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Learning vocabulary in childhood

Learning new vocabulary in childhood: Effects of semantic training on lexical consolidation
and integration

Abstract

Research suggests that word learning is an extended process with offline consolidation crucial for the strengthening of new lexical representations and their integration with existing lexical knowledge (as measured by engagement in lexical competition). This supports a dual-memory systems account, in which new information is initially sparsely encoded separately from existing knowledge and integrated with long-term memory over time. However, previous studies of this type exploited unnatural learning contexts, involving fictitious words in the absence of word meaning. In this study children aged 5-9-years-old learned real science words (e.g., “hippocampus”) with or without semantic information. Children in both groups were slower to detect pauses in familiar competitor words (e.g., “hippopotamus”) relative to control words 24 hours after training but not immediately, confirming that offline consolidation is required before new words are integrated with the lexicon and engage in lexical competition. Children recalled more new words 24 hours after training than immediately (with similar improvements shown for the recall and recognition of new word meanings); however, children who were exposed to the meanings during training showed further improvements in recall after one week and outperformed the children who were not exposed to meanings. These findings support the dual memory systems account of vocabulary acquisition and suggest that the association of a new phonological form with semantic information is critical for the development of stable lexical representations.

Keywords. vocabulary acquisition, complementary learning systems, pause detection, lexical integration.

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Learning new vocabulary in childhood: Effects of semantic training on lexical consolidation and integration

Numerous studies have demonstrated the efficiency with which infants and young children form mappings between words and their referents (Bloom & Markson, 1998; Carey & Bartlett, 1978; Spiegel & Halberda, 2011). Consequently, vocabulary acquisition has been conceptualised as a 'relatively simple affair' (Plunkett & Wood, 2006, p. 165). However, an alternative view is that vocabulary learning in childhood is partial and incremental (e.g., Dockrell, Braisby & Best, 2007; Nagy & Scott, 2000). Recent developmental studies suggest that a prolonged period of time is needed for a novel nonword (e.g., biscal) to become integrated with the existing lexicon (Brown, Weighall, Henderson & Gaskell, 2012; Henderson, Weighall, Brown & Gaskell, 2013) with sleep playing an important role in the 'off-line consolidation' (stabilisation and integration) of new phonological forms (Henderson, Weighall, Brown & Gaskell, 2012). These results have been explained within the *Complementary Learning Systems* (CLS) framework, which proposes that new information is initially stored separately from existing knowledge and integrated over time (Davis & Gaskell, 2009; McClelland, McNaughton, & O'Reilly, 1995; Norman & O'Reilly, 2003; O'Reilly & Norman, 2002). However, previous research has tended to study fictitious nonword learning in the absence of word meaning and crucially we do not know whether providing meaning during training changes this prolonged time course of lexical integration. Since the purpose of language is to extract and convey meaning arguably a word cannot be deemed to be fully acquired until has been integrated with semantic knowledge; hence, it is imperative that we understand how children utilize meaning in the process of word learning. The current study presents a more naturalistic test of the CLS framework and

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examines how real (rather than fictitious) words and their meanings are acquired and integrated with the lexicon. Specifically, we address whether providing information about word meaning during training influences the time course of spoken word learning, focusing on the extent to which a new word has been integrated with existing word knowledge and the ease with which it can be retrieved over time.

The time course of word learning

One way of establishing whether a new word has been acquired is to examine when it begins to exhibit hallmarks of lexical processing typically observed for existing words (Leach & Samuel, 2007). One such hallmark of an established lexical entry acknowledged by numerous models of spoken word recognition is its ability to compete with similar-sounding entries for identification (McClelland & Elman, 1986). Hence, a strong test of whether a new speech sequence has been integrated with the lexicon is whether it engages in lexical competition with existing representations during speech perception (e.g., Gaskell & Dumay, 2003).

Gaskell and colleagues have examined how lexical activity changes when adults (Dumay & Gaskell, 2007; Gaskell & Dumay, 2003) and school-aged children (Brown et al., 2012; Henderson et al., 2012; Henderson et al., 2013) learn fictitious novel nonwords (e.g., biscal). Participants made speeded decisions about the presence of a silent pause inserted in existing words with the same onsets (e.g., bisc_uit). Pause detection latency provides an on-line index of lexical activity at the point in the word the pause is encountered, with slower pause detection latency indicating more lexical activity (Mattys & Clark, 2002). Gaskell and colleagues showed that pause detection latencies in existing words become slower if participants have recently learned an onset competitor (e.g., "biscal"). Studies with adults

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(Dumay & Gaskell, 2007) and children aged 7-12-years-old (Henderson et al., 2012) have shown that this 'lexical competition' effect emerges 12-hours after exposure to novel nonword competitors, but only if that 12-hour period includes sleep. In both studies sleep also benefited explicit recall of the novel nonwords and the children retained this knowledge one-week later, providing evidence for long-lasting phonological word learning following a short training phase. This finding is consistent with previous reports of delayed improvements in the recognition of newly trained words (without additional exposure) in children aged 3-7 years (Dockrell et al., 2007; Storkel, 2001). Together, these findings have led to a significant shift in our understanding of vocabulary acquisition, suggesting that offline consolidation facilitates the integration of novel fictitious words into the developing lexicon and plays a role in the stabilisation of new phonological representations.

Complementary learning systems (CLS) theory (McClelland et al., 1995; Norman & O'Reilly, 2003; O'Reilly & Norman, 2002) provides a good explanation for these findings. This framework can account for vocabulary acquisition in terms of the operation of general memory systems, whereby new information is initially stored independently from existing knowledge and then integrated over time (Davis & Gaskell, 2009). Under this view, novel word representations are initially sparsely coded in the hippocampus, with offline interactions resulting in strengthening of distributed representations in long-term neocortical memory (Davis et al., 2009; French, 1999; Wilson & McNaughton, 1994). Tamminen et al. (2011) reported that sleep spindle activity (11-15 Hz oscillations lasting up to 3 seconds) is positively associated with overnight increases in lexical competition, suggesting that sleep plays an active role in the process of lexical integration, possibly by enabling the transfer from hippocampal to neocortical representations.

Does semantic training influence the time course of word learning?

The main aim of this study was to address whether previous data on consolidation effects in vocabulary acquisition accurately reflect naturalistic word learning when semantic information is available. We examine whether semantic knowledge shapes the time course with which new lexical information is strengthened such that it can be explicitly retrieved and integrated with existing lexical information (as indexed by the emergence of lexical competition). Previous studies have largely used purely phonological training regimes without providing participants with information pertaining to word meaning (Brown et al., 2012; Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; Henderson et al., 2012; Henderson et al., 2013). It could be argued that the typical finding of a delay in lexical integration of the novel words is an artefact of the impoverished context in which the words have been learned.

Consistent with this position, Leach and Samuel (2007) found that novel nonwords engage with the lexicon immediately after learning (as measured by the retuning of phoneme boundaries) if semantic information has been provided. Participants were trained on novel nonwords containing either an “s” sound or a “sh” sound and then presented with novel nonwords containing an ambiguous phoneme half way between “s” and “sh”. The novel nonwords engaged with the phoneme category level by adjusting phoneme boundaries. This effect occurred immediately after training that attached meaning to the novel nonwords but not when the training was purely phonological. However, it is not clear whether immediate lexical integration effects would be observed after semantic training when integration is measured by lexical competition. According to Davis and Gaskell (2009) the fast learning hippocampal system has a direct link to lexical phonology, and this might

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explain why novel words are able to re-tune phoneme boundaries soon after training even if they have not yet been fully integrated to the extent that they engage in lexical competition.

This explanation is consistent with the findings of Dumay, Gaskell and Feng (2004) who trained adults on novel nonword competitors (e.g., “cathedruke”) in isolation in a phoneme monitoring task or in sentence context during a semantic verification task. In the latter condition the novel nonwords were associated with the name of a conceptual category (e.g., “vegetable”) and two sentences conveying categorical information (“A cathedruke is a variety of vegetable”) and semantic context (“The cook served the boiled cathedruke with a steak and baked potatoes”). For both training conditions, lexical competition effects (e.g., delayed recognition of “cathedral”) only emerged after a delay of at least 24 hours and importantly were still observed one week after training. Hence, in contrast to Leach and Samuel (2007) there was no suggestion of immediate lexical integration of novel words when a semantic learning environment is used.

The above studies all relate to adult vocabulary learning, and it is unclear how semantic context influences the integration and consolidation of novel spoken words earlier in development. McKague, Pratt and Johnston (2001) taught 6-7-year-olds novel phonological forms alone or their phonological forms plus semantic information (as part of an illustrated story) before their orthographic forms were introduced. The semantic manipulation had no effect on reading times for the novel nonwords over a two day period (see also Nation, Angell & Castles, 2007). In a free recall task however, semantically trained items were recalled more reliably than phonologically trained items. This suggests that for children, providing semantics during training may enhance the formation of a new phonological

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representation. This fits with the view that orthographic learning involves the integration of phonological, orthographic and semantic representations, supported by findings that new written words presented with semantic information are identified more accurately than when words are presented in isolation (e.g., Ouellette & Fraser, 2009; see also McKay, Davis, Savage & Castles, 2008; Rueckle & Olds, 1993; Taylor, Plunkett & Nation, 2011; Wang, Nickels, Nation & Castles, 2013; Whittlesea & Cantwell, 1987). Importantly, however, studies are yet to examine the influence of semantic training on spoken word learning and lexical integration in children, hence the present study addresses this important issue.

The consolidation of new semantic and orthographic knowledge

Evidence is clear in pointing to the importance of off-line consolidation for the stabilisation of new phonological information, as reflected by continuing improvements in recall and recognition of new phonological forms over the course of a week (e.g., Henderson et al., 2012). However, it is less clear whether consolidation plays a similar role in the stabilisation of explicit memory for new orthographic and semantic information. Tamminen and Gaskell (2012) taught adults new meaningful nonwords (using written rather than spoken presentation) and found that explicit recall of the nonword meanings *declined* rather than improved over the course of a week. Despite this however, familiar words (that were not presented during training) were primed by the newly related nonwords in both unmasked and masked prime conditions and this effect was strongest one week after training. These data suggest that the nonwords had been integrated with semantic memory (as evidenced by the priming effects) but that the episodic representations of the new meanings that were formed during training weakened over time (as indicated by the decline in explicit recall). Therefore, this suggests a dissociation between the strengthening of

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explicit memory for new phonological forms over time coupled with the weakening of explicit memory for new semantic features. However, it is unclear whether children will show this same pattern (indeed, a recent paper suggests that children show stronger sleep-associated consolidation of explicit aspects of task performance; Wilhelm, Rose, Imhof, Rasch, Buchel & Born, 2013) and whether explicit memory for new orthographic information strengthens or weakens over time.

The present study

In this study we examined the crucial issue of whether semantic training shapes the time course with which newly learned vocabulary is integrated with existing lexical information. An important contribution of this study is the examination of whether the findings from previous studies with children generalise to real (rather than fictitious) word learning hence in this study children learned 14 unfamiliar science words. We acknowledge that the use of fictitious nonwords (e.g., *biscal*) is advantageous in many respects: They enable tight control over linguistic variables (e.g., phonotactic probability, frequency, length), ensure that stimuli are truly novel to participants, and they are typically designed to be phonotactically indistinguishable from real words. However, it is questionable whether participants treat these nonwords as relevant only in the context of the experiment (Potts, St John & Kirson, 1989), particularly when they are not given a meaning (Brown et al., 2012; Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; Henderson et al., 2012; Henderson et al., 2013; Tamminen et al., 2010). Therefore, the present study provides an important opportunity to assess key hypotheses of the CLS account of vocabulary acquisition using real words that are likely to be learned in the classroom.

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Much of the established research on vocabulary acquisition in children focuses on concrete early-acquired words, and studies have rarely examined the factors that support subject-related vocabulary acquisition in school-aged children (although see Dockrell et al., 2007, for an exception). Vocabulary acquisition is crucial for academic development, and in subjects such as Science which make use of increasingly abstract and sophisticated terms the importance is particularly marked. Thus, evidence from science word learning is important for establishing evidence-based strategies for teaching and learning.

During training children were exposed to the spoken forms of the words accompanied either by semantic information (the 'semantic group') or orthographic information (the 'form-only group'). The 'form-only' training was first and foremost designed to be non-semantic in nature to allow us to examine the presence or absence of semantic information on the time course of learning of a new spoken word form. Our aim was to ensure that in both training conditions children were required to associate the phonological form of each word with another form of linguistic information (i.e., either semantic or orthographic). Children were tested immediately after training (0-hrs) and after 24-hrs and 1-week in order to examine the influence of training condition on aspects of word learning before and after periods of off-line consolidation.

The present study also sought to rule out the effects of repeated testing on later consolidation effects. Previous studies have used repeated tests to measure changes in explicit memory and lexical competition for novel words (Brown et al., 2012; Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; Henderson et al., 2012; Henderson et al., 2013). Importantly, these studies have shown that improvements in recall and changes in lexical competition are not dependent upon re-exposure to the novel stimuli or similar sounding

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existing words in the tests. For instance, Henderson et al. (2012) reported improvements in recall and recognition of novel nonwords and the emergence of lexical competition at a 12-hour test but only for children who had been trained in the evening; children trained in the morning and retested after 12 hours without sleep did not show significant improvements. This suggests it was sleep rather than time or repeated exposure that was associated with the changes in explicit memory and lexical competition. However, in Tamminen and Gaskell (2012) there was evidence that repeated retests protected explicit recall of nonword meanings from forgetting. Namely, participants who were retested on meaning recall during the eight day period recalled significantly more novel word meanings in the final session on day 8 than those who were not tested prior to day 8. This suggests that repeated administration of the recall task maintained explicit memory of the meanings (see also Bouwmeester & Verkoeijen, 2011; Roediger & Karpicke, 2006). Furthermore, as mentioned, the Henderson et al. study did not examine word learning in the context of an associated meaning. To assess this issue in the case of learning words with meanings, in the present study only half of the semantic training group received the immediate (0-hour) test, whereas all participants were tested at 24 hours. The participants who did not receive the immediate test were confined to the critical semantic training group.

In summary the aims of this study were three-fold. First, the influence of semantic training on the time-course of explicit recall for newly learned words was explored. It was expected that children would show improvements in their ability to recall newly learned words (e.g., hippocampus) 24-hours after training relative to an immediate (0-hr) test and retain this knowledge 1 week later (similar to previous findings with children; Brown et al., 2012; Henderson et al., 2012; Henderson et al., 2013). Crucially, if the presence of semantic

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information during training leads to more stable phonological representations (McKague et al., 2001) then improvements in cued recall may be larger (at 24-hrs or 1-wk) after semantic training compared with form-only training.

Second, the time course of lexical integration (the ability of a newly learned word to compete for recognition with its existing baseword) was examined. Slower pause detection latencies to similar sounding existing words (e.g., hippopotamus) relative to a control condition were expected 24-hours after training on novel competitors (e.g., hippocampus) but not immediately (Henderson et al., 2012; Henderson et al., 2013). However, if the presence of semantic information during training leads to faster or more efficient lexical integration (Leach & Samuel, 2007), then lexical competition effects may emerge sooner (at 0-hrs) or be stronger (at 24-hrs or 1-wk) after semantic training compared with form-only training.

Third, the consolidation of new semantic and orthographic information over time was explored. If, semantic and orthographic information benefits from a period of off-line consolidation to the same extent as newly learned phonological information, (e.g., Brown et al., 2012; Dumay & Gaskell, 2007; Henderson et al., 2012, 2013), then we may predict that the recognition and recall of new semantic knowledge (measured by picture identification and definition tasks, respectively) and orthographic knowledge (measured by a forced choice recognition task) will improve at the delayed tests relative to the immediate test. Conversely however, it is possible that explicit recall of newly learned semantic information would be subject to forgetting over time (cf Tamminen & Gaskell, 2012).

In addition to these main aims it was also predicted that performance at the 24-hour test would be equivalent regardless of whether participants had received an immediate test

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and that participants first tested after 24 hours would benefit from the consolidation opportunity (showing better recall and stronger lexical integration effects) compared with participants first tested immediately after training.

Method

Participants

Ninety-seven children (five- to nine-years-old; 33 males) were recruited from three mainstream primary schools in North Yorkshire. This age range was selected to examine a younger cohort than previous studies, which have examined children aged 7 years and above (Brown et al., 2012; Henderson et al., 2012; Henderson et al., 2013) or have revealed low levels of learning with younger children that are difficult to interpret (Dockrell et al., 2007). All children were assessed on standardised tests of nonverbal ability, phoneme awareness, and receptive vocabulary to ensure they showed a normal range of performance (see Table 1). Informed parental consent was obtained for all children. Children were free from reported learning or neurological disabilities, had normal or corrected to normal vision and hearing, and were native English speakers. The schools were situated in areas representing a range of socioeconomic backgrounds.

Design

Children were randomly allocated to one of two training conditions: (1) Semantic training (n=64), where children were exposed to the spoken forms of the science words in addition to an associated picture and spoken definition, or (2) Form-only training (n=33), where children were exposed to the spoken forms of the science words in addition to their written forms and spoken sentences providing information about word form. Thirty-one

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children in the semantic training condition were tested immediately after training (0-hrs), 24-hours later (24-hrs) and 1-week later (1-wk); the remaining 33 children were tested after 24-hrs and 1-wk only. Children who received form-only training were tested at 0-hrs, 24-hrs and 1-wk. For both training conditions, these test sessions comprised measures of lexical integration (*pause detection*) and explicit knowledge (*cued recall*) in this fixed order (cf. Henderson et al., 2012, 2013). Following this, children who received semantic training were then assessed on their semantic knowledge of the new science words (*picture identification/definitions*) whereas children who received form-only training were assessed on their orthographic knowledge (*orthographic choice*). Hence, there were three experimental groups: (1) Semantic training (with the immediate test), (2) Semantic training (without the immediate test), and (3) Form-only training.

Stimuli

Twenty-eight stimulus triplets were used comprising a base (known) word (e.g., hippopotamus), a low frequency science word competitor (e.g., hippocampus), and a novel foil for the orthographic choice task (e.g., hippocamtus) (see Appendix a). The base words were picturable nouns that were deemed to be familiar to the age range (as determined in piloting with four children aged 5-7 years). The initial fragments of the base words (e.g., hippo_) had no other possible completions (prior to the children learning the science words). The pauses were positioned at the end of this fragment in the pause detection task. The science words were selected to be related to concepts believed to be familiar to the age range under study: animals, the body, plants, liquids and rocks. These domains were selected to map closely to elements of the UK National Curriculum at Key Stages 1-4. The 28 stimulus triplets were divided into two equal lists (List 1, List 2) matched on number of

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syllables and letters, spoken length, familiarity, age of acquisition (AoA) and imageability (see Appendix b). Familiarity, AoA and imageability of the science words and base words were obtained via ratings from 20 adults. The adult raters were asked to provide the approximate age at which they learned each word (AoA), state how familiar each word was to them (0 = unfamiliar; 10 = highly familiar), and state how easy the word was to visualise (= very difficult; 10 = very easy). Children learned either List 1 or List 2 (balanced within each group), allowing the base words from the unlearned list to act as control words in the pause detection task.

In both training conditions the science words were paired with visual images. For the semantic training condition, pictures used to represent the science words and base words were selected from www.clipart.com and www.fotosearch.com/clip-art. Pictures were coloured photographs with the exception of the picture for the science word 'mastodon', which was a coloured line drawing. For the form-only training condition, the written forms of the words were presented in Calibri Font and were set on a clipart picture of a whiteboard.

Target words were also paired with sentences for both training conditions. Definitions of the science words were produced for the semantic training (e.g. "A hippocampus is a part of your brain that helps you remember things.") (see Appendix C for the full list). All definitions comprised a single sentence which contained the target word as the first or second word. The definitions provided categorical and/or functional information about the word and all provided two or three pieces of information. It should be noted that some of the more abstract concepts (e.g., taxa) had to be simplified significantly to be comprehensible to the targeted age range. For the form-only training sentences conveying

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orthographic information about letters contained within the words were produced (e.g. “Hippocampus has three Ps in it.”) (see Appendix C for the full list). In all cases the letters were referred to by use of their letter names rather than their letter sounds. All sentences contained the target word as the first word. Participants were alerted to letters at the beginning, middle and ends of the words in roughly equal proportions within Lists 1 and 2. The main purpose of the form-only sentences was to control for the linguistic input encountered in the semantic condition, rather than to promote orthographic consolidation. For both training conditions the sentences used for List 1 and List 2 were matched for length (in words). All spoken stimuli were recorded on a Pioneer PDR 509 system by a female native English speaker. For all tasks, stimuli were presented via headphones, using DMDX (Forster & Forster, 2003).

Procedure

Training. Children were told that they would be learning some new science words. Each word was presented 15 times during training. Two training conditions (semantic and form-only) were matched for duration (approximately 20 minutes). Prior to the training each science word was presented once via headphones and the children were asked to state if they recognised the word to determine if they were already familiar with the words. If they responded ‘yes’ then they were asked to say where they had heard it before and describe its meaning. There was no significant group difference in the percentages of science words that were recognised and defined ($F_s < 1$): semantic (immediate test) 1.38% (SD=2.87%), semantic (no immediate test) 2.46% (6.47%), form-only 3.11% (7.58%).

Semantic training. Semantic training comprised three tasks: repetition, phoneme segmentation and semantic decision. In the repetition task children heard each word in

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isolation and repeated it aloud, following this they heard the corresponding definition and simultaneously saw the picture target. Hence, each science word was presented twice per trial (once for repetition and once in the defining sentence) and all trials were presented 3 times in a randomised order. In the phoneme segmentation task children were presented with the picture target and simultaneously heard the science word. They were asked to say the initial (Block 1) or final sound (Block 2) of each science word and the words were presented twice per block in a randomised order. Finally, children completed a semantic decision task in which they heard each science word in isolation followed by the definition simultaneously with the picture target. They then pressed one of three coloured buttons if they thought the word was related to plants (green button), animals (blue button) or neither (red button). Each science word was presented twice per trial and each trial was repeated twice in a randomised order. Thus, the each science word was presented 15 times: once to ascertain familiarity, 6 times in the repetition task, 4 times in the sound isolation task, 4 times in the semantic decision task. Accuracy was recorded in all tasks.

Form-only training. Form-only training exposed children to the spoken and written forms of the science words but did not provide any information on word meaning to permit the investigation of the presence of semantic information on the time course of learning new spoken word forms. Other than the absence of semantic information and the inclusion of orthographic information, however, the form-only training was closely matched to the semantic training. Crucially, in both training conditions children were exposed to new spoken words that were paired with visual objects (a picture depicting the target word or a written word) and sentences (a sentence containing word meaning information or orthographic information). During the repetition task children heard each word in isolation

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and repeated it (as for the semantic training), following this they simultaneously saw the words written form and heard a sentence that described an orthographic feature of the science word (as described above). In the phoneme segmentation task children were presented with the written and spoken forms of the words and isolated the initial or final sound. Finally, children completed a syllabic decision task in which they were presented with the orthographic sentence and the written form of the science word and decided whether the word contained 1, 2, 3 or 4 syllables. This was included to further alert children to the link between the orthographic and phonological forms. They pressed a corresponding button on the keyboard to respond. Efforts were made to make the form-only training condition as engaging for children as the semantic training condition.

Changes in lexical activity. A pause detection task measured changes in lexical activity after exposure to the science word competitors (Mattys & Clark, 2002). Children made speeded decisions (by pressing one of two buttons) on whether a pause was present or absent for each spoken stimulus. Stimuli comprised the 28 base words: 14 for which a science word competitor had been taught (competitor condition) and 14 for which no competitor had been taught (control condition). Twenty-eight fillers were also included. Half of the words in the competitor and control conditions and half of the fillers contained a 200ms pause. Four versions of the task were counterbalanced across participants so that each item was equally represented in the four cells of the design (competitor, pause present; competitor, pause absent; control, pause present; control, pause absent; cf. Dumay & Gaskell, 2007). Pauses were inserted before the second vowel offset if the following consonant was a voiceless plosive and was inserted just after this vowel otherwise. Pause

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detection RT was measured from pause onset. Item presentation was randomised for each participant.

To ensure that children were familiar with the base words of the competitors (e.g., hippopotamus), a *picture-word matching task* was administered at the end of final session of the experiment. For each trial, one target (e.g., hippopotamus) and three distracters (2 other trained pictures and 1 untrained distracter) were displayed in separate quadrants on the screen. A base word was played through headphones and the participant pointed to the matching picture. Untrained distracters were matched on age of acquisition to the base words (according to the MRC Psycholinguistic Database; Wilson, 1988). Trial order was randomised but the same distracter images always occurred with the same target and the position of these four images on screen remained constant. Target pictures were equally distributed across quadrants. All groups performed at ceiling for this task: The semantic group scored a mean 95% correct (SD=6%), the semantic (no immediate re-test) group scored a mean 94% correct (SD=7%) and the no semantic group scored 95% correct (SD=8%); there was no main effect of group in a one-way ANOVA, $F < 1$.

Explicit knowledge of the science words. In all tasks of explicit knowledge item presentation was randomised for each participant. In a *cued recall task*, children heard the first syllable (e.g., hipp) of the 14 science words (from the training phase and were instructed to complete the cue using one of the science words. Accuracy was recorded.

The semantic training group also completed a task to measure semantic knowledge of the science words. On each trial the children heard a science word and were asked to define it (the *definitions task*). Following this they then saw four pictures (one target and three distracters comprising two trained pictures and one untrained picture) and were

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asked to point to the correct picture (the *picture identification* task). The definitions task measured children's ability to recall the new word meanings and also provided an index of the depth of their semantic knowledge whereas the picture identification task measured children's ability to recognise the new word meanings. Each definition was assigned a score of 0, 1, 2 or 3 in accordance to a predefined scoring system for each item. A score of 0 was awarded if a response was completely inaccurate, defined a different item or no information was provided. Scores of 1 and 2 were awarded for limited but correct information, with the latter awarded where more than one piece of information was recalled. A score of 3 was awarded if participants provided the full definition. Inter-rater reliability was calculated based on two independent scorers for a subset of participants: 0-hr ($r(23)=.98, p<.001$), 24-hr, ($r(45)=.99, p<.001$), 1-wk ($r(39)=.98, p<.001$).

The form-only training group completed a task to measure explicit orthographic knowledge. In this 2 alternative-forced choice (2AFC) task children saw both the science word (e.g., hippocampus) and its corresponding foil (e.g., hippocamtus) on the computer screen and pressed a button to indicate which item had been taught during training. The location of the science word – foil word pairs (i.e., on the left or right hand side of the computer screen) was randomised across participants.

Results

Effects of age

Previous studies have not demonstrated clear developmental changes in the strengthening or integration of new phonological forms (e.g., Henderson et al., 2012) and hence we did not make hypotheses about how chronological age may influence the time

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course of learning. However, given the broad age range of participants used in the present study (5-9 years) it is important to ascertain whether the key effects are influenced by age. There were no significant correlations between chronological age and improvements in cued recall of the new words from 0-hrs to 24-hrs, $r(63)=-.14$, $p=.28$, or from 24-hrs to 1-week, $r(97)=-.05$, $p=.65$, or between age and changes in lexical competition from 0-hrs to 24-hrs, $r(58)=-.12$, $p=.35$, or from 24-hrs to 1-week, $r(87)=-.01$, $p=.93$. Furthermore, when Age Group (5-7-years; 8-9-years) was entered as a variable in the ANOVAs reported below, there were no significant interactions with Age Group for any task ($ps>.05$). Therefore, age was not included as a factor in the subsequent analyses.

Performance during training

Table 2 shows performance on the training tasks for the three experimental groups: Semantic training (immediate test), Semantic training (no immediate test) and Form-only training. There were no significant group differences for percent correct word repetitions, final isolations and correct semantic/syllable decisions. Performance for initial sound isolations was close to ceiling for all groups; however, the form-only group showed significantly lower accuracy for initial sound isolations than the semantic (no immediate test) group ($p=.012$, $d=0.89$). This was possibly due to the discrepancy between the initial sound and letter of a small proportion of the science words and this may have reduced accuracy in the form-only group who were shown the written forms of the words (e.g., *cistern* to which the form-only group tended to respond with the letter “c” rather than the sound “s”). There was a numerically smaller difference in accuracy between the form-only group and the semantic group who received the immediate test but this difference was not significant ($p=.18$, $d=0.40$).

Does semantic training influence the time course of word learning?

We first present analyses of changes in lexical integration followed by changes in explicit measures of word learning across the three test points (0-hr, 24-hr and 1-wk). Hence, we first focus on the two experimental groups who completed all tests: the semantic training group who completed the immediate test (the semantic group) and the form-only group.

Lexical integration. The RT and error data for the pause detection task are shown in Table 4. Outliers were removed if RTs were <200ms or >2.5 SDs from the condition mean for each child separately (<2% data for all groups and sessions). Participants were removed from analysis if they made >50% errors for either condition: Three children were removed for the 0-hr test (semantic group $n = 2$ aged 7.75 years and 9.16 years, form-only group $n = 1$ aged 7.66 years) and four children were removed for the 1-wk test (semantic group $n = 2$ aged 7.75 years and 8.75 years, form-only group $n = 2$ aged 8.25 years and 7 years). RT data were analysed for correct responses only.

The RT data for the children who received all tests (0-hr, 24-hr and 1-wk) were entered into a 2 (Condition: Competitor, control) x 3 (Session 0-hr, 24-hr, 1-wk) x 2 (Training Group: Semantic, No Semantic) x 2 (List 1, List 2) mixed-design ANOVA. There was no significant main effect of Condition, $F_1(1, 54)=1.93, p=.17, \eta_p^2=.04, F_2(1, 26)=1.50, p=.23, \eta_p^2=.06$, but there was a marginally significant Session x Condition interaction¹, $F_1(2, 108)=2.91, p=.06, \eta_p^2=.05, F_2(2, 52)=2.23, p=.12, \eta_p^2=.08$: Pause detection latencies were similar for competitor and control conditions at 0-hrs, 95% CIs -65-30ms, $t^1(60)=-0.75, p=.46, d=-.09, t^2(27)=-.69$,

¹ When 'List' was omitted as a between-subject factor from the ANOVA the Session x Condition interaction was significant by participants ($F_1(2, 112)=3.52, p=.033, \eta_p^2=.06, F_2(2, 54)=2.14, p=.13, \eta_p^2=.07$).

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$p=.50$, $d=-0.12$, indicating that the acquisition of the novel competitor had not increased lexical competition at this time point. However, at 24-hrs, children were slower to respond to the competitor words than to control words, 95% CIs 23-107ms, $t^1(63)=3.09$, $p=.003$, $d=0.40$, $t^2(27)=2.28$, $p=.03$, $d=0.43$, suggesting that the new competitor effect was present. Although this pattern of lexical competition remained numerically similar at the 1-wk test, the effect was more variable and did not reach significance, 95% CIs -29 – 107ms, $t^1(59)=1.14$, $p=.26$, $d=0.13$, $t^2(27)=1.19$, $p=.24$, $d=0.23$. The type of training did not affect the time course of engagement in lexical competition: the Session x Condition x Training Group interaction was not significant, $F_1<1$, $F_2<1$, and there were no significant differences between the semantic and form-only groups in the size of lexical competition scores at 0-hrs, $t^1(59)=-.74$, $p=.46$, $d=-.19$; $t^2(27)=-.88$, $p=.51$, $d=-0.18$, 24-hrs, $t^1(62)=.66$, $p=.51$, $d=0.17$; $t^2(27)=.56$, $p=.49$, $d=0.18$, or 1-wk, $t^1(58)=.77$, $p=.45$, $d=0.20$; $t^2(27)=.18$, $p=.81$, $d=0.19$. There was however a significant Session x Training Group interaction, $F_1(2,108)=3.38$, $p=.04$, $\eta_p^2=.06$, $F_2(2, 52)=6.30$, $p=.004$, $\eta_p^2=.20$: When averaging across competitor and control conditions, both groups showed similar RT at 0 hours and 24 hours (semantic group, $t^1(28)=-1.40$, $p=.17$, $d=0.20$, $t^2(27)=1.02$, $p=.32$, $d=0.19$; form-only group, $t^1(31)=-1.15$, $p=.26$, $d=0.14$, $t^2(27)=1.42$, $p=.17$, $d=0.27$); however whilst the semantic group showed no difference in RT between 24 hrs and 1 week, $t^1(28)=-.89$, $p=.38$, $d=0.16$, $t^2(27)=1.39$, $p=.18$, $d=0.27$, the form-only group showed significantly slower RT at 1-wk than at 24-hrs, $t^1(30)=-2.06$, $p=.05$, $d=-0.32$, $t^2(27)=-2.87$, $p=.008$, $d=-0.57$. It is notable that variability in pause detection RT was particularly high for the form-only group at the 1-wk test, which could have accounted for the general increase in RT as well as the lack of a significant lexical competition effect. There were no other significant main effects or interactions.

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The analysis was repeated but with items removed (on a participant by participant basis) if the science-words were familiar on the knowledge check administered at the start of training or if the base words were unfamiliar on the base word picture matching task.

Although the Session x Condition interaction became weaker, $F_1(2,108)=2.36$, $p=.10$, $\eta_p^2=.04$, $F_2(2,52)=1.65$, $p=.20$, $\eta_p^2=.06$, the contrasts comparing competitor and control conditions remained similar to the primary analysis: 0-hrs, $t^1(60)=-.87$, $p=.40$, $d=-0.11$, $t^2(27)=-.74$, $p=.42$, $d=-0.10$, 24-hrs, $t^1(63)=2.97$, $p=.004$, $d=0.37$, $t^2(27)=1.98$, $p=.06$, $d=0.30$, 1-wk, $t^1(59)=1.16$, $p=.25$, $d=0.15$, $t^2(27)=1.29$, $p=.21$, $d=0.16$. All other significant main effects and interactions remained the same.

The error data are presented in Table 4. Errors were equally distributed across pause present ('yes') and pause absent ('no') responses at the 0-hr test, $t^1(63)=-.159$, $p=.12$, $d=-0.28$, the 24-hr test, $t^1(63)=-.71$, $p=.48$, $d=-0.12$, and the 1 wk-test, $t^1(63)=-.06$, $p=.96$, $d=-.01$. The error data for the children who received all tests (0-hr, 24-hr and 1-wk) were also entered into a 2 (Condition: Competitor, control) x 3 (Session: 0-hr, 24-hr, 1-wk) x 2 (Training Group: Semantic, Form-only) x 2 (List 1, List 2) mixed-design ANOVA. However, there were no significant main effects or interactions.

Explicit memory for the science words. A 2 (Training Group; semantic, form-only) x 3 (0-hr, 24-hr, 1-wk) x 2 (List; 1, 2) mixed-design ANOVA was performed for children who completed all tests (see Figure 1). When cued with the first syllable, children were able to recall significantly more words at 24-hrs than 0-hrs, $p=.001$, and at 1-wk than 24-hrs, $p=.001$, Session, $F_1(2, 118)=279.65$, $p<.001$, $\eta_p^2=.83$, $F_2(2,52)=157.55$, $p=.000$, $\eta_p^2=.86$. There was also a significant Session x Training Group interaction, $F_1(2, 118)=16.54$, $p<.001$, $\eta_p^2=.22$, $F_2(2,52)=18.46$, $p=.000$, $\eta_p^2=.42$: Semantic and form-only groups showed similar

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improvements at 24-hrs relative to 0-hrs (semantic mean improvement=35.71%, SD=16.80%, 95% CIs 29.55-41.88%, $t^1(30)=11.84$, $p=.000$, $d=2.22$, $t^2(27)=9.77$, $p=.000$, $d=1.87$; form-only mean improvement=26.34%, SD=18.18, 95% CIs 19.78-32.89%, $t^1(32)=8.51$, $p=.000$, $d=1.49$, $t^2(27)=9.22$, $p=.000$, $d=1.74$, however, the semantic group showed a significantly greater improvement at 1-wk relative to 24-hrs (semantic group mean=20.28%, SD=13.56%, 95% CIs 11.37-22.40%, $t^1(30)=8.32$, $p=.000$, $d=1.58$, $t^2(27)=6.73$, $p=.000$, $d=1.35$; form-only group mean=7.79%, SD=9.68, 95% CIs 4.36-11.22%, $t^1(32)=4.63$, $p=.000$, $d=0.80$, $t^2(27)=3.64$, $p=.001$, $d=0.68$). We also analysed the Session x Group interaction by comparing the semantic and form-only groups at each test point. At the 0-hr test, there was some indication that the form-only group recalled more new words than the semantic group but this was only significant by items ($t^1(62)=1.57$, $p=.12$, $d=0.40$, $t^2(27)=4.05$, $p=.000$, $d=0.54$), at the 24-hr test there was no group difference ($t^1(62)=0.28$, $p=.78$, $d=0.07$, $t^2(27)=0.74$, $p=.47$, $d=0.10$), but the semantic group outperformed the form-only group at the 1-wk test ($t^1(62)=2.77$, $p=.007$, $d=0.70$, $t^2(27)=4.29$, $p=.000$, $d=0.63$). No other main effects or interactions were significant.

Consolidation of new semantic and orthographic knowledge

Semantic knowledge. *Picture Identification.* Children in the semantic group were able to identify >70% of the pictures that were associated with the science words suggesting good levels of learning. The accuracy data for the selection of the appropriate picture when cued with a science word were entered into a 3 x (Session; 0-hr, 24-hr, 1-wk) x 2 (List; 1, 2) ANOVA (for the semantic group who completed all tests). There was a significant main effect of Session, $F_1(2, 58)=5.08$, $p=.009$, $\eta_p^2=.15$, $F_2(2,52)=9.49$, $p<.001$, $\eta_p^2=.27$: accuracy was significantly higher at 24-hrs than 0-hrs (mean improvement 7.14%, SD=16.60%, 95%

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CI_s 1.05-13.23%, $t^1(30)=2.40$, $p=.02$, $d=0.66$, $t^2(27)=3.19$, $p=.004$, $d=0.63$) but there was no difference between the 1-wk and 24-hr session (mean improvement 1.15%, SD=12.92%, 95% CI_s -3.59-5.89%, $t^1(30)=-0.50$, $p=.62$, $d=0.09$, $t^2(27)=-.52$, $p=.61$, $d=0.08$).

Definitions. The scores from the definitions task for the semantic group who completed the immediate test were entered into a 3 (Session; 0-hr, 24-hr, 1-wk) x 2 (List; 1, 2) ANOVA. There was a significant main effect of Session, $F_1(2, 58)=25.19$, $p=.000$, $\eta_p^2=.47$, $F_2(2,52)=29.03$, $p=.000$, $\eta_p^2=.53$: Definition scores were significantly higher at 24-hrs than 0-hrs (mean improvement 9.68%, SD=11.92%, 95% CI_s 5.31-14.05%, $t^1(30)=4.52$, $p=.000$, $d=0.91$, $t^2(27)=5.91$, $p=.000$, $d=1.15$) and at 1-wk than 24-hrs (mean improvement 4.07%, SD=9.08%, 95% CI_s 0.74-7.40%, $t^1(30)=2.50$, $p=.02$, $d=0.45$, $t^2(27)=2.58$, $p=.02$, $d=0.53$).

Orthographic knowledge. Children in the form-only group were able to recognise >80% of the written forms of the science words immediately after learning suggesting that accuracy was near ceiling. The accuracy data were entered into a 3 (Session; 0-hr, 24-hr, 1-wk) x 2 (List; 1, 2) ANOVA. Although there was a small numerical improvement in accuracy from the 0-hr to the 24-hr test that was maintained at the 1-wk test, the main effect of Session was not significant by participants, $F_1(2, 58)=1.81$, $p=.17$, $\eta_p^2=.06$; $F_2(2,52)=3.74$, $p=.03$, $\eta_p^2=.13$. Thus, children's ability to recognise the new written forms maintained (but did not significantly improve) across the three test points.

Does repeated testing influence changes in explicit knowledge and lexical activity?

We compared performance for the children in the semantic group who did and did not receive the 0-hr test in order to determine whether improvements in lexical memory at 24-hr and 1-wk were partly a consequence of the renewed exposure at the 0-hr test. For the

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24-hr and 1-wk tests, there were no significant differences between the two groups for the cued recall, picture identification or definitions tasks (Table 3) or for the lexical competition effects at the 24-hr and 1-wk tests (Table 4). These null effects suggest that the influence of the 0-hr test on subsequent performance was negligible, with changes in performance instead being a consequence of the time delay between test points. We also compared performance on the initial tests for the immediate test group (at 0-hrs) and the no-immediate test group (at 24-hrs) to examine the influence of time delay on performance (see Table 3). Superior performance for the no-immediate test group would further support our prediction that off-line consolidation, rather than repeated exposure or practice effects, is responsible for gains in performance over time. In accordance with this prediction, the no-immediate test group showed significantly higher cued recall scores at their initial (24-hr) test than the immediate test group at their initial (0-hr) test, $t_1(df=62)=6.24$, $p=.000$, $d=1.61$. The no-immediate test group also showed significantly higher definition scores at their initial test than the immediate test group, $t_1(df=62)=2.75$, $p=.008$, $d=0.72$, but there was no significant group difference at initial test for picture recall scores, $t_1(df=62)=1.06$, $p=.29$, $d=0.27$. Similarly, the pause detection RT data from the initial tests were entered into a mixed-design ANOVA with Condition (competitor, control) as the within-subjects variable and Group (immediate test, no immediate test) as the between-subjects variable. The main effects of Condition, $F_1(1, 58)=1.18$, $p=.28$, $\eta_p^2=.02$, and Group, $F_1(1, 58)=0.60$, $p=.44$, $\eta_p^2=.01$, were not significant. However, there was a significant Condition x Group interaction, $F_1(1, 58)=6.10$, $p=.017$, $\eta_p^2=.10$: The no immediate test group showed a substantial (94 ms) lexical competition effect at their initial (24-hr) test (i.e., slower responses to competitor than control conditions), $t_1(62)=2.56$, $p=.016$, $d=0.46$, but the immediate test group showed no evidence of such an effect at their first test point (0-hr) test, $t_1(28)=-0.96$, $p=.35$, $d=0.18$ (see

Table 4). This result in particular provides clear evidence that the engagement of real words with given meanings in lexical competition relies on a consolidation period. Together, these comparisons suggest that the key effects obtained cannot be attributed to repeated exposure or practice effects.

Discussion

The findings presented here advance our understanding of vocabulary acquisition in children aged 5-9-years-old. Previous studies have shown that when children learn fictitious novel nonwords on the basis of their phonological form, there is a delay associated with the strengthening of new phonological representations (Brown et al., 2012) and their engagement in lexical competition (Henderson et al., 2012; Henderson et al., 2013). These findings have been explained by the CLS account of vocabulary acquisition (Davis & Gaskell, 2009), according to which new information is sparsely encoded separately from existing knowledge and integrated with long term memory over time. Crucially, the present study extends this to real word learning in an educationally relevant context, providing important evidence that the delay in lexical integration reported in previous experiments is *not* an artefact of an artificial or semantically impoverished learning environment (as suggested by Leach & Samuel, 2007).

Does semantic training influence the time course of word learning?

Lexical integration. Consistent with our hypotheses and with previous research (Henderson et al., 2012; Henderson et al., 2013), children showed lexical competition effects for existing words 24-hours after they had learned real science word competitors but not immediately. Crucially, this pattern maintained when children had been exposed to the

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word meanings. Specifically, they took longer to detect a pause in an existing competitor word (e.g., hippopotamus) if they had learned a similar sounding science word (e.g., hippocampus) 24 hours earlier. The extent to which the new words competed for recognition with existing words was not influenced by practice or repeated exposure during the tests, suggesting that the effects are most likely due to off-line consolidation.

One week after training there was a numerical lexical competition effect (i.e., responses to competitor words were slower than to control words) but this effect did not reach significance for either training group (see also Henderson et al., 2012). The weakening of lexical competition over time in children is most likely due to a parallel increase in variability in pause detection latencies and a subsequent reduction in statistical power. These findings with children are in sharp contrast to a previous adult study by Tamminen and Gaskell (2008) which found that lexical competition effects between novel words and phonological neighbours persist for as long as 8 months after initial exposure. Given the large variability in children's pause detection RTs it will be important to further examine the effect of semantic information on the time course of lexical integration, especially since the 1-week lexical competition effects were numerically (but not statistically) stronger for the semantic groups. Hence, there was some (weak) suggestion that semantic training may have some benefit for lexical integration in the longer term.

Explicit memory for new phonological forms. Children's ability to explicitly recall the new science words improved 24-hours after training and recall remained stable after one week, consistent with previous findings (Henderson et al., 2012; Henderson et al., 2013). Importantly, children's explicit memory for the new words was not influenced by practice or

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repeated exposure during the tests, suggesting that the effects are most likely due to off-line consolidation.

Despite the lack of an effect of semantic training on the implicit test of lexical integration, there was a clear influence of semantics on the explicit ability to retrieve the new phonological forms. Children who learned the meanings of the science words showed no advantages compared with the form-only group when asked to recall the words immediately and 24 hours after training. Indeed, there was some indication (albeit statistically weak) that form-only trained children recalled more words than semantically trained children at the 0-hr test. Importantly however, the semantic group showed better long-term retention and were able to recall more of the science words one week after training. This is consistent with McKague et al. (2001) who reported a recall advantage for novel words trained with semantics than novel words trained without semantics two days after initial training. These results support the hypothesis that providing semantic information during word learning leads to more robust long-term lexical representations.

The finding that the influence of semantic information on phonological recall took a week to emerge is reminiscent of Tamminen and Gaskell's (2012) finding that familiar words were primed by the newly related nonwords most strongly after one week. Together, this suggests that the influence of semantic information on the learning of new phonological representations is a gradual process that operates over several days and/or nights in both children and adults.

Consolidation of new semantic and orthographic knowledge. Children who received form-only training recognised a high proportion of the orthographic forms immediately after learning and this performance maintained over the week. This suggests that explicit

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recognition of new orthographic forms remains strong after a period of off-line consolidation, similar to previous adult data examining changes in recognition of new phonological forms (Dumay & Gaskell, 2007). Similarly, children in the semantic training group showed improvements in their ability to define the new words and recognise associated pictures after 24-hours, with children's definitions continuing to improve one week later. This fits with the view that word meanings are learned incrementally and are refined with successive encounters (Nagy & Scott, 2000).

The improvements in recall and recognition of new word meanings contrast with Tamminen and Gaskell (2012) who found significant forgetting of nonword meanings over the course of a week, attributed to the weakening of newly formed episodic representations. Explicit recall of nonword meanings in Tamminen and Gaskell was influenced by the presence of the meaning recall test. Namely, participants who were retested during the eight day period recalled significantly more novel word meanings in the final session on day 8 than those who were not tested prior to day 8. This suggests that repeated administration of the recall task maintained explicit memory of the meanings (see also Roediger & Karpicke, 2006). However, that explanation cannot account for the present findings: In this study children who received the immediate test did not recall more word meanings at the 24 hour or one week test than children who did not receive the immediate test. An alternative explanation for the improvements in explicit memory of the new word meanings reported here is that we trained novel but real words that had clear relevance for future use whereas Tamminen and Gaskell trained fictitious nonwords. It is also noteworthy that Tamminen and Gaskell used written presentation whereas here the stimuli were

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presented in spoken form which may have been more advantageous for explicit recall (Craik, 1970).

Theoretical Implications

This study provides evidence for the CLS account of vocabulary acquisition put forward by Davis and Gaskell (2009) in the context of real (rather than fictitious) word learning. According to this view, new information is initially encoded sparsely by the fast-learning hippocampal system where it is stored separately from existing knowledge. The hippocampal system is proposed to play back newly learned memories to the neocortex over an extended period of time, eventually allowing new knowledge to become integrated with the existing lexical-semantic network. The present data strengthens this account by suggesting that providing semantics during training does not mitigate the need for slow processes of lexical integration and stabilisation (counter to Leach & Samuel, 2007). That is, both groups showed a delay in the onset of lexical competition between new and existing words and both groups showed incremental strengthening of explicit memory for new words over a week.

How can we explain the finding that attaching meaning to a new word leads to a lexical representation that is more easily retrieved one week after training? Newly learned information is better assimilated if it is compatible with an existing cognitive framework or schema (Bartlett, 1932; Lewis & Durrant, 2011; Tse et al., 2007; van Kesteren et al., 2010). Hence, providing a semantic context during training may have worked to integrate the new words with existing semantic knowledge and leave this new information less vulnerable to forgetting over time. According to McClelland et al (1995), adaptive adjustments to the weights between neocortical connections take place over a prolonged period of time, over

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the course of many repetitions of the same or substantially similar acts of information processing. Thus, whilst a night of sleep is sufficient to lead to the restructuring of stored phonological knowledge, such that a new word begins to engage in competition with phonological competitors, an extended period of consolidation is required before new semantic knowledge can influence retrieval from long-term lexical memory.

It is perhaps surprising that semantic knowledge did not influence the extent to which new words engaged in competition with existing words during speech perception after one week. However, whilst semantic information may be beneficial in aiding explicit recall of the new word forms, lexical competition (as measured by the pause detection task) reflects activity between word candidates *early* in speech perception as the speech string unfolds and hence may not show the same benefit from semantic knowledge in children.

Educational Implications

Children in the present study were able to accurately recall >20% of the new phonological forms immediately after training and recognise >70% of their associated pictures or orthographic forms. This is consistent with studies showing that children and infants are able to learn novel phonological forms rapidly (Brown et al., 2012; Church & Fischer, 1998; Henderson et al., 2012; Henderson et al., 2013; Jusczyk & Aslin, 1995). In contrast, Dockrell et al. (2007) reported low levels of comprehension (picture identification) and production (picture naming) of newly learned science words in 4-7-year-old children, despite them coming to the training with existing lexical and conceptual knowledge of the domains from which the science words were selected. The training regime used by Dockrell et al involved children watching short video clips containing a single exposure of the science words with picture cues, akin to a typical classroom activity. Thus, more encounters with the

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new words and the explicit nature of the training provided in the present study likely accounts for the higher rates of learning than in Dockrell et al. According to Nagy, Herman and Anderson (1985, cited in Beck & McKeown, 1991), the probability of learning a word from one exposure ranges between 0.05 and 0.11, depending on the criterion utilized. Hence, it is likely that longer term retention would have increased with more exposures (Lloyd & Contreras, 1987; McGuigan, 1990; Rix & Yiannaki, 1996).

The training used by Dockrell et al. could be argued to be akin to indirect vocabulary instruction. Such an approach involves students learning vocabulary through conversation, being read to, or through reading on their own. In contrast, the present study adopted a training regime closer to direct vocabulary instruction (where students are explicitly taught individual words). Although a great deal of vocabulary is learned indirectly, it has been argued by the UK's National Institute of Child Health and Human Development (NICHD; 2011) that some vocabulary should be taught directly. In particular, direct instruction has been argued to assist students in the acquisition of difficult words that represent complex concepts that are not part of the students' everyday experiences. The NICHD emphasizes that specific word instruction should (i) occur before reading a related text to aid vocabulary learning and comprehension of the text, (ii) promote active engagement over an extended period of time, and (iii) involve repeated exposure to vocabulary in multiple and varied contexts. The importance of repeated exposure and active engagement are supported by the present data. Future classroom-based studies are needed to examine the extent to which presenting new words in varied semantic contexts influences the integration of new words with the mental lexicon. Indeed, it may be important for instruction in complex words (such as science vocabulary) to highlight and discuss links between new and familiar

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concepts in order for the new semantic information to be fully integrated in semantic memory, as advocated by Multiple Context Learning (MCL; Beck, McKeown & Kucan, 2002).

Conclusions and future directions

In conclusion, the present data suggest that a period of off-line consolidation is necessary for the strengthening and integration of new vocabulary in children. We present the first evidence that providing semantic information during spoken word learning makes no difference to the time course of lexical integration in children, at least over the course of a week. However, children's ability to explicitly recall the new phonological forms after one week was superior if they had been provided with semantic information during training. This suggests that the presence of semantic information during new word learning is critical for the development of stable long-term lexical representations and increases the ease with which these representations are explicitly retrieved. The present study also provides novel evidence that children's ability to explicitly recall new semantic knowledge improves over a one week period.

Further experiments are now needed to examine the time course with which new semantic knowledge is integrated with semantic memory in children and whether sleep is crucial for this process. The present study used a wide span of children aged 5-9-years-old, capturing a developmental period that is characterised by major changes in literacy knowledge and skills relevant to the development of word knowledge. Despite this however, there were no clear effects of age on the extent to which new words were integrated into the lexicon or were strengthened after a period of off-line consolidation (see also Henderson et al., 2012). Future studies are needed to re-examine this issue with a

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larger sample size to investigate the extent to which changes in cognitive development may influence the acquisition of sophisticated, rare vocabulary.

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Table Headings

Table 1. Descriptive statistics for age and cognitive and language skills of the training groups.

Table 2. Mean percent correct scores (and SDs) for the training tasks for each training condition.

Table 3. Mean % correct (and SDs) for the three training conditions on the tests of explicit knowledge. Pairwise t scores show the lack of significant differences between the immediate test and no-immediate test semantic groups.

Figure Headings

Figure 1. Performance on cued recall task (% correct) for semantic (immediate test) and form-only training groups (standard error bars are shown).

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Table 1. Descriptive statistics for age and cognitive and language skills of the training groups.

	Semantic (n =31, 13males)		Semantic (no immediate test) (n =33, 11 males)		Form Only (n=33, 9 males)		<i>F</i> Values	<i>Effect Size</i> (η_p^2)
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range		
Age	7.98 (1.12)	6.08-9.83	7.99 (1.13)	5.92-9.75	7.93 (0.93)	5.92-9.75	.03	.001
Nonverbal IQ (T) ¹	51.90 (9.73)	34-67	54.94 (9.81)	35-70	53.60 (8.82)	39-73	.83	.02
Elision (sc) ²	11.26 (3.55)	3-18	11.73 (3.03)	7-19	11.58 (2.50)	6-16	.20	.004
Receptive	104.94	78-127	109.10	94-139	108.33 (11.64)	86-132	1.10	.02
Vocabulary (ss) ³	(12.76)		(11.31)					

Note. ss = standard score (mean 100, normal range 85 – 115), T = T score (mean 50, normal range 40 – 60), sc = scaled score (mean 10, normal range 8 – 12) . Standardised tests used: ¹ *Matrix Reasoning from the Wechsler Abbreviated Scales of Intelligence* (Wechsler, 1999), ² *Phoneme Elision and Memory for Digits* from the *Comprehensive Test of Phonological Processing* (Wagner, Torgesen & Rashotte, 1999), ³ *Peabody Picture Vocabulary Test* (Dunn & Dunn, 2007).

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Table 2. Mean percent correct scores (and SDs) for the training tasks for each training condition.

	Semantic	Semantic (No immediate test)	Form-only	<i>F</i> values	<i>Effect Size</i> (η_p^2)
	Mean (SD)	Mean (SD)	Mean (SD)		
Repetitions (%)	97.16 (5.12)	97.84 (4.89)	96.83 (4.15)	.39	.008
Initial isolation (%)	96.66 (4.22)	98.18 (3.23)	94.70 (6.98)	3.85*	.08
Final isolation (%)	83.18 (16.00)	87.34 (12.25)	86.26 (12.05)	.81	.02
Semantic/Orthographic Task	86.76 (9.62)	87.34 (12.18)	86.26 (19.44)	.51	.01

Note. *F* values are shown for one-way ANOVAs.

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Table 3. Mean % correct (and SDs) for the three training conditions on the tests of explicit knowledge. Pairwise *t* scores (with Cohen's *d* effect size in parentheses) show the lack of significant differences between the immediate test and no-immediate test semantic groups.

		Form-only	Semantic (immediate test)	Semantic (no immediate test)	<i>t</i>
Cued Recall (% correct)	0-hr	30.13 (20.90)	22.35 (15.94)	-	-
	24-hr	56.49 (23.10)	58.06 (21.49)	55.41 (25.13)	0.50 (0.11)
	1-wk	64.29 (22.87)	78.34 (17.15)	72.28 (19.46)	1.32 (0.33)
Picture Identification (% correct)	0-hr	-	74.19 (18.69)	-	-
	24-hr	-	81.34 (12.73)	79.00 (17.67)	0.60 (0.15)
	1-wk	-	82.49 (13.90)	80.95 (18.61)	0.37 (0.10)
Definitions (% correct)	0-hr	-	24.81 (13.11)	-	-
	24-hr	-	34.49 (16.98)	37.23 (21.67)	-0.56 (0.15)
	1-wk	-	38.56 (18.44)	42.21 (26.16)	-0.64 (0.16)
Orthographic Choice (% correct)	0-hr	84.20 (16.54)	-	-	-
	24-hr	87.01 (16.70)	-	-	-
	1-wk	87.01 (15.30)	-	-	-

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Table 4. Mean (and SD) pause detection RTs (ms) and errors (%) for Competitor and Control conditions, as a function of training condition.

	Form-only Group			Semantic Group			Semantic Group (no immediate test)		
	Competitor	Control	Lexical Comp	Competitor	Control	Lexical Comp	Competitor	Control	Lexical Comp
<i>RT</i>									
0-hrs	1255 (319)	1256 (308)	-1	1273 (287)	1309 (301)	-36	-	-	-
24-hrs	1234 (303)	1182 (308)	52 [^]	1302 (335)	1222 (252)	80*	1398 (342)	1304 (333)	94*
1-wk	1303 (402)	1289 (355)	14	1258 (277)	1192 (249)	66	1378 (410)	1305 (363)	73
<i>Errors</i>									
0-hrs	16.68 (14.33)	17.62 (13.49)	-0.94	12.50 (12.39)	12.24 (11.80)	0.26	-	-	-
24-hrs	11.19 (9.86)	14.76 (11.85)	-3.57	9.95 (9.98)	10.97 (12.06)	-1.02	17.05 (14.25)	14.52 (11.14)	2.53
1-wk	14.05 (10.19)	13.57 (11.62)	0.48	12.24 (9.69)	12.75 (9.39)	-0.51	15.85 (13.67)	17.19 (13.56)	-1.34

Note * $t^1 p < .05$, [^] $t^1 p = .08$

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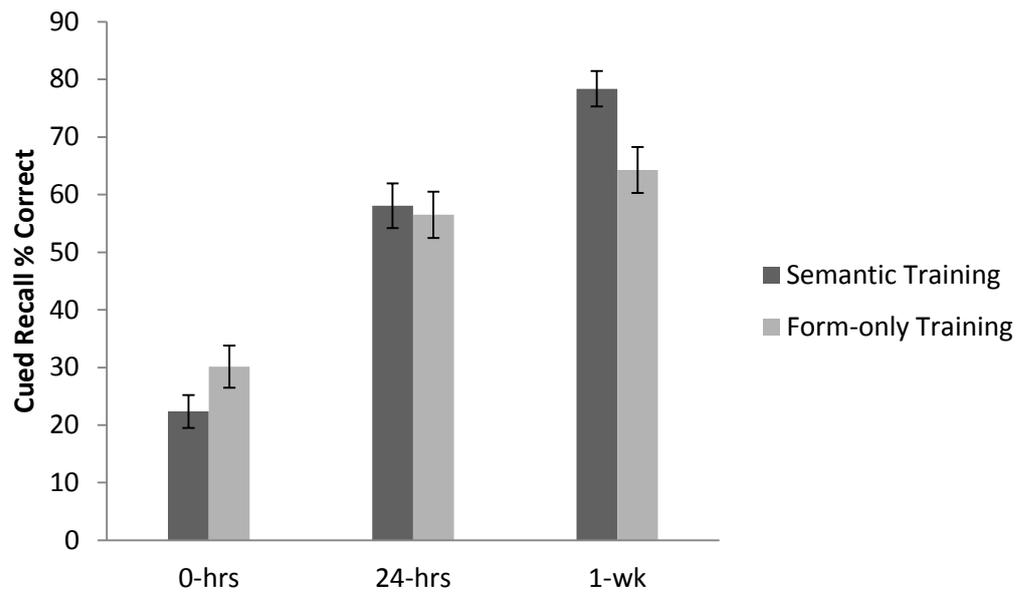


Figure 1. Performance on cued recall task (% correct) for semantic (immediate test) and form-only training groups (standard error bars are shown).

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Appendix a	Science Words	Base word	Foil
<i>LIST 1</i>	beryl	berry	berul
	cistern	sister	cisterp
	catalyst	catalogue	catalysk
	hippocampus	hippopotamus	hippocampud
	gadfly	gadget	gadply
	lantana	lantern	lantanu
	dynamo	dynamite	dynama
	ratite	rattle	ratige
	taxa	taxi	taxu
	pupa	pupil	pupo
	stomata	stomach	stomaza
	gharial	garage	ghariaf
	troposphere	tropical	tropospherd
	mastodon	master	mastodog
<i>LIST 2</i>	quartzite	quarter	quartzife
	pantograph	pantomime	pantograck
	palisade	palace	palisale
	parasite	parasol	parasize
	tropism	trophy	tropist
	crawdad	crawling	crawdak
	rabid	rabbit	rabis
	cornea	cornet	corneu
	miscible	missing	miscikle
	photon	photo	photop
	smolt	smoke	smole
	torpor	torpedo	torpof
	breccia	breakfast	breccig
	sculpin	sculpture	sculpit

Appendix B

	List 1			List 2		
	Science Words	Base Words	Foils	Science Words	Base Words	Foils
Bigram freq (sum)	-	9299 (5890)	-	-	10,541 (4820)	-
Bigram freq (mean)	-	1921 (1026)	-	-	1731 (659)	-
K-F Freq	-	19.92 (19.22)	-	-	20 (18.39)	-
Ortho N Size	-	1.62 (2.50)	-	-	1.07 (1.64)	-
Phono N Size	-	3.92 (6.0)	-	-	2.14 (2.80)	-
OLD	-	2.48 (1.3)	-	-	2.37 (0.60)	-
PLD	-	2.38 (1.35)	-	-	2.27 (0.81)	-
N Letters	6.64 (2.62)	6.78 (2.01)	6.64 (2.62)	7.07 (1.44)	6.93 (1.38)	7.07 (1.44)
N Phonemes	6.36 (1.74)	5.77 (1.83)	6.36 (1.74)	6.43 (1.55)	5.92 (1.33)	6.43 (1.55)
N syllables	2.64 (0.63)	2.43 (0.85)	2.64 (0.63)	2.43 (0.65)	2.14 (0.53)	2.43 (0.65)
AoA	16.35 (1.79)	5.81 (1.49)	-	14.93 (3.19)	5.70 (1.84)	-
Familiarity	4.07 (2.89)	9.50 (0.36)	-	2.94 (3.03)	9.32 (0.67)	-
Imageability	2.96 (2.08)	8.76 (1.07)	-	2.15 (2.31)	8.64 (1.71)	-

Note. AoA Familiarity and Imageability were determined by 20 adult raters. K-F Frequency was obtained from the MRC Psycholinguistic Database (data was missing from one List 1 base word and two List 2 base words; data not reported for science words since only available for 5/14 for List 1 and 3/14 for List 2) . Neighbourhood size, orthographic Levenshtein distance (OLD), phonological Levenshtein distance (PLD), and bigram frequencies were obtained from the English Lexicon Project (<http://elexicon.wustl.edu>) (no missing data for base words; data not reported for science words since only available for 6/14 List 1 items and 5/14 List 2 items). There were no significant differences between List 1 and List 2 for any variables (all $ps < .30$)

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Appendix c	Semantic Sentences	Form-Only Sentences
LIST 1	<p>Beryl is a gem stone</p> <p>A cistern is a water tank</p> <p>A catalyst is something that sparks a reaction</p> <p>The hippocampus is a part of the brain that helps you remember things</p> <p>A gadfly is a fly that annoys cows</p> <p>Lantana is a flowering plant that can be pink and yellow</p> <p>A dynamo is a machine that makes electricity</p> <p>A ratite is a bird that cannot fly</p> <p>A taxa is way of grouping animals into similar categories</p> <p>A pupa is a what a bug looks like early in its life when it's legs are formed</p> <p>Stomata are the tiny holes in leaves that let food in and out</p> <p>A gharial is like a crocodile with a long nose</p> <p>The troposphere is the layer around the earth that includes the sky</p> <p>A mastodon looks like a hairy elephant</p>	<p>Beryl begins with the letter B</p> <p>Cistern has an S in it</p> <p>Catalyst begins with the letter C</p> <p>Hippocampus has three Ps</p> <p>Gadfly begins with the letter G</p> <p>Lantana has a T in it</p> <p>Dynamo ends with the letter O</p> <p>Ratite has two Ts</p> <p>Taxa begins with the letter T</p> <p>Pupa ends with an A</p> <p>Stomata ends with the letter A</p> <p>Gharial has two As in it</p> <p>Troposphere begins with the letter T</p> <p>Mastodon ends with the letter N</p>
LIST 2	<p>Quartzite is a gem stone</p> <p>A pantograph is a machine that stores electricity</p> <p>A palisade is a tiny thing in a plant that helps make them green</p> <p>A parasite is a very tiny creature that eats other animals</p> <p>Tropism is when a plant grows towards or away from something like light</p> <p>A crawdad is like a small lobster and lives in water</p> <p>Rabid means to have a nasty disease that dogs can get</p> <p>A cornea is the see-through bit at the front of your eye</p> <p>Miscible means when two liquids can mix up together</p> <p>A photon is a tiny particle of light</p> <p>A smolt is a baby salmon</p> <p>Torpor is a deep sleep to let the body rest</p> <p>Breccia is a sharp rock</p> <p>A sculpin is a fish with a wide mouth</p>	<p>Quartzite begins with the letter Q</p> <p>Pantograph has a G in it</p> <p>Palisade begins with the letter P</p> <p>Parasite has two As</p> <p>Tropism begins with the letter T</p> <p>Crawdad ends with the letter D</p> <p>Rabid ends with the letter D</p> <p>Cornea has one R</p> <p>Miscible begins with the letter M</p> <p>Photon has two Os in it</p> <p>Smolt ends with a T</p> <p>Torpor has two Os in it</p> <p>Breccia ends with the letter A</p> <p>Sculpin has a C in it</p>

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