Learning to read changes children’s phonological skills: evidence from a latent variable longitudinal study of reading and nonword repetition

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Abstract

Individual differences in nonword repetition are associated with language and literacy development, but few studies have considered the extent to which learning to read influences phonological skills as indexed by nonword repetition performance. We explored this question using a latent variable longitudinal design. Reading, oral language and nonword repetition were assessed in 215 children at age 6 years and one year later at age 7. Reading at 6 years predicted growth in nonword repetition between 6 and 7 years, independent of the effects of oral language skills and the autoregressive effect of nonword repetition at 6 years, but nonword repetition was not a longitudinal predictor of the growth of reading. These findings demonstrate that learning to read has a powerful effect on children’s language processing systems. We consider how learning to read might influence speech processing, and discuss the implications of our findings for theoretical accounts of reading disorder.

Introduction

Nonword repetition – simply asking a child to repeat novel phonological forms – is closely associated with language development. An impressive range of evidence supports this relationship. Longitudinal studies point to an association between nonword repetition and vocabulary growth in early- to mid-childhood (Gathercole, Willis, Emslie & Baddeley, 1992). Experimental studies show that children who are poor at nonword repetition are also poor at learning new words (Gathercole & Baddeley, 1990; Gathercole, Hitch, Service & Martin, 1997) and children with language impairment are poor at nonword repetition (Graf Estes, Evans & Else-Quest, 2007), as are children identified as poor readers (e.g. Catts, Adlof, Hogan & Ellis Weismer, 2005; Snowling, 1981). While evidence for an association between nonword repetition and language learning is clear, theoretical accounts for this association differ.

One influential account sees phonological short-term memory as a language learning device with phonological storage (indexed by nonword repetition) being needed to learn the sound structure of new words. On this view, phonological memory plays a causal role in language development (e.g. Baddeley, Gathercole & Papagno, 1998). An alternative view sees vocabulary development driving the association. As vocabulary size increases, phonological representations become better specified and context-independent, leading to improvements in nonword repetition (e.g. Bowey, 2001; Metsala, 1999; Munson, Edwards & Beckman, 2005). Arguments have also been made for a more interactive view that sees reciprocal relations between language and nonword repetition (e.g. Coady & Evans, 2008; Snowling, 2006). As Ellis Weismer and Edwards (2006, p. 557) note, ‘one would expect that it would be more difficult to analyze phonological representations that are poorly stored and that it also would be more difficult to store poorly specified phonological representations’.

It is clear that nonword repetition is not as simple a task as it first seems. Several factors influence nonword repetition performance including a range of stimulus properties such as wordlikeness (Gathercole, Willis, Emslie & Baddeley, 1991), prosodic structure (Archibald, Gathercole & Joanisse, 2009; Roy & Chiat, 2004), phonotactic probability of phoneme sequences within the stimulus (Edwards, Beckman & Munson, 2004; Munson et al., 2005), speech motor skills (Sasisekaran, Smith & Sadagopan, 2010) and articulatory factors such as complexity and coarticulation (Archibald & Gathercole, 2006; Archibald et al., 2009; Vance, Stackhouse & Wells, 2005). In this paper, we investigate another potential influence on nonword repetition: learning to read.

The potential influence of learning to read on children’s nonword repetition has not been investigated directly. However, data from studies with illiterate
people provide strong support for the view that learning to read an alphabetic orthography improves nonword repetition. Reis & Castro-Caldas (1997) found that illiterate adults were less skilled at nonword repetition than a group of literate control participants. They argued that learning to read makes available the segmental structure of language and that, in turn, this serves to support nonword repetition. Furthermore, neuroimaging studies demonstrate that when illiterate people hear nonwords they do not activate the same neural substrates as literate people, suggesting that learning to read influences the functional organization of language regions in the brain (Castro-Caldas, Petersson, Reis, Stone-Elander & Ingvar, 1998; Petersson, Reis, Askelöf, Castro-Caldas & Ingvar, 2000).

Reflecting on these findings, Frith (1998, p. 1011) likens learning an alphabetic code to acquiring a virus, noting that ‘This virus infects all speech processing, as now whole word sounds are automatically broken up into sound constituents. Language is never the same again. This is not a cause for regret, since a benefit of this sort of “brainwashing” is an improvement in memory; by keeping track of phoneme constituents, novel word sounds are remembered more accurately.’

Why might learning to read influence nonword repetition performance, a task that does not involve written language? One possibility is that in literate people, orthographic information is automatically activated when language is heard, even when it is not needed for task completion (e.g. Seidenberg & Tanenhaus, 1979). On this view, activating orthography provides an additional mnemonic cue that serves to support nonword repetition. Clearly, this support would be available only to literate people. An alternative view, more in line with the account provided by Castro-Caldas et al. (1998), is that learning to read changes the nature of children’s phonological representations such that they begin to incorporate orthographic information (Muneau & Ziegler, 2004; Pattamadilok, Knierim, Duncan & Devlin, 2010; Perre & Ziegler, 2008; Perre, Midgley & Ziegler, 2009). According to this account, as children learn to read ‘contamination’ from orthography causes phonological representations to be restructured. This refinement brings about greater support for nonword repetition in literate vs. non-literate people.

Regardless of which theoretical perspective one adopts, a clear prediction follows: we would expect to see close associations between learning to read and nonword repetition in childhood. Rather surprisingly, this association has not been explored very much, with most evidence bearing on this relationship coming from studies of children with developmental dyslexia. Children with dyslexia are poor at repeating nonwords (e.g. Brady, Shankweiler & Mann, 1983; Catts et al., 2005; Pickering, 2006; Snowling, 1981; Snowling, Goulandris, Bowby & Howell, 1986). A recent meta-analysis (Melby-Lervåg & Lervåg, under review) reported that the nonword repetition deficit seen in dyslexia is large in effect size relative to chronological age controls; in addition, dyslexic children are worse at repeating nonwords than younger typically developing children matched for reading level, with the effect size being moderate to small. While it is generally accepted that these deficits are associated with difficulties in phonological processing, theoretical accounts differ. One view proposes that children with dyslexia have a core deficit in phonological memory which is causally related to their difficulties in learning to read (Gathercole & Baddeley, 1993; Wagner & Torgeson, 1987). An alternative view sees deficits in nonword repetition being a reflection of more general phonological processing impairments that are, in turn, causally related to the reading disorder (Bowey, 2001; Snowling, Chiat & Hulme, 1991; Snowling & Hulme, 1994).

Potentially however, given the findings from studies of illiterate people discussed earlier (e.g. Castro-Caldas et al., 1998), nonword repetition deficits in school-age children with severe reading impairments may be at least in part a consequence, rather than a cause, of reading failure, if learning to read serves to change the nature of phonological representations. One way to address this issue is to measure nonword repetition in young pre-literate children who are at genetic risk of becoming dyslexic. If poor nonword repetition is a consequence of primary deficits in phonological memory, or a reflection of inadequate phonological processing skills, pre-literate children who go on to be dyslexic later in life should show deficits in nonword repetition. While such deficits have been observed, it is important to note that they tend to be accompanied by a range of other oral language weaknesses, including impairments in vocabulary (e.g. Gallagher, Frith & Snowling, 2000; van Alphen, de Bree, Gerrits, de Jong, Wilkensach & Wijnen, 2004). These findings are difficult to interpret with respect to the nature of the relationship between nonword repetition and later reading: it might be that deficits in nonword repetition in at risk samples are a consequence of comitant language impairments, rather than being directly implicated in their reading failure. Consistent with this conclusion, Melby-Lervåg & Lervåg’s (under review) meta-analysis of the nonword repetition deficit in dyslexia found that the effect size of the deficit varied significantly from study to study, and that the status of children’s oral language acted as a powerful moderator variable explaining this variation; put simply, those dyslexic children with co-morbid oral language impairments showed much more severe deficits in nonword repetition.

It is striking that we know so little about the development of nonword repetition and its relationship to reading in typically developing children, given that it features prominently in theoretical accounts of reading disorder and in accounts of other developmental disorders that are associated with reading difficulties including language impairment, autism and Down syndrome (e.g. Archibald & Joanisse, 2009; Bishop & Snowling, 2004; Catts et al., 2005; Conti-Ramsden, 2003;
Baddeley, 1993; Wagner & Torgesen, 1987), studies have contributed to the development of reading (Gathercole et al. 1992) observed significant simple correlations between word reading and nonword repetition in children aged 5, 6 and 7 years. Gathercole and Pickering (2000) reported a significant correlation between a phonological memory factor that included nonword repetition (separate data for nonword repetition alone were not reported) and literacy, both measured concurrently at 7 years. The correlation of phonological memory at 7 years with literacy at 8 years was not significant. In younger children, Gathercole (1995) reported a significant correlation between nonword repetition at 4 years and early reading skills measured at 5 years; surprisingly, however, there was no significant correlation between nonword repetition and literacy when measured concurrently at age 5, once vocabulary was controlled (see also Gathercole, Willis & Baddeley, 1991). These data led Gathercole (1995) to suggest that phonological memory, as indexed by nonword repetition, is most critical for very early aspects of reading development. While this suggestion is consistent with the pattern of data, interpretation is difficult as no descriptive data concerning the children’s reading skills were presented. With a mean age of only 5 years 3 months, it is likely that literacy levels were limited, leading to concerns over the validity of the correlational analyses.

A number of more recent studies have examined the relationship between working memory and literacy outcomes (e.g. Alloway, Gathercole, Willis & Adams, 2004; Alloway, Gathercole, Kirkwood & Elliott, 2009). However, these studies have limited relevance to the present investigation for two reasons. First, they tend to be unidirectional, predicting later reading from earlier measures of working memory whereas we are more concerned with the question of whether learning to read influences phonological storage. Second, nonword repetition and its relationship with reading is not discussed separately from other measures of phonological loop function, or from more general working memory skills; and, in more recent studies by Gathercole, Alloway and colleagues, nonword repetition data are not included. This final point also applies to the series of latent variable longitudinal studies relating phonological processing to reading development, conducted by Wagner and colleagues (e.g. Wagner, Torgesen & Rashotte, 1994). Although these included a phonological memory factor, it was quite broad in scope, comprising memory for sentences, oral and visual digit span, and listening span and, importantly for the present investigation, did not include nonword repetition.

In summary, although there is a general assumption that the skills indexed by nonword repetition might contribute to the development of reading (Gathercole & Baddeley, 1993; Wagner & Torgesen, 1987), studies have not examined the opposite causal relationship, i.e. the extent to which learning to read might influence nonword repetition performance. Yet, data from illiterate adults (e.g. Castro-Caldas et al., 1998; Reis & Castro-Caldas, 1997) suggest that learning to read may have profound effects on the processes that are tapped by nonword repetition. We used a longitudinal design to examine the relationship between reading and nonword repetition, focusing on the question of whether learning to read influences children’s nonword repetition skills. We measured reading, nonword repetition, phonological awareness and other oral language skills at 6 years and one year later when the children were 7 years old. To reduce the influence of measurement error, multiple indicators for each construct were obtained at each time point allowing us to chart concurrent and longitudinal relations between latent variables, controlling for autoregressive effects where appropriate.

To address the hypothesis that learning to read is causally related to growth in nonword repetition, we explored the following critical prediction: Longitudinally, reading at 6 years should predict nonword repetition at 7 years. We also assessed a second prediction, namely that nonword repetition at 6 years should predict reading at 7 years, given the hypothesis that phonological memory is causally related to reading development (Gathercole & Baddeley, 1993). Our models also included measures of oral language (including vocabulary) and phonological awareness; factors which are known to be associated with reading and nonword repetition (e.g. Bowey, 2001; de Jong & van der Leij, 1999; Gathercole et al., 1992; Wagner et al., 1994). This allowed us to address the specific relationship between reading and nonword repetition, alongside their expected associations with language and phonological awareness.

Method

Participants

Seventeen primary schools serving a range of neighbourhoods in Oxfordshire took part in this study. All children entering these schools in 2004 were invited to participate. Informed consent from parents was received for 242 children (141 girls and 108 boys; \(M = 4.83\) years, \(SD = 0.34\)). National Office of Statistics data confirmed the range of socioeconomic circumstances (IMD percentile rank \(M = 59.03, SD = 30.55, range = 15.29–95.38\) that characterized the sample. The majority of the sample (95.18%) were native speakers of British English. We report here data from two phases: time 1 (Year 1 in school, \(M\) age = 6.26 years, \(SD = 0.34; N = 215\)) and 12 months later at time 2 (Year 2 in school, \(M\) age = 7.23 years, \(SD = 0.35; N = 202\). All children followed the UK Literacy Strategy curriculum with a heavy emphasis on phonics instruction.

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Children were tested individually in a quiet room adjacent to their classrooms. The following tests were administered over three sessions, each lasting approximately 20 minutes, as part of a larger testing battery.

**Nonword repetition**

Two tests measured nonword repetition at each time point: the *Children’s Test of Nonword Repetition* (CNRep; Gathercole & Baddeley, 1996) and the *Non-word Repetition* subtest from the *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen & Rashotte, 1999). The CNRep comprises 40 nonwords, varying in length with 10 items of two, three and five syllables. The items also varied in phonological complexity and wordlikeness (for a full discussion of stimulus properties, and an item list, see Gathercole, 1995). Items were digitally recorded and played from a laptop computer while children listened via headphones. Each repetition was scored as correct or incorrect, according to test manual instructions. The 18 items from the CTOPP varied in length from one to six syllables; phonological complexity varied considerably across items but, generally, the items contained few morphemes or embedded words, thus making them non word-like. Items were recorded in British English and presented in the same way as CNRep items.

**Reading**

To assess *Early Word Reading* skills at time 1, we selected 75 words from the lists of age-appropriate sight words published by the National Literacy Strategy. The words were ordered according to written frequency (Masterson, Dixon & Stuart, 2002) and presented on individual cards. Testing was discontinued if the child made 10 consecutive errors. The *British Ability Scales Word Reading Subtest* (Elliott, Smith & McCullouch, 1996) provided an assessment of single-word reading accuracy (untimed) at time 2. To assess fluency, children completed both the *Sight Word Efficiency* component of the *Test for Word Reading Efficiency* (TOWRE; Torgesen, Wagner & Rashotte, 1999) at both time points. Children were presented with a list of progressively more difficult words and were required to read as many as they could in 45 seconds. Their score was the number of words correctly read within the allotted time. All three word reading tests comprised a mixture of regular and irregular words.

**Language**

Expressive vocabulary was assessed at both time points using the vocabulary subtest from the *Wechsler Abbreviated Intelligence Scales* (WASI; Wechsler, 1999). This test requires children to provide definitions for words supplied by the experimenter. Two subtests from the *Clinical Evaluation of Language Fundamentals* (CELF-3UK; Semel, Wiig & Secord, 2000) provided additional estimates of expressive and receptive language skills. *Recalling Sentences* required children to repeat sentences of increasing length and grammatical complexity; *Sentence Structure* assesses acquisition of structural rules at the sentence level by asking children to select a picture that matches the target sentence.

**Phonological awareness**

The *Elision* subtest from the *Comprehensive Test of Phonological Processing* (Wagner et al., 1999) provided a measure of phonological awareness at each time point. Children were presented with 20 spoken words and were asked to delete a segment. Early items required a syllable to be deleted (e.g., ‘toothbrush’ without ‘tooth’) whereas later items required a single phoneme in initial, final or medial position to be deleted.

**Results**

Descriptive statistics for all of the variables at each time point are shown in Table 1. The reliabilities for standardized measures (taken from test manuals) are generally very good. *Early Word Reading* measured at time 1 is not a standardized test but it showed a strong correlation with TOWRE reading at time 1 ($r = .833$) and both reading measures at time 2 (TOWRE $r = .833$; BAS $r = .813$), indicating excellent reliability. Skew and kurtosis were close to zero for all measures with no estimate exceeding 1.8 (this being the kurtosis value for *Recalling Sentences* at time 1). A series of repeated measures analyses of variance established that there was significant growth in every variable over time. All variables correlated significantly ($p < .001$) with each other at both time 1 and time 2 (Table 2).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time 1 (6 years)</th>
<th>Time 2 (7 years)</th>
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</thead>
<tbody>
<tr>
<td><strong>Reliability</strong></td>
<td><strong>M</strong></td>
<td><strong>SD</strong></td>
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<tr>
<td><strong>Nonword repetition</strong></td>
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<td></td>
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<tr>
<td>CNRep</td>
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<td>23.39</td>
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<tr>
<td>CTOPP</td>
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<tr>
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<td>45.12</td>
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<tr>
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<tr>
<td>Recall Sent</td>
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<td>25.58</td>
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<tr>
<td>Sent Struct</td>
<td>.55</td>
<td>15.62</td>
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<tr>
<td><strong>Phonological awareness</strong></td>
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<tr>
<td>Elision</td>
<td>.88</td>
<td>7.92</td>
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(version 5.21, Muthén & Muthén, 2007). Missing data were handled using Full Information Maximum Likelihood estimation.

**Concurrent predictors of nonword repetition at time 1 and time 2**

Using the time 1 data, we formed three latent variables according to our a priori theoretical assumptions: reading (TOWRE and EWR), repetition (CTOPP and CNRep) and language (Vocabulary, Recalling Sentences and Sentence Structure). Phonological awareness was assessed by a single indicator (Phoneme Elision). All factor loadings were high. Figure 1(a) shows a path model in which repetition was predicted from language and phonological awareness. Reading was included in the model and allowed to correlate with language and phonological awareness. The model provided an excellent fit to the data ($\chi^2 = 18.14$, df = 16, $p = .316$, CFI = .997, RMSEA = .025, SRMR = .027) and accounted for a substantial proportion of the variance in repetition ($R^2 = .64$, $p < .001$). Although the path from language to repetition was strong, the path from phonological awareness to repetition was not significant. A second model was tested, including a path from reading to repetition. This did not improve the fit of the model ($\chi^2_{\text{diff}} = 1.10$, df$_{\text{diff}} = 1$, ns), confirming that reading did not predict repetition at this young age.

Turning to time 2, three latent variables were created, following the procedure used at time 1 (in this model BAS word reading replaced the EWR test). Once again, all factor loadings were high. Figure 1(b) shows a path model predicting repetition at time 2 from reading, language and phonological awareness. Again, model fit was

![Figure 1](image-url)
excellent ($\chi^2 = 18.56$, df = 15, $p = .249$, CFI = .997, RMSEA = .033, SRMR = .020), and the model accounts for substantial variance in repetition ($R^2 = .72$, $p < .001$). As at time 1, the path from language to repetition was strong and the path from phonological awareness to repetition was not significant. However, in this model the path from reading to repetition was also significant and, importantly, dropping this path resulted in a significant reduction in model fit ($\chi^2_{\text{diff}} = 4.48$, df$_{\text{diff}} = 1$, $p < .05$).

Concurrent predictors of reading at time 1 and time 2

The same latent variables were used to assess concurrent predictors of reading. Figure 2(a) shows a path model predicting reading at time 1. Model fit was excellent ($\chi^2 = 17.03$, df = 15, $p = .317$, CFI = .997, RMSEA = .025, SRMR = .026), and the model accounts for substantial variance in reading ($R^2 = .57$, $p < .001$). As anticipated, phonological awareness made a significant contribution, as did oral language; nonword repetition, however, did not. A model of the time 2 data is shown in Figure 2(b). Model fit was excellent ($\chi^2 = 18.26$, df = 15, $p = .250$, CFI = .997, RMSEA = .033, SRMR = .020), and again the model accounts for substantial variance in reading ($R^2 = .61$, $p < .001$). At this time point, repetition did predict reading, as did language and phonological awareness.

Longitudinal predictors of repetition and reading at time 2 from time 1 variables

Our final path model examined the prediction of two latent factors at time 2, Repetition and Reading, from time 1 factors (Repetition, Language, and Reading). To keep the model as simple as possible, phonological awareness was not included, given that it made no contribution to repetition at either time point. Figure 3 shows the model which gives an excellent fit to the data ($\chi^2 = 41.80$, df = 34, $p = .186$, CFI = .996, RMSEA = .032, SRMR = .023).

The model explained a very high proportion of variance in repetition at time 2 ($R^2 = .87$, $p < .001$). Not surprisingly, repetition at time 1 was a strong predictor of repetition at time 2. Beyond this autoregressive effect, reading at time 1 made an additional significant contribution to repetition at time 2; however, language at time 1 did not. Turning to the prediction of reading at time 2 ($R^2 = .92$, $p < .001$), the autoregressive effect of reading at time 1 was substantial, indicating excellent stability over time. Neither repetition at time 1 nor language at time 1 were significant predictors of reading at time 2, once the effects of reading at time 1 had been controlled.

Discussion

The primary motivation of our study was to examine the longitudinal relationship between learning to read and nonword repetition. Although reading was not uniquely associated with nonword repetition in the early stages of learning to read, by 7 years of age reading was a unique predictor of nonword repetition when measured concurrently. Longitudinally, reading at 6 years predicted growth in nonword repetition between 6 and 7 years. Notably, this longitudinal relationship was independent of the longitudinal relationship between oral language skills (including vocabulary) and nonword repetition.

Figure 2  Path diagrams predicting reading at (a) time 1 and (b) time 2. Dashed lines represent non-significant paths.
development, and of earlier nonword repetition (the autoregressor effect). These longitudinal findings are clear in demonstrating that growth in one domain (reading) predicts developmental change in another domain (nonword repetition), consistent with written language being incorporated into children’s language processing systems in a highly interactive and dynamic way.

An important question is why learning to read changes children’s phonological processing skills. Ziegler, Muneaux & Grainger (2003) and Muneaux & Ziegler (2004) offer an account that is explicitly developmental. They set their account within the lexical restructuring hypothesis proposed by Metsala (1997) and Metsala & Walley (1998). This hypothesis proposes that early in development, phonological representations are holistic; as vocabulary size increases, however, there is pressure for the system to reorganize, causing phonological forms to be represented in a more segmental way. As Ziegler and colleagues note, although Metsala’s lexical restructuring hypothesis did not propose a role for orthography in lexical restructuring, such a role seems very plausible: as children learn to read and discover sound–spelling mappings at the sublexical level, the similarity relations between similar sounding (and therefore similarly spelled) words will influence phonological restructuring such that words that enjoy consistent support from spelling will develop better specified phonemically structured phonological representations.

This hypothesis provides a ready explanation of our finding that learning to read influences the development of nonword repetition. On this view, the act of learning to read an alphabetic language helps to bring about the creation of segmental phonological representations which, in turn, directly facilitate nonword repetition. Our findings add evidence to Ziegler et al.’s hypothesis by showing that learning to read influences phonological processing longitudinally. Importantly, as we measured the children’s oral language skills at both time points, our models were able to assess whether learning to read influenced the development of nonword repetition beyond any influence of oral language – a factor known to influence lexical restructuring (Metsala, 1997; Metsala & Walley, 1998). Our data are very clear on this point, showing an effect of earlier reading on later nonword repetition, beyond the effect of oral language, as well as the autoregressive effect of earlier nonword repetition itself.

Using multiple indicators to construct latent variables of Reading and Repetition at each time point has the advantage of reducing error variance. However, we are not able to specify precisely which aspects of learning to read are responsible for influencing developmental change in nonword repetition. Complementary findings from cross-sectional experiments by Ventura and colleagues are relevant here. They also reported evidence of orthography influencing phonological processing early in reading development with 2nd grade children showing widespread orthographic effects on auditory lexical decision performance (Ventura, Kolinsky, Pattamadiilok & Morais, 2008; Ventura, Morais & Kolinsky, 2007). Interestingly, however, these children did not show the same pattern that is seen in
experiments with adults. Adults are slower to make auditory lexical decisions to words that contain inconsistent sound–spelling mappings compared to consistent mappings, but stimulus consistency does not influence nonword processing speed (e.g. Ziegler & Ferrand, 1998). In contrast, young children showed more ubiquitous effects with stimulus consistency influencing both word and nonword processing in auditory lexical decision. By 6th grade, however, children showed the same pattern as adults with orthographic effects being restricted to words, not nonwords. Ventura et al. argued that this developmental shift reflects reading development, with children moving from focusing on individual grapheme–phoneme correspondences to more lexical-level reading. Given the age of our children, and that the UK curriculum has a heavy phonics focus during the early years of learning to read, it seems likely that our reading measures are capturing the development of alphabetic reading, and that it is this that is key to influencing nonword repetition performance.

We also assessed a second prediction, namely that nonword repetition at 6 years should predict reading at 7 years, given the hypothesis that phonological memory is causally related to reading development (Gathercole & Baddeley, 1993). Although it is clear that the two skills are strongly correlated, both concurrently and longitudinally, nonword repetition did not uniquely predict growth in reading development, although it must be noted that the autoregressive effect of reading at time 1 captured significant variance in reading at time 2. It could be that earlier in time, emergent literacy measures such as early word reading ability and letter knowledge might be predicted by phonological short-term memory. In children aged 6–7 years, however, this study failed to find any support for the hypothesis that individual differences in skills tapped by nonword repetition are associated with individual differences in learning to read.

In contrast to this, the significant association between learning to read and developmental changes in nonword repetition has two important implications, one methodological and one theoretical. First, it highlights the need to consider orthography as an important stimulus property when devising items to assess nonword repetition alongside other stimulus factors known to influence performance (for example, phonotactic predictability, prosodic structure and wordlikeness). We know that words with inconsistent spellings are processed more slowly in auditory lexical decision (e.g. Ziegler & Ferrand, 1998), and that nonwords containing inconsistent spelling–sound patterns are more difficult to read (Tremain, Goswami & Bruck, 1990). Together, these observations lead to the prediction that nonwords containing units of sound that are associated with inconsistent spellings should be hard to repeat – at least for literate people. It would also be interesting to examine these relationships across languages that vary in orthographic transparency. Pattamadilok, Morais, DeVylder, Ventura and Kolinsky (2009) presented evidence showing that lexical-level orthographic effects on phonological processing appear earlier in development in children learning to read French compared with children learning to read Portuguese – a more consistent language. Given that English is also an inconsistent language, early effects of orthography on phonology across a variety of tasks are to be expected in children learning to read English, consistent with the data we report in this paper.

Arguably a more important implication of our findings concerns the role of deficits in nonword repetition in accounts of the causes of reading disorder. Deficits in nonword repetition are seen in school-age children with developmental dyslexia (e.g. Brady et al., 1983; Catts et al., 2005; Melby-Lervåg & Lervåg, under review; Snowling et al., 1986). Classically, this has been seen as part of the constellation of phonological deficits that play a causal role in the manifestation of dyslexia (Wagner & Torgesen, 1987). However, our finding that later nonword repetition is at least in part a consequence of learning to read cautions against a strong version of this hypothesis. Put simply, poor nonword repetition in children with dyslexia might well be a consequence of reading failure rather than its cause. Consistent with this, phonological awareness and oral language skills predicted early reading at age 6 years but nonword repetition did not; nor did nonword repetition predict growth in reading over time, although it is important to note that the autoregressive effect of early reading on later reading was extremely strong, accounting for a substantial portion of variance. Nevertheless, while growth in reading predicted later nonword repetition, there was no strong evidence that early nonword repetition predicted progress in reading development.

Poor performance at nonword repetition is also associated with a number of other developmental disorders, including language impairment, autism and Down syndrome. As these disorders are also associated with reading difficulties, it might be that nonword repetition difficulties are exacerbated by failing to learn to read. Certainly, reading level is likely to be an important correlate of individual differences in nonword repetition in children with developmental difficulties. Reporting on a longitudinal study of nonword repetition development in adolescents with specific language impairment, Conti-Ramsden & Durkin (2007) described data consistent with this view. They found that word reading skills measured at age 11 years predicted unique variance in nonword repetition at 14 years, and suggested that ‘poor literacy skills may cause nonword repetition skills to stall or decline’ in individuals with language impairment (p. 154). Our own findings from a latent variable study with a larger and a non-clinical sample offer strong support to this suggestion.

In summary, our findings are consistent with the view that learning to read has a powerful effect on children’s language processing systems. While the reciprocal nature of the relationship between phonological awareness and
learning to read has been discussed for a number of years (Perfetti, Beck, Bell & Hughes, 1987), our longitudinal data are the first to show that learning to read influences the later development of nonword repetition, even after the effects of more general oral language skills and phonological awareness (and the autoregressor) are controlled. Our data suggest that the language system quickly assimilates orthographic information, as children learn to read, and that this information is available to influence on-line performance, as children listen to and repeat novel words.

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Received: 4 November 2009
Accepted: 19 July 2010