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Phonological similarity neighborhoods and children's short-term memory: Typical development and dyslexia

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In this article, we explore whether structural characteristics of the phonological lexicon affect serial recall in typically developing and dyslexic children. Recent work has emphasized the importance of long-term phonological representations in supporting short-term memory performance. This occurs via redintegration (reconstruction) processes, which show significant neighborhood density effects in adults. We assessed whether serial recall in children was affected by neighborhood density in word and nonword tasks. Furthermore, we compared dyslexic children with typically developing children of the same age or reading level. Dyslexic children are held to have impaired phonological representations of lexical items. These impaired representations may impair or prevent the use of long-term phonological representations to redintegrate short-term memory traces. We report significant rime neighborhood density effects for serial recall of both words and nonwords, for both dyslexic and typically developing children.

Phonological short-term memory plays an important role in the development of the lexicon. Gathercole and colleagues have shown that individual differences in phonological short-term memory are related to vocabulary acquisition (Gathercole & Baddeley, 1989, 1990; Gathercole, Hitch, Service, & Martin, 1997; Gathercole, Willis, & Baddeley, 1991; Gathercole, Willis, Emslie, & Baddeley, 1992) and have argued that phonological short-term memory plays a critical role in the acquisition of new words. Phonological long-term memory representations for words, in turn, play an important role in determining the capacity of phonological short-term memory. Phonological short-term memory is usually measured by performance in serial recall tasks, which is affected by stored phonological knowledge. Current models of serial recall posit a short-term phonological or *articulatory loop* that retains verbal information on a temporary basis (e.g., Baddeley & Hitch, 1974). Retention is thought to be enhanced by long-term word representations, which help with the *redintegration*, or reconstruction, of decaying traces, thus facilitating recall (Gupta & MacWhinney, 1997; Hulme, Maughan, & Brown, 1991; Hulme et al., 1997; Schweikert, 1993; Turner, Henry, Smith, & Brown, 2004). Because of redintegration processes, nonwords or unfamiliar words are significantly harder to recall than familiar lexical items (e.g., Hulme et al., 1991; Hulme et al., 1997). Similarly, high-frequency words are recalled better than low-frequency words (Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002), and nonwords that are more *wordlike* are recalled better than nonwords that are less *wordlike* (Gathercole, 1995).

There is widespread agreement that phonological representations for familiar words are used to reconstruct decaying traces in temporary memory when serial recall tasks are based on *words*. However, there has been some debate about the role of stored lexical knowledge in the serial recall of *nonwords*. Gathercole and colleagues (Gathercole, Frankish, Pickering, & Peaker, 1999) reported that children recalled nonwords with high phonotactic probabilities better than nonwords with low phonotactic probabilities in a serial recall task. They argued that this was a *nonlexical* effect based on stored phonotactic knowledge. In their experiments, 7- to 8-year-old children's recall accuracy was greater for nonwords containing phoneme combinations that were high in frequency (i.e., nonwords with high-

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probability phonotactics) than for nonwords containing phoneme combinations that were low in frequency (i.e., nonwords with low-probability phonotactics). Gathercole et al. (1999) suggested that, rather than using stored lexical representations to *guess* at the original identity of items, as in redintegration, the children were using their knowledge of the phonotactic properties of the language to enable probability-based reconstruction of incomplete memory traces. They argued that whereas lexical representations lie at the source of the lexicality effect in serial recall, abstracted phonotactic knowledge lies at the source of the nonword probability effect. In a partial replication of this study with dyslexic children, Roodenrys and Stokes (2001) failed to find a significant effect of the wordlikeness of nonwords on serial recall, for both dyslexic and typically developing children. However, all the children were significantly better at recalling words, as compared with nonwords. Roodenrys and Stokes concluded that redintegration processes were unimpaired in dyslexic children.

In work with adults, Roodenrys and colleagues have argued that the phonotactic probability effect found by Gathercole and her colleagues could have a lexical source (Nimmo & Roodenrys, 2002; Roodenrys & Hinton, 2002; Roodenrys et al., 2002). They pointed out that high phonotactic probabilities are correlated with high phonological neighborhood density (Vitevitch, Luce, Pisoni, & Auer, 1999). Phonotactic probability is the frequency with which phonological segments and sequences of phonological segments occur in words in the English language (Jusczyk, Luce, & Charles-Luce, 1994). Phonological neighbors are words that sound similar to each other. The number of phonological neighbors of a given (target) word is the set of words generated by the addition, deletion, or substitution of one phoneme in the target (Luce, Pisoni, & Goldinger, 1990). When many words resemble the target, the neighborhood is said to be dense. When few words resemble the target, the neighborhood is said to be sparse. Unsurprisingly, words with many neighbors tend to be composed of segments and sequences of segments that are frequent in occurrence; that is, phonotactics and neighborhood density are highly correlated.

Roodenrys and Hinton (2002) carried out a pair of experiments in which either phonotactic probability was manipulated while neighborhood density was held constant or neighborhood density was manipulated while phonotactic probability was held constant. All the items were nonwords, and as the authors themselves commented, the constraints involved in generating suitable stimuli meant that a relatively small item pool was used. Nevertheless, the effects were very clear. When neighborhood density was manipulated, there was a significant recall advantage for nonwords from dense phonological neighborhoods. When phonotactic probability was manipulated, there was no recall advantage for high phonotactic probability nonwords. Roodenrys and Hinton argued that it was clear that the long-term memory contribution to serial recall for nonwords arose from lexical representations. Long-term representations for words were contributing to nonword recall because parts of the nonwords were shared with real words and more parts were shared with more words when the phonological neighborhood was dense. They recommended that future work on neighborhood density relax the control for phonotactic probability, since this had such a restrictive effect on item selection.

The possibility that the phonotactic probability effect in children demonstrated by Gathercole et al. (1999) was actually due to the structural characteristics of the developing phonological lexicon had occurred to us for different reasons. In recent work, we had demonstrated that the phonological neighborhood structure of spoken English highlights the rime (De Cara & Goswami, 2002; the rime is the subsyllabic unit comprising the vowel and coda). We had also shown that young children have particularly accurate phonological representations for the rimes of words that reside in dense rime neighborhoods (De Cara & Goswami, 2003). Since words with high phonotactic probability tend to reside in dense phonological neighborhoods, the children studied by Gathercole et al. (1999) could have been using salient subunits of *words* within dense neighborhoods, such as rime units, as a basis for the redintegration of nonwords. If these accurate representations for rimes help redintegration processes in serial recall, the children should have shown a recall advantage for nonwords with common rimes. Inspection of the stimuli used by Gathercole et al. (1999) revealed that some of the *low* and *very low* probability nonwords used actually contained rimes from words residing in dense rime neighborhoods (e.g., *gip*, 26 rime neighbors; *vack*, 30 rime neighbors; *gin*, 24 rime neighbors). We therefore inspected the original data collected by Gathercole et al. (1999),[1] comparing recall for these low-probability nonwords with recall for high-probability nonwords in the experiment that contained rimes from sparse rime neighborhoods (*nom*, *guck*, *juve*). The nonwords from the dense rime neighborhoods were recalled accurately by 52% of the children, on average, despite their low phonotactic probabilities. The nonwords from the sparse rime neighborhoods were recalled accurately by 40% of the children, on average, despite their high phonotactic probabilities. We therefore decided to explore systematically the role of rime neighborhood density on phonological short-term memory performance in children. Here, we report two experiments comparing serial recall for words and nonwords that belong either to dense rime neighborhoods or to sparse rime neighborhoods.

Our second aim in these experiments was to examine the effects of phonological similarity neighborhoods on the serial recall performance of *dyslexic* children. Children with developmental dyslexia are characterized, in part, by poor phonological short-term memory. The classic view is that there are three areas of phonological weakness in developmental dyslexia: a weakness in phonological short-term memory, a weakness in phonological awareness, and a weakness in rapid access to and output of phonological information (defined by impaired performance on rapid automatized naming tasks). Phonological awareness tasks measure children's ability to reflect on or manipulate the sound structure of spoken words, and performance in phonological awareness tasks is highly predictive of literacy acquisition. Performance in phonological awareness tasks is also thought to provide an index of the representational adequacy of a child's long-term phonological representations (e.g., Constable, Stackhouse, & Wells, 1997; Swan & Goswami, 1997a). In dyslexia, the phonological component of lexical representations is thought to be underspecified (e.g., Goswami, 2000; Snowling, 2000).

Presumably, for redintegration processes to support serial recall efficiently, the underlying lexical representations need to be well specified. The underspecification of phonological aspects of lexical representations characteristic of developmental dyslexia should impair redintegration processes and, hence, lead to impairments in phonological short-term memory. Many studies have indeed shown that phonological short-term memory is less efficient in dyslexic children (e.g., Brady, Mann, & Schmidt, 1987; McDougall, Hulme, Ellis, & Monk, 1994; Roodenrys & Stokes, 2001). Nevertheless, the phonological system may be acting to reconstruct decaying traces in the same way for dyslexic children as for typically developing children (by using redintegration) but may simply do so less efficiently in dyslexia (because of the poorer quality of long-term representations). If this were the case, the effects of phonological neighborhood density on serial recall performance should be comparable for dyslexic and typically developing children, even though overall recall in dyslexia should be impaired. This prediction is plausible, given that vocabulary acquisition appears unimpaired in developmental dyslexia (Swan & Goswami, 1997b). Therefore, factors such as phonological neighborhood density may operate on the developing lexicon in similar ways for typically developing and dyslexic children.

On this theoretical account, the development of phonological representations depends on the same parameters in dyslexia as in typical development, but development is significantly slower and less efficient in dyslexia (perhaps because of low-level auditory-processing problems that hamper accurate phonological specification; see Goswami 2003b). It is also theoretically possible that the phonological system in dyslexic children develops according to quite different parameters. In this case, factors such as phonological neighborhood density may not affect the serial recall performance of dyslexic children. Alternatively, divergent effects may occur for real words versus nonwords. Since phonological representations are less well specified in dyslexia, poorer representations of parts of these words may impair the use of redintegration processes for reinstating nonword traces, particularly in sparsely populated neighborhoods. Although a *different development* account is a priori plausible, it would not account for Roodenrys and Stokes's (2001) finding that redintegration in dyslexic children appeared to be comparable to that in typically developing children when serial recall of words and nonwords was compared. Nevertheless, these authors also found that serial recall in children was not significantly affected by the *wordlikeness* of nonwords. Since they used a subset of the nonwords from Gathercole et al. (1999), the same problems regarding neighborhood density apply to their experiment.

A third alternative is that dyslexic children have fully specified phonological representations that act to support redintegration processes in the same way as in typically developing children but that, for *other reasons*, short-term phonological representations are of poorer quality. This alternative was proposed by Roodenrys and Stokes (2001). In their experiment, they found that dyslexic children attained the same levels of serial recall accuracy as younger reading-level–matched controls (see also de Jong, 1998; Johnston, Rugg, & Scott, 1987). Roodenrys and Stokes suggested that learning to read could play a causal role in short-term memory development, producing representations of words that could be accessed by other processes to support performance in serial recall tasks. The process actually suggested was that dyslexic children may make conscious or explicit use of long-term phonological representations to aid short-term recall, once they realized that the "automatic" clean-up of degraded information (redintegration) had been insufficient. However, since the explicit use of phonological information is exactly what dyslexic children are poor at, this explanation seems unlikely. Cross-language data certainly suggest that learning to read enables dyslexic children to improve the specificity and quality of their phonological representations (see Goswami, 2003a). Indeed, dyslexic children in transparent languages are often comparable to *age-matched* controls in accuracy in phonological tasks. At the same time, however, they are extremely slow in any task requiring the conscious use of phonology, suggesting that accurate performance requires great effort. It therefore seems more plausible to explain the link with reading level in terms of the effects of orthography on representational quality. Reading in dyslexic children may have developed to the extent enabled by the current quality of their phonological representations.

Phonological similarity neighborhood effects have not yet been much explored with dyslexic children. However, it is clear that phonological neighborhood density plays a role in developing high-quality phonological representations for typically progressing children. Metsala (1999) found that 3- to 4-year-old children performed better in a spoken phoneme blending task when target words came from dense neighborhoods, and De Cara and Goswami (2003) found that 5-year-olds were better at making rhyme judgments about words from dense neighborhoods. Storkel (2002) found that young children were more likely to acquire new words from dense neighborhoods. Coady and Aslin (2003) reported a series of analyses showing that the phonological neighborhoods of young children were denser than those of adults, once vocabulary size was taken into account. Theoretically, the dense neighborhood advantage has been explained according to models of the development of lexical representations. For example, lexical restructuring theory (Metsala & Walley, 1998) suggests that phonological representations are initially holistic, with increasingly detailed representation developing in response to such factors as phonological neighborhood density, word frequency, and age of acquisition. Words in dense phonological neighborhoods will need to develop more detailed specification earlier than will words in more sparsely occupied areas. However, many researchers in language acquisition believe that, if there is a period of holistic representation, it is very brief. There is evidence for the representation of segment-level information by the 2nd year (e.g., Bailey & Plunkett, 2002; Swingley & Aslin, 2002). Clearly, for redintegration processes to operate, it is necessary to go beyond holistic phonological representations.

In the first experiment reported here, we investigated whether typically developing and dyslexic children would show an advantage in a serial recall task for words when the items were from dense rime neighborhoods. This advantage would be expected on the basis of redintegration, since it should be easier to reconstruct or redintegrate words from dense neighborhoods (since these words theoretically have more detailed phonological specification). However, dyslexic children may show weaker effects, since it is thought that all phonological representations are underspecified in dyslexia, even representations for words in dense neighborhoods. In the second experiment, we investigated whether an advantage for dense rime neighborhoods would extend to the serial recall of nonwords. We again compared dyslexic with typically developing children.

We chose to manipulate *rime* neighborhood density, rather than overall neighborhood density, in both experiments, following the work of De Cara and Goswami (2002, 2003). They showed that most phonological neighbors in dense neighborhoods in spoken English are rime neighbors (e.g., *hot*/*cot*) and that this preponderance of rime neighbors affects performance in phonological awareness tasks for children. Rime neighborhood density appears to be particularly important within a developing phonological system, and so we manipulated rime neighborhood density in our experiments. However, the high correlation between rime neighborhood density and overall neighborhood density (De Cara & Goswami, 2002) means that the item sets also differed significantly in neighborhood density (see the Appendices). We do not intend to make any theoretical claims about the relative effects of rime neighborhood density versus neighborhood density here. Our use of a developmental density metric was simply the most convenient way to explore the effects of phonological similarity neighborhoods in children's serial recall performance.

EXPERIMENT 1

Method

Participants

One hundred twenty-six children from the southeast of England took part. The participants consisted of two cohorts of children assessed using the same serial recall task in two consecutive years.[2] Forty-seven of the children (42 boys; mean age of 9 years, 4 months; $SD = 7$ months) had a statement of dyslexia from their local education authority. None of the dyslexic children had additional difficulties (e.g., dyspraxia, ADHD, autistic spectrum disorder, or specific language impairment). Forty-one children (24 boys) were chronological-age–matched controls (mean age of 9 years, 4 months; $SD = 10$ months) with no reading or spelling problems. Thirty-eight children made up a reading-level–matched control group (16 boys; mean age of 7 years, 4 months; $SD = 5$ months), whose reading age matched that of the dyslexic children. All the groups were matched on WISC IQ. Full characteristics of participants are shown in Table 1. All the participants were volunteers whose parents gave informed consent. The study was approved by the Joint University College London/University College London Hospitals (UCL/UCLH) Committees on the Ethics of Human Research.

Tasks

Psychometric tests. The children received several psychometric tests. Receptive vocabulary was measured using the British Picture Vocabulary Scales (Dunn, Dunn, Whetton, & Pintilie, 1982). The child is required to point to one picture out of four that best represents the word read out loud by the experimenter. Standardized tests of word reading and spelling were administered (from the standardized British Ability Scales; Elliott, Smith, & McCulloch, 1996), along with the Graded Test of Nonword Reading (GNRT; Snowling, Stothard, & McLean, 1996). The children received four subtests of the Wechsler Intelligence Scale for Children (WISC–III; Wechsler, 1992): block design, picture arrangement, similarities, and vocabulary. IQ scores were then prorated for each child from these subtests, following the procedure adopted by Sattler (1982).

Phonological short-term memory task. The children's phonological short-term memory was assessed using an immediate serial

Table 1
Participant Characteristics in Experiment 1

	Dyslexic ($n = 47$)		CA Match ($n = 41$)		RL Match ($n = 38$)	
Standardized Tests	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years and months)	9;4	7	9;4	10	7;4	5
Reading standard score	88.6	5.4	118.8**	9.7	110.4**	10.8
Reading age (years and months)	7;7	9	11;1**	23	7;10	12
Nonword decoding/20	11.8	4.9	18.5**	1.7	12.4	5.7
IQ	111.7	11.0	110.9	16.1	111.8	12.6
BPVS	105.3	8.6	104.6	13.5	104.5	12.9

Note—CA Match, chronological age match; RL Match, reading-level match; IQ, intelligence quotient using WISC short form (Wechsler, 1992); BPVS, British Picture Vocabulary Scale. As can be seen, the British Ability Scales (restandardized in 1996, just before the advent of the U.K. National Literacy Strategy) are now producing consistently elevated scores for the different age groups (see also Richardson et al., 2004). $^{**}p < .001$.

recall task of 16 trials with four monosyllabic consonant–vowel–consonant (CVC) words per trial. Three orders of trial presentation were used, and these were counterbalanced across children. No phoneme occurred more than once in each trial. Half of the 16 trials comprised words from dense rime neighborhoods, and the other half comprised words from sparse rime neighborhoods. An earlier version of the De Cara and Goswami (2002) database containing 3,619 monosyllabic words was used in the selection of the stimuli. In the selected words, the mean number of rime neighbors for dense stimuli was 18.0 ($SD = 3.3$), and the mean number of rime neighbors for sparse stimuli was 7.0 [$SD = 2.7$; $t(62) = 215.14$, $p < .001$]. The dense and sparse words did not differ in lead neighborhoods (words sharing the same onset and vowel), spoken frequencies (Celex Lexical Database; Baayen, Piepenbrock, & Gulikers, 1995), or familiarity (Luce & Pisoni, 1998). The words differed in overall neighborhood density and in overall phonotactic probability as measured via summed biphone frequencies based on log-frequency–weighted counts (see Vitevitch & Luce, 1998, 1999),[3] although there were no significant differences in summed segmental frequency. It would not have been possible to match our lists for phonotactic biphone probability, given that the stimuli needed to be real words that were familiar to children. This is because the CV and VC combinations allowed in real English words are quite constrained (e.g., Kessler & Treiman, 1997) and, furthermore, some combinations are overrepresented in dense rime neighborhoods, whereas others are overrepresented in sparse rime neighborhoods (De Cara & Goswami, 2002). The stimulus lists employed are shown in Appendix A.

Procedure

The children were assessed individually in a quiet room within their school. The tasks were given in the following order, across separate sessions: BPVS, word reading, nonword reading, spelling, WISC–III (four subscales), and the serial recall task. The words in the phonological short-term memory task were presented by computer and were spoken by a native female speaker of standard Southern British English. After hearing all the four words in a trial, the children were required to repeat them in the correct order. Two practice trials were given immediately before the test trials were presented. The children listened to the words through headphones, and their responses were recorded using an audio recorder.

Results

Following Gathercole et al. (1999), serial recall accuracy was scored in terms of the percentage of correct items and the percentage of correct phonemes produced. To be scored as correct, words and phonemes had to be accurately realized in the correct serial order. The group means and standard deviations are shown in Tables 2 and 3.

Table 2
Percentage of Correct Phonemes in the Phonological Short-Term Memory Task by RND and as a Function of Reading Group

	Dyslexic		CA Match		RL Match	
RND	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dense	78.1	11.8	87.0	9.8	74.9	11.6
Sparse	73.0	13.4	81.8	12.4	69.6	10.5

Note—CA Match, chronological age match; RL Match, reading-level match; RND, rime neighborhood density.

Table 3
Percentage of Correct Words in the Phonological Short-Term Memory Task by RND and as a Function of Reading Group

	Dyslexic		CA Match		RL Match	
RND	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dense	72.4	11.3	82.2	11.4	69.7	12.4
Sparse	67.9	14.4	76.8	13.1	64.7	11.1

Note—CA Match, chronological age match; RL Match, reading-level match; RND, rime neighborhood density.

Phonemes

A 2 (rime neighborhood density: dense or sparse) × 3 (group: dyslexic, chronological age control, or reading-level control) ANOVA was run by participant (F_1) and by item (F_2), taking the mean percentage of correct phonemes as the dependent variable. The analyses showed main effects of rime neighborhood density [$F_1(1,123) = 36.67$, $MS_e = 4,643$, $p < .001$; $F_2(1,126) = 7.36$, $MS_e = 40,674$, $p < .01$] and group [$F_1(2,123) = 14.05$, $MS_e = 22,786$, $p < .001$; $F_2(2,252) = 73.76$, $MS_e = 7,415$, $p < .001$]. The main effect of group arose because the chronological age controls remembered more items. Post hoc tests (Tukey HSD) that explored the group effect showed that both the dyslexic children and the reading-level–matched children were significantly poorer in the phonological short-term memory task, in comparison with the chronological age control children ($p < .001$; differences between the dyslexic children and the reading-level controls were not significant). Children's responses showed that the dense rime neighborhood words were significantly easier to recall than the sparse rime neighborhood words for all groups. The interaction between rime neighborhood density and group was not significant [$F_1(2,123) = 0.002$, $F_2(2,252) = 0.02$].

Words

A further 2 (rime neighborhood density) × 3 (group) ANOVA was run by participant (F_1) and by item (F_2), this time taking the mean percentage of correct words as the dependent variable. This analysis replicated the results of the phoneme accuracy analysis. There were main effects of rime neighborhood density [$F_1(1,123) = 27.00$, $MS_e = 57$, $p < .001$; $F_2(1,126) = 4.06$, $MS_e = 553$, $p < .05$] and group [$F_1(2,123) = 13.20$, $MS_e = 250$, $p < .001$; $F_2(2,252) = 53.20$, $MS_e = 104$, $p < .001$]. An inspection of the main effect of group, using post hoc tests (Tukey HSD), showed that the chronological age control group performed better than both the dyslexic ($p < .001$) and the reading-level control ($p < .001$) groups. The differences between the dyslexic children and the reading-level controls were not significant. Dense rime neighborhood words were significantly easier to recall than sparse rime neighborhood words for all groups. The interaction between rime neighborhood density and group was not significant [$F_1(2,123) = 0.08$, $F_2(2,252) = 0.06$].

Discussion

The results of our first experiment were straightforward. A serial recall advantage was found for words from dense rime neighborhoods, and this advantage was significant across all participant groups. Dyslexic children showed exactly the same effects as typically developing children, and the magnitude of the effect was remarkably similar across groups. This suggests that redintegration processes were supporting serial recall for all the children (see also Roodenrys & Stokes, 2001; Turner et al., 2004). Furthermore, the efficiency of redintegration was determined not by vocabulary development, which was similar in the dyslexics and their chronological-age–matched controls, but by phonological development, which was similar in the dyslexics and their reading-level controls.[4] We therefore decided to explore whether rime neighborhood density would also affect the serial recall of nonwords. Since lexical effects are found in nonword phonological short-term memory tasks with adults (see Nimmo & Roodenrys, 2002; Roodenrys & Hinton, 2002), rime neighborhood density would be expected to affect children's nonword serial recall performance. However, such effects may be smaller or nonexistent in dyslexic children, given their impaired phonological representations. Since lexical representations are already degraded in dyslexia, poorer representations of parts of words should impair the use of redintegration processes for reinstating nonword traces, particularly in sparse neighborhoods. This may also lead to a higher incidence of lexicalization errors in the dyslexic children, as compared with their typically developing controls.

EXPERIMENT 2

Method

Participants

The study involved 73 children from southeast England. None of the children had participated in Experiment 1. Twenty-four of the children (19 boys; mean age of 9 years, 0 months; $SD = 11$ months) had a statement of dyslexia from their local education authority. None of the dyslexic children had additional difficulties (e.g., dyspraxia, ADHD, autistic spectrum disorder, or specific language impairment). Twenty-five children (10 boys) were chronological-age–matched controls (mean age of 9 years, 0 months; $SD = 8$ months) with no reading or spelling problems. Twenty-four children made up a reading-level–matched control group with no reading or spelling problems (11 boys; mean age of 7 years, 11 months; $SD = 4$ months), whose reading age matched that of the dyslexic children. All the children were matched on WISC IQ (short form). Full participant characteristics are provided in Table 4.

Tasks

Psychometric tests. The subtests of word reading and spelling from the British Ability Scores were again administered, along with the GNRT. The children received four subsets of the WISC–III: block design, picture arrangement, similarities, and vocabulary.

Phonological short-term memory task. The children were given 10 trials of three monosyllabic CVC nonwords to recall. Trials were shortened to three items because of the greater difficulty of recalling nonwords, as compared with real words. Two orders of trial presentation were used, and these were counterbalanced across children. No phoneme occurred more than once in each trial. Half of the 10 trials comprised nonwords from dense rime neighborhoods, and the other half comprised nonwords from sparse rime neighborhoods. The De Cara and Goswami (2002) lexical database was used in the creation of the stimuli. In the selected nonwords, the mean rime neighborhood density for dense stimuli was 19.6 ($SD = 4.6$), as compared with 6.1 ($SD = 2.8$) for sparse stimuli [$t(28) = 10.12$, $p < .001$]. The dense and sparse nonwords did not differ in lead neighborhood density. As with real words, there was a difference in overall neighborhood density and in overall phonotactic probability as measured via summed biphone frequency, although not via summed segmental frequency. The stimuli lists employed are shown in Appendix B.

Procedure

The procedure was exactly the same as that in Experiment 1.

Results

Responses were scored in terms of percentage of correct nonwords and phonemes recalled. The group means and standard deviations are shown in Tables 5 and 6.

Phonemes

A 2 (rime neighborhood density: dense or sparse) × 3 (group: dyslexic, chronological age control, or reading-level control) ANOVA was run by participant (F_1) and by item (F_2), taking the mean percentage of correct phonemes as the dependent variable. The analyses showed a main effect of rime neighborhood density by participant [$F_1(1,70) = 23.80$, $MS_e = 9$, $p < .001$; $F_2(1,88) = 2.63$, $MS_e = 771$, $p = .12$] and a main effect of group by participant and item [$F_1(2,70) = 6.11$, $MS_e = 27.3$, $p < .01$; $F_2(2,176) = 25.29$, $MS_e = 59$, $p < .001$]. Recall scores were significantly higher for the dense than for the sparse lists. Post hoc tests (Tukey HSD) exploring the group effect confirmed a significant recall advantage in

Table 4
Participant Characteristics in Experiment 2

	Dyslexic ($n = 24$)		CA Match ($n = 25$)		RL Match ($n = 24$)	
Standardized Tests	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years and months)	9;0	11	9;0	8	7;11	4
Reading standard score	87.3	7.6	112.0**	10.5	102.4**	9.2
Reading age (years and months)	7;6	6	10;2**	17	7;11	7
Nonword decoding/20	7.4	5.5	15.7**	4.0	11.3*	5.1
IQ	109.1	11.4	111.9	11.0	105.7	10.6
Vocabulary (IQ subtest)/19	12.3	2.4	13.8	3.4	10.8	1.7

Note—CA Match, chronological age match; RL Match, reading-level match; IQ, Intelligence Quotient using WISC short form (Wechsler, 1992). $^*p < .05$. $^{**}p < .001$.

Table 5
Percentage of Correct Phonemes in the Phonological Short-Term Memory Task by RND and as a Function of Reading Group

	Dyslexic		CA Match		RL Match	
RND	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dense	81.7	7.8	89.2	5.4	82.6	8.8
Sparse	76.3	12.6	83.7	6.7	77.2	12.9

Note—CA Match, chronological age match; RL Match, reading-level match; RND, rime neighborhood density.

Table 6
Percentage of Correct Nonwords in the Phonological Short-Term Memory Task by RND and as a Function of Reading Group

	Dyslexic		CA Match		RL Match	
RND	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dense	54.7	16.0	70.7	15.4	57.5	17.7
Sparse	48.1	19.9	58.7	16.2	51.1	21.4

Note—CA Match, chronological age match; RL Match, reading-level match; RND, rime neighborhood density.

both list types for the chronological age control group, as compared with the dyslexic children ($p < .001$) and the reading-level–matched control group ($p < .01$). The difference in performance for the latter two groups was not significant. The interaction between rime neighborhood density and group was not significant [$F_1(2,70) = 0.004$, $F_2(2,176) = 0.01$].

Nonwords

A further 2 × 3 (rime neighborhood density × group) ANOVA was then run by participant (F_1) and by item (F_2), taking the mean percentage of correctly reported nonwords as the dependent variable. Replicating the phoneme analyses, this analysis yielded a main effect of rime neighborhood density by participant [$F_1(1,70) = 15.56$, $MS_e = 164$, $p < .001$; $F_2(1,28) = 2.05$, $MS_e = 750$, $p = .16$] and a main effect of group for both participant and item analyses [$F_1(2,70) = 5.07$, $MS_e = 475$, $p < .01$; $F_2(2,56) = 16.48$, $MS_e = 87$, $p < .001$]. Post hoc tests (Tukey HSD) showed that there was a significant recall advantage in both list types for the chronological age control group, as compared with the dyslexics ($p < .001$). The comparison between the chronological age control group and the reading-level–matched children just missed significance ($p < .06$). Recall scores were significantly higher for the dense than for the sparse lists. The interaction between rime neighborhood density and group was not significant [$F_1(2,70) = 0.76$, $F_2(2,56) = 0.78$].

Types of Errors

The nature of the errors made by the children was investigated to see whether more errors preserved either the CV segment of the nonwords or the VC segment. Since phonological neighborhood density was supporting recall, more successful VC preservations might be expected for items from dense rime neighborhoods, which contained highly frequent rimes (VCs). Table 7 shows CV and VC preservations by group and neighborhood density. CV preservations are clearly more frequent for both types of neighborhood. However, if VC preservations are compared for dense and sparse stimuli, there is an apparent advantage for VC preservations in dense rime neighborhoods. This was explored by a 2 (rime neighborhood density: dense or sparse) × 3 (group: dyslexic, chronological age control, or reading-level control) × 2 (preserved unit: CV or VC) ANOVA taking the percentage of errors as the dependent variable. The ANOVA yielded a main effect of rime neighborhood density [$F(1,21) = 11.44$, $MS_e = 199$, $p < .01$], with a higher proportion of CV and VC preservations occurring in dense rime neighborhoods. There was also a main effect of preserved unit [$F(1,21) = 20.96$, $MS_e = 977$, $p < .001$], with CV preservations most frequent. There was no main effect of group [$F(2,20) = 2.79$, $MS_e = 223$, $p = .22$]. The only significant interaction was that between density and preserved unit [$F(1,21) = 4.41$, $p < .05$]. Post hoc tests (Tukey HSD) showed that although there was no effect of density for CV preservations, a greater proportion of VC preservations occurred for stimuli within dense neighborhoods ($p < .01$).

Although the proportion of CV versus VC preservations did not differ by group, we predicted that the proportion of lexicalization errors would yield group differences. If dyslexic children have long-term phonological representations that are underspecified, it is possible that errors caused by the child's repeating back a real lexical item will be more frequent in dyslexia. The proportions of lexicalization errors made by each group are shown in Table 8. The other main error type was primarily phonological, based on either the transposition of phonemes within the trials (e.g., *gip* realized as *jip*) or substitution with an unheard phoneme (e.g., *gip* realized as *thip*).

Table 7
Percentages of CV Versus VC Errors Made, Scored by Density and Group

	Dyslexic		CA Match		RL Match	
Stimuli	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dense						
CV	39.8	21.8	52.2	27.3	44.5	18.0
VC	39.1	22.6	35.5	27.0	32.8	19.2
Sparse						
CV	50.3	24.9	53.2	26.8	39.1	25.7
VC	20.02	21.6	19.7	20.1	26.3	20.4

Note—CA Match, chronological age match; RL Match, reading-level match.

Table 8
Percentages of Lexicalization Errors Made by Reading Group

	Dyslexic		CA Match		RL Match	
Stimuli List	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dense	68.9	21.6	54.4	22.2	53.7	18.2
Sparse	47.3	19.8	43.5	22.2	43.1	17.5

Note—CA Match, chronological age match; RL Match, reading-level match.

A 2 (rime neighborhood density) × 3 (group: dyslexic, chronological age control, or reading-level control) ANOVA was carried out with percentage of lexicalizations as the dependent variable. The analysis revealed a main effect of both group [$F(2,70) = 3.51$, $MS_e = 483$, $p < .05$] and density [$F(1,70) = 16.20$, $MS_e = 347$, $p < .001$], with no interaction [$F(2,70) = 1.82$]. More lexicalization errors occurred for the dense rime neighborhood stimulus sets. This would appear logical, given that for sparse stimulus sets, with few real-word neighbors, there will not be that many real words to substitute for the nonwords. The dense stimulus sets, however, with many real-word neighbors, led to more lexicalization errors by all groups. Post hoc tests (Tukey HSD) exploring the group effect showed that, as was predicted, lexicalization errors were significantly more frequent for the children with dyslexia than for their reading-level controls ($p < .05$) or for their chronological-age–matched controls ($p = .05$).

Discussion

A significant recall advantage for nonwords from dense rime neighborhoods was found, and this advantage occurred across all participant groups. This finding is consistent with the neighborhood density effect reported for adults by Roodenrys and Hinton (2002). It suggests that lexical processes support nonword recall via redintegration. Children use information from stored real words in the lexicon to reconstruct nonwords, and this process is more efficient for items from dense rime neighborhoods. Furthermore, when only the rime is correctly recalled, this is more likely to occur for stimuli within dense rime neighborhoods. Dyslexic children show the same effects of phonological similarity neighborhoods as typically developing children. However, a significantly higher proportion of their errors are real-word intrusions. This effect is not found in either of the typically developing groups. Our interpretation is that phonological representations are, indeed, less well specified in the dyslexic group. Parts of words such as rimes are, therefore, less available to redintegrate the nonword traces, leading to guessing of real-word items. This effect is not driven by reading level, since it is not found in the younger reading-level–matched children.

GENERAL DISCUSSION

Overall, the results reported here support the idea that automatic redintegration processes affect serial recall in children, for both real words and nonwords (see also Roodenrys & Stokes, 2001; Turner et al., 2004). Serial recall in both typically developing and dyslexic children is sensitive to the phonological neighborhood characteristics of both words and nonwords, and phonological neighborhood density is a lexical variable. All groups were better able to recall items when the phonological similarity neighborhood was dense. This suggests that the developing lexicons of dyslexic children are essentially shaped by the same factors as the lexicons of other children. Although previous studies of dyslexic children have shown this in relation to such factors as word frequency (Swan & Goswami, 1997a), only one other study has looked at the role of neighborhood density in relation to representational quality (Metsala, 1997), and no studies (to our knowledge) have looked at neighborhood density in phonological short-term memory tasks.

These findings suggest that, even by the age of 7 years, lexical representations are sufficiently well specified to support redintegration processes. However, the determining factor appears to be phonological development, rather than vocabulary development. Dyslexic children showed significantly poorer levels of overall recall, as compared with their age-matched peers, despite having equivalent receptive vocabularies. As compared with their younger reading-level–matched controls, the dyslexic children showed equivalent performance. Since phonological development was also equivalent in these two groups (although note that most of the dyslexics received intensive phonological remediation), it seems plausible that the efficiency of redintegration was constrained by the developmental level of the children's phonological representations, rather than by how large their vocabularies were. Since reading helps to specify phonological information (Ziegler & Goswami, 2005), reading development was also related to overall performance.

For nonword recall, the dyslexic children were significantly more likely than the other groups to respond by converting the nonword item to an already known word (e.g., *jat* to *jack*). This suggests that the underlying long-term lexical representations used to support short-term recall were less well specified in the dyslexic children. The poorer quality of these phonological representations made it more difficult for them to segment their lexical representations in order to redintegrate nonwords. Interestingly, this would suggest that dyslexic children are less proficient at *online* phonological retention of nonwords because of deficiencies in their long-term phonological knowledge, rather than because of a deficiency in short-term phonological representations (the phonological loop; see Adams & Gathercole, 2000; Gathercole & Baddeley, 1989; Roodenrys & Stokes, 2001).

One way to investigate these ideas further would be to carry out in-depth longitudinal case studies, mapping children's individual lexical development and its phonological characteristics across time, while at the same time measuring the development of short-term memory. Both verbal and nonverbal measures of memory span could be utilized, and item-specific manipulations could be made in nonword repetition tasks. Such explorations would enable the dynamic development of similarity neighborhoods to be explored, along with any accompanying changes in phonological processing ability and phonological memory. Furthermore, it would be of interest to carry out an intervention study in which exposure to many words from the same phonological neighborhood would be accompanied by explicit help in organizing and distinguishing these items. Targeting intervention to denser phonological neighborhoods could allow children to improve the degree of phonological specification for words in these neighborhoods, possibly leading to related improvements in nonword serial recall and nonword repetition. This could help to increase understanding of the characteristics of the organizational units in the emerging phonological system.

The findings are also informative with respect to the three alternative theoretical positions set out at the beginning of this article. A priori, we argued that the phonological system may act to reconstruct decaying traces in the same way for dyslexic children as for typically developing children (by using redintegration) but may simply do so less efficiently in dyslexia (because of the poorer quality of long-term representations). This view was supported by the finding that the effects of phonological neighborhood density on serial recall performance were comparable for dyslexic and typically developing children, even though overall recall in dyslexia was impaired. Alternatively, we noted that it was theoretically possible that the phonological system in dyslexic children would develop according to quite different parameters. In this case, either phonological neighborhood density should not affect serial recall in dyslexic children or divergent effects for real words versus nonwords might be found. Neither of these possibilities was reflected in the data. Finally, the possibility that dyslexic children have fully specified phonological representations that act to support redintegration processes in the same way as in typically developing children was noted, with short-term phonological representations being of poorer quality for other reasons (see Roodenrys & Stokes, 2001). This possibility appears unlikely, given the significantly increased tendency to make lexicalization errors found for the dyslexic children only. If the long-term phonological representations of dyslexic children had been equivalent in quality to those of their reading-level controls, they should not have guessed real words more frequently than did younger children when trying to recall nonwords. In summary, therefore, the pattern of performance suggests that serial recall is impaired in dyslexic children because of their well-documented problems in establishing high-quality long-term phonological representations for words (Snowling, 2000). These poor-quality phonological representations affect short-term recall because of automatic processes, such as redintegration, which function in the same way in dyslexic and typically developing children.

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NOTES

1. We are very grateful to Sue Gathercole for providing us with her original data.

2. These two cohorts were originally treated as independent; however, since exactly the same experimental effects were found, we will report data from both together.

3. These statistics were kindly provided by Michael Vitevitch.

4. In each cohort of children, the dyslexic children did not differ from their reading-level controls on measures of phonological awareness, such as oddity and same–different judgment tasks (see Richardson, Thomson, Scott, & Goswami, 2004).

Appendix A
List of Words Used in Experiment 1

Dense RND				Sparse RND			
thumb	hale	scene	ring	hem	dull	join	song
boom	thing	rule	tone	dome	gown	tong	curl
bone	pail	king	gum	gong	turn	comb	pull
ping	fun	doom	ball	home	down	wool	wrong
hat	weak	jug	shop	word	league	ripe	nib
knit	laid	rack	pub	nook	bud	type	rib
fed	tub	shake	lip	wipe	bird	hook	leg
root	knob	map	lake	fib	road	peg	shook

	Dense RND *M*	Dense RND *SD*	Sparse RND *M*	Sparse RND *SD*
RND	18.0	3.3	7.0	2.7
LD	9.5	4.5	9.2	5.4
ND	32.7	7.1	21.6	6.3
Fam	6.6	0.6	6.7	0.8
LSF	1.107	0.832	1.020	0.997
SBF	0.006	0.005	0.004	0.003
SSF	0.143	0.047	0.135	0.035

Note—RND, rime neighborhood density; LD, number of lead neighbors; ND, number of overall neighbors; Fam, familiarity ranking out of a maximum of 7, according to the Luce and Pisoni (1998) norms; LSF, spoken frequency (Celex psycholinguistic database; Baayen et al., 1995); SBF, sum of biphone frequencies; SSF, summed segmental frequencies.

Appendix B
List of Nonwords Used in Experiment 2, With International Phonetic Alphabet (IPA) Transcriptions Given in Brackets

Dense RND			Sparse RND		
zick	yane	mot	woss	rerd	pul
[z ɪ k]	[j eɪ n]	[m ɒ t]	[w ɒ s]	[r ɜ d]	[p ʌ l]
bock	jat	gip	fong	mib	vut
[b ɒ k]	[dz æ t]	[g ɪ p]	[f ɒ ŋ]	[m ɪ b]	[v ʊ t]
lod	thag	pess	chud	jope	geb
[l ɒ d]	[ð æ g]	[p e s]	[tʃ ʌd]	[j əʊ p]	[g e b]
wooz	feek	vap	lish	kern	sipe
[w u z]	[f i k]	[v æ p]	[l ɪʃ]	[k ɜ n]	[s aɪ p]
teed	rill	shum	shof	bup	heg
[t i d]	[r ɪ l]	[ʃ ʌ m]	[ʃ ɒ f]	[b ʌ p]	[h e g]

	Dense RND *M*	Dense RND *SD*	Sparse RND *M*	Sparse RND *SD*
RND	19.6	4.6	6.1	2.8
LD	7.0	4.8	8.1	6.6
ND	30.00	9.4	16.9	7.4
SBF	0.007	0.006	0.003	0.003
SSF	0.146	0.045	0.134	0.038

Note—RND, rime neighborhood density; LD, number of lead neighbors; ND, number of overall neighbors; SBF, sum of biphone frequencies; SSF, summed segmental frequencies.

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