The Role of Orthographic and Semantic Learning in Word Reading and Reading Comprehension

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Abstract

We tested the theoretically driven hypotheses that children's orthographic and semantic learning are associated with their word reading and reading comprehension skills, even when orthographic and semantic knowledge are taken into account. A sample of 139 English-speaking Grade 3 children completed a learning task in which they read stories about new inventions. Then, they were tested on their learning of the spelling and meaning of the inventions (i.e., orthographic and semantic learning, respectively). Word reading and reading comprehension were assessed with standardised tasks, and orthographic and semantic knowledge were assessed with choice tasks targeting the spelling and meaning of existing words. The results of our structural equation modeling indicated that orthographic learning predicted word reading directly and reading comprehension indirectly via word reading. We also found that semantic learning predicted reading comprehension directly. These findings support integration of the self-teaching hypothesis and the lexical quality hypothesis.

The Role of Orthographic and Semantic Learning in Word Reading and Reading Comprehension

Orthographic knowledge corresponds to the ability to access one's existing representations of the spelling of words (Deacon, Benere, & Castles, 2012). Similarly, semantic knowledge is the ability to access one's existing representations of the meaning of words (Perfetti & Hart, 2002). Orthographic and semantic knowledge are crucial for reading (e.g., Cunningham, Perry, & Stanovich, 2001; Nation & Snowling, 2004; Ouellette, 2006; Roth, Speece, & Cooper, 2002; Wagner & Barker, 1994). However, what remains unclear is whether this stored knowledge, which some claim is actually indistinguishable from the ability to read (Deacon, Pasquarella, Marinus, Tims, & Castles, 2018), is sufficient to explain individual differences in reading. It might be the case that children's facility in acquiring knowledge, that is, their ability to learn, also matters (Deacon et al., 2012, 2018). The objective of the present study was to examine the role that such learning plays in reading. Specifically, we investigated two types of learning: learning of the spelling of new written words during reading, or orthographic learning (Share, 1995), and learning of the meaning of new written words during reading, or semantic learning (Ricketts, Bishop, & Nation, 2008). We tested the theoretically driven hypotheses that children's orthographic and semantic learning are associated with their word reading and reading comprehension skills.

Theoretical Views on Reading

The self-teaching hypothesis (Share, 1995) proposes that the accurate translation of a written word into its spoken form (i.e., phonological decoding) enables orthographic learning, the formation of an orthographic representation for the word. This orthographic learning in turn facilitates the reading of the word at a later time. As such, the self-teaching hypothesis predicts that children's orthographic learning, and not only their stored orthographic knowledge, underlies the development of their word reading skills (Share, 1995). Given that children need to use their word reading skills in order to understand written text, as encapsulated by the simple view of reading (Gough & Tunmer, 1986), orthographic learning should also contribute indirectly to reading comprehension via its effect on word reading.

Other influential theories of reading, such as the lexical quality hypothesis (Perfetti & Hart, 2002), speculate that semantic representations, in addition to phonological and orthographic representations, are key to reading (see also Ehri, 2014; Plaut, McClelland, Seidenberg, & Patterson, 1996)[1]. In other words, knowing the meaning of a word, in addition to knowing how it is pronounced and spelled, should help with reading that word. In fact, according to the lexical quality hypothesis, having many high quality lexical representations, that is, representations that contain tightly integrated phonological, orthographic, and semantic information, will support better word reading and reading comprehension.

The lexical quality hypothesis focuses on acquired lexical representations, with little discussion of individual differences in the ability to achieve this acquisition. Yet, when children encounter a new word in text, it is likely that the resulting semantic representation will vary across children. Therefore, if we extend the lexical quality hypothesis to the process of acquisition of semantic representations, as the self-teaching hypothesis does for orthography, we can postulate that children's semantic learning will be a source of individual differences in word reading and reading comprehension, in addition to semantic knowledge. As children's understanding of texts depends on their understanding of words' meaning (e.g., Ouellette, 2006), we expect semantic learning to contribute to reading comprehension directly.

Empirical Research on Orthographic and Semantic Learning

In empirical studies of orthographic learning (e.g., Bowey & Miller, 2007; Cunningham, 2006; Ouellette & Fraser, 2009; Ricketts, Bishop, Pimperton, & Nation, 2011; Tucker, Castles, Laroche, & Deacon, 2016; Wang, Castles, Nickels, & Nation, 2011), children typically read stories containing new words (e.g., *veap*), and they are then asked to spell or choose the correct spelling of those new words (e.g., *veap* or *veep*). Research has shown that such measures of orthographic learning were significantly correlated with scores on standardised measures of word reading and reading comprehension in 7- and 8-year-old children (Bowey & Miller, 2007; Cunningham, 2006; Ricketts et al., 2011). Such correlations resonate with observations of impaired orthographic learning in children with poor word reading skills, relative to typically developing children of the same age (Bailey, Manis, Pedersen, & Seidenberg, 2004; Wang, Marinus, Nickels, & Castles, 2014). Interestingly, children with poor reading comprehension skills but age-appropriate word reading skills do not show deficits in orthographic learning (Ricketts et al., 2008). This finding suggests that the relation between orthographic learning and reading comprehension observed in other studies (e.g., Ricketts et al., 2011) is indirect through word reading.

In most orthographic learning studies, new words have been presented in meaningful stories such that children may have used this context to infer the meaning of the words. However, only a handful of studies have investigated such semantic learning and its relation to reading (Cain, Oakhill, & Elbro, 2003; Cain, Oakhill, & Lemmon, 2004; Ricketts et al., 2008, 2011). In these studies, after reading the stories containing new words, children were asked to define or choose a picture depicting the meaning of the new words (e.g., a giraffe or a lion). Ricketts et al. (2011) found significant associations between such measures of semantic learning and scores on standardised measures of word reading and reading comprehension in 8-year-old children. In addition, Cain et al. (2003, 2004) and Ricketts et al. (2008) showed that 8- and 9-year-olds with poor reading comprehension skills were impaired on semantic learning, in comparison to typically developing children of the same age.

In sum, a review of the extant literature suggests that each of orthographic learning and semantic learning is associated with both word reading and reading comprehension. Importantly, however, the main objective of prior studies was to identify the skills predicting orthographic and semantic learning rather than the skills predicted by orthographic and semantic learning. Indeed, although several researchers reported significant zero-order correlations between orthographic learning and word reading, the main finding of their studies was that phonological decoding and orthographic knowledge contributed to orthographic learning (Bowey & Miller, 2007; Cunningham, 2006; Ricketts et al., 2011). Similarly, despite reporting a significant zero-order correlation between semantic learning and reading comprehension, Ricketts et al.'s (2011) main conclusion about semantic learning was that it was best predicted by semantic knowledge.

The present study sought to take a different approach, investigating whether individual differences in orthographic and semantic learning could predict individual differences in word reading and reading comprehension in a design including important control variables. It is well established that orthographic and semantic knowledge are associated with orthographic and semantic learning (Cunningham, 2006; Ricketts et al., 2011) as well as with word reading and reading comprehension (Barker, Torgesen, & Wagner, 1992; Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Cunningham et al., 2001; Deacon, 2012; Nation & Snowling, 2004). As such, it is imperative to take orthographic and semantic knowledge into account to determine whether there are direct relations between learning and reading that are not driven by the relations between knowledge and reading. The present study builds on previous research by including measures of orthographic and semantic knowledge as controls in investigating the associations between orthographic and semantic learning and word reading and reading comprehension.

Another methodological issue is worth noting. In previous studies on semantic learning of new written words (Cain et al., 2003, 2004; Ricketts et al., 2008, 2011), children have learned new labels for existing concepts, which is more akin to second than first language acquisition. For example, *lork* was a new label for a giraffe, a very specific existing concept (Ricketts et al., 2011), and *wut* was a new label for a bouncing ball, a somewhat broader existing concept (Cain et al., 2004). However, to our knowledge, no study has yet assessed semantic learning with new written words labelling new concepts, a fundamentally different task that children encounter throughout school years and beyond (Graves, 2006). Admittedly, generating genuinely new concepts for children to learn in an experimental setting is not straightforward. Yet, Wang et al. (2011), who investigated orthographic but not semantic learning, tried to adopt this approach by presenting new inventions (e.g., a fish tank cleaner) to children. In the present study, we extend this paradigm to semantic learning.

The Present Study

The objective of the present study was to examine whether orthographic and semantic learning are associated with word reading and reading comprehension. We expected such relations, albeit in different ways for each type of learning. Specifically, we hypothesised that orthographic learning would be associated directly with word reading and indirectly with reading comprehension through word reading. Furthermore, we hypothesised that semantic learning would be associated directly with both word reading and reading comprehension. Importantly, we investigated whether these relations would hold after taking into account orthographic and semantic knowledge, along with other control measures.

Method

Participants

This study has been approved by the Social Sciences and Humanities Research Ethics Board of Dalhousie University. Following prior work, we recruited 8- and 9-year-old children in Grade 3 (see Bowey & Miller, 2007; Cain et al., 2003, 2004; Ricketts et al., 2008, 2011). At this age, most children have sufficient reading skills in order to read to acquire new information (Chall, 1983). We recruited children from a combination of urban and rural public elementary schools in Nova Scotia. We obtained parental consent for 139 children. All but four children (3%) spoke English as their first language. This is representative of people's home language in Nova Scotia (Government of Canada, Statistics Canada, n.d.). Participants (74 boys and 65 girls) had a mean age of 8.80 years at the time of testing (*SD* = 0.29; range: 8.15–9.37). As illustrated by the standardised means presented in Table 1, participants represented a sample of typically developing children.

Materials

Learning task. We measured orthographic and semantic learning within the same learning task in order to reduce any unnecessary differences between the measures (see Ricketts et al., 2008, 2011). We designed the learning task based on the orthographic learning paradigm described in the literature (see Bowey & Miller, 2007; Cunningham, 2006; Ricketts et al., 2011; Tucker et al., 2016; Wang et al., 2011). Participants were asked, in the exposure phase, to read stories that contained non-words. Then, they were questioned on the spelling and meaning of those non-words in orthographic and semantic learning post-tests, respectively.

Exposure phase. *Stories*. Participants were asked to read 12 stories out loud (for an example, see Appendix A). The stories were adapted from Wang et al.'s (2011) work. Each story contained four repetitions of one non-word. All stories were made of five sentences and were built with the same structure: The first sentence stated the context and the problem; the second sentence described an initial action between the character and the invention; the third sentence explained the function of the invention; the fourth sentence described an action between the character, the invention, and the object of the problem; and the fifth sentence described an action between the character and the invention when the problem was solved.

During the reading of the stories, the experimenter provided feedback as needed, that is, whenever a word or non-word was mispronounced, skipped, or added. This ensured that semantic learning could occur in all participants, even those with poor word reading skills. We thought that a child who could not read a word would have difficulty understanding the function of the invention being described in the story. Furthermore, a child who could not decode a non-word (e.g., *veap*) would have difficulty learning its meaning without a label, especially since we referred to it orally in some of the post-tests.

Non-words. The non-words presented in the stories represented new concepts, that is, new inventions created by a fictitious professor (e.g., a fish tank cleaner). In accordance with previous research, we followed strict criteria to select the non-words and their spellings (see Ricketts et al., 2011). First, to confirm that the non-word forms were novel to the children, we checked that none of them were listed in the Children's Printed Word Database (http://www.essex.ac.uk/psychology/cpwd). Second, the spellings of all the non-words were regular, such that their expected pronunciation was based on the typical grapheme-phoneme correspondence rules listed in Rastle and Coltheart (1999). Third, we selected non-words that had a similar structure (monosyllabic four-letter non-words starting and ending with a consonant sound) but that were distinct enough from each other (they each started with a different letter). Finally, the non-words were designed to contain a target sound (e.g., /i/) that could be spelled in different ways (e.g., *ea* or *ee*). This was done so that we could use the alternative spelling as a distractor in the orthographic choice post-test. To control for any preference for a given spelling, each target sound was present in two non-words and spelled differently in each of them (e.g., /i/ in *veap* and *seef*). In addition, half of the participants were presented with one spelling of the non-words (e.g., *veap*) and the other half were presented with the alternative spelling (e.g., *veep*). See Table 2 for a list of the non-words.

Orthographic learning post-tests. After reading a set of three stories, participants were asked to complete a spelling post-test. In this post-test, the experimenter asked the participants to spell each non-word on a sheet in a pre-randomised order (e.g., "Spell *veap*"). Participants' answers were each scored as correct or incorrect. All reversed letters were considered as incorrect. This decision was made because some of the non-words contained letters that looked like a different letter when reversed (e.g., *b*, which looks like a *d* when reversed). It would then have been impossible to tell whether a child wrote the wrong letter or inversed the right letter. Considering all reversed letters as incorrect ensured that all non-words were scored equally.

After reading all 12 stories, participants were asked to complete an orthographic choice post-test. In this post-test, the experimenter showed four spellings to the participants and asked them to identify the spelling of the invention they read about (e.g., "Show me the spelling of *veap*"). The four choices were presented on one page so that one choice was on each corner. The order of the items and that of the choices were pre-randomised. One of the distractors corresponded to the alternative spelling of the target non-word (e.g., *veep*). The two other distractors were identical to the correct and alternative spellings of the target non-word except for the first or last letter (e.g., *feap* and *feep*).

No feedback was given during any of the orthographic learning post-tests. The post-tests reached satisfactory reliability for research purposes (≥ .65; DeVellis, 1991; Hair, Black, Babin, & Anderson, 2010; Roszkowski & Scott Spreat, 2011). For spelling, Cronbach's alpha for our sample was .78. For orthographic choice, like in several studies on orthographic learning, we assessed both immediate recall and delayed retention by asking children to complete the post-test twice: once immediately after the exposure phase and again a few days after the exposure phase (see the Procedure section for more details; see Ouellette & Fraser, 2009; Tucker et al., 2016; Wang et al., 2011). The correlation between immediate and delayed orthographic choice was .73.

Semantic learning post-tests. After reading a set of three stories, participants were asked to complete a definition post-test. In this post-test, the experimenter asked the participants to orally define each non-word in a pre-randomised order (e.g., "Tell me what a veap is used for"). In order to be considered as correct, an answer had to include the object related to the invention (e.g., clean fish tanks and not only clean) and to be associated with the correct non-word (e.g., clean fish tanks as an answer to *veap* and not another non-word). Synonyms were accepted.

After reading all 12 stories, participants were asked to complete two post-tests: a matching post-test and a semantic choice post-test. In contrast with the other orthographic and semantic post-tests, the matching post-test was novel to our study. We made this addition to assess children's ability to distinguish between the meanings of different new words. The experimenter presented cards to the participants and asked them to put them back in order (i.e., to match them). The beginning of the third sentence of the stories (e.g., "The veap is used to…") was written on half of the cards and the ending of the sentence (e.g., "… clean fish tanks") was written on the other half. The cards were presented in sets of three sentences in the same order as the stories. Within each set, the order of the cards was pre-randomised with the beginnings always presented first, followed by the endings. The experimenter read each card out loud in order to reduce any effect of word reading skills on performance.

In the semantic choice post-test (for an example, see Appendix B), the experimenter showed four pictures to the participants and asked them to identify the picture of the invention they read about (e.g., "Show me the picture of a veap"). The four choices were presented on one page so that one choice was on each corner. The order of the items and that of the choices were pre-randomised. One of the distractors corresponded to an invention related to the same object as that of the target non-word (e.g., a fish tank painter). The two other distractors were related to the same new object (e.g., a sock matcher and a sock fixer).

No feedback was given during any of the semantic learning post-tests. The definition and semantic choice post-tests reached satisfactory reliability for research purposes (≥ .65; DeVellis, 1991; Hair et al., 2010; Roszkowski & Scott Spreat, 2011), but the matching post-tests did not. For definition, Cronbach's alpha for our sample was .66. Furthermore, two research assistants scored this post-test for 15 randomly chosen participants and the intra-class correlation coefficient was .97. For matching and semantic choice, like for orthographic choice, the post-tests were each done twice: immediately after the exposure phase to measure immediate recall and a few days after the exposure phase to measure delayed retention (see the Procedure section for more details). The correlation between immediate and delayed matching was .42. As explained in the Results section, these measures were not included in the final analyses. The correlation between immediate and delayed semantic choice was .69.

Reading measures. To measure word reading, we used two standardised tasks, one of fluency and one of accuracy. Word reading fluency was assessed with the Sight Word Efficiency subtest of the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999). In this task, participants were given 45 seconds to read a list of words as fast as possible. The manual reports a reliability of .93 for this task. Word reading accuracy was assessed with the Word Identification subtest of the revised version of the Woodcock Reading Mastery Tests (WRMT-R; Woodcock, 1998), in which participants were asked to read words that became increasingly more difficult. The manual reports a reliability of .97 for this task. To measure reading comprehension, we used the Level 3 Comprehension subtest of the fourth edition of the Gates-MacGinitie Reading Tests (GMRT-4; MacGinitie, MacGinitie, Maria, Dreyer, & Hughes, 2007). In this task, participants were given 35 minutes to read short texts silently and answer multiple-choice questions. The manual reports a reliability of .93 for this task. All these reading measures were administered and scored according to the corresponding manual's guidelines.

Control measures. We included three standardised tasks as control measures because of their recognised involvement in reading (see Cain, 2007; Deacon, 2012; Deacon et al., 2012). First, we measured non-verbal reasoning, as it was found to be correlated with word reading in Grade 3 children (e.g., Deacon et al., 2012). We used the Matrix Reasoning subtest of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), in which participants were shown incomplete patterns and asked to identify, out of five choices, the piece that completed each pattern. The manual reports a reliability of .86 for this task. Second, we measured working memory, as it is associated with both word reading and reading comprehension in 9-year-old children (e.g., Cain, 2007). We used the Digit Span subtest of the fourth edition of the Wechsler Intelligence Scale for Children (WISC-4; Wechsler, 2003). In this task, participants were asked to repeat series of digits of increasing length in the same order or backwards. The manual reports a reliability of .91 for this task. Finally, we measured phonological awareness, as it was found to be correlated with word reading in Grade 3 children (e.g., Deacon, 2012). We used the Elision subtest of the second edition of the Comprehensive Test of Phonological Processing (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013), in which participants were asked to repeat words without pronouncing certain phonemes (e.g., "cup" without /k/). The manual reports a reliability of .93 for this task. All these control measures were administered and scored according to the corresponding manual's guidelines.

Furthermore, orthographic knowledge and semantic knowledge are associated with word reading and reading comprehension and with orthographic and semantic learning in 7- to 10-year-old children (e.g., Cunningham, 2006; Deacon, 2012; Ouellette, 2006; Ricketts et al., 2011).

As such, we included these controls as well. Based on previous research, we measured orthographic knowledge with a task adapted from Olson, Kliegl, Davidson, and Foltz (1985; see Barker et al., 1992; Berninger et al., 1994; Cunningham et al., 2001; Deacon, 2012). In this task, participants were presented with 25 written sentences in which the last word was spelled in two different ways: One spelling was correct and the other one was a non-word homophone (e.g., "At night, we go to sleap/sleep"). The correct spelling was presented first for half of the sentences and second for the other half. The experimenter read each sentence out loud to the participants, who were then asked to circle the correct spelling. Cronbach's alpha for this task was .77 for our sample. Finally, to measure semantic knowledge, we used a 51-item version of the third edition of the standardised Peabody Picture Vocabulary Test (PPVT-3; Dunn & Dunn, 1997). This shortened version was validated by Sparks and Deacon (2015) in Grade 1 to 3 children. In this task, participants were shown sets of four black and white pictures and asked to identify the picture that corresponded to each spoken word. Cronbach's alpha for this task was .79 for our sample.

Procedure

Participants completed the tasks in two individual sessions and one group session. In the first individual session, they completed the Sight Word Efficiency subtest of the TOWRE. Then, they completed the exposure phase of the learning task. After each set of three stories, they completed the spelling and the definition post-tests for the non-words they had just read. After reading all 12 stories, they completed the matching, the orthographic choice, and the semantic choice post-tests. Then, they completed the Matrix Reasoning subtest of the WASI.

The second individual session was completed one to nine days after the first one (*M* = 1.93; *SD* = 1.39). In this session, participants completed for a second time the orthographic choice, the semantic choice, and the matching post-tests. Then, they completed the Word

Identification subtest of the WRMT-R, the adaptation of the PPVT-3, the Digit Span subtest of the WISC-4, and the Elision subtest of the CTOPP-2. For 90% of the participants, the delay between the first and the second session was one to three days. However, the delay was longer for some children due to special circumstances such as absenteeism. A longer delay is likely to be associated with lower scores in delayed retention in the learning task. If due to absenteeism, it might also be indicative of lower school achievement in general, including reading. As such, the delay between the sessions was used as a control variable in the analyses.

The group session was completed in groups of up to 12 participants one to nine days after the first individual session ($M = 2.27$; $SD = 2.12$). In this session, participants completed the orthographic knowledge task and the Comprehension subtest of the GMRT-4.

Results

We conducted descriptive and correlational analyses in IBM SPSS Statistics 23. During the exposure phase of the learning task, participants read a mean of 95% of the words and 77% of the non-words accurately. Descriptive statistics of the other measures are presented in Table 1. In the orthographic choice post-tests of the learning task, children's mean performance was above the chance level of 6 out of 24, $t(137) = 35.21$, $p < .001$. The alternative spelling of the target non-word (e.g., *veep* instead of *veap*) was chosen 24% of the time, and together, the other distractors (e.g., *feap* and *feep*) were chosen 3% of the time. In the semantic choice post-tests, children's mean performance was also above the chance level of 6 out of 24, $t(137) = 43.77$, $p < .001$. The invention related to the same object as that of the target non-word (e.g., a fish tank painter instead of a fish tank cleaner) was chosen 15% of the time, and together, the other distractors (e.g., a sock matcher and a sock fixer) were chosen 6% of the time. Correlations between all measures are presented in Table 3. As expected, most correlations within the learning task measures and between the learning task measures and the reading measures were significant, and they ranged from modest to strong. The control measures were also significantly correlated with many of the learning task and reading measures, indicating their relevance as control variables.

To investigate the role of orthographic and semantic learning in word reading and reading comprehension, we conducted structural equation modeling with Mplus 7. Structural equation modeling enabled us to group our several variables into latent factors and to simultaneously test several paths between our variables. By contrast, regression would have required numerous separate analyses, increasing Type I error and resulting in a harder-to-interpret picture. It should be noted, nevertheless, that we have replicated our main results with regression analysis.

In our structural equation modeling analyses, we used raw scores only and chose the MLR estimator, which is robust to non-normality. All available data were used (our sample contained less than 1% of missing data). In terms of model fit, we used the following guidelines: The χ^2/df ratio should not exceed 3 (Iacobucci, 2010; Schermelleh-Engel, Moosbrugger, & Müllerm, 2003), values of CFI should be close to .95 or higher, and values of SRMR should be close to .08 or lower (Hu & Bentler, 1999). We did not place too much importance in the *p* value associated with χ^2, given the influence of moderate to large sample sizes on this statistic (Iacobucci, 2010). Furthermore, we did not rely on RMSEA, as suggested by Hu and Bentler (1999) for samples of 250 participants or fewer.

Measurement model. First, we tested a measurement model to ensure that our multiple measures of orthographic learning, semantic learning, and word reading well represented those constructs. In this model, we included an Orthographic Learning latent factor that consisted of the three orthographic learning post-tests: spelling, immediate orthographic choice, and delayed orthographic choice. Similarly, we included a Semantic Learning latent factor that consisted of the five semantic learning post-tests: definition, immediate matching, delayed matching, immediate semantic choice, and delayed semantic choice. Finally, we included a Word Reading latent factor that consisted of the two measures of word reading: fluency and accuracy. Following Hermida's (2015) recommendations, we did not allow errors to correlate since we did not have a priori hypotheses about which measures would correlate together the most (e.g., different measures from the same session vs. the same measures from different sessions).

The initial model fitted our data poorly, $\chi^2(32) = 128.71$, $p < .001$, $\chi^2/df = 4.02$, CFI = .85, SRMR = .11. As illustrated in Figure 1a, all orthographic learning and word reading measures loaded properly on their respective factors. Immediate and delayed semantic choice also loaded properly on the Semantic Learning factor. However, definition, immediate matching, and delayed matching loaded weakly on the Semantic Learning factor (.27–.37). These measures also had the lowest reliability values ($\alpha = .66$ for definition and $r = .42$ for matching). As such, these three measures were removed from the model. This modification resulted in an acceptable fit, $\chi^2(11) = 30.02$, $p = .002$, $\chi^2/df = 2.73$, CFI = .96, SRMR = .04 (see Figure 1b).

Predictive model. To test our hypotheses, we created a predictive model from our modified measurement model. We included paths from orthographic learning to both word reading and reading comprehension. Likewise, we included paths from semantic learning to both word reading and reading comprehension. Moreover, we included a path from word reading to reading comprehension to test the hypothesis that orthographic learning is associated with reading comprehension indirectly through word reading. We also included seven control variables: age, delay between the sessions, non-verbal reasoning, working memory, phonological awareness, orthographic knowledge, and semantic knowledge. Finally, we included correlations between all predictors (orthographic learning, semantic learning, and the control variables) to account for the covariance between these variables.

Our main results are summarised in Figure 2. The model fitted our data well, $\chi^2(43) = 84.72$, $p < .001$, $\chi^2/df = 1.97$, CFI = .95, SRMR = .04. It explained 82% of the variance in word reading and 59% of the variance in reading comprehension.

When examining the significance of the paths predicting word reading and reading comprehension, it is important to bear in mind what these paths represent: the effects of the predictors on the residual variance in word reading and reading comprehension (i.e., the variance that is left after all the other predictors have been taken into account). We found that orthographic learning had a significant direct effect on word reading (standard estimate = .35, $p < .001$) but not on reading comprehension (standard estimate = -.11, $p = .383$). By contrast, we found that semantic learning had a significant direct effect on reading comprehension (standard estimate = .17, $p = .045$) but not on word reading (standard estimate = .03, $p = .676$). To test the indirect effect of orthographic learning on reading comprehension via word reading, we fixed the path from word reading to reading comprehension to 0. This significantly reduced the model fit, Satorra-Bentler $\Delta\chi^2 = 27.92$, $\Delta df = 1$, $p < .001$, indicating that orthographic learning had a significant indirect effect on reading comprehension via word reading. We confirmed this finding with the IND command (standard estimate = .22, $p = .003$).

We also used the IND command to test the effects of the control variables (see Table 4). The delay between the sessions had a significant effect on both word reading and reading comprehension, such that a longer delay was associated with lower scores. Moreover, working memory, phonological awareness, orthographic knowledge, and semantic knowledge had a positive direct effect on word reading and a positive indirect effect on reading comprehension via word reading.

Discussion

The objective of this study was to test the theoretically driven hypotheses that orthographic and semantic learning are associated with word reading and reading comprehension. To do so, we studied a sample of English-speaking children in Grade 3 and analysed our data with structural equation modeling. We used several control variables in our analyses, including orthographic and semantic knowledge. Our results partly confirmed our hypotheses. As expected, orthographic learning had a direct effect on word reading and an indirect effect on reading comprehension via word reading. Furthermore, semantic learning had a direct effect on reading comprehension but, contrary to our hypothesis, no direct effect on word reading.

Our results build on previous studies that have examined orthographic and semantic learning and their associations with word reading and reading comprehension. For instance, Ricketts et al. (2011), who examined the skills predicting orthographic and semantic learning, reported modest to moderate zero-order correlations between all their measures of learning and reading. Our results, which reflect the investigation of orthographic and semantic learning as predictors of word reading and reading comprehension, refine this pattern by suggesting more specific relations between these variables. Notably, our findings offer strong evidence that these relations are not due to other established contributors to reading outcomes, such as orthographic and semantic knowledge, which might have been the case in previous research (Bowey & Miller, 2007; Cain et al., 2003, 2004; Cunningham, 2006; Ricketts et al., 2008, 2011; Wang et al., 2014). They also reflect children's learning of both new labels and new concepts, and not of new labels and existing concepts, as in previous research (Cain et al., 2003, 2004; Ricketts et al., 2008, 2011).

Although not the main focus of our study, we also found that each of orthographic knowledge and semantic knowledge was associated with both word reading and reading comprehension. The effect of orthographic knowledge on reading comprehension was mainly through word reading. Perhaps more surprisingly, the effect of semantic knowledge on reading comprehension was also mainly through word reading. The non-significant direct effect of semantic knowledge on reading comprehension could be due to the fact that other predictors (e.g., semantic learning) left no residual variance in reading comprehension for semantic knowledge to predict. This non-significant effect could also be attributable to the task we used to measure semantic knowledge. Indeed, non-significant effects of semantic knowledge on reading comprehension have been observed in studies assessing vocabulary breadth in a manner similar to ours (e.g., Levesque, Kieffer, & Deacon, 2017; Ouellette, 2006; but see Ouellette & Beers, 2010). Future studies should capture semantic knowledge across its diversity, including depth of word meanings.

Taken together, our findings suggest that we need to consider an integrated view across theories of reading development. First, our finding that orthographic learning contributes to word reading is in line with the self-teaching hypothesis (Share, 1995), which focuses on phonological decoding and orthographic learning to explain the development of word reading. Second, our finding that orthographic learning contributes to reading comprehension indirectly through word reading is in accordance with the simple view of reading (Gough & Tunmer, 1986). Indeed, by suggesting that reading comprehension is the product of oral language and word reading, the simple view of reading implies that any influence on word reading will affect reading comprehension indirectly. Third, our finding that semantic learning contributes to reading comprehension broadly aligns with the lexical quality hypothesis (Perfetti & Hart, 2002), which highlights the importance of phonological, orthographic, and semantic representations in the development of reading.

Our findings also extend theories of reading development, at least as they apply to Grade 3 children. On the one hand, they extend the self-teaching hypothesis (Share, 1995) by showing that semantic learning, in addition to orthographic learning, is involved in reading. On the other hand, they extend the lexical quality hypothesis (Perfetti & Hart, 2002) by showing that semantic learning, in addition to semantic knowledge, is involved in reading. Interestingly, our results indicate that these additions to theory apply to reading comprehension specifically, as we found no evidence of an association between semantic learning and word reading. In other words, children's ability to learn the meaning of words, in addition to their ability to learn the spelling of words and their acquired knowledge of words' meaning, contributes to their ability to understand texts but not to read words.

Along with these theoretical considerations, our study also has potential educational implications about the role of orthographic and semantic learning in reading development. For instance, we could hypothesise that developing children's facility in acquiring orthographic knowledge could enhance their word reading, and thereby their reading comprehension. Similarly, we could hypothesise that teaching children strategies to learn more easily the meaning of the new words they encounter during reading could help them better understand texts. Of course, these suppositions would need to be tested empirically. Yet, they parallel instruction studies focusing on orthographic and semantic knowledge. These studies show that increasing children's orthographic knowledge results in better performance in word reading (e.g., Graham, Harris, & Chorzempa, 2002) and that enhancing semantic knowledge improves reading comprehension (e.g., Lesaux, Kieffer, Faller, & Kelley, 2010). It is possible that adding a learning strategies component to such training might help children further.

Our study also contributes to discussions of the best measurement of orthographic and semantic learning. In our initial measurement model, both spelling and orthographic choice contributed to the Orthographic Learning factor; however, only semantic choice contributed importantly to the Semantic Learning factor, definition and matching failing to load properly on this factor (these last two measures also had the lowest reliabilities, especially matching). This could mean that semantic choice is a better index of semantic learning than definition and matching, at least when measured as in the present study. More specifically, these results suggest that the semantic learning variable that best predicts reading comprehension is the ability to distinguish between meanings encountered previously and new meanings, as measured by the semantic choice post-tests.

Before concluding, we need to consider study limitations. First, our sample was rather small for structural equation modeling. Increasing it would be beneficial in further research to test small effects we might have been unable to detect. A second limitation to our study is its correlational design. Based on theories of reading development (Perfetti & Hart, 2002; Share, 1995), we hypothesise that early orthographic and semantic learning play a role in the development of later word reading and reading comprehension skills. This hypothesis should be tested in future longitudinal studies. Third, we provided feedback to children as they were reading the stories in the learning task to ensure that they all had an equal chance at semantic learning. However, providing feedback deviates from the independent reading described in Share's (1995) self-teaching hypothesis, and it might have increased children's orthographic learning. Reassuringly, prior studies of orthographic learning have suggested that providing feedback results in similar findings as not doing so (Share, 2008). Finally, due to the strict criteria we used to create the non-words and the stories, the learning task might have seemed artificial to children. As a result, children might have used learning strategies different from the ones they typically use when reading. Further research could examine orthographic and semantic learning in relation with word reading and reading comprehension using a greater diversity of non-words and stories (e.g., Cain et al., 2004).

In conclusion, the present study clarifies the relations between children's learning and reading skills. We showed that children's ability to learn the spelling of new written words during reading was associated with their word reading and, indirectly, their reading comprehension skills. We also showed that children's ability to learn the meaning of new written words during reading was associated with their reading comprehension skills. These associations were observed even when children's knowledge of the spelling and meaning of existing words was taken into account, along with other control measures. These findings are in accordance with Share's (1995) hypothesis that better orthographic learning facilitates word reading, and thereby reading comprehension (see Gough & Tunmer, 1986). Most importantly, our findings extend this hypothesis by suggesting that better semantic learning facilitates reading comprehension, a postulation that broadly aligns with the lexical quality hypothesis (Perfetti & Hart, 2002). These novel findings point to the value in integrating two prominent theoretical approaches as to the nature of reading development.

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Footnotes

[1]Although semantic representations are not the focus of the self-teaching hypothesis, Share (1995) does mention that reading words in context might help at the beginning stages of reading and in the case of irregular words.

Table 1

Descriptive Statistics for the Measures of Orthographic Learning, Semantic Learning, Word Reading, Reading Comprehension, and Control

Measure (maximum score)	*M*	*SD*	Range	Skewness
Orthographic learning				
1. Spelling (12)	5.77	3.23	0-12	-0.24
2. Immediate orthographic choice (12)	8.91	2.23	3-12	-0.66
3. Delayed orthographic choice (12)	8.56	1.88	4-12	-0.03
Semantic learning				
1. Definition (12)	4.21	2.53	0-10	0.46
2. Immediate matching (12)	6.24	2.68	1-12	0.37
3. Delayed matching (12)	6.46	2.77	1-12	0.18
4. Immediate semantic choice (12)	9.28	1.95	3-12	-0.80
5. Delayed semantic choice (12)	9.67	1.83	2-12	-0.92
Word reading				
1. Fluency[a]	102.82	15.20	59-138	-0.33
2. Accuracy[a]	105.13	11.48	65-126	-0.58
Reading comprehension[b]	41.69	21.87	1-99	0.26
Control				
1. Non-verbal reasoning[c]	47.73	10.48	24-70	0.04
2. Working memory[d]	9.13	2.56	1-18	0.19
3. Phonological awareness[d]	9.06	2.66	3-15	0.15
4. Orthographic knowledge (25)	19.17	3.76	9-25	-0.68
5. Semantic knowledge (51)	31.87	5.02	19-46	-0.20

Note. [a]Age-based standard scores ($M = 100$; $SD = 15$) are reported for these measures. [b]Norm curve equivalent ($M = 50$; $SD = 21.06$) is reported for this measure. [c]T score ($M = 50$; $SD = 10$) is reported for this measure. [d]Scaled scores ($M = 10$; $SD = 3$) are reported for these measures. Raw scores are reported for all other measures.

Table 2

Non-Words Used in the Learning Task

Target sound	Version A		Version B	
/i/	veap	seef	veep	seaf
/ɜ/	merl	turg	murl	terg
/eɪ/	zabe	yaif	zaib	yafe
/ju/	fude	hewl	fewd	hule
/oʊ/	bope	loak	boap	loke
/k/	kleb	crig	cleb	krig

Note. Half of the participants read Version A, and the other half read Version B.

Table 3

Correlations Between the Measures of Orthographic Learning, Semantic Learning, Word Reading, Reading Comprehension, and Control

	Orthographic learning			Semantic learning					Word reading			Control				
Measure	1	2	3	1	2	3	4	5	1	2	RC	1	2	3	4	5
Orthographic learning																
1. Spelling	–															
2. Immediate OC	.59*	–														
3. Delayed OC	.56*	.73*	–													
Semantic learning																
1. Definition	.30*	.34*	.29*	–												
2. Immediate matching	.24*	.26*	.20*	.34*	–											
3. Delayed matching	.27*	.37*	.43*	.40*	.42*	–										
4. Immediate SC	.25*	.25*	.29*	.19*	.18*	.16	–									
5. Delayed SC	.30*	.21*	.30*	.29*	.20*	.11	.69*	–								
Word reading																
1. Fluency	.62*	.47*	.46*	.29*	.12	.30*	.30*	.27*	–							
2. Accuracy	.70*	.55*	.54*	.31*	.13	.26*	.37*	.30*	.86*	–						
RC	.55*	.36*	.32*	.24*	.21*	.18*	.40*	.30*	.68*	.68*	–					
Control																
1. Non-verbal reasoning	.18*	.03	.10	.09	-.06	.00	.24*	.34*	.19*	.17*	.16	–				
2. Working memory	.32*	.19*	.17	.14	-.01	.01	.21*	.18*	.44*	.45*	.31*	.31*	–			
3. Phonological awareness	.62*	.37*	.34*	.25*	.08	.17	.35*	.35*	.56*	.63*	.44*	.30*	.36*	–		
4. Orthographic knowledge	.58*	.46*	.43*	.35*	.02	.13	.28*	.18*	.72*	.74*	.59*	.11	.41*	.49*	–	
5. Semantic knowledge	.26*	.24*	.29*	.27*	.13	.11	.33*	.30*	.33*	.44*	.41*	.16	.10	.34*	.27*	–

Note. OC = orthographic choice; SC = semantic choice; RC = reading comprehension.

*$p < .05$

Table 4

Effects of the Control Variables on Word Reading (WR) and Reading Comprehension (RC) in the Predictive Model

	Direct effect on WR		Direct effect on RC		Indirect effect on RC via WR		Total effect on RC	
Measure	Estimate	*p*	Estimate	*p*	Estimate	*p*	Estimate	*p*
Age	-.02	.628	.01	.946	-.01	.635	-.01	.891
Delay between the sessions	-.13	.004	-.13	.048	-.09	.019	-.22	< .001
Non-verbal reasoning	-.04	.484	-.01	.841	-.02	.472	-.04	.581
Working memory	.16	.002	-.03	.675	.11	.016	.08	.241
Phonological awareness	.17	.010	-.07	.373	.11	.040	.05	.581
Orthographic knowledge	.38	< .001	.14	.159	.24	.004	.38	< .001
Semantic knowledge	.12	.050	.08	.248	.08	.088	.15	.018

Note. Standardised estimates are reported.

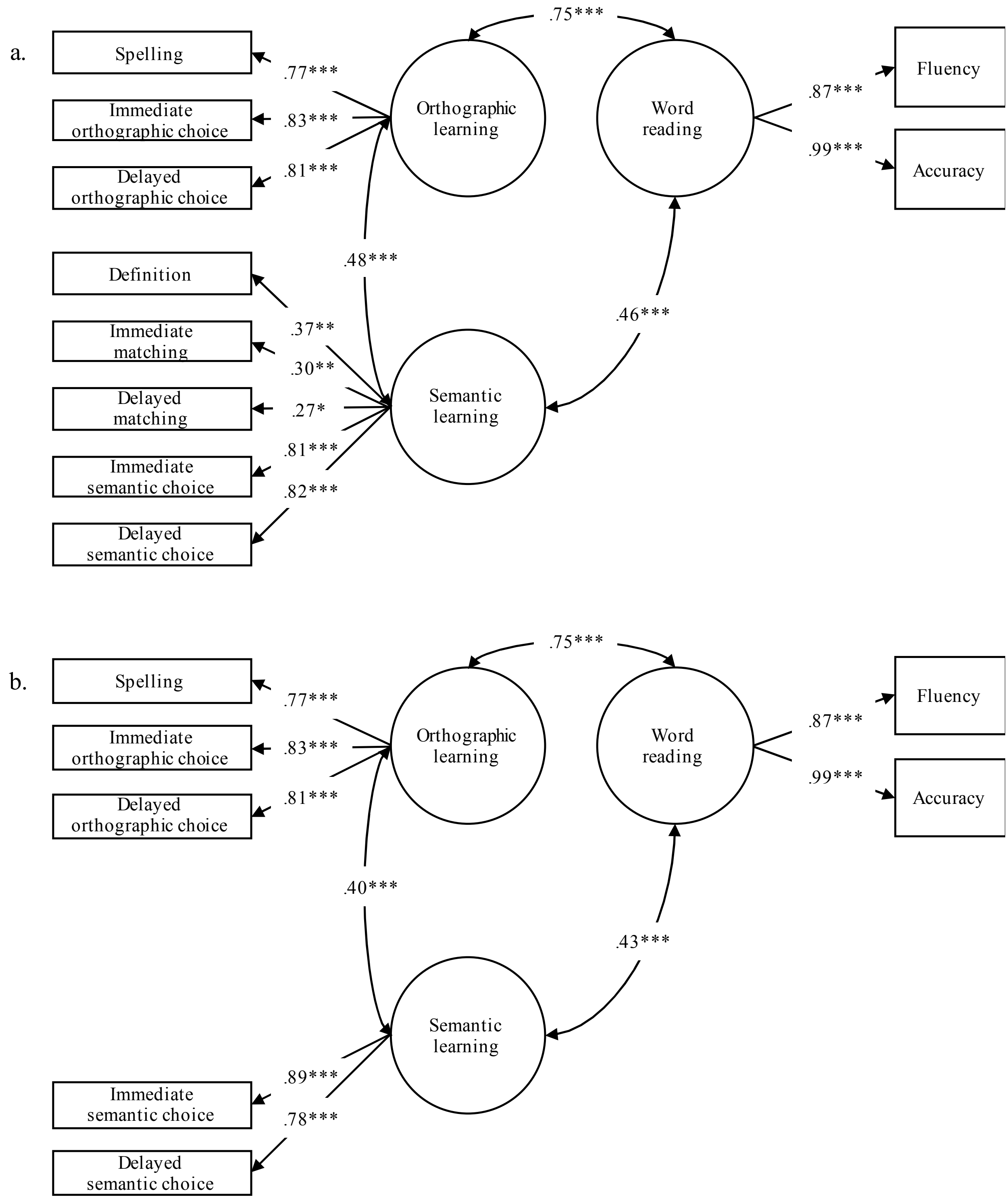

Figure 1. Initial (a) and modified (b) measurement models. Standardised estimates are presented.

*$p < .05$. **$p < .01$.***$p < .001$

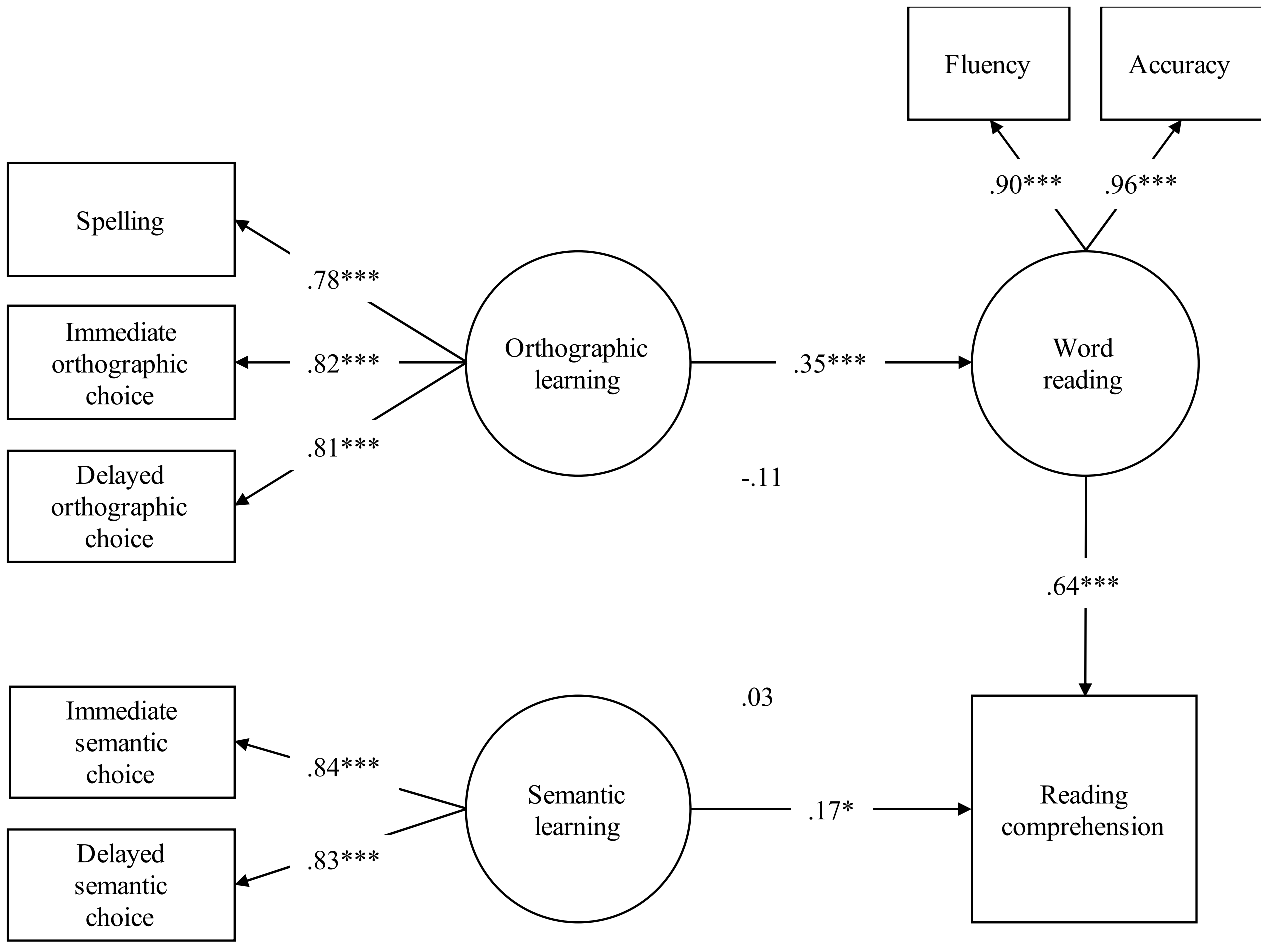

Figure 2. Simplified representation of the model predicting word reading and reading comprehension from orthographic learning and semantic learning. Standardised estimates are presented. Grey dotted lines represent non-significant effects.

$^{*}p < .05$. $^{***}p < .001$

Appendix A

Example of Story Presented in the Exposure Phase of the Learning Task

Ben was at the pet shop and the fish tank looked dirty. Ben picked up the veap. The veap is used to clean fish tanks. Ben placed the veap in the fish tank. When the fish tank was clean, Ben put away the veap.

Appendix B

Example of Item Presented in the Semantic Choice Post-Test of the Learning Task