Effects of Orthographic, Morphological and Semantic Overlap on Short-Term Memory for Words in Typical and Atypical Development

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ABSTRACT

Little is known about implicit morphological processing in typical and atypical readers. These studies investigate this using a probe detection task with lures sharing morphological, orthographic, or semantic overlap with the probe. Intermediate and advanced readers (reading ages = 9;1–12;9) perform more poorly when there is more linguistic overlap. Novice readers (reading ages = 5;7–8;0) were influenced only by orthographic overlap and not by semantics, indicating that use of orthographic processes typically precedes integration of semantic and morphological skills. Children with otitis media (repeated ear infections) had phonological awareness difficulties but performed age appropriately on the probe detection task, indicating that morphological processing is not constrained by phonology. In contrast, dyslexic children's performance reflected a failure to remember distinctions between words sharing root morphemes. Dyslexic children are sensitive to morphology but may over-rely on root morphemes. This pattern differed from reading-ability-matched children and children with circumscribed phonological difficulties.

Morphological awareness is closely linked to literacy attainment (Casalis, Deacon, & Pacton, 2011; Deacon & Kirby, 2004). A useful distinction can be made between morphological awareness and morphological processing. Morphological awareness refers to the ability to explicitly manipulate morphemes, often productively. Morphological processing is the implicit use of morphemes in reading or spelling (Deacon, Parrila, & Kirby, 2008). Most prior research into morphological processing in literacy development and impairment has correlated explicit measures of morphological awareness with reading ability (e.g., Berninger et al., 2006; Casalis, Colé, & Sopo, 2004; Cunningham & Carroll, 2015; Shankweiler et al., 1995), for example, segmenting complex words into morphemes or generating complex words for a given stem. Research that has examined morphological processing has focused on spelling of morphologically complex words using paradigms that similarly require explicit manipulation of morphemes (e.g., Egan & Pring, 2004; Tsesmeli & Seymour, 2006). Less is known about the development of morphological processing in reading. This article examines the development of morphological processes in typical and atypical reading development.

Most models of reading development confer a pivotal role on phonological awareness and decoding. Meanwhile, the roles of morphological and semantic awareness and processing are rarely discussed in much depth (Deacon, Tong, & Mimeau, in press). Reading models that do mention morphology typically suggest that it is integrated into the system after an initial phase of basic phonemic decoding and is closely linked to orthographic processing (Ehri, 1995; Ehri, Cardoso-Martins, & Carroll, 2013; Nunes, Bryant, & Bindman, 1997b). For example, although traditional dual

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route models (Coltheart, 2005) do not explicitly describe the role for morphology, more recent conceptualisations describe the use of multiple fine-grain codes (including morphemes) to access meaning through the orthographic route (Grainger, Lété, Bertand, Dufau, & Ziegler, 2012; Grainger & Ziegler, 2011). Development involves the acquisition and parallel use of multiple and increasingly coarse-grain codes. Decoding first theories predict not only that morphological processing emerges late in development but also that phonological difficulties would further hold back morphological processing. Others, however, argue that morphology can be used from the earliest stages of literacy acquisition (Deacon, Conrad, & Pacton, 2008; Pacton & Deacon, 2008; Treiman & Bourassa, 2000; Treiman & Cassar, 1996).

Both morphological awareness and processing are impaired in dyslexia (Deacon, Parilla, et al., 2008; Deacon et al., in press). Children with dyslexia have been shown to perform below chronological-age- (CA-) matched peers on morphological awareness measures in many languages (Berthiaume & Daigle, 2014; Carlisle, 1987; Casalis et al., 2004; Duranovic, Tinjak, & Turbic-Hadzagic, 2014; Egan & Pring, 2004; Egan & Tainturier, 2011; Joanisse, Manis, Keating, & Seidenberg, 2000; Leong, 1999; McBride-Chang et al., 2008; McBride-Chang, Liu, Wong, Wong, & Shu, 2012; Shu, McBride-Chang, Wu, & Liu, 2006; Siegel, 2008; Tsesmeli & Seymour, 2006; Vogel, 1977). They have also been shown to use morphological processes (in reading and spelling) less than age-matched peers (Breadmore & Carroll, 2016; Carlisle, Stone, & Katz, 2001; Fisher, Shankweiler, & Liberman, 1985; Hauerwas & Walker, 2003; Leong, 1989). To examine whether children with dyslexia show atypical morphological processing given their level of literacy skills, a better comparison is against younger, reading-ability-matched peers. For the most part, children with dyslexia perform similarly to reading-ability-matched children on oral measures of morphological awareness (Casalis et al., 2004; Egan & Pring, 2004; Egan & Tainturier, 2011; Robertson, Joanisse, Desroches, & Terry, 2012; Tsesmeli & Seymour, 2006). However, the picture for morphological processing is less clear. Some have found weaknesses in morphological spelling (Carlisle, 1987; Egan & Pring, 2004; Egan & Tainturier, 2011; Hauerwas & Walker, 2003; Tsesmeli & Seymour, 2006) whereas others have found no difference compared to ability matches (Bourassa, Treiman, & Kessler, 2006; Breadmore & Carroll, 2016). However, it is worth noting that very few studies have examined morphological processing in dyslexic children using a reading-ability-match design (Deacon et al., in press).

Despite the abundant evidence of morphological difficulties in dyslexia, the underlying cause of these difficulties are subject to ongoing debate (Deacon, Parilla, et al., 2008). Joanisse et al. (2000) argued that phonological and morphological impairments in children with language impairment and phonological dyslexia are both outcomes of a central underlying linguistic or metalinguistic difficulty. Others argue that a morphological deficit can result from a phonological deficit (Cunningham & Carroll, 2015). This could be because of the complex phonological properties of morphemes or because morpho-orthographic representation occurs only after an initial focus on phonemic decoding (Ehri et al., 2013; Nunes, Bryant, & Bindman, 1997a, 1997b). One way to examine this issue is to focus on children with relatively circumscribed phonological difficulties (those with a history of repeated ear infections) to investigate whether this group shows morphological impairments.

The majority of previous assessments have used offline morphological awareness tasks. For example, children are asked whether there is a "little word" inside words such as *corner* or *teacher* (Carlisle & Nomanbhoy, 1993) or which word correctly completes a morphological analogy (e.g., teach: teacher/bake: ?; Nunes et al., 1997a). These tasks require children to reflect upon the language they use and therefore make metalinguistic demands (Gombert, 1992). Recent evidence suggests that children with dyslexia may show particular deficits in metalinguistic tasks despite normal lexical representations (Mundy & Carroll, 2012; Ramus, Marshall, Rosen, & Van Der Lely, 2013; Ramus & Szenkovits, 2008). Here we introduce and assess a task that measures use of morphological information in short-term memory with minimal metalinguistic demands. We compare typically developing children, children with dyslexia, and children with atypical phonology but relatively good literacy to tease apart influences of dyslexia, literacy, and phonological skill.

It has been suggested that difficulties using phonemic decoding may lead individuals with phonological impairments to rely on morphological processing to a greater extent than typical individuals (profoundly deaf children: Breadmore, Olson, & Krott, 2012; dyslexic adults: Leikin & Hagit, 2006). At the beginning of development, this strategy is less successful than phonemic decoding, and therefore children who use morphemes early in reading acquisition gain less experience of accurately decoding the meaning of words, which could further hold back the development of phonological awareness/decoding and advanced morphological skills (Deacon, Parilla, et al., 2008).

Rastle, Davis, and New (2004) used a priming paradigm to demonstrate morphological decomposition in word recognition (lexical decision) by typical adults. Although this paradigm is free from metalinguistic demands, some studies have found poor readers to perform at chance in childhood (Duncan, Grey, Quemart, & Casalis, 2010). Moreover, priming relies on rapid and automatic activation of lexical items, which may be less consistent in children, particularly those with dyslexia (Breadmore & Carroll, in press; Carroll & Breadmore, under review). Hence the priming paradigm may not be appropriate for studying linguistic processes within developmental dyslexia. An alternative approach is to examine the effect of overlap between morphologically related words in short-term memory.

Representation of linguistic features in short-term memory is often examined by manipulating within-list similarity. Phonological and/or orthographic similarity reduces recall accuracy, resulting in false recall and recognition (Baddeley & Hitch, 1994; Walker, Hitch, & Duroe, 1993). Semantic similarity also leads to false recall, but the magnitude of the effect is weaker than phonological similarity (McDermott & Watson, 2001; Thapar & McDermott, 2001). In the present studies, within-list items are unrelated. Linguistic overlap is instead manipulated between a target lure on the list and a recognition probe. This paradigm has been used less often but avoids strategic use of overlapping information. Consistent with the findings for within-list similarity, probe paradigms similarly induce high rates of false recognition for probes with orthographic, phonological, or semantic similarity to a lure (Breadmore, 2007; Coane, McBride, Raulerson, & Jordan, 2007; Crosson et al., 1999; Shulman, 1970). High rates of false recognition are observed for target probes with morphological overlap; indeed the effect may be greater than that attributed to the combination of orthographic/phonological and semantic properties (Breadmore, 2007). To our knowledge, only Breadmore (2007) previously used this paradigm to investigate use of linguistic information by children, but here the focus was on the abilities of profoundly deaf adolescents.

The present study

Children memorised visually presented lists of words and then pressed a keyboard button to indicate whether a probe word was on the list. We manipulated the relationship between the probe and a target lure such that there was either no relationship or morphological (e.g., *postal–post*), pseudo-morphological (e.g., *metal–met*), or semantic (e.g., *street–road*) overlap. In this way we examine whether children retained detailed representations of this linguistic information. Deacon, Parilla, et al. (2008) argued that written presentation and nonverbal response reduces the impact of phonological weaknesses in dyslexia. Hence, in the present study we avoided any explicit oral output.

Participants make a signal detection decision on the basis of whether the match between the probe word and their memory of the target is good enough. Linguistic overlap between probe and target lures hence increases the likelihood that participants falsely accept that the probe was present on the list. The more overlapping information, the more likely participants are to incorrectly accept that they have seen the probe on the list (a false positive). The use of this information is implicit rather than strategic. This task can, in principle, be completed by children even if the words on the list are not in their lexicon and they use purely visual processes to memorise the words. Hence the task is particularly useful for examining development of implicit processing. On the basis of dual/multiple route models of reading (Grainger et al., 2012; Grainger & Ziegler, 2011), we hypothesise

that advanced readers use multiple sources of linguistic information in this task and therefore are more likely to falsely accept probes that share many features with the target lure (i.e., in the morphological condition where the words overlap in terms of morphological, orthographic/phonological, and semantic information) than probes that share only one feature (i.e., pseudo-morphological or semantic overlap conditions).

In Experiment 1 we present evidence that the paradigm is sensitive and reliable in typically developing children and examine effects of linguistic overlap across development by comparing novice, intermediate, and advanced readers. "Decoding first" accounts (Ehri, 1995; Ehri et al., 2013; Nunes et al., 1997b) predict that younger children will show only effects of orthographic/phonological processing, whereas effects of morphological and semantic processing will emerge later in development. In contrast, some theoretical accounts might argue that even novice readers will be sensitive to morphological overlap (Deacon, Conrad, et al., 2008; Pacton & Deacon, 2008; Treiman & Bourassa, 2000; Treiman & Cassar, 1996).

In Experiment 2 we examine whether phonological skills influence use of morphology by examining children with otitis media (OM)—repeated ear infections that often cause fluctuating hearing levels (also known as glue ear). Accounts highlighting the link between phonology and morphology (e.g., Cunningham & Carroll, 2015) predict that the phonological difficulties resulting from OM will also impair morphological and semantic processing.

In Experiment 3 we examine whether dyslexia uniquely affects performance. We hypothesise that children with dyslexia will have weaknesses in sensitivity to precise linguistic information, and therefore we anticipate that they will generally make more false positives when linguistic properties of the probe overlap with the target lure. Of particular interest, though, is whether use of morphological processing is impaired in dyslexia, as has been found with explicit morphological awareness tasks.

Experiment 1: Typical development

Experiment 1 examines use of linguistic information in short-term memory in typical development. We compare novice, intermediate, and advanced readers' ability to reject a probe word that shares morphological, pseudo-morphological, semantic, or no overlap in linguistic features with a target lure.

Comparisons of the magnitude of effects in different conditions will illustrate the extent to which children use each source of linguistic information in memory. We hypothesise that advanced readers will process pseudo-morphological, semantic, and morphological information, consistent with dual/multiple route models of skilled reading (Grainger et al., 2012; Grainger & Ziegler, 2011). All conditions where the target lure and probe overlap will increase rates of false positives compared to when they are unrelated. Moreover, because words that share morphological overlap (e.g., *postal–post*) also share these other linguistic properties (orthographic, phonological, and semantic overlap), the morphological effect will be greater than any other condition.

We expect to see general developmental differences on performance on the task. Accuracy will increase with literacy skill as lexical representations become increasingly well specified and more rapidly accessible. Hence, we predict that novice readers will generally (across all conditions) have lower performance than intermediate readers, who in turn will be weaker than advanced readers.

Most important, "decoding first" theories lead us to hypothesise that novice readers with incomplete or slow decoding skills will initially focus on the orthographic/phonological properties of words in order to perform this task. Only orthographic/phonological overlap will increase rates of false positives for novice readers; there will be less effect of semantic overlap (e.g., *street–road*). Hence, rates of false positives for words sharing morphological (e.g., *postal–post*) and pseudo-morphological (e.g., *metal–met*) overlap will be equal, because these conditions are matched for orthographic/phonological overlap and the semantic information is not automatically activated.

Method

Participants

Typically developing participants were 135 (63 female) primary school children ages 5;7–11;6 years, with standard scores on the British Ability Scales: Third Edition word reading test (Elliot & Smith, 2011) between 90 and 120. They were recruited from 20 primary schools in the Midlands, United Kingdom, through opt in consent as part of a larger study (Authors blinded for review) and were all monolingual native English speakers. None of these children's parents reported their having dyslexia, hearing impairment, or a history of repeated ear infection. Some of these children acted as reading age (RA) and CA controls in Experiments 2 and 3. One child had missing data from two trials.

Three groups were formed on the basis of the children's reading ability. Twenty-four (13 female) novice readers had an RA of 5;7–8;0 years, 47 (24 female) intermediate readers had an RA of 8;1–10;0, and 64 (26 female) advanced readers had an RA of 10;1–12;9 years. Each group is summarised in Table 1. The three participant groups differed in CA and RA, as well as phonological awareness and word classes scores (a test of semantic knowledge in which children select which of two words go together) from the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF4; Semel, Wiig, & Secord, 2006).

Stimuli and design

Each trial consisted of a seven-item list of unrelated words, followed by a probe word. One of the list items was a target lure. The relationship between the target lure and the probe was manipulated within-subjects. Eight lure-probe pairs shared morphological overlap (four derivations and four inflections; e.g., *drive–driver*), eight pairs had pseudo-morphological overlap (e.g., *off–offer*), eight had semantic overlap (e.g., *all–everyone*), and eight were unrelated (e.g., *little*, which was unrelated to all words on the list). In each case the trial was also repeated with the probe word present (replacing the target lure) on the list. A complete stimulus list is provided in the appendix. Hence, in total, participants responded to 64 trials (32 target present and 32 target lure trials).

When the probe was a word that was absent from the list, it was always longer/more complex than the target lure (e.g., the inflection was the probe and the root word was the target lure in the morphological condition). When target lure and probe shared pseudo-morphological overlap, the words shared orthographic and phonological properties but not semantic information. Semantic overlap words shared semantic but not orthographic or phonological properties. In the morphological overlap condition, words shared semantic, orthographic, and phonological properties and were morphological relatives. Pseudo-morphological probes contained the same word final letters as morphological probes (e.g., *met–metal* and *post–postal*). Independent samples *t* tests confirmed that between conditions, target lures and probe words were matched for frequency and number of orthographic neighbours from the Children's Printed Word Database (*p*s > .4 and *p*s > .1; Masterson, Stuart, Dixon, & Lovejoy, 2010), written frequencies from the Medical Research Council psycholinguistics database (*p*s > .2; Kucera & Francis, 1967; Wilson, 1988), word length (number of letters *p*s > .1; syllables *p*s > .2), and the difference in the number of letters in the probe and target lures (*p*s > .4; see Table 2).

To control for semantic similarity, 55 (seven male) native English speakers provided ratings for 100 word pairs using an online form. Participants had a mean age of 38 years (range = 25–68), a minimum of college-level education, and A-level qualifications. Ratings were provided on a Likert scale of 1 (*completely different meanings*) to 7 (*practically the same meaning*). Twenty-five word pairs were morphological relatives, 25 were pseudo-morphologically related, 25 had high semantic relatedness, and 25 were unrelated. Experimental items were then selected to have high semantic similarity in morphological and semantic overlap conditions (*M* rating = 3.85 or greater) and low semantic similarity in the pseudo-morphological and unrelated conditions (*M* rating = 1.09 or less). Independent samples *t* tests confirmed equally high semantic similarity for morphological and semantic overlap, *t*(14) = −1.8, *p* = .1, and equally low for pseudo-morphological and unrelated

Table 1. Characteristics of participants.

	Exp 1: Typical Development			Exp 2: OM			Exp 3: Dyslexia		
	Novice	Intermediate	Advanced	OM	RA	CA	Dyslexic	RA	CA
N (n female)	24 (13)	47 (24)	64 (26)	29 (9)	29 (15)	29 (10)	27 (16)	27 (16)	27 (15)
Chronological age (total months)									
M (SD)	86 (12.2)	103.6 (9.4)	115 (9.4)	111 (9)	102 (16)	110 (9)	111 (10)	92 (13)	111 (11)
Range	67–107	77–125	93–138	96–129	67–138	93–127	95–129	72–111	93–130
t test	(nov, int); (nov, adv); (int, adv)	t(69) = −6.7, p < .001; t(86) = −11.8, p < .001; t(109) = −6.3, p < .001		(OM, RA); (OM, CA)	t(56) = 2.4, p = .019; t(56) = 0.2, p = .9		(dys, RA); (dys, CA)	t(52) = 5.8, p < .001; t(52) = −0.0, p = 1.0	
Reading age (from BAS3 word reading, total months)									
M (SD)	86.9 (8)	110.2 (7)	133.8 (9.1)	110 (19)	112 (17)	126 (13)	90 (9)	92 (10)	125 (13)
Range	70–94	99–117	123–153	70–147	70–147	105–153	70–105	70–105	91–147
t test	(nov, int); (nov, adv); (int, adv)	t(69) = −12.7, p < .001; t(86) = −22.3, p < .001; t(109) = −14.8, p < .001		(OM, RA); (OM, CA)	t(56) = −0.4, p = .7; t(56) = −3.7, p < .001		(dys, RA); (dys, CA)	t(52) = −0.7, p = .5; t(52) = −11.6, p < .001	
CELF4 phonological awareness raw score									
M (SD)	67.9 (6.6)	72.6 (6.5)	76.2 (4.5)	69.8 (8.3)	73.5 (7.2)	75.3 (4.7)	66.9 (9.2)	69.1 (7.2)	73 (5.2)
Range	56–77	57–84	68–85	53–81	57–85	64–84	39–80	56–83	56–83
t test	(nov, int); (nov, adv); (int, adv)	t(69) = −2.9, p = .006; t(86) = −6.8, p < .001; t(109) = −3.5, p < .001		(OM, RA); (OM, CA)	t(56) = −1.8, p = .073; t(56) = −3.2, p = .003		(dys, RA); (dys, CA)	t(52) = −1.0, p = .3; t(52) = −3.0, p = .004	
CELF4 word classes raw score									
M (SD)	10.5 (5)	16.3 (4)	22.2 (7)	16.8 (5.5)	16.2 (6.7)	20.3 (6.4)	15.7 (7.2)	12.5 (5.8)	20.4 (6.3)
Range	2–20	5–26	9–36	5–26	2–36	11–33	0–32	2–25	9–33
t test	(nov, int); (nov, adv); (int, adv)	t(69) = −5.0, p < .001; t(86) = −7.4, p < .001; t(109) = −5.0, p < .001		(OM, RA); (OM, CA)	t(56) = 0.3, p = .7; t(56) = −2.3, p = .028		(dys, RA); (dys, CA)	t(52) = 1.8, p = .074; t(52) = −2.6, p = .013	

Note. Exp. = Experiment; OM = otitis media; RA = reading age; CA = chronological age; nov = novice; int = intermediate; adv = advanced; dys = dyslexic; BAS3 = British Ability Scales: Third Edition word reading test; CELF4 = Clinical Evaluation of Language Fundamentals–Fourth Edition.

Table 2. Mean (standard deviation) descriptive statistics for target and probe stimuli in morphological, pseudo-morphological, semantic, and unrelated conditions.

	Morphological	Pseudo-Morphological	Semantic	Unrelated
Target				
Length: N letters	4.1 (0.6)	3.5(1.2)	3.8 (0.5)	4.5 (1.2)
N syllables	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.1 (0.4)
Children's printed word frequency	602.1 (837.7)	612.8 (958.5)	965.4 (1657.0)	1118.6 (1573.8)
N orthographic neighbours	4.6 (2.5)	6.0 (5.0)	6.9 (3.9)	4.9 (4.9)
Kucera & Francis written frequency	246.5 (240.8)	367.8 (367.4)	505.5 (1022.8)	884.0 (1885.0)
Probe				
Length: N letters	5.8 (0.5)	5.0 (1.5)	5.4 (1.2)	5.6 (1.2)
N syllables	1.6 (0.5)	1.6 (0.5)	1.3 (0.7)	1.6 (0.5)
Children's printed word database: Frequency	714.9 (956.9)	686.6 (1820.0)	509.1 (656.8)	642.8 (1124.2)
N orthographic neighbours	1.5 (1.4)	4.5 (5.1)	3.0 (3.6)	2.1 (2.4)
Kucera & Francis written frequency	61.6 (75.1)	953.3 (2443.0)	149.6 (195.0)	220.1 (302.2)
Probe length—Target length	1.6 (0.5)	1.5 (0.5)	1.6 (1.4)	1.1 (1.6)
M similarity judgement	4.9 (0.6)	1.0 (0.0)	5.5 (0.7)	1.0 (0.0)

overlap, $t(7.9) = 1.7$, $p = .1$. The difference between the high semantic similarity (morphological and semantic) and low semantic similarity conditions (unrelated and pseudo-morphological) was significant ($ps < .001$). Despite our attempts at matching semantic relatedness, it is important to recognise that the nature of the semantic overlap inevitably differs when words are morphological relatives compared to when they are not. This is another reason why words that share morphemes share more linguistic overlap than other words.

Across trials the position of the target word was counterbalanced from Position 1 to 7 on the list. Filler words that were used on the lists had a similar distribution of word frequencies and length as the experimental stimuli.

Procedure

Instructions were provided in writing and reiterated verbally, and two practice trials were completed with feedback prior to beginning experimental trials. Participants were asked to memorise the lists of words and then press a key to indicate whether a word had been on the preceding list.

A Toshiba Satellite Pro L850-1DV was used to run the experiment using E-prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002) to control stimulus presentation and record responses. Words were presented in lowercase, in the center of the screen, black on white in 28-point Monaco font.

Each trial began with a fixation cross in the center of the screen, requiring a key press to commence the trial. Seven words were then presented consecutively for 1,000 ms per word with a 500 ms interstimulus interval (blank screen). After each list there was a blank screen (1,000 ms), red question mark (500 ms), and blank screen (500 ms), and then the probe was displayed in red until the participant responded. To respond "yes, the word was on the list" participants pressed the C key with their left index finger. To respond "no, the word was not on the list" participants pressed M with their right index finger. Stickers depicting a tick and a cross were placed over the appropriate keys. Every 10 trials participants viewed a scoreboard with a short animation as an incentive to continue (scores were linked to speed and accuracy).

Results and discussion

The dependent variable in our analyses was d'. d' is a measure of sensitivity based on signal detection theory (Green & Swets, 1966), which removes response bias. This is a calculation that allows one to consider rates of correct detection after taking into account rates of false alarms. For a detailed description of how and why to calculate d', see Stanislaw and Todorov (1999). We calculated d' from each participants' proportion of responses that were hits and false alarms[1] within each condition,

adding 0.5 to each cell to avoid infinite d' (Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999). Here, we are interested in whether the noise or the confusion caused by the overlapping linguistic relationship between the probe and target lure reduces d' (by increasing false alarms). High d' indicates high sensitivity to the presence and absence of the probe on the list—a good ability to distinguish between the probe and target lure. Zero d' indicates a complete lack of sensitivity to the presence or absence of the probe—an inability to distinguish between probe and target lure. Based on our hypotheses, we expect advanced readers to have particularly low d' for words sharing morphological overlap (e.g., *postal-post*), while the difference between d' on morphological and pseudomorphological (e.g., *metal-met*) conditions distinguishes between 'decoding first' and other theories. High d' would be expected in the unrelated condition, where there is no linguistic overlap. All participants (in this and future studies) had d' greater than 0 in the unrelated condition, indicating that they were able to perform the task in the absence of linguistic overlap between probe and target lure.

A split-plot analysis of variance (ANOVA) with d' as the dependent variable was conducted by participants and items (see Figure 1). In analyses by participants (F_1), overlap (morphological, pseudo-morphological, semantic, unrelated) was repeated-measures and participant group was between-subjects. In analyses by items (F_2), overlap was between-items and participant group (novice, intermediate, advanced) repeated-measures. Because item variability was constrained by the stimulus design rather than randomly sampled, participant effects are more appropriate than item effects for drawing conclusions (Raaijmakers, Schrijnemakers, & Grenmen, 1999). Nonetheless, because all item variability cannot be controlled, we include analyses by both participants and items. In the omnibus analyses, both main effects were significant: overlap, $F_1(3, 396) = 34.5$, $p < .001$, $\eta_p^2 = 0.21$; $F_2(3, 28) = 4.1$, $p = .016$, $\eta_p^2 = 0.30$; group $F_1(2, 132) = 15.9$, $p < .001$, $\eta_p^2 = 0.19$; $F_2(2, 56) = 45.7$, $p < .001$, $\eta_p^2 = 0.62$. The main effect of group indicates that more proficient readers were more accurate overall. The main effect of overlap indicates that accuracy differed across conditions. The interaction did not reach significance by participants (but did by items), $F_1(6, 396) = 1.8$, $p = .11$; $F_2(6, 56) = 3.4$, $p = .006$, $\eta_p^2 = 0.27$.

Planned comparisons contrasted each overlap condition to the unrelated condition to test whether that specific linguistic feature created noise. Morphological overlap created noise, but the magnitude was not influenced by literacy skill. The main effect of overlap (morphological, unrelated) and group were significant, but the interaction was not significant by participant (although marginal by items): overlap $F_1(1, 132) = 89.6$, $p < .001$, $\eta_p^2 = 0.40$; $F_2(1, 14) = 8.7$, $p = .011$, $\eta_p^2 = 0.38$; group $F_1(2, 132) = 12.4$, $p < .001$, $\eta_p^2 = 0.16$; $F_2(2, 28) = 22.2$, $p < .001$, $\eta_p^2 = 0.61$; interaction $F_1(2, 132) = 0.9$, $p = .4$, $\eta_p^2 = 0.01$; $F_2(2, 28) = 3.2$, $p = .054$, $\eta_p^2 = 0.19$.

Pseudo-morphological overlap created noise, and the magnitude was not affected by literacy skill. The main effects of overlap (pseudo-morphological, unrelated) and group were significant, but the interaction was not: overlap $F_1(1, 132) = 26.5$, $p < .001$, $\eta_p^2 = 0.17$; $F_2(1, 14) = 5.2$, $p = .039$, $\eta_p^2 = 0.27$; group $F_1(2, 132) = 18.3$, $p < .001$, $\eta_p^2 = 0.22$; $F_2(2, 28) = 40.8$, $p < .001$, $\eta_p^2 = 0.75$; interaction $F_1(2, 132) = 0.3$, $p = .7$, $\eta_p^2 = 0.01$; $F_2(2, 28) = 0.1$, $p = .9$, $\eta_p^2 = 0.01$.

Semantic overlap created noise, but the magnitude was influenced by literacy skill. The main effect of group was significant, the main effect of overlap (semantic, unrelated) was significant (by participant but not items), and the interaction was significant by items but not participants: overlap $F_1(1,132) = 9.8$, $p = .002$, $\eta_p^2 = 0.07$; $F_2(1, 14) = 1.8$, $p = .2$, $\eta_p^2 = 0.11$; group $F_1(2, 132) = 11.9$, $p < .001$, $\eta_p^2 = 0.15$; $F_2(2, 28) = 20.1$, $p < .001$, $\eta_p^2 = 0.59$; interaction $F_1(2, 132) = 2.4$, $p = .097$, $\eta_p^2 = 0.04$; $F_2(2, 28) = 6.4$, $p = .005$, $\eta_p^2 = 0.31$. Simple effects indicated that the difference between semantic and unrelated conditions was not significant for novice readers but was for intermediate and advanced readers (by participants): novice $t_1(23) = 0.2$, $p = .9$; t_2

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[1]Hits are the proportion of trials when the probe occurred on the list that its presence was correctly identified. False alarms are the proportion of times when the probe was not on the list that participants incorrectly identified the probe as present (i.e., when the matched target lure was there instead).
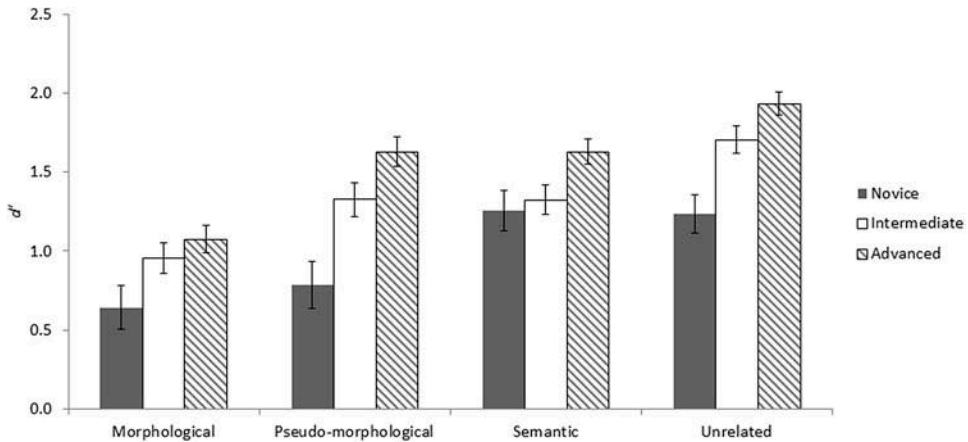
Figure 1. Typically developing novice, intermediate, and advanced readers' sensitivity (d') to the presence of the probe on the list when a target word shared morphological, pseudo-morphological, or semantic overlap, or was unrelated. *Note.* Error bars indicate standard error.

(14) = 1.3, p = .23; intermediate t_1(46) = −3.4, p = .001; t_2(14) = −1.6, p = .12; advanced t_1 (63) = −3.1, p = .003; t_2(14) = −1.9, p = .08.

Finally, to examine whether the noise created by morphological overlap could be distinguished from other forms of linguistic overlap, we compared the morphological condition first to pseudo-morphological and then semantic. In the comparison between morphological and pseudo-morphological conditions, the main effect of overlap was significant (by participants but not items): F_1(1, 132) = 24.2, p < .001, η_p^2 = 0.16; F_2(1, 14) = 1.4, p = .25, η_p^2 = 0.09; the main effect of group was significant: F_1(2, 132) = 10.5, p < .001, η_p^2 = 0.14; F_2(2, 28) = 26.6, p < .001, η_p^2 = 0.67; and the interaction was marginal: F_1(2, 132) = 2.6, p = .079, η_p^2 = 0.04; F_2(2, 28) = 3.2, p = .055, η_p^2 = 0.19. Simple effects analyses indicated that accuracy in the morphological condition was lower than pseudo-morphological for intermediate and advanced readers, but not novice readers: novice t_1 (23) = −0.8, p = .5; t_2(14) = −0.4, p = .7; intermediate t_1(46) = −3.6, p = .001; t_2(14) = −0.9, p = .4; advanced t_1(63) = −5.9, p < .001; t_2(14) = −1.8, p = .09. Hence, morphological overlap created more noise than pseudo-morphological overlap for intermediate and advanced readers but not novices.

In the comparison between morphological and semantic conditions, the main effect of overlap was significant (marginal by items): F_1(1, 132) = 49.2, p < .001, η_p^2 = 0.27; F_2(1, 14) = 4.1, p = .063, η_p^2 = 0.23; the effect of group was significant; F_1(2, 132) = 5.8, p = .004, η_p^2 = 0.08; F_2(2, 28) = 8.6, p = .001, η_p^2 = 0.38; but the interaction was not; F_1(2, 132) = 1.1, p = .35, η_p^2 = 0.02; F_2(2, 28) = 1.6, p = .22, η_p^2 = 0.10. Therefore, morphological overlap consistently created more noise than semantic overlap regardless of literacy skill.

In summary, we observed a general increase in performance on the task with development. However, we also found specific influences of literacy ability on particular linguistic processes. Morphological, pseudo-morphological, and semantic overlap between probe and target lure all created noise and reduced typically developing children's accuracy. Consistent with hypotheses, the amount of noise caused by semantic overlap was smaller for novice than intermediate readers. Nonetheless, morphological overlap created more noise than semantic overlap for all participants. The difference between morphological and pseudo-morphological overlap was also influenced by literacy skill. These conditions created equal amounts of noise for novice readers, whereas intermediate and advanced readers were less accurate in the morphological overlap condition. Semantic and morphological information had little effect on novice readers beyond any co-occurring overlap in orthography/phonology.

Experiment 2: Otitis Media

Experiment 2 examines use of linguistic information in short-term memory by children with a history of OM (repeated ear infection). OM causes fluctuating hearing levels that may cause phonological impairments, but literacy is typically mildly delayed or unimpaired (Roberts, Burchinal, & Zeisel, 2002; Teele, Klein, Chase, Menyuk, & Rosner, 1990; Winskel, 2006). If dyslexic children's reported difficulties with morphology result from their underlying phonological difficulties, one would expect to see a similar pattern of results in other groups of children who have phonological impairments—such as those with OM.

Unlike dyslexia, in OM we understand what has caused phonological impairments and have little reason to expect deficits in semantic or morphological processing (Carroll & Breadmore, under review). We also know that OM generally has only a small effect on literacy ability, so one would expect these children to generally behave similarly to typically developing peers (of the same reading ability). However, if a phonological impairment necessarily constrains processing of morphological information, children with OM should differ from typically developing children.

Consistent with the view of phonological difficulties as a possible cause of morphological difficulties (Cunningham & Carroll, 2015), we predict that the phonological difficulties resulting from OM will also impair morphological and semantic processing compared to age-matched typically developing peers. Because children with OM have been shown to have variable literacy outcomes, we also compare against pairwise matched typically developing children of the same reading ability. In this way we can examine whether patterns of strengths and weaknesses are in line with reading level (Bradley & Bryant, 1978; Joanisse et al., 2000) or whether children with OM show unusual patterns of development. This control is standard in dyslexia research but has rarely been included in research into literacy in OM.

Method

Methodology was identical to previous experiments, only participants differed.

Participants

Participants with a history of OM were recruited from the same schools as participants in Experiment 1. There were 29 children (nine female) whose parents reported a history of repeated ear infections (more than seven episodes by age 3) or a clinical diagnosis of Glue Ear or OM. Each of these children was individually pairwise matched to two typically developing children, one matched for RA and one for CA. Two participants had missing data—two missing trials for one OM participant and one missing trial for one RA. All children were monolingual native English speakers, and none reported dyslexia. Participant group summary information is provided in Table 1. Note that there is some overlap in the reading ability of RA- and CA-matched children, as several children with OM were able to read age appropriately. Independent sample t tests confirmed that OM children did not differ from RA-matched controls on any background measures apart from age. In contrast, they were significantly lower than CA-matched controls on every background measure apart from age.

Results and discussion

The d' was computed as in Experiment 1 (see Figure 2). If phonological difficulties impair morphological and semantic processing, then children with OM will have equally low d' on the morphological and pseudo-morphological conditions. If they are able to process this information, then they will have lower d' on the morphological overlap condition.

A split-plot ANOVA with d' as the dependent variable and participant group (OM, RA, CA) and overlap (morphological, pseudo-morphological, semantic, unrelated) as independent variables indicated a significant main effect of overlap: $F_1(3, 252) = 36.4$, $p < .001$, $\eta_p^2 = 0.30$; $F_2(3, 28) = 3.8$, $p = .020$,
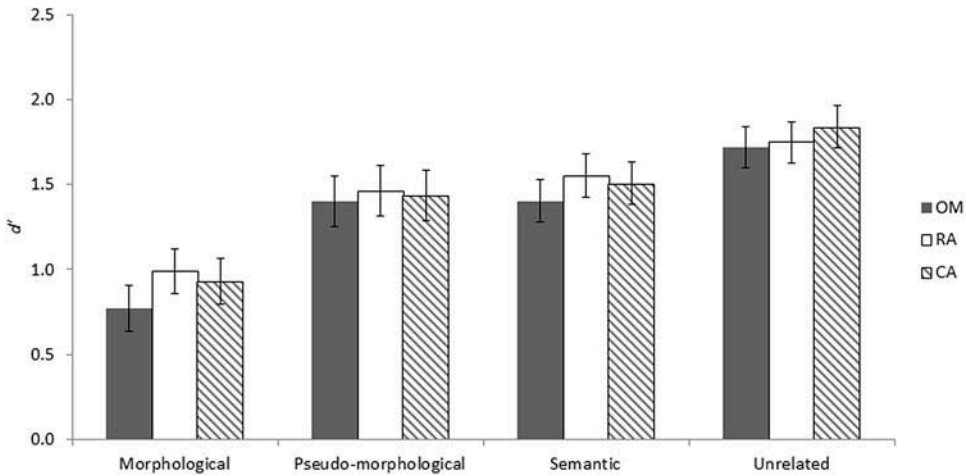
Figure 2. Children with a history of repeated ear infection (otitis media [OM]), reading age (RA), and chronological age (CA) matched typically developing readers' sensitivity (d') to the presence of the probe on the list when a target word shared morphological, pseudo-morphological, or semantic overlap, or was unrelated. *Note.* Error bars indicate standard error.

$\eta_p^2 = 0.29$. However, neither the main effect of group nor the interaction were significant: group $F_1(2, 84) = 0.4$, $p = .7$; $F_2(2, 56) = 1.1$, $p = .4$; interaction $F_1(6, 252) = 0.2$, $p = 1.0$; $F_2(6, 56) = 0.5$, $p = .8$. Figure 2 indicates that OM children performed very similarly to their peers in every condition.

Planned comparisons in the morphological overlap condition confirmed that even in this condition the main effect of group was not significant: $F_1(2, 84) = 0.7$, $p = .5$; $F_2(2, 14) = 1.7$, $p = .2$. Thus, although OM children's mean d' in the morphological overlap condition was lower than their RA and CA controls, the difference was not significant. Hence we conclude that children with OM performed similarly to typically developing peers, and therefore morphological processing is not necessarily constrained by phonological difficulties.

Experiment 3: Dyslexia

Experiment 3 examines the impact of dyslexia on use of linguistic information in short-term memory. Dyslexic children commonly have verbal short-term memory difficulties, which have been attributed to underlying limitations in phonological processing and/or executive function (Berninger et al., 2006; Gathercole, Alloway, Willis, & Adams, 2006; Swanson & Berninger, 1995). Hence we hypothesise that dyslexic children will show a generalised reduction in accuracy across conditions.

Of particular interest in the present study is whether all verbal processing is similarly impaired. We compare children with dyslexia to typically developing children of the same CA and younger children of the same reading ability. Differences between dyslexic and RA-matched children can thus be ascribed to dyslexia rather than reading ability. Only if dyslexic children's performance across conditions differs from reading-ability-matched children can we conclude that these difficulties are causally related to dyslexia rather than literacy development per se. In Experiment 1 we found that typically developing novice readers focused on orthographic/phonological overlap but did not show effects of morphological or semantic overlap. If dyslexic children's reading is simply delayed, one would expect to see a similar pattern. If, on the other hand, dyslexic children have a particular difficulty with certain linguistic properties, differences might emerge in particular conditions. If dyslexic children have a particular difficulty with morphological processing, beyond that attributable to orthographic, phonological, and semantic overlap, they will differ from their peers on the morphological overlap condition only.

Method

Methodology was identical to Experiment 1, only participants differed.

Participants

Children with dyslexia were selected from the same schools as typically developing children in Experiment 1. Twenty-seven children (16 female) with a standardised score below 90[2] on British Ability Scales: Third Edition word reading (Elliot & Smith, 2011) took part. Each child with dyslexia was individually pairwise matched to two typically developing children, one for RA and one for CA. One trial was missing from one RA child's data. All children were monolingual native English speakers, and none reported hearing impairment or a history of repeated ear infection. Participant group summary information is provided in Table 1. Independent sample t tests confirmed that dyslexic children did not differ significantly from RA on any measures apart from CA. Dyslexic children were matched to CA on age but differed on every other measure.

Results and discussion

The d' was computed as in Experiment 1 (see Figure 3). If dyslexic children's reading is simply delayed, we predicted that d' in the morphological and pseudo-morphological conditions would be equally low and that there would be now differences between dyslexic readers and RA-matched peers.

A split-plot ANOVA with d' as the dependent variable and participant group (dyslexic, RA, CA) and overlap as independent variables indicated that the interaction and both main effects were significant: interaction $F_1(3, 234) = 29.4$, $p < .001$, $\eta_p^2 = 0.27$; $F_2(6, 56) = 2.7$, $p = .022$, $\eta_p^2 = 0.23$; overlap $F_1(6, 234) = 2.8$, $p = .013$, $\eta_p^2 = 0.07$; $F_2(3, 28) = 5.1$, $p = .006$, $\eta_p^2 = 0.35$; group $F_1(2, 78) = 3.2$, $p = .047$, $\eta_p^2 = 0.08$; $F_2(2, 56) = 17.8$, $p < .001$, $\eta_p^2 = 0.39$.

Because both the main effect of group and the interaction with overlap were significant in the omnibus analyses, we compared performance between participant groups in each condition. Dyslexic children's sensitivity in the morphological condition was significantly less than RA or CA; RA t_1
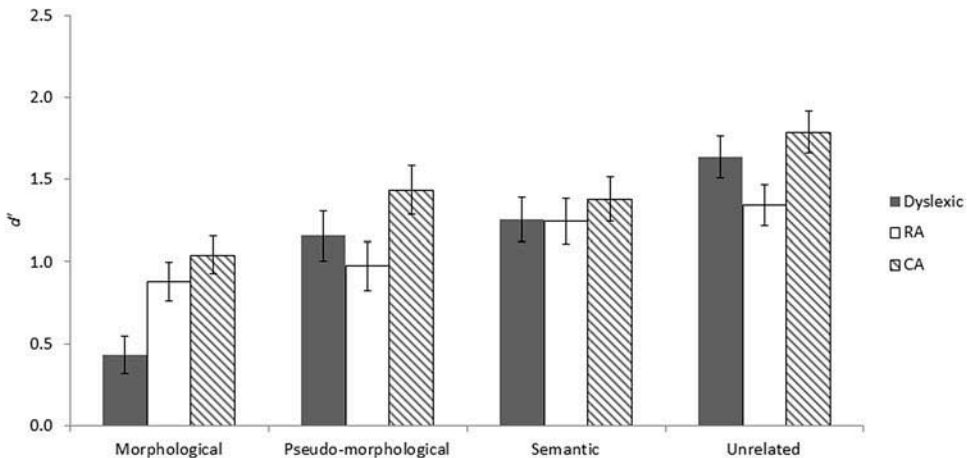
Figure 3. Dyslexic, reading-age- (RA) and chronological-age- (CA) matched typically developing readers' sensitivity (d') to the presence of the probe on the list when a target word shared morphological, pseudo-morphological, or semantic overlap, or was unrelated. *Note.* Error bars indicate standard error.

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[2]Note that although our criteria using a standard score of 90 may seem lenient for the general population, children in the same classrooms as our poor readers generally had better reading skills than the standardization sample. Despite excluding above-average readers, the overall mean across all typically developing children in Experiments 1 to 3 was 105.7.

(52) = −3.0, p = .005; $t_2(7)$ = −4.3, p = .003; CA $t_1(52)$ = −3.6, p = .001; $t_2(7)$ = −4.5, p = .003. However, dyslexic children didn't differ from RA in any other condition: pseudo-morphological t_1 (52) = 0.8, p = 0.4; $t_2(7)$ = 1.0, p = 0.3; semantic $t_1(52)$ = 0.1, p = 1.0; $t_2(7)$ = −0.3, p = 0.8; unrelated t_1 (52) = 1.6, p = 0.1; $t_2(7)$ = 2.1, p = 0.08. Moreover, the difference between dyslexic children and CA was not significant in any other condition (marginal by items only for pseudo-morphological and unrelated conditions); pseudo-morphological $t_1(52)$ = −1.4, p = 0.2; $t_2(7)$ = −2.3, p = 0.053; semantic $t_1(52)$ = −0.6, p = 0.5; $t_2(7)$ = −1.4, p = 0.2; unrelated $t_1(52)$ = −0.8, p = 0.4; $t_2(7)$ = −2.2, p = 0.06. Hence, dyslexic children appear to have a circumscribed difficulty with the morphological condition rather than generalised difficulty with the task.

To ensure that effects were not driven by generalised weaknesses in the task, planned comparisons contrasted each overlap condition to the unrelated condition.[3] For children with dyslexia, morphological and pseudo-morphological effects were significantly different from unrelated, but the semantic effect was not; morphological $t_1(26)$ = −7.4, p < 0.001, $t_2(14)$ = −5.1, p < 0.001; pseudo-morphological $t_1(26)$ = −3.9, p = 0.001, $t_2(14)$ = −2.1, p = 0.050; semantic $t_1(26)$ = −2.6, p = 0.014, t_2 (14) = −1.5, p = 0.2. Next we examined whether the noise caused by morphological overlap differed from pseudo-morphological[4] and semantic[5] overlap. In both cases the morphological effect was larger; pseudo-morphological $t_1(26)$ = −4.5, p < 0.001; $t_2(14)$ = −2.7, p = 0.018; semantic t_1 (26) = −4.7, p < 0.001; $t_2(14)$ = −3.3, p = 0.005.

To summarise, Experiment 3 indicates that children with dyslexia had a specific difficulty distinguishing the probe from a target lure that shared morphological overlap, rather than a generalised difficulty distinguishing the probe from a target lure regardless of the nature of overlap. The noise caused by morphological overlap was significantly greater than semantic or pseudo-morphological overlap. Moreover, children with dyslexia were less accurate than RA in the morphological overlap condition, but equal in all other conditions. Hence we conclude that the morphological overlap effect was significantly greater for children with dyslexia than any other participant group.

Comparisons between experiments

Children with a history of OM and children with dyslexia were well matched by age and phonological skill (see Table 1 for means). This was confirmed by independent samples t tests, which revealed no significant differences in CA, $t(54)$ = 0.0, p = .98; CELF phonological awareness, t (54) = −1.2, p = .2; or CELF word classes, $t(54)$ = −0.6, p = .5. However, children with dyslexia has significantly lower reading levels, $t(54)$ = −5.0, p < .001. Comparisons between these groups therefore enable us to separate effects of phonological and literacy skills.

Comparing OM and dyslexic children's d' sensitivity across all conditions revealed that only the main effect of overlap was significant, $F_1(3, 162)$ = 37.0, p < .001, η_p^2 = 0.41; $F_2(3, 28)$ = 8.6, p < .001,

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[3]Analyses with the between-subjects factor participant group indicated that the interaction between overlap (overlap, unrelated) and group (dyslexic, RA, CA) was significant only in comparison between unrelated and morphological conditions: $F_1(2, 78)$ = 6.1, p = .003, η_p^2 = 0.14; $F_2(2, 28)$ = 6.6, p = .005, η_p^2 = 0.32; pseudo-morphological $F_1(2, 78)$ = 0.2, p = .8; $F_2(2, 28)$ = 0.1, p = .9; semantic $F_1(2, 78)$ = 1.3, p = .3; $F_2(2, 28)$ = 2.0, p = .15. The main effect of overlap was significant in all comparisons: morphological $F_1(1, 78)$ = 85.3, p < .001, η_p^2 = 0.52; $F_2(1, 14)$ = 13.1, p = .003, η_p^2 = 0.48; pseudo-morphological $F_1(1, 78)$ = 25.4, p < .001, η_p^2 = 0.25; $F_2(1, 14)$ = 5.4, p = .036, η_p^2 = 0.28; semantic $F_1(1, 78)$ = 11.7, p = .001, η_p^2 = 0.13; $F_2(1, 14)$ = 1.9, p = .19, η_p^2 = 0.12. As was the main effect of group: morphological $F_1(2, 78)$ = 4.5, p = .015, η_p^2 = 0.10; $F_2(2, 28)$ = 14.1, p < .001, η_p^2 = 0.50; pseudo-morphological $F_1(2, 78)$ = 3.5, p = .034, η_p^2 = 0.08; $F_2(2, 28)$ = 13.6, p < .001, η_p^2 = 0.49; and semantic (by items only) $F_1(2, 78)$ = 1.8, p = .2, η_p^2 = 0.04; $F_2(2, 28)$ = 6.8, p = .004, η_p^2 = 033.

[4]Analyses with the independent factors participant group (dyslexic, RA, CA) and overlap (morphological, pseudo-morphological) indicated significant main effects and interaction: overlap $F_1(1, 78)$ = 22.7, p < .001, η_p^2 = 0.23; $F_2(1, 14)$ = 2.9, p = .11, η_p^2 = 0.17; group $F_1(2, 78)$ = 4.1, p = .02, η_p^2 = 0.10; $F_2(2, 28)$ = 12.6, p < .001, η_p^2 = 0.47; interaction $F_1(2, 78)$ = 4.6, p = .013, η_p^2 = 0.11; $F_2(2, 28)$ = 4.5, p = .021, η_p^2 = 0.24.

[5]Analyses with the independent factors participant group (dyslexia, RA, CA) and overlap (morphological, semantic indicated significant main effects and interaction): overlap $F_1(1, 78)$ = 32.7, p < .001, η_p^2 = 0.30; $F_2(1, 14)$ = 5.2, p = .039, η_p^2 = 0.27; group $F_1(2, 78)$ = 3.4, p = .039, η_p^2 = 0.08; $F_2(2, 28)$ = 9.1, p = .001, η_p^2 = 0.39; interaction $F_1(2, 78)$ = 3.1, p = .050, η_p^2 = 0.07; $F_2(2, 28)$ = 3.0, p = .068, η_p^2 = 0.17.

$\eta_p^2 = 0.48$. The main effect of group was significant by items but not participants, $F_1(1, 54) = 1.8$, $p = .18$; $F_2(1, 28) = 6.6$, $p = .016$, $\eta_p^2 = 0.19$. The interaction was not significant, $F_1(3, 162) = 0.6$, $p = .6$; $F_2(3, 28) = 0.2$, $p = .9$. Nonetheless, a planned comparison in the morphological overlap condition revealed that dyslexic children's accuracy was marginally less than OM children's, $F_1(1, 54) = 4.0$, $p = .052$, $\eta_p^2 = 0.07$; $F_2(1, 7) = 4.7$, $p = .066$, $\eta_p^2 = 0.40$. This is not consistent with the view that phonological impairments necessarily constrain morphological skill and literacy acquisition.

General discussion

A series of three experiments examined whether literacy level, phonological skill, or dyslexia influenced the impact of linguistic overlap between a target lure on a list of words to be remembered and a recognition probe. As predicted by dual/multiple route models of reading (Grainger et al., 2012; Grainger & Ziegler, 2011), the more linguistic information that was shared between the probe and target lure, the more likely participants were to incorrectly accept that the probe had been present on the list. Hence, the probe paradigm is a useful tool to study morphological processes without requiring explicit manipulation of morphemes or the necessity for rapid activation of lexical items. Future research could further examine the cause of the effects within this paradigm by manipulating serial position, scrutinizing the impact of degree of semantic or orthographic overlap, and examining effects cross-linguistically.

Participant groups showed different profiles of performance on the tasks. Consistent with "decoding first" accounts (Ehri, 1995; Ehri et al., 2013; Nunes et al., 1997b), novice readers (RA = 5;7–8;0 years, Experiment 1) did not show effects of morphological and semantic overlap, which suggests that they use only orthographic and phonological features of words to perform the task, and are not yet sensitive to the increased similarity of morphologically related items. In the semantic overlap condition, these features do not overlap and so performance is good. In morphological and pseudo-morphological conditions the overlap is good enough for novice readers to (incorrectly) accept the probe as having been present on the list. This differs from intermediate and advanced readers (RA = 9;1–12;9 years) whose performance on the task was reduced by both pseudo-morphological and semantic overlap, and further still by morphological overlap. We conclude that novice readers fail to access or activate the semantic and morphological properties of their lexical representations, suggesting that their word recognition is not yet automatic.

Children with dyslexia (RA = 5;10–8;9 years, Experiment 3) also showed a generalised weakness in the task and reduced semantic effect (semantic overlap did not differ from the unrelated condition). However, unlike for novice readers, the effect of morphological overlap was larger than any other condition. In fact, children with dyslexia had far more difficulty distinguishing the probe from a target lure in the morphological overlap condition than reading ability, CA-matched peers or children with OM. Thus, the combination of orthographic, phonological, semantic, and morphological overlap meant that children with dyslexia were far more likely to incorrectly accept that the probe had been on the preceding list. This difference cannot be explained away trivially by claiming that children with dyslexia were somehow less able or slower to read the words on the list, because they performed similarly to RA-matched children in all other conditions, nor can this difference be explained purely by reference to orthographic/phonological or semantic properties, and suggests that there is something unique about the way in which children with dyslexia process morphology that differs from their peers and other children with phonological awareness difficulties. This finding is not consistent with "decoding first" accounts (Ehri, 1995; Ehri et al., 2013; Nunes et al., 1997b), because this suggests that children with dyslexia processed morphology but did so inefficiently, which led them to confuse morphologically related words.

The fact that the children with OM showed age-appropriate performance on the task despite having impairments in phonological awareness is also contrary to accounts highlighting the primacy of phonological processing (Cunningham & Carroll, 2015) and suggests that different phonological difficulties have different consequences on literacy development. Morphological skills can develop

well in the context of phonological difficulties, and therefore the difficulties that dyslexic children have with morphology are not necessarily caused by difficulties with phonology.

This pattern of findings provides an interesting contrast with other tasks carried out with the same sample of dyslexic children. The dyslexic children show morphological awareness and use of morphology in spelling similar to RA controls and below the level of CA controls (Breadmore & Carroll, in press). It therefore appears that children with dyslexia are reading ability appropriately sensitive to morphology but do not use it effectively to support short-term memory for words. The present study differs from many previous studies in that involves implicit morphological processing. This could be why our findings contrast with some other studies examining morphological awareness. However, we would argue that in comparison to explicit oral morphological awareness measures, this implicit activation of morphology in the present study should be more closely linked to that which occurs during reading.

The way in which dyslexic children used morphological information resulted in impaired performance on this task. It could be that dyslexic children use lexical representations that lack specificity in relation to morphological properties. That might be interpreted as children with dyslexia relying more heavily on root morphemes but seems also to mean that they are paying less attention to suffixes. Crucially, in this study the probe was always more complex than the target (in morphological and pseudo-morphological conditions, the target lure was the root morpheme and the probe was the root plus an additional suffix/pseudosuffix). This pattern of results cannot, therefore, be explained as simple forgetting of word final graphemes. Rather, children with dyslexia were more likely to incorrectly accept that they saw a longer, more complex word form, with additional semantic and morphological information to the word they actually saw on the list. The difficulty with this paradigm, however, is that it is impossible to identify at what stage of processing this occurs. The lack of specification of the target could have occurred during encoding, storage, or retrieval, or relate to underlying lexical representations for the words. Future research should aim to distinguish between these factors.

Conclusions

This is the first published study to use a short-term memory probe paradigm to examine morphological processing in typical and atypical development. The evidence presented here supports the use of this paradigm even with novice readers. By examining developmental differences, phonological difficulties resulting from OM and dyslexia, the present study has wide generalizability. Our findings indicate that novice typically developing readers confuse words with a large amount of visual overlap but not semantic overlap. Morphological and semantic features become increasingly important in reading acquisition. In contrast, children with dyslexia find words that share morphological features particularly confusable. Phonological difficulties in the absence of significant literacy impairment (children with OM) did not impact on performance on the task. This, we argue, indicates that dyslexia alters the processing of morphology and that this is not simply because of literacy or phonological skills per se but is unique to dyslexia.

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Appendix

Table A1. Stimuli.

Condition	Word Pair (Target–Probe)
Morphological	post–postal
	drive–driver
	farm–farmer
	dirt–dirty
	ask–asked
	look–looked
	long–longer
	thing–things
Pseudo-morphological	met–metal
	off–offer
	should–shoulder[a]
	stud–study
	see–seed
	war–ward
	corn–corner
	hi–his[a]
Semantic	all–everyone
	bag–sack
	ball–globe
	home–house
	pole–stick
	road–street
	rock–stone
	soil–earth
Unrelated	called–little
	car–hope
	donkey–artist
	had–cleaning
	house–going
	join–bread
	plane–shower
	scar–ninth

[a]These items do not share full phonological overlap.