Running head: PRIOR KNOWLEDGE IN WORD LEARNING

Offline consolidation supersedes prior knowledge benefits in children’s (but not adults’) word learning

Emma James, M. Gareth Gaskell, and Lisa M. Henderson

Department of Psychology, University of York

Corresponding author: Dr Lisa Henderson, Department of Psychology, University of York, York, YO10 5DD; [lisa-marie.henderson@york.ac.uk](mailto:lisa-marie.henderson@york.ac.uk); 01904 324362

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**Research highlights**

* Novel words with neighbours in the English language are better recalled by children and adults immediately after learning, compared to words without neighbours.
* Novel words that do not have word-form neighbours receive greater benefit from offline consolidation than those with neighbours, and this benefit is larger for children.
* Existing vocabulary ability predicts explicit recall and recognition of new words.
* Adults with better vocabulary are more likely to benefit from a single word neighbour during word learning than those with poorer vocabulary.

**Abstract**

Prior linguistic knowledge is proposed to support the acquisition and consolidation of new words. Adults typically have larger vocabularies to support word learning than children, but the developing brain shows enhanced neural processes that are associated with offline memory consolidation. This study investigated contributions of prior knowledge to initial word acquisition and consolidation at different points in development, by teaching children and adults novel words (e.g., *ballow*) that varied in the number of English word-form “neighbours” (e.g., *wallow, bellow*). Memory for the novel word-forms was tested immediately after training, the next day, and one week later, to assess the time-course of prior knowledge contributions. Children aged 7-9 years (Experiments 1, 3) and adults (Experiment 2) recalled words with neighbours better than words without neighbours when tested immediately after training. However, a period of offline consolidation improved overall recall and reduced the influence of word-form neighbours on longer-term memory. These offline consolidation benefits were larger in children than adults, supporting theories that children have a greater propensity for consolidating phonologically distinctive language information. Local knowledge of just a single word-form neighbour was enough to enhance learning, and this led to individual differences in word recall that were related to adults’ global vocabulary ability. The results support the proposal that the relative contributions of different learning mechanisms change across the lifespan, and highlight the importance of testing theoretical models of word learning in the context of development.

**Keywords:** Vocabulary, learning, consolidation, word neighbour, memory, prior knowledge

1. **Introduction**

Word knowledge is essential for efficient language comprehension and has widespread ramifications for academic achievement (Spencer, Clegg, Stackhouse, & Rush, 2016), particularly literacy (e.g., Braze, Tabor, Shankweiler, & Mencl, 2007; Catts, Adlof, & Weismer, 2006). The ability to learn new words is highly variable across individuals: an 8-year-old child in the highest quartile of vocabulary ability already knows over 3000 more words than a child in the lowest quartile (Biemiller & Slonim, 2001), and this performance gap persists or even broadens over time (Biemiller, 2003; Cain & Oakhill, 2011). Yet, the mechanisms that underlie this broadening variability are poorly understood. Taking a developmental perspective, this study strives to better understand the mechanisms by which prior vocabulary knowledge may impact further word learning in children and adults.

**1.1 Matthew effects in vocabulary acquisition**

The importance of a child’s existing vocabulary ability in contributing to further word learning has long been acknowledged: the well-cited *Matthew effect* (Stanovich, 1986) describes how the “rich” get “richer” in literacy skills. Stanovich proposed that this broadening skill gap is perpetuated by differences in literacy exposure: children with good language skills enjoy reading more, engage in more literacy activities, and encounter more new words in doing so. Indeed, comprehension skill *and* reading experience have been shown to predict vocabulary growth (Cain & Oakhill, 2011), and are argued to be fundamental to literacy development (Nation, 2017). From this perspective, accelerated rates in vocabulary acquisition for children with good vocabulary skills are due to their increasing engagement with texts.

However, Matthew effects in word learning have also been demonstrated in a number of experimental settings where exposure levels are controlled (e.g., Cain, Oakhill, & Lemmon, 2004; Wilkinson & Houston-Price, 2013). For example, Penno, Wilkinson, and Moore (2002) showed that children with better vocabulary ability learned more words from listening to stories than children of lower vocabulary, and these differences were sustained even in conditions that included direct word teaching. That is, even when children with lower vocabulary ability are given the same learning opportunities, they continue to show differences in new word acquisition. These findings implicate learning mechanisms or processes as a source of individual differences in word learning. If so, then what do children with better vocabulary bring differently to the task of word learning?

**1.2 A Complementary Learning Systems approach to understanding Matthew effects**

The present study set out to test one (not mutually exclusive) alternative to the literacy exposure hypothesis as an account of vocabulary Matthew effects. With reference to neurocognitive theories of memory, James, Gaskell, Weighall, and Henderson (2017) proposed that existing vocabulary knowledge might act as a “language schema” that speeds the acquisition and integration of new words. It was predicted that a child with good vocabulary knowledge to support these intrinsic processes would consolidate new words more rapidly than a child with poorer vocabulary, leading to a cumulative benefit in language development.

This account draws upon the Complementary Learning Systems (CLS) model of memory (McClelland, McNaughton, & O'Reilly, 1995) which Davis and Gaskell (2009) proposed as a useful framework for understanding lexical consolidation. In this context, the CLS model posits two interacting systems for learning new words. An encounter with an unfamiliar word forms a new distinct representation in memory that is initially dependent on hippocampal mechanisms (e.g., Warren & Duff, 2014). Over time, reactivation of this representation enables it to become gradually integrated with existing vocabulary knowledge in the neocortex, decreasing hippocampal dependence (Davis, Di Betta, Macdonald, & Gaskell, 2009). This reactivation process can occur “offline”, and a number of studies have demonstrated that sleep (versus wake) can strengthen and integrate a new word with existing knowledge in adults (Dumay & Gaskell, 2007) and children (Henderson, Weighall, Brown, & Gaskell, 2012). In both age groups, memory improvement is associated with slow-wave sleep (SWS) duration (Smith et al., 2017; Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010): the sleep stage characterised by slow neural oscillations which are argued to reflect systems communication in memory replay (Diekelmann & Born, 2010). Thus, different factors may support the initial encoding and longer-term storage of newly learned words, making it important to assess word recall immediately and after opportunities for offline consolidation in studies of vocabulary acquisition.

Recent domain-general CLS accounts have considered that prior knowledge may contribute to initial learning and/or consolidation (Kumaran, Hassabis, & McClelland, 2016; McClelland, 2013). In line with studies showing enhanced acquisition of schema-consistent information (e.g., Tse et al., 2007), it has been argued that new information consistent with existing knowledge can undergo faster consolidation*.* However, the underlying mechanisms are not well understood. One possibility is that schematic knowledge can advance neocortical learning of related information, reducing the need for hippocampal replay to occur offline (Kumaran et al., 2016). By this cortical learning account, individuals with more prior knowledge should benefit immediately when learning information that can capitalise upon it. Alternatively, the neural connections formed between new and existing memory representations during learning may facilitate offline consolidation itself: the information overlap to abstract (iOtA) model proposes that these shared connections cause co-activation of new and existing representations during sleep, enabling integration to happen more efficiently than when prior knowledge connections are more limited (Lewis & Durrant, 2011). By this account, individuals with more prior knowledge should benefit more from their richer connections during offline consolidation.

Therefore both the cortical learning and iOtA interpretations of the CLS account assume that related prior knowledge is helpful, but with one emphasising an advantage in initial encoding and the other proposing that the advantage is strongest during the consolidation process. Returning to questions of whether “language schema” might similarly facilitate word learning, we proceed to discuss two ways to conceptualise the relationship between a new word and prior lexical knowledge: the first emphasising the global properties of an individual (i.e., the size and richness of their vocabulary), and the second emphasising more local properties of the word (i.e., the similarity between a new word and existing word neighbours).

**1.3 Global associations between vocabulary knowledge and word learning**

Evidence for prior knowledge contributions to word learning comes from analyses of individual differences: several developmental studies showed a positive correlation between vocabulary ability and memory for new words measured immediately after learning (e.g., Penno et al., 2002) and over a period of consolidation (e.g., Horváth, Myers, Foster, & Plunkett, 2015). Henderson, Devine, Weighall, and Gaskell (2015) found that children with better expressive vocabulary ability showed greater overnight improvements in word-form recall than those with poorer vocabulary, even when controlling for differences in immediate performance. Consistent with the iOtA model (Lewis & Durrant, 2011), recent studies suggest that this prior vocabulary knowledge might be particularly important for supporting the offline integration of overlapping memory traces: for new words learned across multiple story contexts (Henderson & James, 2018), and for their integration with existing word knowledge (Henderson et al., 2015; James et al., 2017). Together, these studies suggest that prior global vocabulary knowledge offers support in consolidating new words.

**1.4 Local associations between vocabulary knowledge and word learning**

Studies that have examined the global associations between general vocabulary ability and word learning cannot elucidate causal mechanisms. Does the association between new word learning and existing vocabulary ability simply arise because good word learners have the skills that have built them a more extensive vocabulary, or does this existing vocabulary knowledge actively support new word acquisition? We address this question by manipulating the local word-form connections between particular new words and real words that may be present in an individual’s language schema. If existing knowledge *actively* supports acquisition and consolidation then new words that overlap with real words should be better acquired and consolidated than words that do not.

Previous studies have manipulated this local overlap by training participants on pseudowords that varied in the number of existing word-form neighbours: real words that could be created by changing a single letter/phoneme. A number of these studies have shown that pseudowords with more phonological neighbours are recalled better in picture-naming tasks than those with fewer neighbours, for pre-schoolers (Hoover, Storkel, & Hogan, 2010) and adults (Storkel, Armbrüster, & Hogan, 2006). This neighbour benefit also appears to be related to preschoolers’ expressive vocabulary (e.g., Storkel & Hoover, 2011), supporting the utility of this paradigm for addressing individual differences in prior knowledge. In other words, the benefit of local neighbours to the acquisition process will only be obtained if those neighbours are known to the individual, and the likelihood of knowing the neighbours is predicted by global vocabulary measures.

**1.5 Developmental differences in prior knowledge contributions to word learning**

A final, broader approach to assessing prior knowledge contributions to word learning is to compare adults and children: whilst both groups *can* benefit from prior knowledge, adults will typically have a larger body of prior knowledge to support language acquisition. However, children may receive greater benefit from offline consolidation, which could facilitate language acquisition despite often receiving less global support from prior knowledge (Wilhelm, Prehn-Kristensen, & Born, 2012). This proposal stems from evidence of sleep architectural changes across development: children show larger proportions of SWS (Ohayon, Carskadon, Guilleminault, & Vitiello, 2004; Wilhelm et al., 2013) that are tightly linked to ongoing neural reorganisation (Feinberg & Campbell, 2010). In comparing children and adults, two clear predictions can be made to isolate the contribution of prior knowledge: adults will show larger and/or more robust effects of local prior knowledge, given that they should know more local word neighbours; and, children will show larger overnight consolidation effects than adults under conditions of limited local knowledge connections (James et al., 2017; Wilhelm et al., 2012).

**1.6 The current study**

Our study manipulated the availability of local word-form neighbours in explicit word learning, extending existing findings in three important ways. First, we examined the longevity of neighbour effects: we taught children (Experiments 1, 3) and adults (Experiment 2) novel words that systematically varied in the number of word-form neighbours, and tested word recall immediately after training, the next day, and one week later. Very few studies have assessed the longer-term benefit of word-form neighbours (although see Hoover et al., 2010), and none to our knowledge have carried out a comprehensive assessment of *when* during the learning and consolidation process a novel word might place demands on connections to existing vocabulary. Studies by Storkel and colleagues suggest that this benefit might be apparent immediately, but studies relating overnight changes in word learning to global vocabulary suggest there may be a further benefit during consolidation. We continued to track memory performance a week later, given that differences can emerge with more prolonged periods of consolidation than a single night (e.g., Henderson, Weighall, & Gaskell, 2013).

Second, by examining individual differences in the benefit of word-form neighbours for word learning, we aimed to further understand the relationship between individuals’ global vocabulary knowledge and their ability to acquire and consolidate new words. Crucially, if this relationship is due to general differences in word-learning skill (i.e., good word learners *acquire* a better vocabulary), then we would expect to see this association between vocabulary ability and word learning performance regardless of a novel word’s neighbours (note that we use “vocabulary ability” to refer to performance on standardised assessments of vocabulary). However, if existing vocabulary *actively* supports consolidation processes, in accordance with a CLS approach to Matthew effects (James et al., 2017), then we might expect participants with good vocabulary ability to show a stronger benefit for novel words with neighbours compared to novel words that do not have close neighbours, under the assumption that more of the neighbours will exist in their lexicon.

Third, in testing adults and children, we examined how the contributions of prior knowledge and offline consolidation might differ across development. Whilst consolidation effects are anticipated in both age groups, children’s higher proportions of SWS compared to adults might lead us to expect greater improvements in novel word recall at subsequent time points in our experiments with children (Experiments 1, 3) regardless of our word neighbour manipulation. Adults, on the other hand, have superior linguistic knowledge than children and are proposed to more readily access this knowledge during learning. As such, adults may show larger and more persistent benefits of word-form neighbours on learning novel words.

**2. Experiment 1**

**2.1 Experiment 1 Hypotheses**

Three hypotheses were pre-registered at osf.io/fnu6c: 1) There will be a positive correlation between vocabulary ability and the overnight improvement in word memory; 2) Novel words with many word-form neighbours will be recalled more easily than novel words with no/few word-form neighbours, and this benefit could arise immediately and/or after opportunities for consolidation; and 3) Children with better vocabulary ability will experience a greater benefit from word-form neighbours than children with poorer vocabulary.

Experiments were approved by the University of York Psychology Ethics Committee.

**2.2 Experiment 1 Methods**

**Participants**

Ten Year 3 and 4 classes from three North Yorkshire schools participated. Two children were excluded for reported learning disabilities, and three had low levels of English that prevented participation. A further 22 datasets could not be analysed due to the child’s absence during the vocabulary assessment. The resulting sample included 232 children (124 males) aged 7;03-9;03 years old (*M*=8;03). This age group maximised comparability with previous studies showing overnight improvements in word learning and associations with vocabulary ability (Henderson et al., 2015). The large sample size allowed screening for poor comprehenders for a future study and was considered appropriate to compensate for the increased noise in the data while using whole-class testing procedures.

**Design and procedure**

Children participated in three 60-90 minute whole-class sessions, which incorporated word-learning measures and cognitive tests. On Day 1, children learned 16 fictitious words with no or many orthographic neighbours, and completed the memory tests for the new words (T1). Memory for the words was tested again the next day (T2) and one week later (T3). The timing of the sessions was constrained to the school day (9am-3pm), and each of the three sessions were scheduled at a similar time of day for each class.

During these sessions, children also took part in shortened versions of standardised tests adapted for whole-class administration: vocabulary ability, alongside spelling, nonverbal IQ and listening comprehension. The latter (unreported) measures were included for identifying poor comprehenders for a subsequent study.

**Experimental stimuli**

Sixteen pseudowords were selected from the English Lexicon Project (Balota et al., 2007) for having no orthographic neighbours (e.g., *peflin*, for which substituting any individual letter cannot create a known English word) or many orthographic neighbours (e.g., *ballow,* for which letters can be substituted to create multiple known words, including *bellow, wallow, ballot,* etc*.*; Table S1). Pseudowords with no orthographic neighbours also had significantly lower phonological neighbourhood density and phonotactic probability (Marian, Bartolotti, Chabal, & Shook, 2012). All pseudowords were bisyllabic, 5-6 letters, and began with a single consonant and vowel. The two lists were matched for number of phonemes and letters, as well as bigram probability (Table 1). We trained orthographic forms to enable testing for new word memory in a group setting, supported by spoken word presentations to reduce differences attributed to reading ability.

Although our primary research question related to word form learning, the purpose of new vocabulary is to convey meaning. As such, the pseudowords were paired with novel objects to provide a basic semantic component. Two sets of eight novel objects were selected from the NOUN database (Horst & Hout, 2016). The assignment of each set to the word neighbour condition was counterbalanced across classes.

Table 1

*Characteristics of novel words included in each of the experimental neighbour conditions*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Orthographic neighboursa | Phonological neighboursb | Length (letters) | Length (phonemes) | Bigram frequencya | Biphone probabilityb |
| All experiments |  |  |  |  |  |  |
| None | 0 | 0.38 | 5.63 | 5 | 1368.63 | 0.003 |
| Many | 8.38 | 10.13 | 5.63 | 4.63 | 2053.75 | 0.006 |
| Experiments 2&3 |  |  |  |  |  |  |
| One | 1 | 0.88 | 5.63 | 5.25 | 1223.5 | 0.005 |
| *p*-value | <.001 | <.001 | 1 | .130 | .106 | .035 |

*Note.* Mean values were computed from a) English Lexicon Project (Balota et al., 2007), and b) CLEARPOND (Marian et al., 2012). There were 8 items in each condition, although only a subset of 6 were used for Experiment 3. Patterns of significance were identical for the stimuli used in each experiment.

**Novel word training**

The training tasks were set in the context of a discovery adventure of two popular film characters. In a fixed random order, the class was presented with each word-form on screen and a recording of its pronunciation, and repeated the word aloud. After two rounds of form-only repetition, a further two rounds also presented the novel object on screen. As well as repeating the word aloud, children had to find each object in training booklets and write its name, enabling practice with the orthographic form.

The final rounds of training consisted of a multiple-choice quiz. In the first round, children were presented with an object and asked to select which of three words was its name. The second round presented a word with three objects to choose from. Children circled their answers in booklets, with the correct answer presented on screen afterwards.

**Novel word tests**

**Cued form recall.** A stem completion task assessed explicit recall of the new forms. Children were given the first consonant and vowel of each word in written form (e.g., *ba* for *ballow*), and heard the cue recorded by the same speaker as in training. Children were asked to write the rest of the word in their test booklets, and encouraged to attempt answers even if unsure. Test items were presented in a fixed random order, re-randomised for each time point. To minimise confounds of spelling ability, children could ask for help spelling words, and answers were scored correct if they were phonologically accurate (e.g., *balloe, balo*).

**Recognition.** A four-alternative-forced-choice task assessed familiarity with the word-forms and semantic mappings. Children were presented with each object, and asked to choose its name from: the correct answer, a phonological foil for the correct answer (vowel change; e.g., *ballew*), an incorrect learned novel word, plus its matched phonological foil. Children heard recordings of the four options, alongside the written form on screen, and circled answers in test booklets. Test items were re-randomised at each time point, but each item’s answer options remained consistent across sessions.

**Spelling.** To identify children whose performance in cued-recall may reflect spelling difficulty rather than word learning, a spelling test for the novel words was administered at the end of T3. Each item was read aloud for spelling. Items that would have been scored as incorrect according to the cued-recall scoring principles were excluded from the cued-recall analysis on a by-participant basis (e.g., if a child spelled *ballow* as *blowe*, this item was treated as missing data). These items were excluded across all cued-recall test points regardless of performance, given that incorrect answers would have been impossible to interpret in the context of unreliable spelling (i.e., not remembered vs. not spelled correctly).

**Vocabulary ability**

Measures of expressive and receptive vocabulary were administered, but neither provided a stronger correlate of overall task performance (see Supporting Information). Therefore, we used the expressive task as a measure of global vocabulary ability during analysis for consistency with previous studies highlighting relationships between vocabulary and word learning (e.g., Storkel & Hoover, 2011; Henderson et al., 2015).

**Expressive vocabulary.** Children were asked to provide written definitions for a subset of 11 age-appropriate items from the British Ability Scales-II Word Definitions task (Elliot, Smith, & McCulloch, 1997). Children heard each item read aloud, and were asked to write down its meaning. An example was provided at the start. Because this method of administration could not prompt children for further detail (as is standard to oral administration), a bespoke scoring system was developed that enabled item scores of 0 (incorrect), 1 (borderline/vague), or 2 (correct), summed for an overall score.

**Analyses**

Analyses used R (R Core Team, 2015), with graphs using *yarrr* (Phillips, 2017)and *ggplot2* (Wickham, 2009). For each measure of word learning, we used *lme4* (Bates, Maechler, Bolker, & Walker, 2014) to fit a mixed-effects binomial regression model to the data with fixed effects of session, neighbourhood condition, vocabulary ability, and all interactions between them. Two orthogonal contrasts were set for the three-level factor of session: *delay1* contrasted words with or without the opportunity for consolidation (T1 vs. T2&T3), *delay2* contrasted performance at T2 vs. T3. Vocabulary score was scaled and centred before entering into the model.

For all experiments, we had pre-registered an initial attempt at maximal random effects structures, but these frequently suffered convergence issues and required model simplification. We therefore pruned higher-order interactions from fixed-effects where not contributing to the model to allow better-specified random-effects structures, using pairwise likelihood ratio tests to confirm that simplified models were not significantly poorer in their fit to the data. We then used a forward-best-path approach (Barr, Levy, Scheepers, & Tily, 2013) to test between simple and progressively complex random-effects structures, retaining only random-slopes that improved model fit according to a liberal criterion, *p*<.2 (Barr et al., 2013; Bates, Kliegl, Vasishth, & Baayen, 2015).

**2.3 Experiment 1 Results[[1]](#footnote-1)**

**Cued form recall**

Five participants were excluded on the basis of unintelligible handwriting on the novel spellings test. A further 5.92% of the remaining data was excluded on a by-item basis for individual participants, where poor spelling during the novel spelling test rendered the data uninterpretable.

There was no evidence for a three-way interaction between session, neighbour condition, and vocabulary ability, and this was pruned from the final model (Table 2) with no reduction in model fit (χ2=0.198, *p*=.91). Recall was significantly better at later sessions than T1 (*delay1* contrast), and also improved between T2 and T3 (*delay2*). The presence of word neighbours did not affect cued-recall performance overall (*neighb*), but did in interaction with test session (*delay1:neighb*): the negative coefficients show that the benefit of word neighbours was larger at T1 compared to subsequent tests (Figure 1). There was no further reduction in neighbour benefit between T2 and T3 (*delay2:neighb*) which, in the context of no overall neighbour effect, indicates that the neighbour benefit was only present at T1.

Vocabulary positively predicted cued-recall performance (*vocab*; Figure 2), but contrary to hypotheses did not interact with improvements over time or word-neighbours.

**Recognition**

Performance was good across all conditions (*M*=.80, *SD=*.18), with a slight decline between T2 and T3 that was not significant (*b*=-0.08, *Z*=-1.73, *p*=.08). Only vocabulary emerged as a significant predictor (*b*=0.79, *Z*=8.54, *p*<.001). Of limited theoretical interest, the full model is presented in Table S2 (Figure S1).

**2.4 Experiment 1 Discussion**

Children aged 7-9 years became familiar with the new words very quickly (with recognition at ~80%), but word neighbours and a period of consolidation facilitated the acquisition of higher quality lexical representations as reflected by superior production in the recall task. Children benefited from existing neighbours during novel word retrieval immediately after initial learning, consistent with our hypotheses and previous findings (Hoover, Storkel & Hogan, 2010; Storkel,

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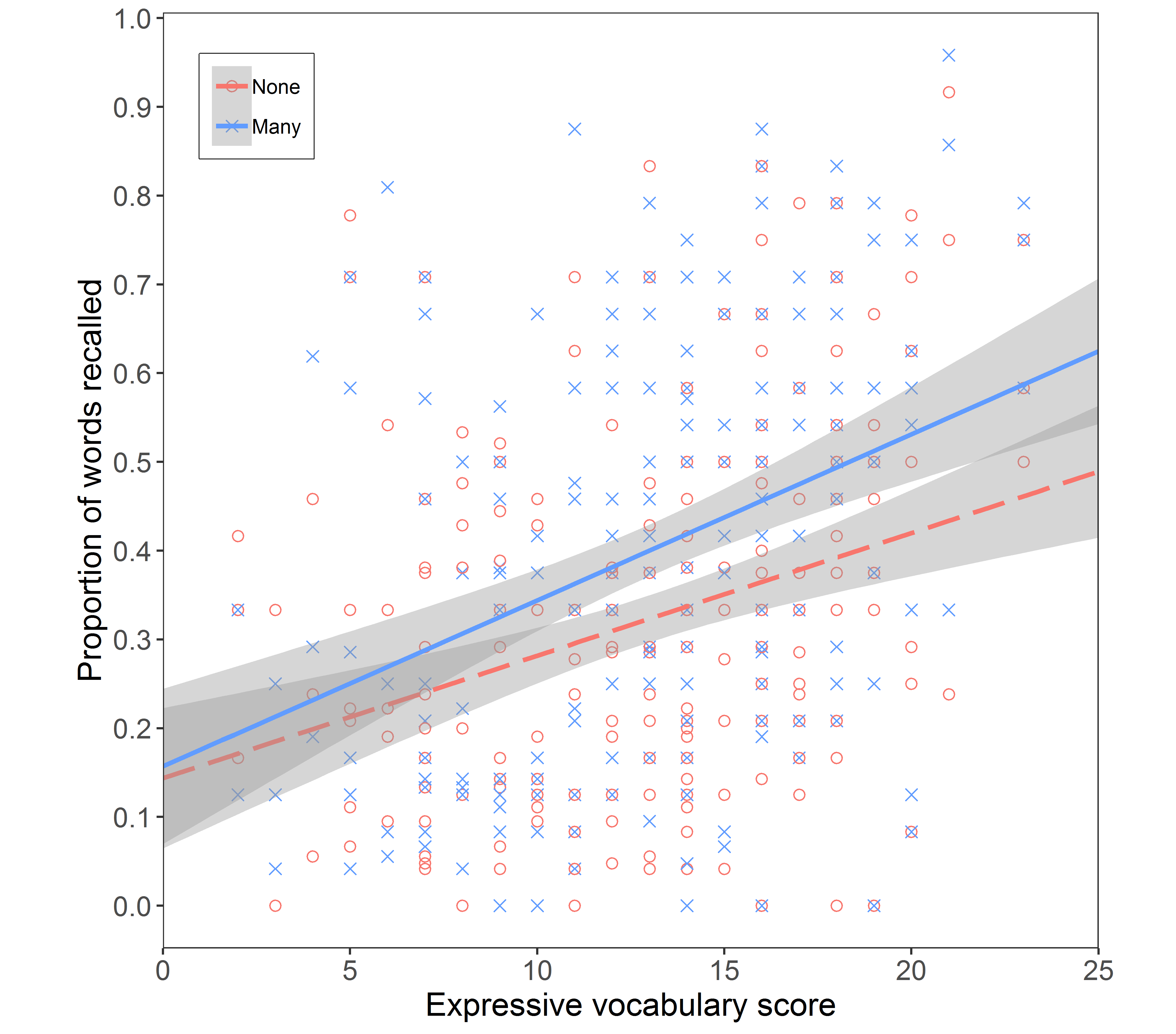


Figure 2. Scatterplot of mean number of words recalled for each word neighbour condition in Experiment 1 (collapsed across test sessions), plotted against children’s expressive vocabulary score. Grey shaded areas represent 95% confidence intervals.

Figure 1. RDI plot of children’s cued form recall performance in Experiment 1, plotted by neighbour condition and test session. The dark coloured bars can be interpreted as traditional bar charts, with the outlined areas representing smoothed distribution curves. Thick black horizontal bars represent the mean for each condition, and surrounding boxes mark +/-1 standard error of the mean. Black dots indicate by-participant means for each condition.

Table 2

*Predictors of cued recall performance in Experiment 1*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Fixed effects |  | *SE* |  |  |  |
| (Intercept) | -0.87 | 0.27 | -3.20 | .001 |  |
| **delay1** | **0.27** | **0.04** | **6.63** | **<.001** |  |
| **delay2** | **0.42** | **0.04** | **11.13** | **<.001** |  |
| neighb | 0.25 | 0.26 | 0.96 | .337 |  |
| **vocab** | **0.50** | **0.09** | **5.75** | **<.001** |  |
| **delay1:neighb** | **-0.11** | **0.04** | **-2.82** | **.005** |  |
| delay2:neighb | -0.03 | 0.04 | -0.71 | .480 |  |
| delay1:vocab | 0.02 | 0.02 | 1.07 | .283 |  |
| delay2:vocab | -0.04 | 0.03 | -1.24 | .215 |  |
| neighb:vocab | 0.05 | 0.04 | 1.25 | .211 |  |
| Random effects | Variance | *SD* | Correlations | | |
| participant: (intercept) | 1.47 | 1.21 |  |  |  |
| participant: (slope) neighb | 0.11 | 0.33 | 0.23 |  |  |
| item: (intercept) | 1.06 | 1.03 |  |  |  |
| item: (slope) delay1 | 0.02 | 0.14 | 0.36 |  |  |
| item: (slope) delay2 | 0.01 | 0.08 | -0.28 | 0.31 |  |
| item: (slope) vocab | 0.01 | 0.10 | 0.28 | 0.61 | 0.83 |

*Note.* Model formed from 10,135 observations, collected from 227 participants across 16 items. Orthogonal contrasts were used for the three-level factor of session: delay1 (Session 1 vs. Sessions 2&3), delay2 (Session 2 vs. Session 3).

Armbruster, & Hogan, 2006). However, this neighbour benefit diminished at the 24-hour test, leaving no overall benefit of word neighbours. We therefore propose that it is the new words without local connections to prior knowledge that subsequently show greater strengthening from offline consolidation processes (see van Kesteren, Rijpkema, Ruiter, & Fernández, 2013, for a similar interpretation). As such, learning in the context of this paradigm is more in line with a cortical learning approach to prior knowledge, and does not support the iOtA model.

As with previous studies (e.g., Penno et al., 2002), global vocabulary ability predicted word learning across both tasks. However, the results did not support our predicted relationship between vocabulary ability and overnight improvements in performance, as has been found in numerous previous studies (e.g., Henderson et al., 2015). In many respects this finding is consistent with our theoretical approach: if prior knowledge benefits are apparent immediately and *weaken* during consolidation, then we would no longer predict existing vocabulary knowledge to support the overnight improvements. However, it still limits our ability to draw conclusions regarding the ways in which global vocabulary knowledge might support *consolidation* of new words in relation to earlier studies.

The results also failed to support the hypothesis that those with good vocabulary ability would show bigger benefits of word neighbours, which is somewhat puzzling considering the clear benefit for local neighbour connections themselves. One could interpret this lack of interaction as evidence in support of the general skill account: better word learners simply learn more words to acquire a better vocabulary. However, given the clear benefit for knowing some word neighbours, we consider a number of explanations for the lack of individual differences in this benefit. First, the group training and testing nature of Experiment 1 introduces a significant amount of noise into the data compared to previous studies. Second, whilst we took care to minimise the impact of spelling on recall performance (i.e., providing spelling help, removing problematic items during analysis), children’s ability to produce the written words may have been constrained by their writing and spelling ability. These individual differences in orthographic knowledge may have made it more challenging to identify individual differences related specifically to vocabulary ability.

We also consider a third—more theoretically interesting—account of our lack of neighbourhood interaction with vocabulary ability: that the number of neighbours is crucial. Computational models of visual word recognition have suggested that one neighbour influences word processing, but that there is little impact of additional neighbours (Davis & Andrews, 1996, as cited in Bowers, Davis & Hanley, 2005). If this primary benefit for one neighbour is also true during learning, we may have maximised the potential for *all* children to have known and activated *at least one* neighbour during training by using stimuli that had many possible neighbours to benefit from. For example, one child might access *ballow*’s neighbour *bellow* whilst another might access *wallow*, but with nothing further to be gained from accessing both. Indeed, previous studies demonstrating a relationship between global vocabulary ability and overnight consolidation have trained novel words related to a single existing word in order to study lexical integration (e.g., *dolpheg* derived from *dolphin*, James et al., 2017). We therefore added a ‘one-neighbour’ condition to subsequent experiments to explore whether this condition is as beneficial as having many neighbours, first in adults (Experiment 2) and then children (Experiment 3). Importantly, we asked whether the one-neighbour condition would be more sensitive to individual differences in learning and consolidation.

**3. Experiment 2**

**3.1 Experiment 2 Hypotheses**

The pre-registered hypotheses (osf.io/tm538) were: 1) Vocabulary ability will be an overall predictor of word-learning ability in adults (as for children in Experiment 1); 2) Memory for new words will improve with opportunities for consolidation, and—consistent with children in Experiment 1—initial overnight improvement will be larger for words without neighbours; 3) Novel words with only one neighbour will benefit from this prior knowledge compared to words without neighbours; and 4) Existing vocabulary ability will most strongly predict performance in the one-neighbour condition, under the assumption that the most critical benefits arise from activating *at least one* neighbour and that this lower end of the scale will be more sensitive to individual differences in existing vocabulary. Importantly, Experiment 2 also provides the opportunity to draw developmental comparisons with Experiment 1, under the assumptions that adults have greater prior knowledge that might be more readily activated during learning, but that children benefit more from offline consolidation.

**3.2 Experiment 2 Methods**

**Participants**

Seventy-nine adults participated (15 male), aged 18–35 years (*M*=20;02). This smaller sample size was appropriate given the reduced noise in this dataset: adults show better compliance during group training, have tighter phonological-orthographic mappings, and were tested individually. Participants were recruited via lecture advertisements or participant database, and were native monolingual English speakers, with normal/corrected-to-normal vision and hearing. Note that although the gender balance did not match Experiments 1 and 3, gender did not predict recall performance alone (*p* = .22), nor in interaction with time or neighbour (all *p*s > .1)

**Design and procedure**

Participants learned novel words in a 30-minute group training session in an IT suite (scheduled between 10am and 4pm). They then completed three test sessions independently via an online web link, scheduled as before. Participants were asked to complete the tests at a similar time each day, but we retained data from all sessions completed on the correct day. Mean hour of test remained highly similar across all three sessions (T1: *M*=2.12pm, *SD* = 3.42 hours; T2: *M*=2.41pm, *SD*=3.31 hours; T3: *M*=1.53pm, *SD*=4.39 hours). An additional online session (completed at any time over the week) collected background and vocabulary information.

**Experimental stimuli**

Twenty-four novel words were trained from three conditions. The no- and many-neighbour conditions were identical to Experiment 1, but a third set of eight words with only one orthographic/phonological neighbour was created, and matched to the other conditions on length and bigram frequency (Table 1).

A third set of novel objects was selected from the NOUN database (Horst & Hout, 2016). The assignment of each set to each word-neighbour condition was altered across two counterbalancing conditions, such that each set of objects appeared in two of the three conditions across participants.

**Novel word training**

As Experiment 1, with the exception that participants labelled items and submitted their multiple-choice answers via a web browser, consistent with the testing format.

**Novel word tests**

All three test sessions exploited an online survey platform (Qualtrics, Provo, UT). We retained the written test format, given that adults have much tighter spoken-written language mappings (Samuels & Flor, 1997), reducing variability in orthographic support.

**Cued form recall.** As Experiment 1, except participants were instructed to click a speaker to hear the cue presented through speakers/headphones (unrestricted), and provided typed responses. Item order was fully randomised.

**Recognition.** As Experiment 1. Item order was randomised, and participants clicked an icon to hear each item spoken aloud.

**Vocabulary ability**

Participants provided typed definitions for 13 age-appropriate written items selected from WASI-II Vocabulary (Wechsler, 2011), adapted for online administration (for the receptive vocabulary measure see Supporting Information). An example was provided. Answers were scored as 0, 1, or 2, according to manual guidelines.

**Analyses**

As Experiment 1. The additional neighbour condition enabled us to test the following orthogonal contrasts: *neighb1* was set to compare the presence versus absence of neighbours (no vs. one+many), and *neighb2* contrasted one versus many neighbours[[2]](#footnote-2).

**3.3 Experiment 2 Results**

**Cued form recall**

All fixed-effects were retained in the final model (Table 3). As in Experiment 1, individuals with better vocabulary ability performed better on the cued recall task (*vocab*), and overall levels of performance improved after a period of consolidation (*delay1*). However, for adults there was no further improvement between T2 and T3 (*delay2*). The presence of one/more word neighbours did not significantly affect recall across the week (*neighb1*: *p*=.053), and nor did its influence change with test session (*delay1:neighb1*: *p*=.06; all other *p*s>.75). That is, there was weak statistical evidence for a benefit of word-neighbour connections, and for the prioritisation of no-neighbour items in consolidation (Figure 3).

Consistent with our prediction that only one neighbour is needed to support learning, there was no overall difference between recall performance in the one- and many-neighbour conditions (*neighb2*: *p*=.52). However, the inclusion of this manipulation enabled us to identify individual differences in neighbour benefit related to vocabulary ability (in support of an active role for prior knowledge in word learning): there was a significant interaction between neighbour condition and vocabulary ability (*neighb2:vocab*). As depicted by Figure 4, there was a stronger association between vocabulary ability and performance in the one-neighbour condition compared to the many-neighbour condition, with only participants with poorer vocabulary showing a difference between these conditions. However, as in Experiment 1, vocabulary ability did not predict differences in recall performance for words with/without neighbours overall (*neighb1:vocab*). Thus, the weaker association between vocabulary ability and performance in the many-neighbour than one-neighbour condition may result from the increased chance that all participants know at least one neighbour.

Vocabulary ability was related to the change in adults’ recall performance between T2 and T3 (*delay2:vocab*: *p*=.038). Adults with good vocabulary ability showed a slight benefit in retention of their new word knowledge across the week compared to adults with poorer vocabulary. However, vocabulary ability did not interact with any neighbourhood effects on retention.

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Figure 4. Scatterplot of mean number of words recalled for each word neighbour condition in Experiment 2 (collapsed across test sessions), plotted against adults’ expressive vocabulary score. Grey shaded areas represent 95% confidence intervals.

Figure 3. RDI plot of adults’ cued form recall performance in Experiment 2, plotted by neighbour condition and test session. Thick black horizontal bars represent the mean for each condition, and surrounding boxes mark +/-1 standard error of the mean.

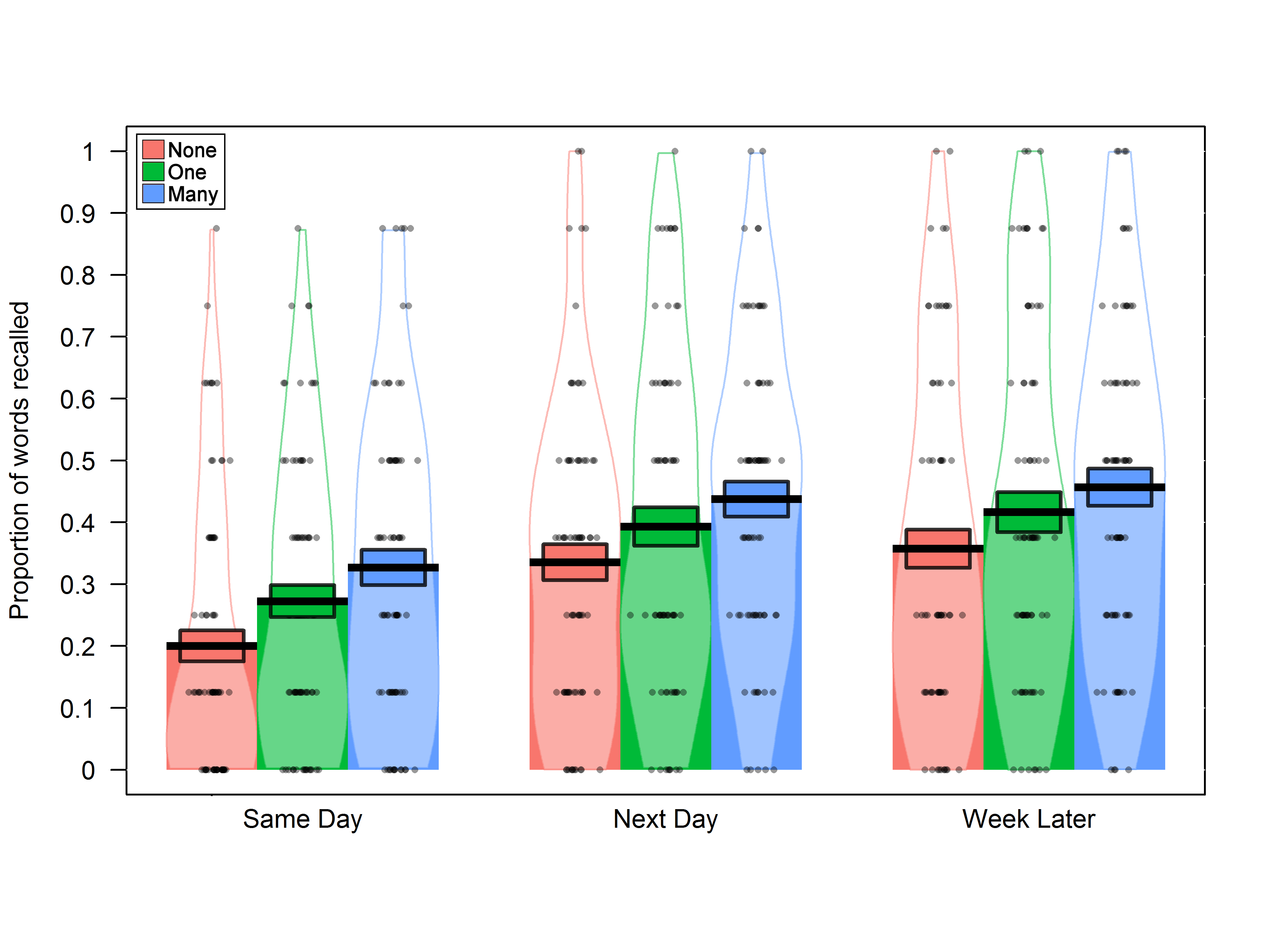


Table 3

*Predictors of cued recall performance in Experiment 2*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fixed effects | |  | | | *SE* | | |  | | |  | | | |
| (Intercept) | -0.89 | | | 0.20 | | | -4.36 | | | <.001 | | |
| **delay1** | **0.29** | | | **0.04** | | | **7.22** | | | **<.001** | | |
| delay2 | 0.08 | | | 0.04 | | | 1.77 | | | .077 | | |
| neighb1 | 0.22 | | | 0.11 | | | 1.93 | | | .053 | | |
| neighb2 | 0.12 | | | 0.19 | | | 0.64 | | | .522 | | |
| **vocab** | **0.40** | | | **0.14** | | | **2.80** | | | **.005** | | |
| delay1:neighb1 | -0.04 | | | 0.02 | | | -1.88 | | | .060 | | |
| delay2:neighb1 | 0.00 | | | 0.03 | | | -0.07 | | | .947 | | |
| delay1:neighb2 | -0.01 | | | 0.03 | | | -0.31 | | | .759 | | |
| delay2:neighb2 | -0.01 | | | 0.05 | | | -0.17 | | | .866 | | |
| delay1:vocab | 0.01 | | | 0.04 | | | 0.31 | | | .760 | | |
| **delay2:vocab** | **0.09** | | | **0.04** | | | **2.07** | | | **.038** | | |
| neighb1:vocab | -0.02 | | | 0.04 | | | -0.42 | | | .677 | | |
| **neighb2:vocab** | **-0.12** | | | **0.06** | | | **-2.16** | | | **.031** | | |
| delay1:neighb1:vocab | 0.01 | | | 0.02 | | | 0.77 | | | .444 | | |
| delay2:neighb1:vocab | 0.02 | | | 0.03 | | | 0.52 | | | .605 | | |
| delay1:neighb2:vocab | -0.02 | | | 0.03 | | | -0.72 | | | .474 | | |
| delay2:neighb2:vocab | 0.07 | | | 0.05 | | | 1.42 | | | .157 | | |
| Random effects | Variance | | *SD* | | | Correlations | | | | | | | | |
| participant: (intercept) | 1.41 | | 1.19 | | |  | | |  | | |  | |  |
| participant: (slope) delay1 | 0.07 | | 0.26 | | | 0.09 | | |  | | |  | |  |
| participant: (slope) delay2 | 0.02 | | 0.14 | | | 0.02 | | | 0.98 | | |  | |  |
| participant: (slope) neighb1 | 0.06 | | 0.24 | | | -0.29 | | | 0.16 | | | 0.02 | |  |
| participant: (slope) neighb2 | 0.07 | | 0.26 | | | 0.25 | | | -0.13 | | | -0.11 | | -0.04 |
| item: (intercept) | 0.54 | | 0.73 | | |  | | |  | | |  | |  |
| item: (slope) vocab | 0.01 | | 0.09 | | | 0.83 | | |  | | |  | |  |

*Note.* Model formed from 5,640 observations, collected from 79 participants across 24 items. Orthogonal contrasts were used for three-level factors: delay1 (Session 1 vs. Sessions 2&3), delay2 (Session 2 vs. Session 3), neighb1 (no vs. one&many), neighb2 (one vs. many).

**Recognition**

Recognition performance was very high (M=.90, SD=.1) and, as with Experiment 1, only vocabulary ability significantly predicted performance (*b*=0.37, *Z*=2.52, *p*=.012) (Table S3; Figure S2).

**3.4 Experiment 2 Discussion**

Adults, like children, improved in their explicit recall of new words after opportunities for consolidation, and global vocabulary ability was a strong predictor of word learning overall. Crucially, by including stimuli with only one neighbour, we demonstrated that global vocabulary can *actively* support new word acquisition: adults with good vocabulary showed a comparable benefit for words with one and many neighbours, whereas adults with poorer vocabulary showed poorer performance for the words with more limited local overlap compared to many-neighbour words. As before, support from word neighbours, although statistically weak, was apparent immediately.

Unlike Experiment 1, the interaction between word neighbour condition and time did not reach significance. This weaker consolidation of no-neighbour novel items relative to the findings from children in Experiment 1 may result from introducing a third condition (with an increase of items from 16 to 24). However, this finding might reflect genuine developmental differences in the mechanisms supporting consolidation: whilst children have superior sleep-associated mechanisms to support the consolidation of novel information, adults are argued to retain greater dependence on prior knowledge across the course of consolidation (James et al., 2017; Wilhelm et al., 2012).

Experiment 3 sought to replicate the superior consolidation for no-neighbour items in children found in Experiment 1, alongside the introduction of the one-neighbour condition. We taught only spoken word-forms to remove the possibility that orthographic knowledge was constraining the identification of a relationship between vocabulary ability and overnight change in performance in Experiment 1.

**4. Experiment 3**

**4.1 Experiment 3 Hypotheses**

The hypotheses were pre-registered at osf.io/4abw3 as follows: 1) Again, vocabulary ability will be an overall predictor of word learning performance; 2) Memory for the new words will improve after opportunities for consolidation, and the improvement for no-neighbour words will be larger than for words with many neighbours; 3) Novel words with only one neighbour would benefit from this local prior knowledge in word learning compared to words with no neighbours, but this could either be apparent immediately or require consolidation to emerge; and 4) Vocabulary ability will show the strongest relationship with learning in the one-neighbour condition, emerging either immediately (as Experiment 2) or after opportunities for consolidation (as with previous developmental studies, e.g., Henderson et al., 2015).

**4.2 Experiment 3 Methods**

**Participants**

Four classes of Year 3/4 children from one school took part (adopting eligibility criteria from Experiment 2). 78 participants met these criteria, but a further six were excluded due to self-withdrawal (*n*=1), inattention (*n*=2), technical errors (*n*=2) and teacher-reported speech and language difficulties that made testing unfeasible (*n*=1). The final sample comprised 72 children (38 male) aged 7;06–10;05 (*M*=8;08).

**Design and procedure**

Children participated in whole-class training in the morning, but completed the memory tests individually. All sessions took place within the school day (9am-3pm). After the memory tests or in a separate session, children completed a standardised assessment of expressive vocabulary. Assessments of nonverbal IQ, reading efficiency and reading comprehension were also administered for another study.

**Experimental stimuli**

A subset of 18/24 items were selected from Experiment 2, allowing six words in each neighbour condition. Given that only spoken word-forms were trained, these words were selected to ensure that the strict neighbour criteria withheld across phonological as well as orthographic neighbours. The assignment of each set of novel objects to each word-neighbour condition was altered across two counterbalancing conditions.

**Novel word training**

As Experiment 1, except that there was no written presentation or writing practice at any point. For multiple-choice tasks, children circled numbers corresponding to spoken answer options.

**Novel word tests**

**Cued form recall.** Children heard the cue through headphones, and spoke the remainder of the pseudoword. Item presentation was randomised, and the experimenter recorded responses on an answer sheet.

**Recognition.** The previous recognition tasks had four response options per trial, testing form and semantic specificity together. However, with the removal of orthographic support, this was deemed to be too demanding on working memory, and thus response options were reduced to two per trial. Because it was important to maintain the level of between-test exposure across experiments, two tests were created to test form and semantic recognition separately. Two practice trials with real words and pseudowords were administered, and trials timed out after 7 seconds.

*Form-recognition.*Children heard each item and its phonological foil through the headphones, and used a key press to respond whether they had learned the first or second item presented.

*Form-picture recognition.*Children heard two learned pseudowords through headphones, and used a key press to indicate which word was the name of the presented object.

**Vocabulary ability**

Only expressive vocabulary ability (Vocabulary subtest from the WASI-II; Wechsler, 2011) was measured, given well-established relationships with cued-recall in Experiments 1 and 2.

**Analyses**

As Experiment 2.

**4.3 Experiment 3 Results**

**Cued form recall**

The initial model provided no evidence of a three-way interaction between delay, neighbour condition, and vocabulary ability, which was therefore pruned with no reduction in model fit (χ2=1.70, *p*=.79). The final model is presented in Table 4.), There was a clear improvement in recall performance across all three test sessions (*delay1*; *delay2*). There was no overall benefit of word neighbours on recall performance across the week (*neighb1*), but there was an initial benefit that changed with consolidation (*delay2:neighb1*). This interaction was consistent with—although later to emerge than in—Experiment 1: there was a larger benefit of having at least one word neighbour (vs. no neighbours) at earlier test points (T2 benefit =.09), which diminished by T3 (benefit =.01, Figure 5).

Figure_6Figure_5

Figure 6. Scatterplot of mean number of words recalled for each word neighbour condition in Experiment 3 (collapsed across test session), plotted against children’s expressive vocabulary score. Grey shaded areas represent 95% confidence intervals.

Figure 5. RDI plot of children’s cued form recall performance in Experiment 3, plotted by neighbour condition and test session. Thick black horizontal bars represent the mean for each condition, and surrounding boxes mark +/-1 standard error of the mean.

Table 4

*Predictors of cued recall performance in Experiment 3*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Fixed effects |  | *SE* |  |  | | | |
| (Intercept) | -2.36 | 0.29 | -8.17 | <.001 | | | |
| **delay1** | **0.55** | **0.07** | **8.00** | **<.001** | | | |
| **delay2** | **0.60** | **0.08** | **7.61** | **<.001** | | | |
| neighb1 | 0.32 | 0.19 | 1.71 | .087 | | | |
| neighb2 | 0.07 | 0.32 | 0.22 | .822 | | | |
| **vocab** | **0.36** | **0.13** | **2.69** | **.007** | | | |
| delay1:neighb1 | -0.08 | 0.05 | -1.71 | .087 | | | |
| **delay2:neighb1** | **-0.16** | **0.05** | **-3.00** | **.003** | | | |
| delay1:neighb2 | -0.08 | 0.07 | -1.10 | .271 | | | |
| delay2:neighb2 | 0.04 | 0.08 | 0.45 | .653 | | | |
| delay1:vocab | 0.05 | 0.04 | 1.18 | .237 | | | |
| delay2:vocab | -0.07 | 0.06 | -1.28 | .202 | | | |
| neighb1:vocab | -0.04 | 0.05 | -0.89 | .372 | | | |
| neighb2:vocab | -0.05 | 0.08 | -0.72 | .473 | | | |
| Random effects | Variance | *SD* | Correlations | | | | | |
| participant: (intercept) | 0.99 | 0.99 |  |  |  | |
| participant: (slope) neighb1 | 0.03 | 0.17 | -0.61 |  | |  |
| participant: (slope) neighb2 | 0.13 | 0.37 | -0.19 |  | | 0.42 |  | | |
| item: (intercept) | 1.13 | 1.06 |  |  | |  |  | | |
| item: (slope) delay1 | 0.03 | 0.16 | -0.34 |  | |  |  | | |
| item: (slope) delay2 | 0.03 | 0.18 | -0.01 |  | | 0.94 |  | | |

*Note.* Model formed from 3852 observations, collected from 72 participants across 18 items. Orthogonal contrasts were used for three-level factors: delay1 (Session 1 vs. Sessions 2&3), delay2 (Session 2 vs. Session 3), neighb1 (no vs. one&many), neighb2 (one vs. many).

Consistent with Experiment 2, only one neighbour mattered in influencing performance: there were no significant differences in recall between the one- and many-neighbour conditions overall (*neighb2*) or in interaction with the test session (*delay1:neighb2; delay2:neighb2*). However, in contrast to the adult study, this one-neighbour condition was not more sensitive to individual differences relating to children’s vocabulary ability (*neighb2:vocab*). Vocabulary ability was a significant predictor of cued-recall performance overall (*vocab*), but did not interact with neighbour benefit or changes across the week (Figure 6).

**Recognition**

**Form-recognition.** Recognition performance was very high (*M*=.88, *SD*=.32) and showed significant improvements across the week: performance was lower at T1 than subsequent tests (*b*=0.28, *Z*=4.94, *p*<.001), and continued to improve between T2 and T3 (*b*=0.39, *Z*=3.48, *p*<.001). The improvement after T1 was also related to changes in neighbour benefit, consistent with the cued-recall data: there was a larger difference between no and one/many neighbours (*b*=-0.06, *Z*=-2.18, *p*=.029) and between one and many neighbours (*b*=-0.11, *Z*=-2.13, *p*=.034) at T1 compared to the subsequent sessions (Figure 7). As with previous experiments, vocabulary ability was a significant predictor of performance (*b*=0.53, *Z*=3.89, *p*<.001), but not in interaction with any other variable. No other factors/interactions predicted performance (Table S4).

**Form-picture recognition.** Performance was slightly worse in picture-recognition than form-recognition (*M*=.77, *SD*=0.42), but remained stable over time. As with recognition tasks in previous experiments, only vocabulary ability was a significant predictor of performance (*b*=0.34, *Z*=3.05, *p*=.002; Table S5; Figure S3).

**4.4 Experiment 3 Discussion**

Experiment 3 provided further evidence that children benefit from word neighbours in initial word acquisition, but that this benefit is short-lived: consolidation processes can facilitate memory for highly distinctive information in this age group (note we use the term “distinctive” to refer to pseudowords that are phonologically dissimilar to real English words). These no-neighbour words were slower to “catch up” with many-neighbour words in Experiment 3 than in Experiment 1: this may have resulted from the additional condition competing for consolidation processes, and/or overall weaker lexical representations that might be more demanding on consolidation processes to strengthen (Drosopoulos, Schulze, Fischer, & Born, 2007). Importantly though, the presence of this neighbour-by-delay interaction remained even using a different testing format (spoken versus

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Figure 7. RDI plot of children’s form recognition performance in Experiment 3, plotted by neighbour condition and test session. Thick black horizontal bars represent the mean for each condition, and surrounding boxes mark +/-1 standard error of the mean. The dashed line indicates chance level performance.

written) and at a lower level of average recall performance than in Experiment 1, and was apparent even in recognition data.

Vocabulary ability remained a clear predictor of overall performance in both the recall and recognition tasks, lending support to global prior knowledge contributions to word learning. Contrary to our hypotheses, this global vocabulary ability again did not interact with neighbour benefit and/or test session in predicting performance. This is somewhat surprising considering the interactions seen in Experiment 2 with the single neighbour condition, and alongside previous studies showing associations between standardised measures of vocabulary and overnight consolidation of novel words that overlap with one real word (e.g., Henderson et al., 2015). However, as noted above, recall performance was substantially lower in this experiment (*M*=3.20/18 words, *SD*=6.88), leaving less variability in performance to distinguish individual differences in experimental manipulations than in Experiment 2 (*M*=8.4/24 words, *SD*=11.46).

**5. Comparison between children and adults**

Experiments 1 and 3 showed a clear pattern with children: an initial benefit of word neighbours that declined after opportunities for consolidation, leaving no overall benefit for local knowledge connections on memory. For adults however (Experiment 2), this pattern was less clear, featuring weaker evidence of a decline in neighbour benefit. This developmental difference is consistent with the hypothesis that children have a greater propensity for offline consolidation of distinctive information (James et al., 2017; Wilhelm et al., 2012). To further explore this possibility, we carried out an additional unregistered cross-experiment analysis on cued recall data. We analysed just the no- and many-neighbour conditions (as the one-neighbour manipulation was absent in Experiment 1). Two orthogonal contrasts compared performance across experiments: the group contrast compared adults (Experiment 2) versus children (Experiments 1 & 3), whereas the modality contrast compared the two child experiments that differed in the inclusion of orthography (Experiment 1) versus spoken language only (Experiment 3). Contrasts were set for test session as in previous analyses.

**Cross-experiment results**

The full model is presented in Table 5. We were predominantly interested in differences in consolidation between children and adults. Children continued to improve to a greater extent than adults later in the week (T2 to T3; *group:delay2*). Most importantly, there was a significant three-way interaction between participant group, test time (T1 vs. T2&T3), and the neighbour effect (*group:delay1:neighb*). The negative coefficient shows that children experienced a larger reduction in neighbour effect at later time points than adults (Figure 8).

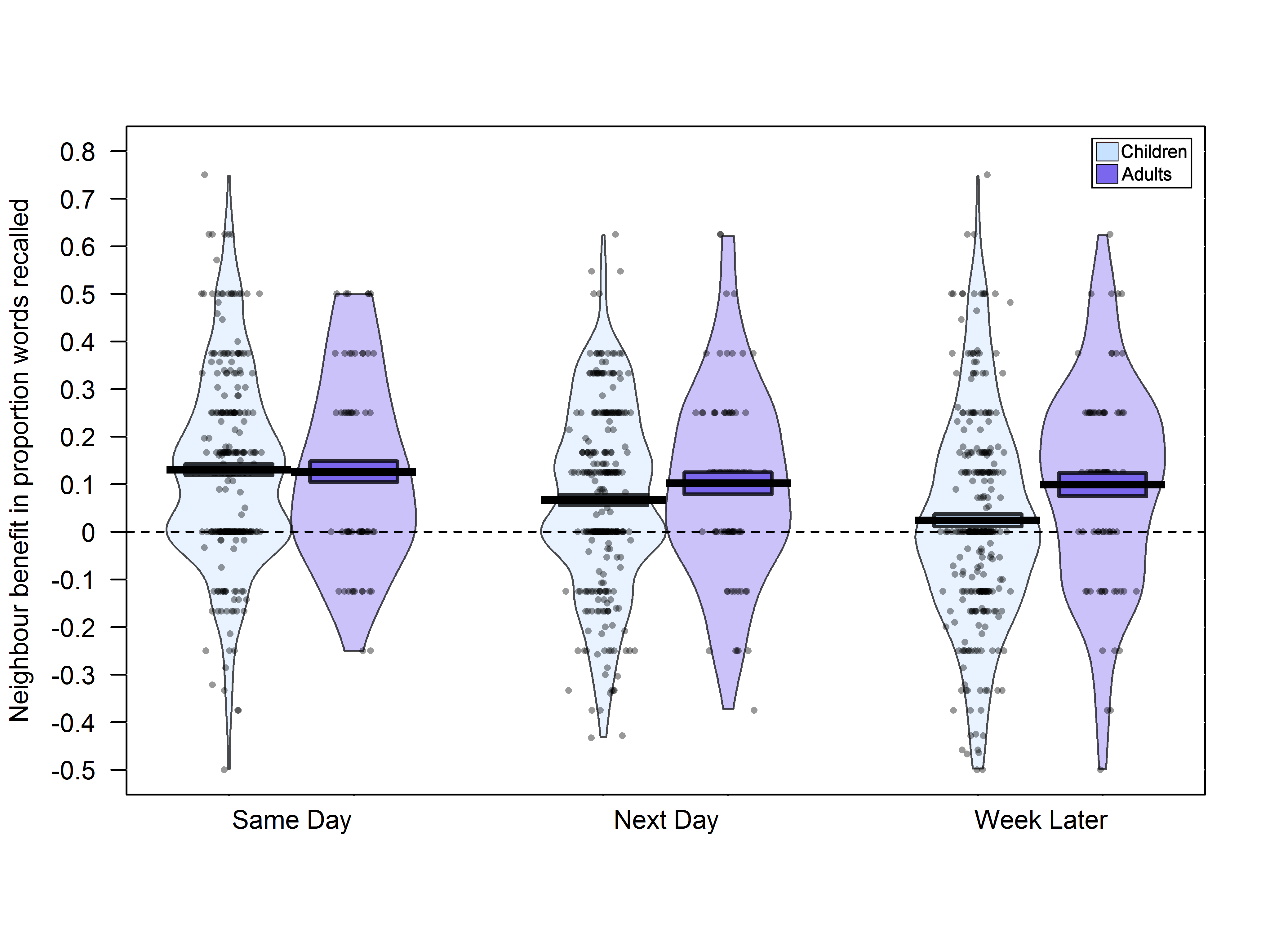


Figure 8. RDI plot of the neighbour benefit at each time point for child and adult participants across experiments. Thick black horizontal bars represent the mean difference in performance for many and no neighbour words, and surrounding boxes mark +/-1 standard error of the mean. The dashed line indicates no difference in performance across neighbour conditions, such that positive values mean better performance in the many-neighbour condition.

Table 5

*Comparing cued recall performance across all three experiments (no vs. many neighbours)*

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fixed effects |  | *SE* | |  | | |  | | | |
| (Intercept) | -1.44 | 0.25 | | -5.77 | | | <.001 | | | |
| **group** | **-0.27** | **0.09** | | **-3.11** | | | **.002** | | | |
| **modality** | **-0.80** | **0.13** | | **-6.39** | | | **<.001** | | | |
| **delay1** | **0.35** | **0.04** | | **9.72** | | | **<.001** | | | |
| **delay2** | **0.40** | **0.04** | | **11.09** | | | **<.001** | | | |
| neighb | 0.26 | 0.24 | | 1.07 | | | .283 | | | |
| group:delay1 | 0.03 | 0.02 | | 1.91 | | | .057 | | | |
| **modality:delay1** | **0.11** | **0.03** | | **3.45** | | | **.001** | | | |
| **group:delay2** | **0.17** | **0.02** | | **7.45** | | | **<.001** | | | |
| **modality:delay2** | **0.15** | **0.04** | | **3.53** | | | **<.001** | | | |
| group:neighb | -0.05 | 0.07 | | -0.71 | | | .477 | | | |
| modality:neighb | -0.05 | 0.10 | | -0.49 | | | .627 | | | |
| **delay1:neighb** | **-0.11** | **0.03** | | **-3.33** | | | **.001** | | | |
| **delay2:neighb** | **-0.08** | **0.03** | | **-2.47** | | | **.013** | | | |
| **group:delay1:neighb** | **-0.03** | **0.01** | | **-2.14** | | | **.033** | | | |
| modality:delay1:neighb | -0.03 | 0.03 | | -0.89 | | | .374 | | | |
| group:delay2:neighb | -0.04 | 0.02 | | -1.77 | | | .077 | | | |
| **modality:delay2:neighb** | **-0.09** | **0.04** | | **-2.16** | | | **.031** | | | |
| Random effects | Variance | | *SD* | |  | | | | | | |
| participant: (intercept) | 1.64 | | 1.28 | |  |  | |  | |
| participant: (slope) neighb | 0.11 | | 0.34 | |  |  | | |  |
| participant: (slope) delay1 | 0.02 | | 0.13 | |  |  | | |  |  | | |
| participant: (slope) delay2 | 0.01 | | 0.12 | |  |  | | |  |  | | |
| item: (intercept) | 0.88 | | 0.94 | |  |  | | |  |  | | |
| item: (slope) group | 0.06 | | 0.24 | |  |  | | |  |  | | |
| item: (slope) modality | 0.09 | | 0.29 | |  |  | | |  |  | | |
| item: (slope) delay1 | 0.01 | | 0.11 | |  |  | | |  |  | | |
| item: (slope) delay2 | 0.00 | | 0.05 | |  |  | | |  |  | | |

*Note.* Model formed from 16463 observations, collected from 378 participants across 16 items. Orthogonal contrasts were used for three-level factors: delay1 (Session 1 vs. Sessions 2&3), delay2 (Session 2 vs. Session 3), group (exp2 vs. exp1&3), modality (exp 1 vs. exp3)

**6. General Discussion**

This study examined the ways in which prior linguistic knowledge supports new word learning, and how this might differ from childhood to adulthood. First, we manipulated pseudowords’ local connections to prior knowledge, using word-form neighbourhoods, and demonstrated that a pseudoword’s similarity to existing English word-forms was advantageous for its immediate recall. Contrary to our initial hypotheses, our findings suggested that these neighbour benefits may be relatively short-lived: a period of offline consolidation reduced the influence of word neighbours on longer-term memory, notably more so for children than for adults. Second, we assessed more globally the prior linguistic knowledge that individuals bring to the task, and showed that existing vocabulary ability was a strong predictor of performance in all measures of pseudoword learning in both children and adults. However, in relating this to our word-neighbour manipulation, our adult data suggest that having one related word-form in vocabulary may be sufficient to facilitate recall of a new word. This supports an active role for prior knowledge in word learning, albeit more constrained than initially hypothesised.

**6.1 The influence of local neighbourhood in learning and consolidating new words**

Consistent with previous experiments using a similar word-neighbour paradigm (e.g., Hoover et al., 2010; Storkel et al., 2006), our experiments showed an initial learning benefit for pseudowords with existing neighbours. We interpret this result as demonstrating that local connections with existing knowledge can facilitate initial acquisition and/or immediate recall of new words, consistent with accounts of memory processing that highlight benefits of schematic knowledge in learning new information (e.g., van Kesteren, Ruiter, Fernández, & Henson, 2012). One plausible mechanism for this facilitation is that it is the word forms themselves provide the schematic structure for supporting learning. Alternatively, neighbouring word forms may provide access to alternative semantic information that can implicitly or strategically facilitate learning (Dumay et al., 2004). Subjective reports collected from Experiment 2 supported this latter proposal, and we consider ways to further elucidate the causal mechanisms in Section 6.4.

The present study set out to specifically address *when* prior knowledge connections might support word acquisition and consolidation. Based on the iOtA model, one possibility was that the overlap between novel words and their neighbours would provide further support during offline consolidation, leading to a larger benefit for novel items with multiple neighbours. However, our data were not in line with these predictions, and instead showed the opposite pattern: words with no local connections to existing knowledge showed greater improvements with a period of offline consolidation, reducing the benefit of word neighbours over time. We consider two possible interpretations for this finding. First, in accordance with the cortical learning interpretation of the CLS model, we proposed that these no-neighbour words are more reliant on hippocampal mechanisms during initial acquisition and thus undergo the biggest changes during subsequent consolidation. By this account, the prior knowledge available to support the learning of words with neighbours is proposed to speed neocortical encoding (Kumaran et al., 2016; McClelland, 2013), without the need for this integration to happen offline (van Kesteren et al., 2013). This neocortical learning account would similarly explain why existing vocabulary knowledge had no further role in consolidation in the present studies. Alternatively, we could also consider that the reduced offline improvements for items with neighbours can be attributed to increased interference when integrating the words with existing vocabulary knowledge (Storkel, Bontempo, & Pak, 2014), not present for words without neighbours. Future studies will benefit from using behavioural or neuroimaging markers of lexical integration to distinguish these processes of initial acquisition and consolidation.

It is important to acknowledge that the effects we attribute to offline consolidation may be partly a consequence of repeated retrieval practice (e.g., Tamminen & Gaskell, 2013). However, it has been demonstrated that overnight recall improvements occur in the absence of repeated retrieval practice (Henderson et al., 2013). Furthermore, Havas et al. (2017) found similar changes in schema benefit to occur over a 12-hour period containing sleep and not over an equivalent period of wake. This suggests that reductions in schema benefit can be at least partially attributed to offline consolidation processes, given that the wake group will have had identical amounts of retrieval practice. We anticipate that offline consolidation processes contribute to the changes seen at T2 alongside other sources of variability, and similarly at T3 despite other influences being greater. Our key questions remain of theoretical interest in these contexts: the differences acquiring and consolidating words that can/cannot benefit from connections to prior knowledge, and differences attributable to the learner’s existing vocabulary ability.

**6.2 Developmental differences in the influence of word neighbours**

The reduction of neighbour influence after opportunities for offline consolidation was most striking in the two child experiments: both showed an initial neighbour benefit on the same day as learning that had disappeared by the following week, despite differences in test format and levels of performance. However, the reduction in neighbour influence over the week of the experiment did not reach significance when modelling the adult data alone (*p*s ≥ .06). Our cross-experiment analysis showed that children receive greater benefit from offline consolidation than adults overall, and that this supported a larger reduction in neighbour influence overnight. As such, the data suggest that children have a greater propensity for consolidating schema-unrelated information than adults.

We speculate that this dissociation may relate to changing neural mechanisms that support learning and consolidation across development. As reviewed in James et al. (2017), children typically show a higher proportion of consolidation-relevant processes (e.g., slow neural oscillations) during sleep than adults (Feinberg & Campbell, 2010; Ohayon et al., 2004), which may support their enhanced consolidation of new words (see also Gómez & Edgin, 2015, for a review of sleep and memory changes earlier in childhood). Adults have a greater amount of prior knowledge to support consolidation, which may compensate for reduced levels of sleep-associated consolidation processes in many tasks (Wilhelm, Diekelmann, & Born, 2008; Wilhelm et al., 2012). Interestingly, using a motor sequence task that could not benefit from prior knowledge, Wilhelm et al. (2013), children showed greater gains in recall performance than adults over sleep, which could be linked to their higher levels of slow-wave sleep activity. Our present findings are consistent with this pattern, but a valuable future direction will be to measure brain activity during sleep to discover whether differences can indeed be attributed to sleep-associated processes in this domain.

**6.3 Relating global vocabulary knowledge to the influence of word neighbours**

Given that local connections to prior knowledge appeared to speed word learning, we asked whether individuals with good global vocabulary knowledge could capitalise upon their superior lexical knowledge when learning words that could benefit from such connections. Experiment 1 did not offer support for this hypothesis: although children with good vocabulary ability emerged as better word learners, they did not show a superior benefit of word neighbours than children with poorer vocabularies. However, it became apparent in Experiment 2 that adults’ global vocabulary ability was a better predictor of performance in the one-neighbour condition, suggesting that those with good vocabulary may actively benefit compared to those with poorer vocabulary when learning such items. Although there is some evidence of a linear relationship between the number of word neighbours and learning performance in preschool children (Storkel, Bontempo, Aschenbrenner, Maekawa, & Lee, 2013), these effects have been very small, and not investigated at the lower end of the scale (≥ 4 neighbours). Our data suggest that the most critical difference appears to be in having one versus no neighbours activated in learning (Bowers et al., 2005), and thus that learning words with many neighbours is less sensitive to vocabulary-related differences because most participants will access at least one neighbour.

Despite the clear influence of existing vocabulary ability on learning one-neighbour words for adults, we did not observe this finding in our subsequent child study (Experiment 3). One explanation is that the neighbours of our selected stimuli may not have been readily accessed during learning by children of this age. Interestingly, whilst the neighbours spanned age-of-acquisition ratings aimed to maximise differences between individual children, we instead observed these individual differences only in adults. This leads us to suggest that the support offered by accessing a word neighbour may be driven by the quality of the individual’s lexical representation (Perfetti, 2007) and their experiences with the word (Vitevitch, Storkel, Francisco, Evans, & Goldstein, 2014), rather than simply word familiarity. Lexical quality is likely lower in children than adults, and also in adults with lower expressive vocabulary ability – a measure that arguably probes well-specified and rich lexical representations. These differences could account for the variability in benefiting from a single neighbour in word learning in two ways: by affecting the likelihood of activating the neighbour, or by whether this activated representation is rich enough to provide support. Perhaps one neighbour is sufficient if this representation is of high quality, but that cumulative activations are necessary for those with weaker lexical representations.

However, there was no significant difference between performance in the one and many neighbour conditions for children overall, suggesting that children were still receiving some support from existing knowledge in this single neighbour condition. One possibility is that this support could be being driven by a different mechanism than in adults. Alternatively, we think it likely that the significant reduction in overall performance in Experiment 3 may have reduced the variability present to detect individual differences in neighbour benefit between children. Whilst the overall pattern of neighbour influence in relation to vocabulary ability looked very similar in Figures 4 and 6, the lower overall levels of cued-recall makes clear the lack of variability across participants. Future studies should thus closely examine conditions under which individual differences in prior knowledge benefit emerge, by manipulating the levels of learning performance and the accessibility of word neighbours.

It is also interesting to consider that the ways in which local and global prior knowledge contribute (and interact in contributing) to word learning performance might vary depending on the retrieval conditions. Whilst we saw influences of test session and local neighbour manipulations in tasks primarily assessing knowledge of the new word forms (cued recall, Experiment 3 form recognition), only global vocabulary knowledge remained a significant predictor in tasks that also presented the novel objects as a cue (recognition in Experiments 1, 2; picture-form recognition in Experiment 3). There are many differences between these tasks beyond the presence of semantic information: the latter tasks primarily tested familiarity rather than holistic retrieval of all elements, they require only a button press response from presented options, and performance levels are much higher. Given that previous studies have demonstrated recall benefits for many-neighbour words when cued with pictures rather than stem completion tasks, we speculate that the performance differences seen are largely driven by differences in retrieval demands. Nevertheless, it remains an interesting avenue to explore the kinds of learning and memory that are most influenced by prior knowledge.

**6.4 Evidence for prior knowledge contributions to Matthew effects**

If vocabulary-related differences in the neighbour benefit only emerge when a new word has one existing neighbour, it begs the question of whether prior knowledge really makes an active contribution to Matthew effects in word learning in light of other explanations: do we readily encounter new words with only one neighbour that enable some individuals to benefit more than others? Whilst vocabulary ability is undoubtedly related to word learning performance in ways beyond prior knowledge support (as suggested by its strong association with performance across all experimental tasks regardless of other manipulations), three arguments make the prior knowledge account worthy of further investigation. First, we do learn a substantial number of words with very small neighbourhoods: 9.94% of the 40,481 entries in the English Lexicon Project have only one orthographic and phonological neighbour, making it plausible that some individuals may be able to excel in learning this new vocabulary quicker than others. Second, individual variability in knowing at least one word-neighbour is greater when the lexicon is smaller, suggesting that there could be a greater contribution of prior knowledge to Matthew effects in younger children.

Third, the lack of individual differences in the many-neighbour condition may have partly resulted from the training paradigm used here, in which learners could make use of strategies that actively involved neighbouring words. As noted above, adults reported using explicit strategies to link the novel words to known neighbours, and develop semantic connections between the two. In encountering a new word within more naturalistic contexts, the activation of a word-neighbour may be less reliable and greater influenced by the quality of the learner’s existing lexical representations. Furthermore, without opportunities to make explicit linguistic connections during training, benefits of prior knowledge may be more likely to emerge offline during consolidation. Indeed, when Henderson et al. (2015) presented novel words within a story context, existing vocabulary ability correlated *only* with overnight improvements in cued-recall, and not with immediate performance. This difference in learning context may be a key factor in explaining why we did not find a relationship between existing vocabulary knowledge and consolidation of new words (see also Henderson & James, 2018): there may be no further benefit for prior linguistic knowledge during consolidation when explicit strategies can be used during learning, whereas more implicit connections to existing knowledge may be strengthened by consolidation (in line with the iOtA model). We therefore speculate that prior knowledge-related differences in naturalistic word learning may be understated by the present experiments, and suggest that future studies should consider using alternative training paradigms.

**6.5 Conclusions**

This study revealed that children and adults benefit from local connections to prior linguistic knowledge during word learning: novel words with one or more neighbours were recalled better at the initial test points, suggesting they could be acquired more quickly than words with no neighbours in the English language. This immediate benefit for prior knowledge favours accounts of memory consolidation that permit early neocortical learning for schema-related information. However, children’s but not adults’ memory for no-neighbour words reached equivalent performance levels by the end of the week, supporting proposals that ongoing neural development in children may provide increased support for consolidating large amounts of new information during this developmental period. These data demonstrate that the CLS model of learning could be further informed by taking developmental approaches that seek to contrast the contributions of different mechanisms to learning and consolidation. Furthermore, understanding how the relative reliance on prior knowledge changes across the lifespan may also be important for understanding why early language difficulties can persist to adulthood, and stresses the importance of targeting difficulties whilst learning mechanisms are most able to overcome such constraints.

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1. Note that the original pre-registration specified an additional subgroup analysis on children identified as poor comprehenders. However, our individual follow-up assessments with these children indicated that very few met traditional criteria for specific comprehension difficulty in this sample (*n* = 3/254). As such, it was deemed inappropriate to analyse and interpret these as a distinct group. [↑](#footnote-ref-1)
2. By setting orthogonal contrasts, analyses were deemed to be highly comparable but more informative than the treatment contrasts initially pre-registered for Experiment 2, removing the need for follow-up comparisons to fully interpret the model. [↑](#footnote-ref-2)