ANOVA revealed a significant interaction between condition and group, $F(10, 212) = 6.71$, $p < .001$, $\eta_p^2 = .240$, and main effects of condition, $F(2, 212) = 132.35$, $p < .001$, $\eta_p^2 = .555$, and group, $F(5, 106) = 5.26$, $p < .001$, $\eta_p^2 = .199$. We explored the interaction by first carrying out a series of one-way ANOVAs to detect significant group differences within each condition. For the no-change condition there was no effect of group, $F(5, 106) = 0.92$, $p = .472$. The group effect for the viable condition just missed significance, $F(5, 106) = 2.24$, $p = .056$. For the unviable condition, however, the effect of group was significant, $F(5, 106) = 9.21$, $p < .001$. Post hoc testing (Bonferroni corrected) revealed that the SLI + dyslexia group reported the target word significantly more often on the unviable condition than did the dyslexia-only ($p = .017$), LA2 ($p = .006$) and CA ($p < .001$) groups, while the SLI-only group reported the target word significantly more often than did the CA group, $p = .003$. No other group differences approached significance. Both SLI groups therefore perform below chronological age expectations with respect to word reporting in the unviable condition, with the SLI + dyslexia group performing below their vocabulary-matched controls (i.e., the LA2 group). Both groups are, however, performing in line with their sentence comprehension and word reading controls (i.e., LA1 for the SLI + dyslexia group, and LA2 for the SLI-only group).

Next, we tested the factor "condition" within each group. For all groups this was significant: SLI + dyslexia, $F(2, 48) = 11.56$, $p < .001$, $\eta_p^2 = .325$; SLI only, $F(2, 18) = 5.24$, $p = .016$, $\eta_p^2 = .368$; dyslexia only, $F(2, 34) = 33.08$, $p < .001$, $\eta_p^2 = .661$; LA1, $F(2, 26) = 15.88$, $p < .001$, $\eta_p^2 = .550$; LA2 $(2, 30) = 31.10$, $p < .001$, $\eta_p^2 = .675$; CA $(2, 56) = 82.55$, $p < .001$, $\eta_p^2 = .747$.

The high rates of reporting in the unviable condition (see Table 5) suggest that there are biases in word reporting. Further, these rates seem to vary across groups, with the SLI + dyslexia group showing the highest levels and the CA group the lowest. Therefore, the best way to evaluate the significance of compensation effects, and to compare them across groups, is to carry out a signal detection analysis.

Signal detection analysis

We use signal detection analysis to separate word reporting from response bias, using a classification model with three stimuli (no change, assimilated in viable context, assimilated in unviable context) assumed to be represented along a single dimension (similarity to the target word) and classified into two categories (present or absent; Macmillan & Creelman, 2005).

We first recoded our reporting rates into hits (baseline hit rate = % word reporting in the no-change condition, and compensation hit rate = % word reporting in the viable condition) and false alarms (false-alarm rate = % word reporting in the unviable condition) and computed two d' values:

- *Word-reporting* $d' = z$ (baseline hit rate) − z(false-alarm rate), where z is the inverse of the normal distribution function. This measure indexes the sensitivity of overall word reporting in the task.
- *Compensation* $d' = z$ (compensation hit rate) − z (false-alarm rate) indexes the sensitivity of assimilated word reporting specifically in the viable context. As such, it indexes the degree to which compensation for assimilation is specific to the contexts defined by English phonological grammar.
- We also calculated the overall *bias* for producing a "word" response, where bias = z (false-alarm rate).

These results are shown in Table 7 and Figures 1 and 2.

Word-reporting d' indexes the general ability to perform the word-reporting task. All groups showed a d' significantly greater than 0 (one-sample t tests, all p values $< .05$), reflecting their better than chance performance in this task (see Figure 1). However, word-reporting d' differed significantly between the groups of children, $F(5, 111) = 8.35$, $p < .001$. Post hoc testing (Bonferroni corrected) revealed that the SLI + dyslexia group differed significantly from the LA2 and CA groups ($p = .011$ and $p < .001$, respectively) and that the LA1 group differed significantly from the CA group ($p = .040$). No other differences reached significance.

All groups have significantly negative bias values (one-sample t tests, all p values $<.001$), as illustrated in Figure 2, reflecting a general tendency to respond "word" by default whenever in doubt. This is understandable given that in the unviable condition, participants had to refrain from pressing the button despite hearing a string that was minimally different from the target word. Furthermore, the unique identification point of the word was likely to have been reached prior to the end of the word, which could also trigger the participants pressing the button. Bias is correlated with word-reporting d' ($R = .598$, $p < .001$). Thus, the more difficult the children find the task, the more likely they are to adopt a liberal bias.

Finally, compensation d' reflects the ability to compensate for place assimilation by reporting words in viable as opposed to unviable contexts. Compensation d' is significantly greater than 0 for all groups—SLI + dyslexia, $t(24) = 2.590$, $p = .016$; dyslexia only, $t(17) = 5.377$, $p < .001$; LA1, $t(13) = 2.924$, $p = .012$; LA2, $t(15) = 5.533$, $p < .001$; CA, $t(28) = 9.529$, $p < .001$—except for the SLI-only group, $t(9) = 2.005$,

Table 7. *Word-reporting* d′, *compensation* d′, *and bias*

	SLI + dyslexia		*SLI only*		*Dyslexia only*		*LA1*		*LA2*		*CA*		*Adults*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Word-reporting d'	0.55	0.62	0.77	0.94	0.68	1.29	0.94	0.68	1.29	0.62	1.68	0.73	2.48	0.48
Compensation d'	0.27	0.53	0.29	0.35	0.45	0.64	0.35	0.45	0.64	0.46	0.88	0.50	1.11	0.54
Bias	−1.27	0.42	−1.16	0.96	−0.84	0.43	−0.96	0.43	−0.84	0.48	−0.65	0.34	−0.49	0.18

Note: SLI = specific language impairment. LA = language/literacy ability. CA = chronological age.

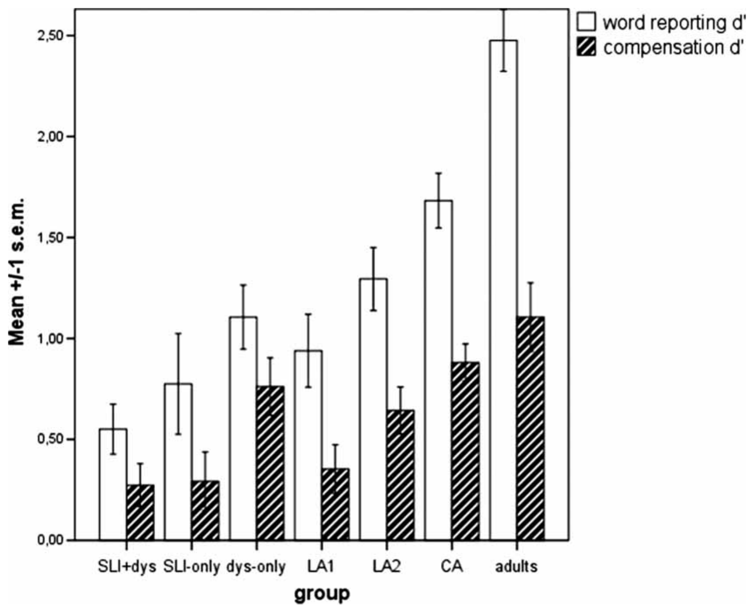

Figure 1. *Word-reporting* d′ *and compensation* d′. *SLI = specific language impairment. LA = language/literacy ability. CA = chronological age. dys = dyslexia.*

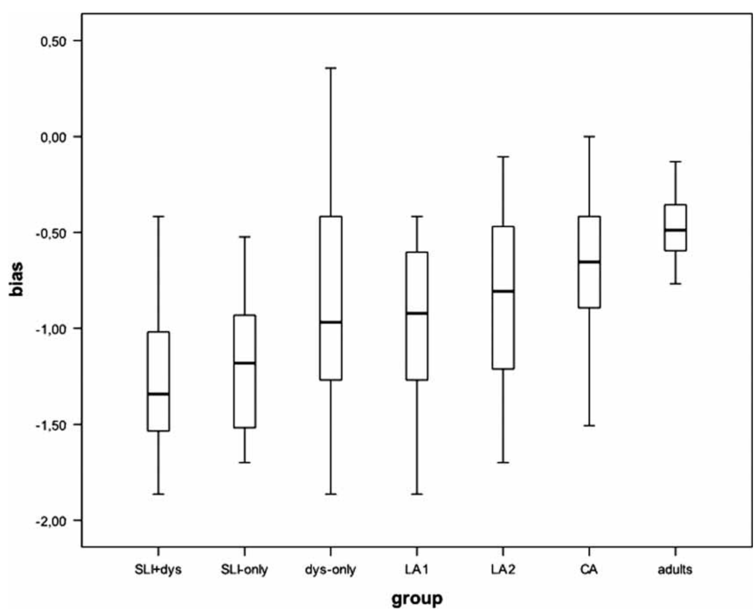

Figure 2. *Boxplots of bias values. SLI = specific language impairment. LA = language/literacy ability. CA = chronological age. dys = dyslexia.*

Table 8. *Correlation matrix between compensation* d′, *word-reporting* d′, *and all their potential predictors, with age partialled out*

		Word-reporting d′	*RPM*	*BPVS*	*PhAB rhyme*	*PhAB spoonerisms*	*Digit span*	*Picture–word matching*
Compensation *d′*	*R*	.585	.216	.344	.311	.349	.240	.280
	p	<.001	.024	<.001	.001	<.001	.012	.003
Word-reporting *d′*	*R*		.362	.557	.519	.454	.422	.393
	p		<.001	<.001	<.001	<.001	<.001	<.001
RPM	*R*			.358	.348	.377	.099	.329
	p			<.001	<.001	<.001	.306	<.001
BPVS	*R*				.455	.420	.389	.369
	p				<.001	<.001	<.001	<.001
PhAB rhyme	*R*					.690	.483	.306
	p					<.001	<.001	.001
PhAB spoonerisms	*R*						.519	.388
	p						<.001	<.001
Digit span	*R*							.325
	p							.001

Note: Key to tests: RPM: Raven's Progressive Matrices (Raven, 1998). BPVS: British Picture Vocabulary Scales (Dunn, Dunn, Whetton, & Burley, 1997). PhAB: Phonological Assessment Battery (Frederickson, Frith, & Reason, 1997).

$p = .080$. Although the effect is not significant for the SLI-only group, compared to the SLI + dyslexia group compensation d' is actually larger for the SLI-only group and the variance smaller. Therefore we assume that it is the low sample size of the SLI-only group that decreased the statistical power of the test. Hence there is good evidence that all the groups do compensate for assimilation to some extent. However, there are significant group differences, $F(5, 112) = 5.51$, $p < .001$. Post hoc testing (Bonferroni corrected) for group reveals that the SLI + dyslexia group has a significantly lower compensation d' than the dyslexia-only group, $p = .037$, and than the CA group, $p < .001$. The SLI-only and LA1 groups also have a lower compensation d' than the CA group, $p = .033$ and $p = .030$, respectively.

However, children's possibility of reporting words differently in the viable and unviable contexts (compensation d') is intrinsically limited by their capacity to perform the word detection task correctly (word-reporting d'). The question then is: Do group differences in compensation d' reflect differences specifically in the ability to compensate for assimilation, or are they simply due to differences in how the groups report words in a sentence? Rerunning the 3 (condition: no change, viable, unviable) × 6 (group) ANOVA with word-reporting d' as a covariate results in a significant effect of word-reporting d', $F(1, 112) = 34.08$, $p < .001$, but group no longer emerges as a significant factor, $F(5, 112) = 1.52$, $p = .189$. We therefore conclude that, once word-reporting abilities are controlled for, there are no significant differences in the magnitude of the compensation effect between groups.

In order to assess to what extent average results reported above are representative of each group, boxplots are shown in Supplementary Figures 1 and 2. They show in particular that at least 75% of the children in the SLI groups and 100% of children in the dyslexia-only group had d' values greater or equal than 0, which suggests that the average compensation abilities reported are representative.

Predictors of word-reporting abilities

In order to test the hypothesis that verbal short-term memory, metaphonological skills, and/or phonological representations at the word level affect word-reporting rates in our cohort of SLI, dyslexic, and control children, we multiple linear regressions of word-reporting d' with all the relevant predictors that we had in our data set. Because word-reporting d' indexes absolute performance, we used only raw (rather than age-standardized) scores of the relevant variables. Table 8 shows the partial correlation matrix between compensation d', word-reporting d', and all their potential predictors, with age partialled out.

We carried out multiple stepwise linear regressions with word-reporting d' as the dependent variable and with the following regressors: age, the Raven's Progressive Matrices, BPVS (receptive vocabulary), rhyme awareness and spoonerisms (both indexing metaphonological abilities), digit span (indexing verbal working memory), and the task testing the precision of segmental phonological representations in simple CVC words: picture–word matching (all raw scores).

We found that rhyme awareness entered first into the model, $F(1, 108) = 34.7$, $p < .001$, adjusted $R^2 = .24$, then vocabulary, $F(1, 107) = 17.6$, $p < .001$, additional $R^2 = .11$, then age, $F(1, 106) = 4.7$, $p = .03$, additional $R^2 = .03$, and finally picture–word matching, $F(1, 105) = 4.4$, $p = .04$, additional $R^2 = .03$. The total amount of variance explained was 37.9% (adjusted R^2). Entering the group factor[3] in a last step did not significantly increase the amount of variance explained, $F(1, 104) = 1.7$, $p = .20$, suggesting that these predictors adequately account for the observed group differences in word-reporting abilities. In the final model, vocabulary shows the greatest contribution to word-reporting d' (semipartial $R = .31$), then rhyme awareness (semipartial $R = .24$), then age (semipartial $R = -.20$)[4] and picture–word matching (semipartial $R = .16$).

We tested the robustness of vocabulary as the main predictor of word-reporting d' by constructing various regression models with all predictors but vocabulary entered simultaneously, then vocabulary entered last. This was done using either all putative predictors or only the significant ones as revealed by the previous analysis, and with or without the group factor. In all cases, vocabulary explained significant additional variance (at least 5%) and became the leading predictor of the complete regression model (semipartial $R > .23$).

These results suggest that the tolerance for minimal deviations from canonical word forms decreases primarily with vocabulary growth, and secondarily with metaphonological abilities and with the precision of phonological representations. Taken together, these three factors seem sufficient to account for the observed group differences, and thus for SLI children's limited word-reporting abilities.

Finally, we ran a similar stepwise regression with compensation d' as the dependent variable and including the very same predictors plus word-reporting d' We found that only word-reporting d' entered the model, $F(1, 108) = 60$, $p < .001$, explaining 35.1% of the variance. Furthermore, the group factor did not explain additional variance, $F(1, 107) = 0.61$. This confirms that compensation abilities are limited mostly by word-reporting abilities.

Discussion and conclusions

This study set out to test whether children with SLI and/or dyslexia compensate for lawful phonological variation during lexical access, by investigating their ability to compensate for place assimilation in a word-reporting task. We argued that this approach allows us to investigate whether phonological representations at the segmental level are impaired in these groups and in addition allows us to investigate one aspect of their phonological grammar (by which we mean the set of abstract rules or

[3] For the purpose of this analysis, the group factor is a four-level nominal variable coding for each of the three pathological groups and the control group.

[4] The negative partial correlation between age and word-reporting d' can be explained by the fact that the raw scores in the model carry most of the age-related variance. However, absolute performance levels off with age, hence the additional negative contribution of age.

constraints that map a surface form to its underlying form).

Our results are as follows: (a) Signal detection analyses reveal that children in all three clinical groups (SLI + dyslexia, SLI only, and dyslexia only) compensate for place assimilation; (b) differences in the magnitude of compensation effects across groups are primarily due to differences in word-reporting abilities; and (c) vocabulary level is the main predictor of word-reporting abilities.

Our central finding is that children with SLI and/or dyslexia do indeed compensate for place assimilation, in the specific context-dependent manner prescribed by English phonological grammar. The group of children with dyslexia only do not differ from their age-matched peers in their performance on the word-reporting task. In contrast, the two SLI groups do not perform age appropriately on the task. Yet the performance of the two SLI groups can be explained by task effects: They are more liberal in their acceptance of alternative phonological forms of words, but do not differ from the control and dyslexia-only groups in anything specific to compensation for place assimilation.

The age-appropriate performance of children with dyslexia in the assimilation task stands in marked contrast to their performance on other phonological tasks—namely, rhyming, spoonerisms, rapid naming, and digit span, where they performed significantly below their chronological-age controls (and, in the case of the digit span task, more poorly than their reading-age controls). Our results suggest that children with dyslexia are able to acquire implicit knowledge of this aspect of the phonological grammar of their native language. Furthermore, they suggest that children with dyslexia have relatively accurate representations of the phonological features that may be assimilated, as well as of the phonological contexts in which assimilation may take place. Such results are difficult to reconcile with the hypothesis that dyslexic children have degraded phonological representations: That hypothesis would predict either less compensation for assimilation, or a more generalized pattern of compensation (less dependent on the phonological context). In both cases their compensation d' should be lower than normal, which was not the case. Our findings therefore replicate and extend the results obtained for Dutch children by Blomert et al. (2004) and for French adults by Szenkovits et al. (2011).

The groups of children with SLI + dyslexia and SLI only differ from the dyslexia-only group in that they are more biased towards giving a "word" response: They are more likely to accept the assimilated form of a word, regardless of whether the word was presented in a viable or an unviable context. Yet, despite this strong response bias, they do show a significant sensitivity to the phonological context in which assimilations were presented, compensating more in viable than in unviable contexts: This suggests that they are able to learn the context-specific place assimilation rule. The results are not easily reconciled with a degraded phonological representations hypothesis, or with a hypothesis that they might have an impairment in acquiring phonological rules.

The numerically low compensation d' values observed in SLI and dyslexia groups may seem to conflict with this conclusion. However, it should be noted that compensation d' cannot get very high given that participants are not expected to compensate all the time. Indeed, even adult participants compensate for place assimilation in only about 60% of the trials, which is consistent with the previous study by Darcy et al. (2009). It follows that their compensation d' is only around 1.1, less than half their word-reporting d'. Not surprisingly, children show a similar pattern, but since they have a lower word-reporting d' to start with, their compensation d' is correspondingly lower.

The main source of concern in the present study is word-reporting abilities, which are more liberal than we would have hoped for. It is undeniable that the task was complex and was perhaps not fully understood or correctly performed by all children. The main consequence is to increase the noise in our data and to limit our ability to observe specific compensation effects. Future replications of this study should certainly aim to further reduce the complexity of this task, improve the instructions and training, and therefore enhance children's overall performance. Nevertheless, these limitations played against our ability to detect compensation effects. It is therefore remarkable that in spite of these difficulties, we observed a significantly positive compensation d' even in the children with the most severe disorders, which supports the conclusion that they have acquired a sensitivity to the phonological contexts for place assimilation in English.

Even so, children's liberal acceptance of alternative phonological forms of words, particularly amongst the two SLI groups, requires an explanation. Of course, some degree of tolerance for minor deviations from the canonical word form is expected, since speech errors are common. Listeners must therefore have a general bias towards automatically assimilating minimally deviant pseudowords to the nearest lexical item. This is indeed reflected in the bias measure of our adult participants. Nevertheless, this tolerance is limited, and listeners do readily notice many speech errors. Furthermore, there is a clear developmental trend—that is, a reduction of this tolerance with vocabulary growth, as shown in our data by the effect of raw vocabulary scores on word-reporting d'. Regression analyses showed that vocabulary size was the main developmental predictor of the ability to reject mispronunciations of words, but that metaphonological skills, and to a minor extent phonological representations, also played a part. The poorer performance of the two SLI groups on the assimilation task is therefore explained by the demands of the task.

A possible explanation for vocabulary size as a predictor of word-reporting ability is that while young children have a relatively small lexicon, phonological neighbourhoods are sparse, and there are few competitors for word recognition. Any word form in the neighbourhood of a lexical item can be assimilated to this item, unless the semantic context dictates that these must be two different words. On the other hand, as the lexicon grows, phonological neighbourhoods become denser, and there is a need to consider finer phonetic details to access the correct lexical items.

That phonological representations have some predictive role in word-reporting abilities is not surprising: A child who has difficulty perceiving the difference between those minimal phonetic differences (as between "browm" and "brown") is likely to match both forms to the lexical item. However, this does not seem to be the major problem in these SLI children, most of whom have high levels of performance in picture–word matching. On the other hand, metaphonological skills also predicted word-reporting abilities, presumably because judging whether a word is a good phonetic match (vs. a mispronunciation) taps metaphonology, an area where children with SLI and dyslexia have difficulties.

Once word-reporting abilities are controlled, group effects in compensation abilities disappear—that is, lose statistical significance. This may be seen as a null result, and one might worry that our statistical power to detect group differences in compensation d' while controlling for word-reporting d' was limited. Indeed, the observed power for this test was 51.6%, so the conclusion that compensation abilities are really the same across all groups remains tentative. A further caveat with respect to our interpretation is that the participants with SLI and dyslexia were tested when they were between 10 and 15 years of age, and so we can say nothing about their development of compensation for assimilation at a younger age.

Despite these caveats, we conclude that our results add to a growing body of evidence that phonological representations are not necessarily impaired in dyslexia. The less accurate performance of the children with SLI in the task reduced the range of performance within which their compensation for assimilation could be observed. Nevertheless, within that limited range, they did show a sensitivity to the phonological contexts in which target words were embedded and compensated more for assimilation in viable than in unviable contexts. Thus, it seems that children with SLI, as well as those with dyslexia, are able to learn this aspect of phonological grammar.

The growing body of evidence that phonological representations are not necessarily impaired in dyslexia challenges models attributing the phonological deficit in dyslexia to degraded or altered phonological representations. It is more commensurate with proposals that the deficit is in *accessing* phonological representations (Blomert et al., 2004; Dickie, 2008; Ramus & Szenkovits, 2008; Soroli et al., 2010). According to this latter proposal, it is when phonological tasks place heavy demands on short-term memory, conscious awareness, and time constraints that individuals with dyslexia perform poorly. Another, compatible, theoretical proposal attributes the phonological deficit to short- and medium-term storage of phonological representations (the "anchoring" deficit; Ahissar, 2007). Importantly, our proposal does not challenge the existence of a phonological deficit in dyslexia, but it makes the claim that the phonological deficit does not lie in the quality of the phonological representations themselves.

Finally, with respect to models of the overlap between dyslexia and SLI, this is the third study investigating phonology in this same cohort of participants with dyslexia only, SLI only, and SLI + dyslexia. On a nonword repetition task that manipulated the position of clusters in nonwords, all groups performed poorly compared to even language-matched children, and yet there were qualitative differences between the SLI-only group and the two groups with dyslexia (Marshall & van der Lely, 2009). In a separate test of prosodic skills, using the Profiling Elements of Prosodic Systems–Child Version (Peppé & McCann, 2003), no differences were found between the dyslexia and SLI groups, and few children had difficulties with the tasks, which involved same/different judgements of, and imitation of, prosodic forms (Marshall et al., 2009). Taken together, the results of the three studies suggest that phonological impairments are indeed where dyslexia and SLI overlap, but that the phonological impairments in the two disorders are not necessarily identical, nor are they necessarily present in every domain of phonology. Further studies of the type presented in here, using tasks that move beyond the traditional phonological awareness, rapid naming, and short-term memory tasks, and instead focusing on the nature of the phonological representation itself, are needed. Finally, a developmental perspective is of course essential, so that a picture of phonological development and its relationship to language and literacy over the lifespan can be constructed.

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APPENDIX A

Items for the picture–word matching task

		Word-initial contrast		*Word-final contrast*	
Manipulation		*Target*	*Distractor*	*Target*	*Distractor*
Noisy					
	Voice	pear	bear	eyes	ice
		bull	pull	cart	card
		down	town	peg	peck
		sip	zip	back	bag
	Place	cap	tap	mud	mug
		pick	tick	lake	late
		tall	call	rat	wrap
		fox	socks	wait	wake
	Manner	fill	pill	late	lace
		sew	toe	beep	beef
		pan	fan	rose	road
		top	shop	put	push
No noise					
	Voice	coat	goat	bad	bat
		tie	die	seat	seed
		fan	van	log	lock
		buy	pie	dice	dies
	Place	date	gate	neck	net
		tight	kite	pack	pat
		pea	tea	knot	knock
		sat	fat	harp	heart
	Manner	shoe	two	hiss	hit
		full	pull	card	cars
		tail	sail	mash	mat
		pin	fin	toes	toad

Note that our participants have nonrhotic accents, therefore for them words such as “heart” and “harp” do not contain final clusters.

APPENDIX B

Adjectives for the assimilation experiment

Table B1. *Target words, their various forms, and their contexts*

Target	*Final consonant*	*Unchanged form*	*Changed form*	*No-change context*	*Unviable context*	*Viable context*
lean	n	lean	leam	shadow	silhouette	body
plain	n	plain	plaim	landscape	churches	buildings
fun	n	fun	fung	day	drive	game
thin	n	thin	thim	leaf	sheet	book
clean	n	clean	cleam	fork	spoon	pan
brown	n	brown	browm	roof	lamp	bell
own	n	own	owm	choice	life	plan
green	n	green	greeng	salad	lemon	grapefruit
wild	d	wild	wilg	swan	snake	goose
sad	d	sad	sab	song	role	book
red	d	red	reg	mattress	mirror	garment
cold	d	cold	colb	meat	dish	beer
fat	t	fat	fap	monkey	squirrel	puppy
short	t	short	shorp	fight	match	play
sweet	t	sweet	sweek	melon	liqueur	cocktail
smart	t	smart	smark	mac	suit	coat