

The effect of oral vocabulary training on reading novel complex words

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Note. The corresponding materials, data and analysis scripts have been made available via the OSF repository (https://osf.io/y82r7/?view_only=None).

Abstract

Do readers benefit from their knowledge of the phonological form and meaning of stems when seeing them embedded in morphologically complex words for the first time in print? This question was addressed using a word learning paradigm. Participants were trained on novel spoken word stems and their meanings (“tump”). Following training, participants then saw the novel stems for the first time in print, either in combination with a real affix (*tumpist*, *tumpor*) or a non-affix (*tumpel*, *tumpain*). Untrained items were also included to test if the affix effect was modulated by the prior training of the spoken word stems. First, the complex words were embedded in meaningful sentences which participants read as their eye movements were recorded (first orthographic exposure). Second, participants were asked to read aloud and spell each individual complex novel word (second orthographic exposure). Participants spent less time fixating on words that included trained stems compared to untrained stems. However, the training effect did not change depending on whether stems were accompanied by a real affix or a non-affix. In the reading aloud and spelling tasks, there was no effect of training, suggesting that the effect of oral vocabulary training did not extend beyond the initial print exposure. The results indicate that familiarity with spoken stems influences how complex words containing those stems are processed when being read for the first time. Our findings highlight the flexibility and adaptability of the morphological processing system to novel complex words during the first print exposure.

Keywords: oral word learning, eye tracking, reading acquisition

How people acquire knowledge about spoken and written words is typically investigated in distinct streams of research. Similarly, how morphologically complex written words are learned and processed is also considered somewhat separately from the literature that focuses on monomorphemic words. Clearly, however, these areas of enquiry overlap, and it is important to understand the interplay between spoken and written word knowledge as morphologically complex written words are learned and processed. The aim of the current study was to use a word learning paradigm to test the mechanisms involved in identifying morphological structures when seeing complex novel words for the first time in print, if one of the morphemic constituents is already familiar in its oral form.

Children and second language learners often encounter new written words they are already familiar with orally. Pre-existing oral word knowledge, comprising the pronunciations and meanings of words, is generally thought to confer an advantage when words are first experienced in print, compared to words that are unfamiliar orally. Support for a direct relationship between spoken word knowledge and word reading is drawn from work employing cross-sectional item-level analyses (Kearns & Al Ghanem, 2019; Kearns et al., 2016; Nation & Cocksey, 2009; Ricketts, Davies, Masterson, Stuart, & Duff, 2016), which relate a person's knowledge of individual spoken English words to their ability to read those same words. Such studies converge on the view that knowing a spoken word is directly associated with word reading among samples of school age children. Stronger evidence for the existence of a causal relationship between spoken word knowledge and reading comes from training studies in which participants are first taught novel oral vocabulary before experiencing those items for the first time in print, along with orally unfamiliar items. Studies with children show that orally trained novel words are associated with a reading accuracy advantage (e.g., Duff & Hulme, 2012; Hogaboam & Perfetti, 1978; McKague, Pratt, & Johnston, 2001) and an online processing advantage (e.g., Wegener et al., 2018; Wegener,

Wang, Nation, & Castles, 2020) during the first few visual exposures, compared to untrained items. The benefits of prior oral vocabulary knowledge for learning new written words are not unique to individuals at the lower end of the reading proficiency scale. Several experiments with adults have shown that oral word knowledge is quickly integrated into automatic reading processes (Beyersmann, Wegener, et al., 2021; Johnston, McKague, & Pratt, 2004; McKague, Davis, Pratt, & Johnston, 2008), thereby providing converging evidence for the importance of oral word knowledge in written word learning even among skilled readers¹.

What is not clear from prior studies is whether the influence of oral word knowledge is evident when reading longer and more complex novel words. Some relevant data were reported by Beyersmann, Wegener, et al. (2021) who found that learning morphologically complex words in terms of their spoken form and meaning influences how the embedded stems are processed when subsequently seen in print for the first time. However, it is uncertain how the reading system handles novel morphologically complex words because prior oral word training studies have only investigated the reading of morphologically simple words. This is an important problem to address because the orthographic forms of novel words can vary widely, particularly with regard to morphological complexity (e.g., *vaping*, *zooming*, *youtuber*, *screenager*). And, as exemplified by the COVID-19 pandemic, exposure to new words is accelerated by the need to coin new words and phrases (e.g., *zoomfatigue*, *promask*, *antimask*, *superspreader*, *doomscrolling*).

¹ While there is evidence for semantic influences in word reading in general (for reviews, see Keenan & Betjemann, 2007; Taylor, Duff, Woollams, Monaghan, & Ricketts, 2015), the question of whether the relationship between oral vocabulary and reading is driven by knowledge of phonological form alone, or by phonology in combination with semantics, remains unresolved; there is some evidence for the former (Duff & Hulme, 2012; McKague et al., 2001; Nation & Cocksey, 2009) and some for the latter (Kearns & Al Ghanem, 2019; Kearns et al., 2016; Ricketts et al., 2016; Taylor, Plunkett, & Nation, 2011). What is clear is that prior oral vocabulary knowledge supports subsequent word reading, and that when this prior knowledge is of both phonological form and meaning, a potential role for semantics in written word processing should be considered.

One effective mechanism that can be used to derive meaning from a novel word like *antimasker* is to decompose the word into morphemic sub-units (*anti* + *mask* + *er*; “someone who refuses to wear face masks”). As we know from several decades of visual word recognition research, skilled readers are experts at rapidly decomposing morphologically complex letters strings during the early, pre-lexical stages of visual word recognition (for reviews, see Amenta & Crepaldi, 2012; Rastle & Davis, 2008). Morphological parsing is applied rapidly to any letter string with a morphological surface structure (e.g., Beyersmann et al., 2016; Longtin, Segui, & Hallé, 2003; Rastle, Davis, & New, 2004), including both semantically transparent (e.g., *farmer*) and semantically opaque complex words (e.g., *corner*). Given that morphemes often occur at the ‘edges’ of a letter string, morpheme identification is additionally aided by the principle of ‘edge-alignedness’ by which spaces are used as anchor points to guide orthographic encoding (e.g., Beyersmann & Grainger, in press; Beyersmann et al., 2018; Fischer-Baum, Charny, & McCloskey, 2011; Grainger & Beyersmann, 2017), a point we return to in the Discussion. In a similar vein, eye-tracking studies have revealed that morphemes are accessed and processed rapidly during sentence reading (e.g., Deutsch, Frost, Pelleg, Pollatsek, & Rayner, 2003; Hyönä, Yan, & Vainio, 2018; Yan et al., 2014; Yen, Tsai, Tzeng, & Hung, 2008). For instance, words with high frequency morphemic constituents are fixated for shorter periods of time than words with low frequency constituents (Kuperman, Schreuder, Bertram, & Baayen, 2009) and evidence from both the fast-priming paradigm (Mousikou & Schroeder, 2019) and the gaze-contingent boundary priming paradigm (Hyona, Heikkila, Vainio, & Kliegl, 2020) points to embedded stem effects for complex nonwords. Moreover, it has been shown that constituent frequency hinders visual word processing when the meaning of the constituent is unrelated to the meaning of the whole word as is the case in both opaque compound words (Marelli &

Luzzatti, 2012) and opaque affixed words (Amenta, Marelli, & Crepaldi, 2015), suggesting that morphological processing is modulated by semantic transparency.

Crucially, the process of morphological decomposition works on the assumption that readers are familiar with the embedded units (e.g., *anti*, *mask* and *er*). But what happens if novel words contain morphemic units that readers have only heard, but never previously seen in print (e.g., *tumpist* = *tump* + *ist*)? If people are able to rapidly integrate words that are familiar in spoken language into a morphologically complex context during sentence reading, this would provide key evidence for the flexibility and adaptability of the morphological parsing system. Although previous work provides important insights into the automaticity of the morphological parsing system, it is unknown if morphological processing is similarly efficient and automatic for complex written words when they are first encountered, and how this varies as a function of familiarity with their constituent units. This question formed the focus of our current investigation where we investigated two types of familiarity: familiarity with the meaning and the form of the stem in oral language, induced via training within the experiment itself, and knowledge of the novel stem in combination with existing morphemes (e.g. *-ist*) or non-affixes (e.g., *-ain*).

The Present Study

We used a word learning paradigm with a training phase in which participants learned a set of 16 novel spoken word stems and their meanings (e.g., “tump”). Training occurred in the spoken modality only. In the post-training phase, participants saw the novel stems for the first time in print, either in combination with a real affix (e.g., *tumpist*, *tumpor*), or with a non-affix (e.g., *tumpel*, *tumpain*). A second set of 16 untrained affixed and non-affixed items were also included to test if the affix effect was modulated by the prior training of the spoken word stems. Both the trained and untrained complex novel words were embedded in sentences while participants’ eye movements were recorded. Participants were then asked to

complete (i) a reading aloud task and (ii) a spelling task, in which they were presented with the same set of complex words in isolation (e.g., *tumpist*, *tumpor*, *tumpel*, *tumpain*). This measured whether the effects of training and affix type had an impact on spoken and written word knowledge beyond the first exposure to the orthographic form.

This design allowed us to address two key research questions. We first asked if oral knowledge influences how people read novel complex words that contain familiar (vs. unfamiliar) stems. One possibility is that the benefits of oral word training are initially limited to words that share the exact same form (e.g., *tump*) as the trained spoken word (“tump”). In this case, we would not expect the effect of training to extend to stems appearing in different orthographic forms (e.g., *tumpist* or *tumpel*). That is, fixation times should be comparable for both trained and untrained items. Another possibility is that the reading system is flexible in its adaptation to words appearing in different orthographic forms such that when presented with trained stems embedded in complex words, it is immediately able to integrate familiar oral embedded forms, despite the written form being new. This would be evidenced by shorter fixation times on written words that include trained compared to untrained stems.

Second, we asked if the effect of embedded stem training is modulated by the morphological structure of the target string. Given that the participants are skilled readers who, as already discussed earlier, tend to be highly proficient at parsing morphologically complex words into morphemic subunits, we tested whether morphological decomposition is unique to complex words in which participants are familiar with the written forms of their morphemic building blocks (e.g., *anti* + *mask* + *er*), or also applies to novel words consisting of units that participants have never previously seen (e.g., the *tump* in *tumpist*)? If the proficiency of the morphological parsing system is developed to a point that it can rapidly integrate affixes with trained novel word stems, we would expect to see an interaction

between training and affix type, with a facilitatory effect of affix type in the trained but not in the untrained condition. We further hypothesised that if the effects of training and affix type extend to spoken and written word production, beyond the initial orthographic exposure in the eye-tracking task, we would expect to see an interaction between training and affix type in the reading aloud and spelling tasks. More specifically, the effect of training was expected to be evidenced by faster and more accurate responses in the trained compared to the untrained condition, and the effect of affix type by faster and more accurate responses in the affix compared to the non-affix condition.

Method

Participants

Sixty-four students from Macquarie University (50 female; mean age: 21.3 years [SD = 5.1]), all English native speakers, participated for course credit. They were randomly split into two groups of 32. The first group was trained on Set 1 and the second group on Set 2. Participants were also assessed on a standardised reading fluency test (Test of Word Reading Efficiency [TOWRE]; Torgesen, Wagner, & Rashotte, 1999), Form A, to check for participants' reading proficiency across item lists. Both word and nonword subtests were administered, each measuring the number of items named in 45 seconds. The participants achieved a mean standard score of 112 for word reading (SD = 13) and 111 for nonword reading (SD = 13), with no difference between the two groups (all $ps > .05$).

Materials

Novel words. Materials consisted of a list of morphologically simple novel oral words (introduced as oral forms during the training phase) and a list of morphologically complex novel written words (introduced as written forms during the post-training test phase). Morphologically simple novel words were 32 (3-4 phoneme) monosyllabic nonwords (for a full item list, see Appendix A) were constructed. Drawing on Ziegler, Stone, and Jacobs

(1997), words were designed to be regular for reading and to have highly predictable spellings based on their phonology. This approach was taken in view of prior findings showing that oral training influences online processing the first time such items are seen in print (Beyersmann, Wegener, et al., 2021; Wegener et al., 2018; Wegener et al., 2020). Items were then split into two sets (Sets 1 and 2) and arranged in 16 different pairs (e.g., item 1 in set 1 [semp] was paired with item 1 in set 2 [deld], etc.). The 16 item pairs were matched on number of letters, number of phonemes, orthographic neighbourhood, and consonant-vowel (CV) structure (with the exception of *jorm/foob* that did not provide an exact match in CV-structure). Set 1 served as trained items during oral exposure for half of the participants, and Set 2 for the other half (see Appendix A).

Four morphologically complex written words were created for each novel stem (*tump*) by combining it with two different derivational suffixes (*-ist* and *-or*) and two different non-suffixes (*-ain* and *-el*), resulting in *tumpist*, *tumpor*, *tumpain*, *tumpel*). Suffixes and non-suffixes were matched as closely as possible on ending frequency (i.e., the number of occurrences in final string position in all words listed in the SUBTLEX-UK database; Van Heuven, Mandera, Keuleers, & Brysbaert, 2014) and the mean logarithmic word frequency of all words containing a given suffix ($M = 2.03$; $SD = 0.06$) or non-suffix ($M = 2.18$; $SD = 0.17$).

Oral training. Participants were trained individually, and each novel stem was encountered as a verb. They were told that they would be learning about ‘Professor Parsnip’s Inventions’ and engaged in a range of activities to learn about the function and perceptual features of each invention. For example, they heard that “Professor Parsnip has invented a machine that allows you to tump. The machine is used to remove sand stuck to your skin at the beach. It has brushes and moves up and down.” Each invention was paired with a picture demonstrating its features (see Figure 1).

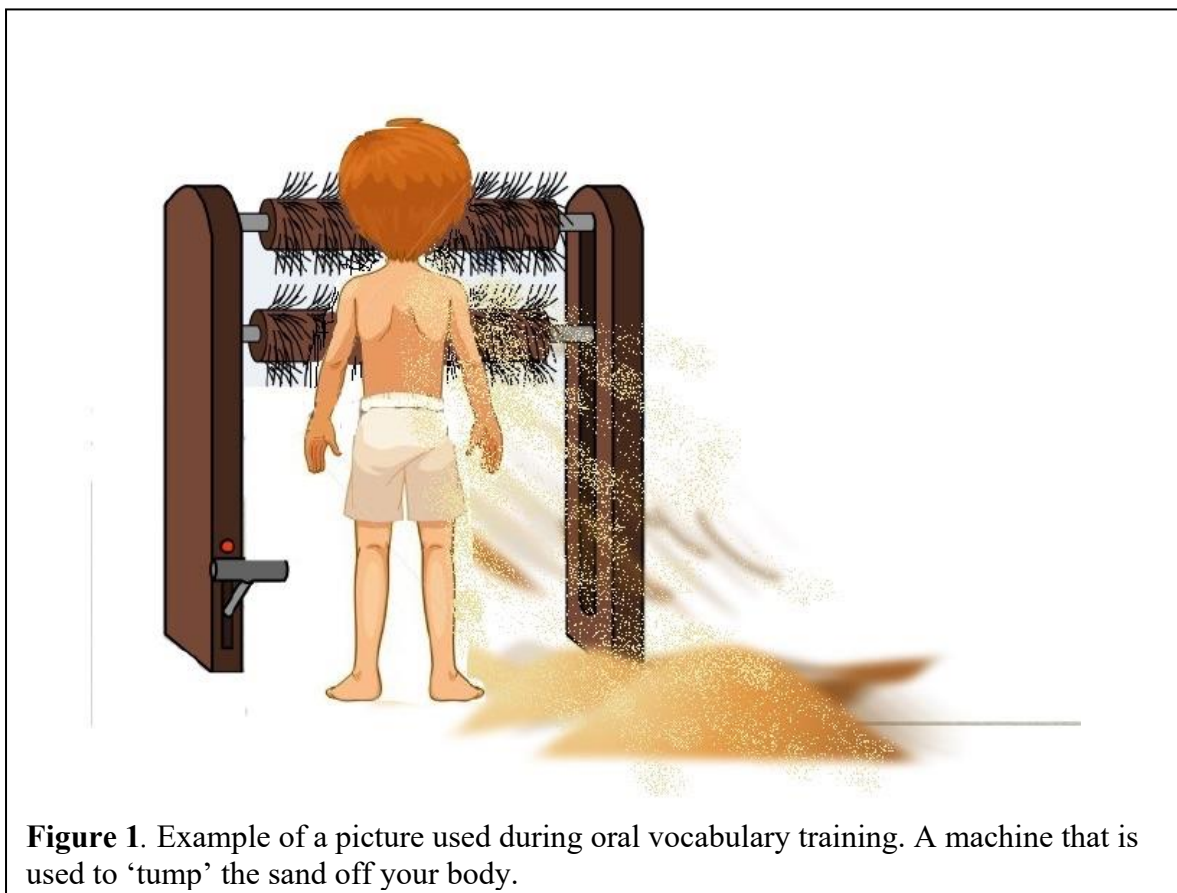


Figure 1. Example of a picture used during oral vocabulary training. A machine that is used to ‘tump’ the sand off your body.

Post-Training Sentences for Reading. Complex novel words (*tumpist*, *tumpor*, *tumpain*, *tumpel*) were embedded in a carrier sentence, and always occurred in mid-sentence position (Appendix B). For example: *Pip showed his sandy body to the tumpor to get it cleaned.* All sentences contained exactly 12 words. To mimic a feature of derivational word formation, by which the addition of affixes often leads to a change in syntactic word class

(e.g., *act* [verb] → *actor* [noun]), the novel word stems (e.g., *tump*) were trained as verbs, but embedded as complex nouns for sentence reading (e.g., *tumpor*). Carrier sentences were designed to be contextually rich and related to the oral training such that they were consistent with the meaning of the newly learned words. The sentences were split into four counterbalanced sets (Appendix B) to ensure that no participant would encounter any novel stem more than once. The order of trials was randomised for each participant.

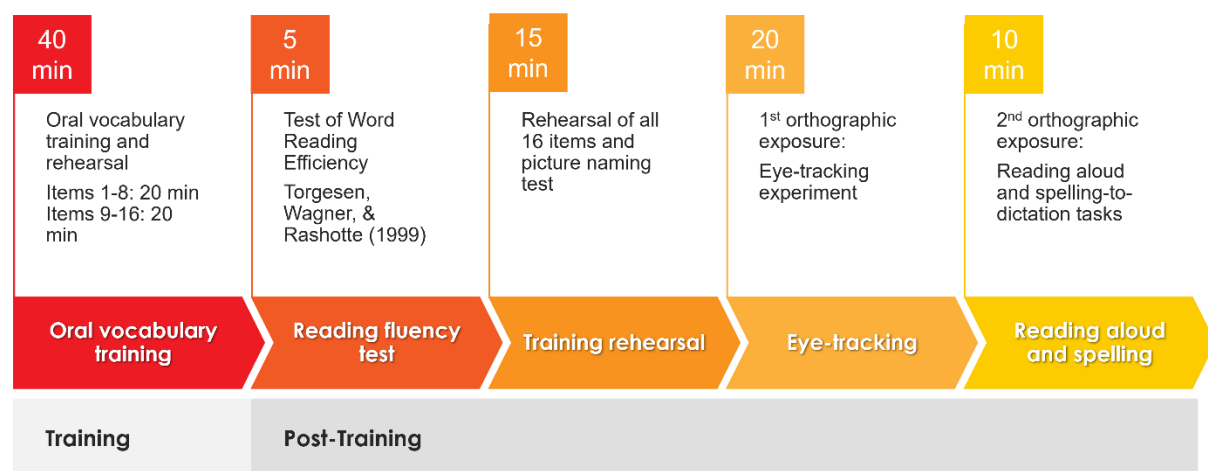


Figure 2. Summary of procedure involving oral vocabulary training and post-training sentence reading.

Procedure

The overall procedure took place in a single session and is summarised in Figure 2.

Oral Vocabulary Training. Oral vocabulary training, including set-up time and calibration, took approximately one hour per participant. Each participant was trained on one set of 16 novel stems (either Set 1 or Set 2), with the other set constituting their untrained items. Sets were counterbalanced across the two groups of people. Items were introduced in groups of 4 and rehearsed once before moving on to the next group of 4 items. In addition, the training included two rehearsals of 8 items, and one rehearsal including all 16 items (see

Table 1). During rehearsal, participants were briefly reminded of each invention's meaning and then asked to repeat the associated novel word forms.

Picture-Naming: Post-Training Check. This was to check that participants had learned the oral forms and their meanings. Participants were shown a picture of each invention and asked what the invention did and what it was used for. Accuracy was recorded for remembering the novel word (1 point) and its meaning (1 point), with a maximum total score of 2 points per item.

Post-Training: First Orthographic Exposure. Participants encountered the written form of the trained and untrained stems for the first time, embedded in complex forms (e.g., tumpist, tumpor, tumpain, tumpel). Each complex word appeared in the middle of a single line sentence and eye movements were monitored as participants read the sentences silently; 16 sentences contained reference to inventions they had learned about (i.e., 'trained' stems) and 16 referenced inventions learned by the other group (i.e., 'untrained' stems). Eye movements were recorded using an Eyelink 1000 eye tracker (SR Research; Mississauga, Canada) in head-stabilized mode, sampling at 1000 Hz as participants read sentences on a computer monitor at a viewing distance of 104 cm. Each character subtended 0.26° of horizontal visual angle. Sentences were presented in black, Courier New font on a white background. Participants read binocularly but only the movements of the right eye were monitored. A three-point calibration procedure was performed (maximum error of 0.30), followed by three practice trials, and then the experimental sentences. The participant fixated a drift correct circle prior to each trial and recalibration was performed as needed; the participant used a button box to terminate each trial when they had finished reading. To promote attention to task, they were required to answer a (yes/no) question after each trial; response accuracy was high (95.4%) indicating that participants were reading for meaning.

Four dependent variables were extracted from eye movement record to capture reading behaviour on the target word: first fixation duration (duration of initial fixation on the target during the first pass through the text); gaze duration (sum of all first-pass fixations made on the target); total reading time (sum of all fixations on the target, including any regressions back to it); and regressions in (probability of making a regression back to the target from a later portion in the sentence).

Post-Training: Second Orthographic Exposure. Participants read aloud 32 affixed and non-affixed words (16 containing trained stems, 16 containing untrained stems), presented individually in the centre of a computer screen using DMDX software (Forster & Forster, 2003). Depending on which item set participants had been previously trained, they were assigned to either Set 1A/2A or Set 1B/2B (see Appendix B). Each trial consisted of an 800-ms fixation cross followed by the target, which remained until response or until 2 seconds had elapsed. Participants were instructed to name each word as quickly and accurately as possible. Reaction times and response accuracy were recorded.

Post-Training: Spelling to Dictation. The experimenter read out the affixed and non-affixed novel words and participants were instructed to spell them exactly as they were written in the sentence reading and reading aloud parts of the experiment. Participants were assigned to the same item set as they had previously seen in the reading aloud task.

Data analysis

Data were analysed in the R computing environment (R Core Team, 2021). Participants' responses on the learning check were summed to give a total score out of 16 orally trained items. Independent samples t-tests were used to compare the performance of participants who learned Set 1 and Set 2. For the eye movement data (first fixation duration, gaze duration, total reading time, regressions in), reading aloud data (RT and errors) and spelling data (accuracy), linear mixed effects (LME) models were constructed. The package

lme4 (Bates et al., 2015) was used for model construction. Fixed effects were training (trained vs. untrained), affix type (affixed vs. non-affixed) and their interaction. Training and affix type were deviation coded (0.5, -0.5). Random effects were participants and items (stems). Following Barr and colleagues (2013), models were initially computed with the maximal random effects structure but these failed to converge and produced singular fits. For this reason, the random intercepts model was computed and random slopes were added incrementally. As per Matuschek and colleagues (2017), a random slope was retained if a likelihood ratio test showed that its addition improved model fit ($p < .2$). Specific details of data preparation steps undertaken prior to analysis are reported separately in each relevant section of the results.

Results

Learning check: Picture naming

Participants correctly recalled an average of 13 of the 16 orally trained invention verbs ($SD = 3.3$). There was no difference in recall between participants who learned Set 1 ($M = 12.4$, $SD = 3.4$) and Set 2 ($M = 13.5$, $SD = 3.1$; $t(63) = 1.99$, $p = .177$). These results indicate that participants learned the complex novel words and were able to match the oral word forms with pictures of the inventions.

Post-Training: First Orthographic Exposure

The area of interest was the target word. Fixations shorter than 80 milliseconds and within one character space of the previous or next fixation were merged, and any remaining fixations shorter than 80 milliseconds or longer than 1200 milliseconds were deleted. Trials were removed if a blink or tracker loss occurred on the target word, or if any of the three prespecified areas – target word, pre-target text, post-target text – were skipped during first pass reading. These cleaning steps resulted in 3.43% of the data being removed and a coding error resulted in the loss of an additional 6.12% of the data. In total, 90.44% of the

experimental data were available for analysis. Time data were log transformed prior to analysis, and *p* values were obtained using the *lmerTest* package (Kuznetsova et al., 2017). For ease of interpretation, arithmetic means and standard errors for each of the dependent variables are plotted in Figure 3 while model outputs are shown in Table 1.

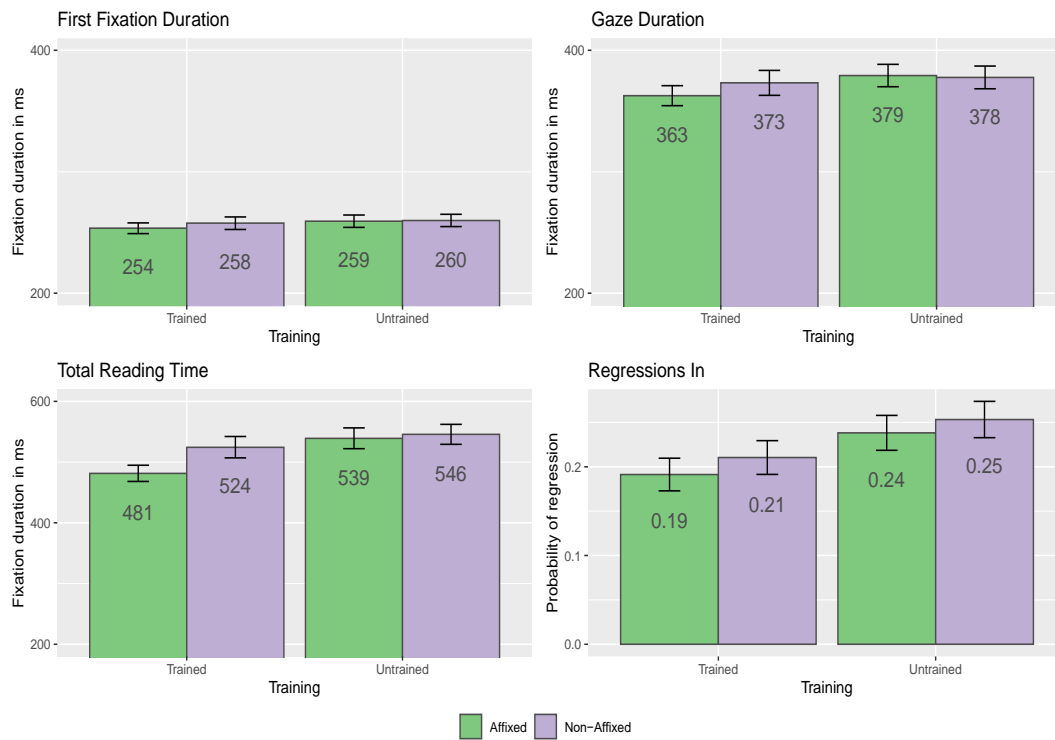


Figure 3. Arithmetic means and standard errors of target word fixation durations and probability of rereading. First fixation duration, gaze duration and total reading time are expressed in milliseconds while regressions in reflects likelihood of occurrence.

Results of the model for first fixation duration showed that there were no fixed effects of training, affix type, or their interaction. Similarly, the model for gaze duration showed that there were no fixed effects of training, affix type, or their interaction. Results of the model for total reading time showed shorter fixations for words containing trained stems than untrained stems. There was no fixed effect of affix type and no two-way interaction between training and affix type. Results of the model reflecting the probability of regressions back to the target word revealed an effect of training, with trained items less likely to attract a regression than

untrained items. There was no effect of affix type and no interaction between training and affix type.

Table 1. Output of the linear mixed effects models of the eye movement data

| Fixed effects | First Fixation | | | | Gaze Duration | | | |
|--------------------|--------------------|-----------|--------------------|----------|---------------------------|-----------|----------|----------|
| | <i>beta</i> | <i>SE</i> | <i>t</i> | <i>p</i> | <i>beta</i> | <i>SE</i> | <i>t</i> | <i>p</i> |
| Intercept | 5.48 | 0.02 | 280.25 | <.001 | 5.8 | 0.04 | 144.43 | <.001 |
| Training | 0.01 | 0.02 | 0.75 | .456 | 0.03 | 0.02 | 1.67 | .096 |
| Affix Type | 0.00 | 0.02 | 0.32 | .752 | -0.00 | 0.02 | -0.00 | .998 |
| Interaction | 0.00 | 0.03 | 0.32 | .752 | 0.00 | 0.04 | 0.01 | .989 |
| Random effects | Var | SD | | | Var | SD | | |
| Intercepts | | | | | | | | |
| Participant | 0.02 | 0.14 | | | 0.07 | 0.27 | | |
| Item (stem) | 0.00 | 0.02 | | | 0.01 | 0.11 | | |
| Fixed effects | Total Reading Time | | | | Regressions In | | | |
| | <i>beta</i> | <i>SE</i> | <i>t</i> | <i>p</i> | <i>beta</i> | <i>SE</i> | <i>z</i> | <i>p</i> |
| Intercept | 6.09 | 0.05 | 112.31 | <.001 | -1.46 | 0.15 | -9.74 | <.001 |
| Training | 0.07 | 0.03 | 2.33 | 0.027 | 0.30 | 0.12 | 2.51 | 0.012 |
| Affix Type | 0.04 | 0.02 | 1.81 | 0.070 | 0.14 | 0.12 | 1.14 | 0.254 |
| Interaction | 0.01 | 0.04 | 0.18 | 0.859 | -0.02 | 0.24 | -0.10 | 0.919 |
| Random effects | Var | SD | Corr. ^a | | Var | SD | | |
| Intercepts | | | | | | | | |
| Participant | 0.12 | 0.35 | | | 0.82 | 0.91 | | |
| Item (stem) | 0.03 | 0.17 | | | 0.15 | 0.39 | | |
| Participant slopes | | | | | | | | |
| Training | 0.01 | 0.09 | 0.69 | | | | | |
| Item slopes | | | | | | | | |
| Training | 0.01 | 0.11 | -0.04 | | | | | |
| Fixed effects | Reading Aloud RTs | | | | Reading Aloud Error Rates | | | |
| | <i>beta</i> | <i>SE</i> | <i>t</i> | <i>p</i> | <i>beta</i> | <i>SE</i> | <i>z</i> | <i>p</i> |
| Intercept | 6.55 | 0.03 | 247.56 | <.001 | 4.70 | 0.41 | 11.47 | <.001 |
| Training | 0.01 | 0.01 | 1.33 | 0.185 | -0.37 | 0.26 | -1.42 | 0.155 |
| Affix Type | 0.02 | 0.01 | 2.98 | 0.003 | -0.48 | 0.26 | -1.86 | 0.063 |
| Interaction | -0.02 | 0.01 | -1.29 | 0.198 | -0.10 | 0.51 | -0.19 | 0.853 |
| Random effects | Var | SD | | | Var | SD | | |
| Intercepts | | | | | | | | |
| Participant | 0.04 | 0.19 | | | 3.25 | 1.80 | | |
| Item (stem) | 0.00 | 0.06 | | | 0.53 | 0.73 | | |

^a Corr. indicates the correlation between the random intercepts and slopes.

Post-Training: Second Orthographic Exposure

Descriptive data for RT and accuracy are shown in Figure 4 and model outputs in Table 1. RTs were log transformed to normalize residuals. The significance of the fixed effects was determined with type III model comparisons using the Anova function in the car package (Version 3.0-10; Fox & Weisberg, 2019).

Incorrect responses were removed from the RT analysis (4.4% of the data). Extreme outliers below 300 ms and above 8000 ms were also excluded (0.05% of the data). Inverse RTs (1/RT) were calculated for each participant to correct for RT distribution skew. A base LME model, including only participants and items as random intercepts, was fitted to the data and data points with residuals exceeding 2.5 SDs were removed (2.6% of the data), following the procedure outlined by Baayen and Milin (2010). RT analyses revealed a significant effect of affix type, showing that affixed novel words were read faster than those containing a non-affix (Figure 4, left panel). No other effects were significant (all $ps > .05$). Error rates were low overall and there was no significant effect of any variable (Figure 4, right panel).

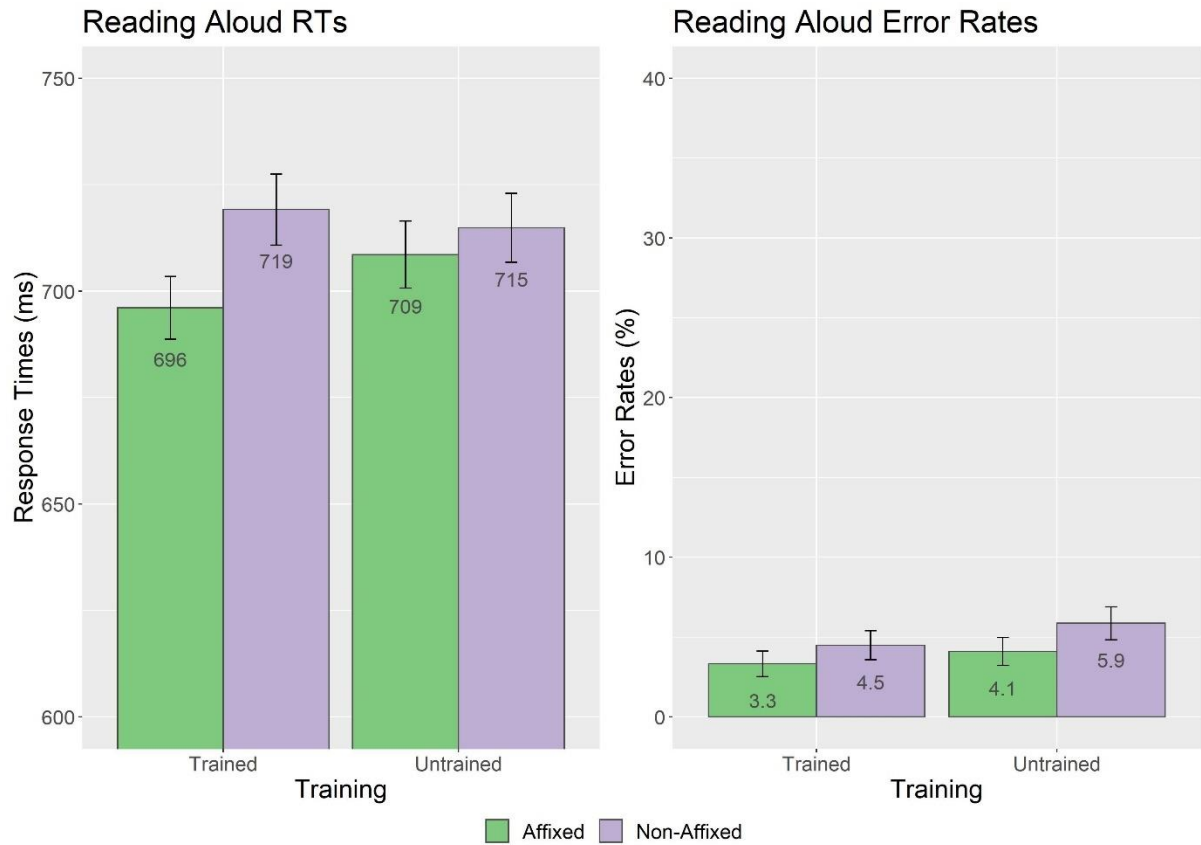


Figure 4. Means and standard errors of reading aloud RTs (left panel) and error rates (right panel).

Post-Training: Spelling to Dictation

Mean error rates across participants were calculated for each condition. Error rates were comparable across conditions (trained affixed: 10.35% [$SD = 30.49$]; trained non-affixed: 9.18% [$SD = 28.90$]; untrained affixed: 13.28% [$SD = 33.97$]; untrained non-affixed: 12.11 [$SD = 32.66$]). None of the effects were significant (all $ps > .05$).

Discussion

The present study used a word learning paradigm to test the effect of oral word knowledge on the reading of novel complex words embedded in meaningful sentences. The initial training phase involved learning a set of novel word stems and their meanings (“tump”), all in the oral modality. In the post-training phase, participants then saw the novel

stems for the first time in print, either in combination with a real affix (*tumpist*, *tumpor*), or with a non-affix, matched for frequency in word-final position (*tumpel*, *tumpain*), while their eye movements were recorded. A second set of untrained items was also included to test if the effect of affix type was modulated by the prior training of the spoken word stems.

The eye-tracking data revealed a significant main effect of training on both total reading time and regressions in, showing that participants spent less time fixating on and were less likely to regress back to words when they included a trained stem, compared to words than contained an untrained stem. Even though participants were never exposed to the written form of the embedded stems during training, vocabulary knowledge clearly influenced reading. This finding supports prior work showing that familiarity in the oral domain influences lexical processing when words are seen in print for the first time (Beyersmann, Wegener, et al., 2021; Wegener et al., 2018; Wegener et al., 2020). Although not directly tested in the current experiment, a likely explanation for the facilitatory effect we observed is that participants generated orthographic expectancies during oral word learning which influenced initial reading times (Wegener et al., 2018). Critically, our results highlight the flexibility of the reading system in that the effects of oral word training are not limited to words that share the exact same form (e.g., *tump*) with the trained spoken word (“tump”) but extend to complex written words that contain the stem. While not evident in the first fixation and gaze duration data, the effect of training was clear in total reading time and regressions data, demonstrating that participants quickly integrate oral word knowledge when first reading complex words that contain stems recently experienced in the oral domain only (the *tump* in *tumpist*, *tumpor*, *tumpel*, *tumpain*).

The embedded word training effect fits with the assumption that embedded stems are used as a bootstrapping mechanism for morphological parsing in reading acquisition (e.g., Beyersmann & Grainger, in press; Beyersmann, Grainger, & Castles, 2019; Grainger &

Beyersmann, 2017). Edge-aligned embedded word activation has been argued to be an entirely non-morphological process of identifying words embedded at the edges of the letter string, independently of whether the word is accompanied by an affix (as in *tumpist*) or a non-affix (as in *tumpel*), and represents one of the key reading mechanisms in Grainger and Beyersmann’s “word and affix” model (Beyersmann & Grainger, in press; Grainger & Beyersmann, 2017). The notion of embedded word processing has also found support from studies using semantic categorization tasks (e.g., Bowers, Davis, & Hanley, 2005), word naming (Beyersmann, Grainger, & Taft, 2019) and lexical decision (e.g., Davis & Taft, 2005; Taft, Xu, & Li, 2017). Moreover, children appear to be particularly proficient at identifying embedded stems, irrespective of morphological structure in the early stages of reading acquisition (e.g., Beyersmann, Grainger, Casalis, & Ziegler, 2015; Beyersmann, Grainger, & Castles, 2019; Beyersmann, Mousikou, et al., 2021; Hasenäcker, Beyersmann, & Schroeder, 2016, 2020; Nation & Cocksey, 2009). It is only after the reading system becomes more proficient that readers begin to acquire a fully proficient morphological parsing system that is able to rapidly decompose affixed words into morphemic subunits (e.g., Beyersmann, Castles, & Coltheart, 2012; Dawson, Rastle, & Ricketts, 2018, 2021; Rastle, 2018; Schiff, Raveh, & Figheh, 2012). To date, empirical support for a stem-initiated bootstrapping mechanism primarily comes from studies examining developing readers; our observation of an embedded stem training effect in skilled readers fits within this framework.

The eye-tracking data further revealed that the interaction between training and affix type was entirely absent across all four dependent variables, showing that the presence of an affix (vs. non-affix) did not modulate the embedded word training effect. Participants spent comparable amounts of time fixating novel words consisting of trained stems accompanied by affixes (e.g., *tumpist*) or non-affixes (e.g., *tumpel*). There are several different explanations for the absence of an affix effect in present data. One possibility is that

participants did not develop a profound enough knowledge of the novel stems during oral word training. The oral word training involved teaching participants the phonological form and meaning of 16 novel words. The learning outcomes showed that participants successfully recalled an average of 13 out of 16 novel words. However, the training was completed within one single session, immediately prior to the eye-tracking experiment, thus giving participants little time to consolidate their newly acquired word knowledge. As a result, there was little opportunity to develop more abstract, generalisable morphemic knowledge that participants were able to draw on when seeing the complex words for the first time in print. A key characteristic of derivational morphology is that the addition of an affixes induces a change in syntactic word class (e.g., *visit* [verb] + *or* = *visitor* [noun]). The change in word class is typically associated with a considerable change in word meaning. As such, the depth of acquisition of higher-level syntactic and semantic word features constitutes an important prerequisite in the processing of derived word forms, which may require more extensive, potentially multi-day training sessions rather than a single session.

An alternative explanation for the absence of an affix effect may be that morphological decomposition requires more substantial reading experience in order to integrate newly acquired word forms into the parsing system. In the current study, eye movements were measured while participants encountered the novel word forms in print for the very first time. Although the main effect of training showed that participants were clearly able to draw on their prior oral word knowledge when seeing the novel words for the first time in print, they may not have had enough print exposures to fully integrate the novel forms within the reading system and rapidly segment the input strings (e.g., *tumpist*) into morphemic subunits (*tump* + *ist*). The aim and strength of the current study was to measure participants' eye movements on initial print exposure and our results show that participants did not attempt a full morphemic parse when seeing the written forms of the novel stems

embedded in complex contexts for the first time. To some extent, these findings mirror the absence of morphological processing effects in beginning readers. It has been shown that the automaticity of morphological processing develops only in the more advanced stages of reading development during the high school years (e.g., Beyersmann et al., 2012; Dawson et al., 2018, 2021; Lázaro et al., 2018; Schiff et al., 2012). During the earlier stages of reading acquisition, children appear to initially rely on their ability to identify embedded stems, which they can then use as a bootstrapping mechanism for morphological parsing later in reading development (Beyersmann & Grainger, in press; Beyersmann, Grainger, & Castles, 2019; Grainger & Beyersmann, 2017; Tucker, Castles, Laroche, & Deacon, 2016). Once again, our findings appear to mirror this developmental aspect, given that significant embedded word training effects were observed independently of whether the stems were accompanied by a real affix or a non-affix. Even though our participants were fully proficient adult readers and therefore expert at rapidly segmenting complex words into morphemic subunits, the present eye-tracking data indicate that a single print exposure may not be sufficient to trigger morphological processing.

It is worth noting that the current study employed a tightly controlled experimental design based on a selection of only two affixal endings (i.e., *-or* and *-ist*) both of which occur in morphemic (e.g., *-or* in *actor* and *-ist* in *egoist*) as well as non-morphemic orthographic sequences (e.g., *-or* in *floor* and *-ist* in *twist*). Although this raises the possibility that the affix effect was washed out by the ambiguity of the morphemic status of the selected items, the orthographic forms of *-or* and *-ist* were used in an entirely non-ambiguous morphemic context (e.g., “Pip showed his sandy body to the tumpist to get it cleaned.”) and are also more standardly encountered as morphemic rather than non-morphemic endings, thus making a non-morphemic interpretation highly unlikely. Future research may build on the current

findings by using a broader variety of affixal endings to further test the generalisability to other items.

Another prospect for future work lies in the investigation of semantic influences of complex word learning (e.g., Keenan & Betjemann, 2007; Taylor et al., 2015). Having established that oral vocabulary knowledge supports subsequent reading of complex forms, more work is necessary to disentangle the role of phonology and semantics in this process. A relationship between oral vocabulary and reading has been observed based on knowledge of phonological form alone (e.g., Duff & Hulme, 2012; McKague et al., 2001; Nation & Cocksey, 2009) and in combination with semantics (e.g., Kearns & Al Ghanem, 2019; Kearns et al., 2016; Ricketts et al., 2016; Taylor et al., 2011). Semantics have also been shown to play a fundamental role in children's acquisition of morphologically complex words (e.g., Beyersmann et al., 2012; Schiff et al., 2012) and are thought to represent an important pre-requisite in the development of novel morphemic knowledge (e.g., Beyersmann & Grainger, in press; Grainger & Beyersmann, 2017). Future work may test the potential role for semantics in complex word acquisition by directly comparing the training of phonological forms with and without semantics.

Finally, in the reading aloud and spelling data, we observed that affixed novel words were read out aloud faster than non-affixed novel words, showing that the presence of familiar affixes facilitated reading, a finding that is typically seen in this modality (e.g., Burani, Marcolini, De Luca, & Zoccolotti, 2008; Mousikou et al., 2020). However, there was no effect of training, suggesting that the effect of oral vocabulary training does not extend beyond the initial print exposure. The reading aloud and spelling tasks were administered following the eye-tracking phase, such that participants had the opportunity to familiarise themselves with the orthographic forms of both trained and untrained items prior to taking part in the follow up tasks. It is also possible that the reading aloud and spelling measures

were generally less sensitive to the training effect observed on eye-tracking measures. This might reflect differences related to the testing modality, but could also reflect differences in task demands. For example, during the spelling task participants may have relied on their knowledge of sound-to-letter mappings to produce their responses. Because the stems were designed to have highly predictable spellings, this would have been sufficient to support performance on both trained and untrained items.

In sum, the current study highlights the flexibility and adaptability of the reading system as it processes novel complex words during the first print exposure. Participants were able to use their prior oral word knowledge to identify novel embedded reading units during silent reading despite never having previously encountered their spellings. Our findings provide evidence for the complex interplay between the spoken and written language modalities. The current data also have implications for reading acquisition, suggesting that the important role of spoken word knowledge is likely to extend to morphologically complex words. Further work is required to explore the nature of this relationship across reading development.

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Appendix A

Lists of novel words used during spoken word training. The number of orthographic neighbours (Orth N) for each item were retrieved using NWatch.

| Set 1 | | | | | |
|-----------|-------|--------|------------|-----------|--------------|
| # | item | Orth N | N phonemes | N letters | CV-structure |
| 1 | semp | 5 | 4 | 4 | CVCC |
| 2 | jorm | 5 | 3 | 4 | CVCC |
| 3 | vesp | 1 | 4 | 4 | CVCC |
| 4 | mulb | 3 | 4 | 4 | CVCC |
| 5 | bist | 8 | 4 | 4 | CVCC |
| 6 | tump | 10 | 4 | 4 | CVCC |
| 7 | hift | 8 | 4 | 4 | CVCC |
| 8 | relp | 4 | 4 | 4 | CVCC |
| 9 | goft | 5 | 4 | 4 | CVCC |
| 10 | lorb | 4 | 3 | 4 | CVCC |
| 11 | fosh | 9 | 3 | 4 | CVCC |
| 12 | poon | 15 | 3 | 4 | CVVC |
| 13 | chust | 2 | 4 | 5 | CCVCC |
| 14 | nesh | 4 | 3 | 4 | CVCC |
| 15 | darb | 7 | 3 | 4 | CVCC |
| 16 | thalp | 0 | 4 | 5 | CCVCC |
| Average | | 5.63 | 3.63 | 4.13 | |
| Std. Dev. | | 3.77 | 0.5 | 0.34 | |
| Set 2 | | | | | |
| # | item | Orth N | N phonemes | N letters | CV-structure |
| 1 | deld | 9 | 4 | 4 | CVCC |
| 2 | foob | 4 | 3 | 4 | CVVC |
| 3 | tisp | 2 | 4 | 4 | CVCC |
| 4 | vilm | 2 | 4 | 4 | CVCC |
| 5 | rusp | 7 | 4 | 4 | CVCC |
| 6 | bimp | 3 | 4 | 4 | CVCC |
| 7 | seft | 10 | 4 | 4 | CVCC |
| 8 | nilt | 10 | 4 | 4 | CVCC |
| 9 | pelm | 5 | 4 | 4 | CVCC |
| 10 | garp | 7 | 3 | 4 | CVCC |
| 11 | lish | 8 | 3 | 4 | CVCC |
| 12 | moil | 7 | 3 | 4 | CVVC |
| 13 | thift | 2 | 4 | 5 | CCVCC |
| 14 | jash | 11 | 3 | 4 | CVCC |
| 15 | hulp | 7 | 4 | 4 | CVCC |
| 16 | chort | 4 | 3 | 5 | CCVCC |
| Average | | 6.13 | 3.63 | 4.13 | |
| Std. Dev. | | 3.05 | 0.5 | 0.34 | |

Appendix B

Full list of eye-tracking materials, including four different sets (1A, 2A, 1B, and 2B).

| SETS 1A AND 2A | | | | | |
|-----------------------|----------|------------|-----------------|-----------------|---|
| # | Targets | Affix Type | Training Set 1A | Training Set 2A | Sentences |
| 1 | vespor | affix | trained | untrained | Rick gave his dirty socks to the vespor to get them cleaned. |
| 2 | lorbor | affix | trained | untrained | Diana gave the best orange to the lorbor to get it juiced. |
| 3 | sempor | affix | trained | untrained | Pam gave the dirty flowers to the sempor to make them shiny. |
| 4 | mulbor | affix | trained | untrained | Max gave his food to the mulbor to remove the green peas. |
| 5 | foshist | affix | trained | untrained | Sara gave her soaking wet hat to the foshist to dry it. |
| 6 | poonist | affix | trained | untrained | Lucy gave the rubbish to the poonist to sort it for recycling. |
| 7 | neshist | affix | trained | untrained | Lucas mentioned his sore tummy to the neshist to get better again. |
| 8 | darbist | affix | trained | untrained | Jennifer gave all her soggy chips to the darbist to crisp them. |
| 9 | bistel | non-affix | trained | untrained | Nick gave the playing cards to the bistel before starting the game. |
| 10 | hiftel | non-affix | trained | untrained | Rex gave the tennis balls to the hiftel as he played fetch. |
| 11 | chustel | non-affix | trained | untrained | James gave the picture to the chustel to work out the name. |
| 12 | relpel | non-affix | trained | untrained | Jane showed her cold feet to the relpel to warm them up. |
| 13 | jormain | non-affix | trained | untrained | Matt gave the boots to the jormain to walk up the wall. |
| 14 | thalpain | non-affix | trained | untrained | Sam saw a bird and asked the thalpain to make it sing. |
| 15 | goftain | non-affix | trained | untrained | Ben gave the fish tank to the goftain to get it cleaned. |
| 16 | tumpain | non-affix | trained | untrained | Pip showed his sandy body to the tumpain to get it cleaned. |
| 17 | tispor | affix | untrained | trained | Rick gave his dirty socks to the tispor to get them cleaned. |
| 18 | garpor | affix | untrained | trained | Diana gave the best orange to the garpor to get it juiced. |
| 19 | deldor | affix | untrained | trained | Pam gave the dirty flowers to the deldor to make them shiny. |
| 20 | vilmor | affix | untrained | trained | Max gave his food to the vilmor to remove the green peas. |
| 21 | lishist | affix | untrained | trained | Sara gave her soaking wet hat to the lishist to dry it. |

| | | | | | |
|----|----------|-----------|-----------|---------|---|
| 22 | moilist | affix | untrained | trained | Lucy gave the rubbish to the moilist to sort it for recycling. |
| 23 | jashist | affix | untrained | trained | Lucas mentioned his sore tummy to the jashist to get better again. |
| 24 | hortist | affix | untrained | trained | Jennifer gave all her soggy chips to the hortist to crisp them. |
| 25 | ruspel | non-affix | untrained | trained | Nick gave the playing cards to the ruspel before starting the game. |
| 26 | seftel | non-affix | untrained | trained | Rex gave the tennis balls to the seftel as he played fetch. |
| 27 | thiftel | non-affix | untrained | trained | James gave the picture to the thiftel to work out the name. |
| 28 | niltel | non-affix | untrained | trained | Jane showed her cold feet to the niltel to warm them up. |
| 29 | foobain | non-affix | untrained | trained | Matt gave the boots to the foobain to walk up the wall. |
| 30 | chulpain | non-affix | untrained | trained | Sam saw a bird and asked the chulpain to make it sing. |
| 31 | pelmain | non-affix | untrained | trained | Ben gave the fish tank to the pelmain to get it cleaned. |
| 32 | bimpain | non-affix | untrained | trained | Pip showed his sandy body to the bimpain to get it cleaned. |

SETS 1B AND 2B

| # | Targets | Affix Type | Training Set 1B | Training Set 2B | Sentences |
|----|---------|------------|-----------------|-----------------|---|
| 1 | vespel | non-affix | trained | untrained | Rick gave his dirty socks to the vespel to get them cleaned. |
| 2 | lorbel | non-affix | trained | untrained | Diana gave the best orange to the lorbel to get it juiced. |
| 3 | sempel | non-affix | trained | untrained | Pam gave the dirty flowers to the sempel to make them shiny. |
| 4 | mulbel | non-affix | trained | untrained | Max gave his food to the mulbel to remove the green peas. |
| 5 | foshain | non-affix | trained | untrained | Sara gave her soaking wet hat to the foshain to dry it. |
| 6 | poonain | non-affix | trained | untrained | Lucy gave the rubbish to the poonain to sort it for recycling. |
| 7 | neshain | non-affix | trained | untrained | Lucas mentioned his sore tummy to the neshain to get better again. |
| 8 | darbain | non-affix | trained | untrained | Jennifer gave all her soggy chips to the darbain to crisp them. |
| 9 | bistor | affix | trained | untrained | Nick gave the playing cards to the bistor before starting the game. |
| 10 | hifto | affix | trained | untrained | Rex gave the tennis balls to the hifto as he played fetch. |
| 11 | chustor | affix | trained | untrained | James gave the picture to the chustor to work out the name. |
| 12 | relpor | affix | trained | untrained | Jane showed her cold feet to the relpor to warm them up. |

| | | | | | |
|----|----------|-----------|-----------|-----------|---|
| 13 | jormist | affix | trained | untrained | Matt gave the boots to the jormist to walk up the wall. |
| 14 | thalpist | affix | trained | untrained | Sam saw a bird and asked the thalpist to make it sing. |
| 15 | goftist | affix | trained | untrained | Ben gave the fish tank to the goftist to get it cleaned. |
| 16 | tumpist | affix | trained | untrained | Pip showed his sandy body to the tumpist to get it cleaned. |
| 17 | tispel | non-affix | untrained | trained | Rick gave his dirty socks to the tispel to get them cleaned. |
| 18 | garpel | non-affix | untrained | trained | Diana gave the best orange to the garpel to get it juiced. |
| 19 | deldel | non-affix | untrained | trained | Pam gave the dirty flowers to the deldel to make them shiny. |
| 20 | vilmel | non-affix | untrained | trained | Max gave his food to the vilmel to remove the green peas. |
| 21 | lishain | non-affix | untrained | trained | Sara gave her soaking wet hat to the lishain to dry it. |
| 22 | moilain | non-affix | untrained | trained | Lucy gave the rubbish to the moilain to sort it for recycling. |
| 23 | jashain | non-affix | untrained | trained | Lucas mentioned his sore tummy to the jashain to get better again. |
| 24 | hortain | non-affix | untrained | trained | Jennifer gave all her soggy chips to the hortain to crisp them. |
| 25 | ruspor | affix | untrained | trained | Nick gave the playing cards to the ruspor before starting the game. |
| 26 | seftor | affix | untrained | trained | Rex gave the tennis balls to the seftor as he played fetch. |
| 27 | thiftor | affix | untrained | trained | James gave the picture to the thiftor to work out the name. |
| 28 | niltor | affix | untrained | trained | Jane showed her cold feet to the niltor to warm them up. |
| 29 | foobist | affix | untrained | trained | Matt gave the boots to the foobist to walk up the wall. |
| 30 | chulpist | affix | untrained | trained | Sam saw a bird and asked the chulpist to make it sing. |
| 31 | pelmist | affix | untrained | trained | Ben gave the fish tank to the pelmist to get it cleaned. |
| 32 | bimpist | affix | untrained | trained | Pip showed his sandy body to the bimpist to get it cleaned. |