

Morphological Sensitivity: A Hierarchical Analysis of Student and Word Factors

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Abstract

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Previous research indicates that morphological information imbedded in words facilitates various literacy skills, however there is still some disagreement as to whether skilled readers are more sensitive to morphological information while reading than their less skilled peers. This study examines whether qualities of words interact with qualities of students ($n = 273$) in a way that explains the disagreement between previous studies. A Hierarchical Linear Modelling (HLM) approach allows for examination of cross-level interactions between students and the words that they read in a lexical decision priming task. The results demonstrate that more skilled readers are more morphologically sensitive while reading words than their less skilled peers, but only after accounting for qualities of the words.

Although in the early elementary grades literacy is largely based on the acquisition of word decoding skills, in the middle elementary grades and beyond, students must be proficient in a wide array of literacy skills including vocabulary and comprehension (Biancarosa & Snow, 2004) as well as decoding increasingly complex words. Some researchers have suggested that phonological awareness, widely regarded as a vital skill for early literacy development (NICHD, 2000), continues to be the primary metalinguistic skill necessary for higher level literacy (Fowler & Liberman, 1995; Windsor, 2000). However a growing body of evidence suggests that explicit morphological awareness uniquely contributes to a variety of literacy outcomes even after accounting for students' phonological awareness (e.g. Carlisle, 1995; Mahoney, Singson, & Mann, 2000; McCutchen, Green, & Abbott, 2009; McCutchen, Logan, & Biangardi-Orpe, 2009; McCutchen & Logan, 2011; Nagy, Berninger, & Abbott, 2006).

One way that morphological awareness may facilitate the higher literacy skills above and beyond the contributions of phonological awareness is by increasing the accessibility of new vocabulary (Anglin, 1993). This may be particularly true for words that students encounter outside of formal vocabulary instruction, for example while reading a book (Nagy & Anderson, 1984). Reichle and Perfetti (2003) suggest that in addition to familiarity, the availability of a word (how much of the word's identity is accessible based on experience with words with similar identities) enhances lexical retrieval. Considering that 60% of unfamiliar words that students encounter are morphologically accessible (Nagy & Anderson, 1984), there are plenty of opportunities for students to leverage word availability while reading. In the late elementary years and beyond, students are encountering new vocabulary so rapidly that it is simply impossible to directly instruct each word (Nagy & Scott, 2000). Morphological awareness seems to be one tool which students use to cope with the demands of vocabulary acquisition.

Morphological awareness may also facilitate higher literacy by serving as an additional tool for decoding complex, multimorpheme words (Carlisle, 2000). Typically, word decoding is viewed purely as the connection between orthography and phonology, and even when morphology is considered, morphemes are treated more as syllables than as units of meaning (Carlisle & Stone, 2005). However Carlisle and Stone suggest that morphemes as units of meaning may facilitate decoding of multimorpheme words, particularly those with base morphemes that are frequently encountered either on their own or as part of other words. This follows from Reichle and Perfetti's (2003) suggestion that lexical retrieval may be facilitated by either familiarity or availability.

Finally, as Perfetti (2007) points out in his Lexical Quality Hypothesis, the way that words are mentally represented has consequences for reading outcomes. Phonological awareness may be an adequate tool to create the mental representations of words necessary for early literacy activities, however additional metalinguistic tools, including morphological awareness, seem to be important for creating the more complex mental representations of words needed for more advanced literacy activities.

Explicit Morphological Knowledge

Explicit morphological tasks directly tap students' morphological awareness by setting aside the demands of an authentic literacy task (e.g. reading a passage) and focusing on the specific metalinguistic demands of morphological analysis. Of course, a potential negative consequence of using these contrived tasks is that the associated effects could be the result of task demands rather than the morphological processing itself. While tasks assessing explicit morphological awareness vary between studies, they generally fall into two categories:

decomposition tasks (e.g. growth: She wanted her plant to ____.) and derivation tasks (e.g. farm: My uncle is a ____). Explicit measures of morphological awareness allow researchers to explore correlations between students' reading skill and their explicit knowledge of morphology. In these studies, reading skill is measured separately since explicit tasks do not measure how students use morphology in the context of authentic literacy activity (i.e. the students' implicit morphological sensitivity).

Early studies correlated reading outcomes with explicit morphological awareness (Mahoney, 1994), and subsequent work addressed the existence of a direct link between explicit awareness and reading ability through developmental studies (Carlisle & Fleming, 2003). More recently, attention has been directed toward investigating the mechanisms by which morphology relates to myriad reading tasks (e.g. McCutchen & Logan, 2011) and writing tasks (e.g. Northey, et al., 2014). Methods of instruction have also been a topic of interest (see Goodwin & Ahn, 2010 for a meta-analysis). By and large, research concerning explicit morphological awareness has moved beyond examining whether or not a relationship exists between it and literacy outcomes since findings on the topic are fairly consistent, if differently interpreted.

One consistent finding in studies of explicit morphological knowledge is that there is a stronger relationship between reading skill and opaquely related words as opposed to transparently related words (e.g. Fowler & Liberman, 1995; McCutchen, et al., 2008; Windsor, 2000). The opacity or transparency of a morphological relationship is based on whether orthography and phonology is shared. For example, the morphological relationship between *muscle* and *muscular* is opaque because *muscular* doesn't include all of the same phonemes in *muscle*, and *muscle* is not orthographically imbedded in *muscular*. The relationship between *add* and *addition*, however, is transparent because *addition* includes all of *add*, both phonologically

and orthographically. Analysis of a transparent morphological relationship should require only morphological awareness while analysis of opaque morphological relationships requires simultaneous morphological and phonological processing.

Windsor (2000) suggests that the pattern of stronger relationships between opaque morphological awareness and reading skill indicates that it is the simultaneous processing of phonological and morphological information (and not morphological processing itself), which characterizes stronger readers. On the other hand, Carlisle (2000) has argued that skill at morphological analysis of both opaque and transparent derivatives is significantly related to reading skill. The tendency for opaque morphological derivative analysis to have a stronger relationship to reading skill should not detract from the significant relationship of transparent derivative analysis to reading skill. Additionally, studies that have controlled for phonological awareness have still found significant effects of morphological awareness on reading outcomes regardless of word opacity (e.g. McCutchen, et al., 2009; Nagy, et al., 2006). Nevertheless, research has still not produced a good explanation for why awareness of morphologically opaque words and awareness of morphologically transparent words are differentially related to reading outcomes.

Studies of students' explicit morphological knowledge has furthered our understanding of the extent of the relationship between morphological awareness and reading outcomes. They have also drawn our attention to aspects of words that affect that relationship. However, in order to understand how the relationship between morphological awareness and reading outcomes works, research which measures students' implicit morphological sensitivity during authentic reading activities is needed (Jarmulowicz & Taran, 2013).

Priming Paradigms: An implicit measure of morphological knowledge

Carlisle (2000) attempted to investigate implicit morphological sensitivity during reading using a word reading task. The word list included morphologically derived words, and students' oral responses were scored for accuracy. Results indicated that skilled readers make use of available morphological information while reading words to a greater extent than their less skilled peers, as evidenced by their accuracy advantage on phonologically transparent (versus opaque) morphologically derived words, as well as on transparent morphologically derived words with high frequency stems (versus low frequency stems). However, in Carlisle's study, children read words aloud, which may not accurately reflect the children's morphological processing during the somewhat different task of reading silently. Additionally, data showing how quickly students read words could facilitate a more complete understanding of how students are implicitly making use of morphological information during word reading. One way to obtain very precise silent reading data is to use computer-administered priming tasks.

Researchers have used computer-administered priming tasks to demonstrate that among adults and children, there is a morphological priming effect. That is, people make lexical judgments more quickly and accurately if the word they are analyzing is preceded by a morphologically related word as opposed to an unrelated word or a word that is related only phonologically, orthographically, or semantically. These results indicate that people access morphological knowledge, when it is available, during reading activities. Priming activities used to study implicit morphological sensitivity during reading can be broadly divided into two categories, word completion tasks and lexical decision tasks.

Word completion tasks require students to complete a word (e.g. bl _ _ k) after being primed some time before by either a morphologically related word (e.g. blanked) or an orthographically related word (blanket). Some researchers have suggested that word completion tasks are the best way to test priming effects among children since children will respond more consistently in word completion tasks than they will in lexical decision tasks (Feldman, et al., 2002). Studies using the word completion paradigm demonstrate that morphological primes are more likely to prompt morphologically related responses than orthographic primes are (Deacon, Campbell, Tamminga, & Kirby, 2010; Feldman, Rueckl, DiLiberto, Pastizzo, & Vellutino, 2002). This indicates that students are sensitive to the morphology of priming words. Despite Feldman and colleagues' (2002) concerns over extraneous variation in children's response times, similar results have also been found in studies utilizing a lexical decision paradigm.

Lexical decision tasks involve a series of words and non-words presented to participants who are asked to decide if the word is real or not and press a key to indicate their choice. Giraudo and Granger (2001), for example, utilized a masked lexical decision task and found a significant priming effect for morphologically primed targets, but not orthographically primed targets. Masked lexical decision tasks involve the prime word being shown very briefly (e.g. 57 milliseconds) before the target word appears. Participants then respond to the target word, which triggers another prime to briefly appear before the next target word.

When Giraudo (2001) used the same paradigm with normally developing and dyslexic children, the normally developing children significantly benefited from morphological priming over orthographic or control priming while their dyslexic peers did not. However the overall pattern of priming effects for both normally developing and dyslexic children was similar. In both cases, reaction times were fastest for morphologically primed words, and orthographically

and control primed words had similar, slower reaction times. Since statistics are not reported, it is difficult to speculate about why the pattern is significant for typically developing students, but not dyslexic students. One plausible explanation, though, is that the masked paradigm simply does not allow weak readers enough time to access the morphological information in the prime before it disappears from the screen.

Continuous lexical decision tasks, in which each word, including the primes, requires a response from the participants, may be a more appropriate alternative to masked lexical decision tasks particularly for young or less skilled readers. This paradigm has been used successfully with adults (Stolz & Feldman, 1995; Raveh & Rueckl, 2000) as well as children (McCutchen, et al., 2009). In McCutchen, et al.'s study, there was a main effect of reading skill on overall reaction times with less skilled readers reacting more slowly regardless of how the target was primed. Additionally, morphological priming resulted in significantly faster reaction times over orthographic, semantic, and control priming regardless of the students' reading skill level. This is in contrast to Giraudo's (2001) finding that reading skill level differentially predicts whether morphological priming is advantageous. However, McCutchen and colleagues (2009) noted that their sample may have included an insufficient number of lower skilled readers to adequately test for a skill x prime interaction.

Many lexical priming studies do not include a measure of reading skill (e.g. Stolz & Feldman, 1995; Raveh & Rueckl, 2000). This is presumably because the authors of these studies concern themselves primarily with which word-level qualities predict strong priming effects, while they are less concerned with student-level qualities that affect lexical priming. For the education community, however, the effect of student-level factors such as reading skill on implicit morphological analysis is significant and warrants investigation.

The Present Study

The present study had three main goals. The first goal is to explore how morphology is used during real-time reading tasks. Specifically, first I examined whether morphologically related words facilitated the reading of target words more than orthographically related words in a continuous lexical decision task, replicating McCutchen et al. (2009). Secondly, I investigated whether more skilled readers were more sensitive to such morphological information when reading words than their less-skilled peers. Higher accuracy and faster response times on morphologically primed words among more skilled readers would suggest that the relationship between explicit morphological tasks and reading skill may be the result of strong readers using morphological information within words as they read. The final goal was to examine interactions between word-level qualities (e.g. how a word is primed and whether the prime-target relationship is opaque or transparent) and student-level qualities (e.g. reading skill and grade level). These cross-level interactions provided insight into why McCutchen et al. (2009), who did not examine reading skill in relation to word transparency, found no interaction between prime type and reading skill.

To accomplish these goals, I used hierarchical linear modelling (HLM) to analyze fifth and eighth grade students' reaction times on a continuous lexical decision task in relation to their score on a standardized comprehension assessment. This study used HLM because it allows for simultaneous examination of word-level qualities and student-level qualities which impact how quickly students respond to words. When utilizing an ANOVA model, variation within subjects and within items cannot be considered simultaneously, so separate analyses must be run. In addition, in ANOVA designs students are often trichotomized into high, average, and low ability groups. When using HLM, comprehension ability is entered as a continuous student-level

variable simultaneously with word-level variables such as transparency. This allows for reading ability to be entered as a continuous variable, which has the benefit of retaining more variance than the trichotomization method.

The participants and measures were also purposefully selected. Fifth and eighth graders were selected for this study because developmentally, morphological awareness of derived forms is relatively weak before fifth grade, and continues to develop through the middle school years (Carlisle, 1995; Tyler & Nagy, 1989). Reading comprehension was selected as a predictor over word reading measures since relatively little research has examined the relationship between comprehension and morphological awareness (Carlisle, 2003). Additionally, research that has investigated the relationship between morphology and reading comprehension utilized explicit morphological tasks (Carlisle, 2000; Carlisle & Fleming, 2003; McCutchen, et al., 2009), so very little is known about whether high and low skill comprehenders differ in their implicit sensitivity to morphological information while engaged in more authentic reading activities. For the measure of morphological sensitivity while reading, a continuous lexical decision paradigm was selected over masked priming paradigms because it more closely resembles how students would read words in a non-experimental environment. Finally, I chose to analyze reaction times in great detail while giving only cursory attention to accuracy for two reasons. First, McCutchen and colleagues (2009) found that fifth and eighth graders are likely to show accuracy ceiling effects on continuous lexical decision tasks. Additionally, reaction time data facilitates more detailed study of the relationships between opaque and transparent derivatives and reading skill (Carlisle, 2000).

Method

Participants

Participants were 273 fifth and eighth grade students from 23 classes in 10 schools in the urban Northwest (5th grade, $n=153$, 8th grade, $n=120$). In both grades, gender was proportional (54% and 58% female in fifth and eighth grade, respectively). The mean age of fifth grade participants was 11 years, 0 months, and the mean age of eighth grade participants was 13 years, 6 months. Self-reported race of participants in this sample was 74% White/European American, 8% Asian American, 4% Black/African American, 1% Native American/Alaskan Native, 1% Pacific Islander, 9% more than one race, and 2% Other. Most participants (88%) self-reported that they were monolingual English speakers, and all students were able to complete the test measures without language support.

Measures

Participants were assessed on standardized and researcher-developed literacy measures by trained graduate student research assistants. Testing occurred between October and March over two school years. Students were tested in both group and individual settings at their schools. Assessments used in this study are described in more detail below.

Reading Comprehension. Students' reading skill was assessed using the comprehension subtask from *Woodcock Johnson III Tests of Achievement (WJ-III)* (Woodcock, McGrew, & Mather, 2001). This individually administered cloze task required students to verbally respond with missing words from short passages that they were instructed to read silently. Test-retest

reliabilities range from .81 to .88 for ages 8-17, according to the test manual (McGrew, Schrank & Woodcock, 2007).

Word Priming. Students also completed a researcher-developed, computer-administered task designed to assess the priming effects associated with words that are morphologically or orthographically related (adapted from McCutchen, et al., 2009).

A continuous lexical decision task was designed to measure how fast students responded to words (targets) that were primed by (i.e. preceded by) morphologically related, orthographically related, or non-related words (primes). For each prime-target pair, trial n was considered the prime for trial $n + 1$. Non-words, selected to be pronounceable, but not homophones of real words, were irregularly interspersed between prime-target pairs, and students were asked to choose whether each stimulus was a real or made-up word.

Morphologically related primes shared a meaningful root word with the target they preceded. In half of the morphological prime-target pairings, the relationship between prime and target was designed to be phonologically transparent and in the other half the relationship was designed to be phonologically opaque. Phonologically transparent morphological primes shared identical spelling and pronunciation of the root with their target (e.g. *addition, add*). Phonologically opaque morphological primes, on the other hand, required some change in spelling and pronunciation between the prime and target (e.g. *wrote, write*).

Orthographically related primes shared overlapping spelling, but no overlapping meaning, with the targets. The amount of overlap was matched to the amount of overlap in the morphological prime-target pairings. That is, if the morphological pairing had a 3 letter overlap (e.g. *addition, add*), then the orthographic pairing would too (e.g. *address, add*). As with the

morphological prime-target relationships, orthographic relationships were designed to be either transparent or opaque. Transparent orthographic prime-target relationships were characterized by the prime sharing the spelling and pronunciation of the target (e.g. *address, add*). Opaque relationships were characterized by less spelling overlap, and no shared pronunciation, between prime and target (e.g. *wrist, write*).

Phonologically transparent primes included an average of 99% of the letters in the target they were priming across both morphological and orthographic prime types (deletion of the final 'e' was allowed in one prime-target pairing in both the morphological and orthographic conditions). Phonologically opaque morphological primes included an average of 85% of the letters in the target words, and phonologically opaque orthographic primes included an average of 83% of the letters in the target words. While a prime-target pairing can be phonologically transparent, but orthographically opaque, or vice versa, in this study only fully opaque and fully transparent words were used.

Target words were also purposefully selected, primarily based on their frequency in written school English (SFI; Carrol, Davies & Richman, 1971). It was not possible to select targets that have the exact same frequency, however all targets were words that older children would quickly recognize with SFIs ranging from 43.1 to 63.2 ($M = 56.55$, $SD = 4.51$). Additionally, target word frequency was included in the analysis to control for variance in reaction times due to frequency.

To counteract the possibility of a particular prime-target pairing affecting students in an unanticipated way, three random, fixed presentation orders were created. Each version of the task included the same 30 target words and 44 non-words. Primes varied between the versions such

that the conditions for a repeated measures, Latin square design were met. That is, in each version, the target would be primed by a different prime type (e.g. Target 1 was morphologically primed in Version 1, orthographically primed in Version 2, and primed by a non-related word in Version 3; see *Table 1*). Each student was randomly assigned to a version of the task. Every participant, regardless of assigned version, saw the same number of each type of prime. No participant saw any word more than once.

The task was administered using the E-Prime 2.0 software (Psychological Software Tools, 2012), which reported response accuracy as well as reaction time data in milliseconds (ms). After viewing instructions and attempting sample items (with feedback provided), students pressed the space bar to indicate that they were ready to begin the task. Words (prime, target, or non-words) were presented one at a time in black, Ariel, 32 point font centered on a white background. Students responded to each word by pressing the “m” key with their right index finger for a positive response (real word) or the “z” key with their left index finger for a negative response (fake word). The keys were marked with stickers (green for the m key “real” response, red for the z key “fake” response) so that students were not required to remember which key to press. Each student saw a total of 104 stimuli separated into 4 blocks with a self-paced break between each block. The task took about 5 minutes to complete for both fifth and eighth grade students.

Although students were instructed to respond as quickly as possible, there was no time limit for response. That is, in order to see the next word, students were required to make a decision about the current word. In the rare circumstance that a student refused to respond to a word, the researcher would press a random key (not “m” or “z”), which allowed the task to progress. This was coded as an incorrect response. Since there was no limit to how long a student

could take to respond, there were occasional outlier reaction times. Outlier reaction times, more than three standard deviations outside the mean ($M = 940\text{ms}$, $SD = 580\text{ms}$) were manually re-assigned the value of the mean value for items of that type. That is, morphologically primed words with outlier reaction times were reassigned to ($M = 835\text{ms}$), orthographically primed outliers were reassigned to ($M = 914\text{ms}$), and control primed outliers were reassigned to ($M = 930\text{ms}$). No student had more than five outlier data points, and no students were excluded from the sample. Overall, 125 reaction times (1.5% of all reaction times) were re-assigned to the mean value for their item type.

Analysis Strategy

Recall that the present study aims to answer three questions. First, are children sensitive to morphological information during real-time reading, as evidenced by morphological priming? Second, are highly skilled comprehenders more sensitive to such morphological information than their less skilled peers? And third, will a priming paradigm tapping real-time reading reveal skill differences related to morphologically opaque and morphologically transparent words, as often seen in tasks using more explicit measures of morphological awareness? Two separate models, specified below, were used to answer the research questions since the third question includes an additional variable (transparency/opacity of the relationship between prime and target word) that the first and second questions do not (because transparency cannot be defined with control primes).

Multilevel modeling was used to test the research questions in order to account for nesting of items within students. Thus, a 2-level model, with the Priming Task target words at Level 1 and students at Level 2, was used in both analyses.

Model 1. At Level-1, the primary predictor of interest was what type of word the target word was primed by (Prime Type). Since there were three possible options for Prime Type (morphological, orthographic, and control), it was dummy coded into 2 variables where control was the reference group. Note that each of the Prime Type variables is comparing only two conditions (as opposed to the two degrees of-freedom comparison in an ANOVA comparing all three conditions at once). At Level-2, the primary predictor of interest was students' reading comprehension skill. For this variable, the raw WJ-III comprehension scores were converted into z-scores separately for 5th and 8th graders such that 5th graders' z-scores would be based on the scores of other 5th graders, and 8th graders' z-scores would be based on the scores of 8th graders.

To determine the unique contributions of reading skill, prime type, and the interaction between the two to the variance in reaction times, additional variables were added to the model as fixed effects. The target word frequency (SFI; Carrol, Davies & Richman, 1971) was included at Level-1 to control for variance in the reaction times caused by word frequency of the target word. At Level-2, the model controlled for two variables. First, grade was included as a dummy coded variable (0=grade 8, 1 =grade 5) to account for variance in reaction times due to level of schooling. Second, version was accounted for in the form of two dummy coded variables where Version 3 was coded as the reference variable. The purpose of including version as a control variable was to provide evidence that no specific list of words contributed significantly to the variance in reaction times.

Altogether, Model 1 was as follows:

$$\text{Level-1: } Y_{ij} = \beta_{0j} + \beta_{1j} (\text{WrdFreq}) + \beta_{2j} (\text{PriTypM}) + \beta_{3j} (\text{PriTypO}) + r_{ij}$$

$$\text{Level-2: } \beta_{0j} = \gamma_{00} + \gamma_{01} (\text{Grade}) + \gamma_{02} (\text{OrdA}) + \gamma_{03} (\text{OrdB}) + \gamma_{04} (\text{CompZ}) + \mu_{0j}$$

$$\beta_{1j} = \gamma_{10}$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21} (\text{Grade}) + \gamma_{22} (\text{CompZ})$$

$$\beta_{3j} = \gamma_{30} + \gamma_{31} (\text{Grade}) + \gamma_{32} (\text{CompZ})$$

This model indicates that the i^{th} target word Reaction Time for the j^{th} student is equal to the sum of: the mean Reaction Time across all students (γ_{00}), the effect of student grade level (γ_{01}), the effect of the student receiving Version 1 of the experiment (γ_{02}), the effect of the student receiving Version 2 of the experiment (γ_{03}), the effect of the student's Reading Comprehension ability (γ_{04}), the effect of the target word's frequency (γ_{10}), the effect of a the word being morphologically primed vs. control primed (γ_{20}), the effect of the interaction between morphological priming and grade (γ_{21}), the effect of the interaction between morphological priming and comprehension ability (γ_{22}), the effect of a word being orthographically primed vs. control primed (γ_{30}), the effect of the interaction between orthographic priming and grade (γ_{31}), the effect of the interaction between orthographic priming and skill (γ_{32}), and the effect of residual error between and within students (μ_{0j} and r_{ij} , respectively).

Model 2. After testing Model 1, a second model was developed to investigate the third research question. At Level-1, prime type remained in the model, and transparency was added to the model. Since control primes cannot be defined as either transparent or opaque (since they

were by definition unrelated to the target), and it was already established that morphological primes were significantly different from control primes in Model 1, control primed items were left out of Model 2. As a result, Model 2 included the following Level-1 variables: target word frequency, one prime type variable (comparing morphological primes to orthographic primes), and one transparency variable (comparing transparent primes to opaque primes). Level-2 of Model 2 remained the identical to Level-2 of Model 1.

Altogether, Model 2 was as follows:

$$\text{Level-1: } Y_{ij} = \beta_{0j} + \beta_{1j} (\text{WrdFreq}) + \beta_{2j} (\text{PriTyp}) + \beta_{3j} (\text{Transp}) + r_{ij}$$

$$\text{Level-2: } \beta_{0j} = \gamma_{00} + \gamma_{01} (\text{Grade}) + \gamma_{02} (\text{OrdA}) + \gamma_{03} (\text{OrdB}) + \gamma_{04} (\text{CompZ}) + \mu_{0j}$$

$$\beta_{1j} = \gamma_{10}$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21} (\text{Grade}) + \gamma_{22} (\text{CompZ})$$

$$\beta_{3j} = \gamma_{30} + \gamma_{31} (\text{Grade}) + \gamma_{32} (\text{CompZ})$$

This model indicates that the i^{th} target word Reaction Time for the j^{th} student is equal to the sum of: the mean Reaction Time across all students (γ_{00}), the effect of student grade level (γ_{01}), the effect of the student receiving Version 1 of the experiment (γ_{02}), the effect of the student receiving Version 2 of the experiment (γ_{03}), the effect of the student's comprehension ability (γ_{04}), the effect of the target word's frequency (γ_{10}), the effect of a the word being morphologically primed vs. orthographically primed (γ_{20}), the effect of the interaction between priming and grade (γ_{21}), the effect of the interaction between priming and comprehension ability (γ_{22}), the effect of a word being transparent (γ_{30}), the effect of the interaction between

transparency and grade (γ_{31}), the effect of the interaction between transparency and skill (γ_{32}), and the effect of residual error between and within students (μ_{0j} and r_{ij} , respectively).

Results

Accuracy

A preliminary analysis of accuracy data confirmed that there were ceiling effects for both fifth and eighth graders. Specifically, fifth graders responded with an average of 98% accuracy on morphologically primed words, 97% accuracy on orthographically primed words, and 95% accuracy on control primed words. Eighth graders had average accuracy rates of 99%, 99%, and 98% for morphological, orthographic, and control priming respectively. Accuracy on non-words was also high (83% and 84% for 5th and 8th graders respectively), which indicates that students were not simply pressing the “yes” key without reading the words. Given the accuracy ceiling effects, all further analysis was conducted on reaction time data.

Model 1

Analysis was run on the mixed model specified above using HLM 6 (Raudenbush, Bryk & Congdon, 2004). *Table 3* presents the results of the multilevel analysis.

The first noteworthy finding was that there is no significant difference between reaction times on Versions 1 and 3 of the task, or between Versions 2 and 3 ($ps > .20$). This suggests that the results presented here are not due to the specific word pairings that were chosen. Rather, the results are likely true for any set of prime-target pairs.

Unsurprisingly, the student’s grade level was a significant predictor of reaction time ($p < .001$) with eighth graders responding more quickly than fifth graders. Additionally, reading

comprehension predicted faster reaction times across all items regardless of prime type ($p < .05$). Morphological priming predicted faster reaction times than control priming ($p < .001$), however orthographic primes did not significantly predict faster reaction times than the control primes ($p > .22$). Finally, target word frequency was significantly related to reaction time ($p < .001$) indicating that it takes more time to read less frequent words.

In Model 1, there were no significant interaction effects ($ps > .06$). These results suggest that the answer to the research question “Are skilled comprehenders more sensitive to morphological information than their less skilled counterparts?” is no. While more skilled comprehenders are overall faster at all item types, this model provides no evidence that skilled readers are at even more of an advantage over less skilled readers when morphological information is available.

Model 1 Discussion. A reaction time of 856ms is expected when all variables equal zero. Two word-level factors impact how fast the reaction time is expected to be. First, for every one point increase in word frequency above the mean of words used in this study ($M = 56.55$), reaction times are expected to be about 12ms faster. Second, if the target word is primed by a morphologically related word, the reaction time will be about 78ms faster than it would be if the target word were primed by an unrelated word. On the other hand, if the target word is primed by an orthographically related word, the reaction time is not expected to be significantly faster than if the target had been primed by an unrelated word.

Student-level factors also provide information about expected reaction times. First, if the student seeing the item is in fifth grade, it is expected that the reaction time will be about 134ms slower than if an eighth grader were seeing the word. Additionally, for every one standard

deviation above the mean a student scores on the comprehension measure, they are expected to respond 26ms faster.

Overall, the significant main effects in this model reflect the findings of other studies (e.g. Giraud, 2001; McCutchen, et al., 2009). Specifically, the finding that morphological primes predict faster reaction times than control primes supports the claim that morphological information is advantageous for word reading; whereas the same is not true for primes sharing only orthographic relationships with targets. However, the lack of significant interaction between prime type and comprehension skill provides no evidence that the correlation between high reading skill and strong explicit morphological knowledge may be because strong readers are better at using available morphological information.

Model 2

The mixed model for Model 2 specified above was also run using HLM 6 (Raudenbush, et al., 2004). Table 5 presents the results of the multilevel analysis.

Not surprisingly, as in Model 1, there was no significant difference between reaction times on Versions 1 and 3 of the task, or between Versions 2 and 3 ($p > .15$), eighth graders were faster than fifth graders ($p < .001$), and more frequent target words had faster reaction times ($p < .001$). Reading comprehension was no longer a significant overall predictor of faster reaction times across all items regardless of prime type ($p = .10$); however, the overall effect may have been compromised by significant interactions involving reading comprehension, as discussed below.

The prime type variable, comparing morphologically primed words to orthographically primed words, was significant ($p > .001$) indicating faster response times for morphologically

primed words. Transparency of the relationship between target and prime words was also significant ($p < .001$) such that responses to transparently primed words were faster than responses to opaquely primed words.

Unlike in Model 1, Model 2 showed a significant interaction between prime type and comprehension ability ($p < .05$) such that students with better comprehension scores were additionally fast on morphologically primed items above and beyond the speed boost that all students experience for morphologically primed items. There was also a significant interaction of transparency and skill level ($p < .01$) such that students with lower comprehension scores benefited more from an item being transparently primed vs. opaquely primed, compared to their more skilled peers. Finally, there were no significant interactions of grade with prime type or transparency ($ps > .07$).

Model 2 Discussion. The discussion of Model 2 is summarized in the Figure 2. Assuming that all variable variables are at the mean or the reference condition (i.e. zero), a reaction time of 872ms is expected.

At the word-level, more frequent targets predict faster reaction times such that for every one point increase in word frequency above the mean of words used in this study ($M = 56.55$), reaction times are expected to be about 12ms faster. Additionally, reaction times for morphologically primed targets will be about 67ms faster than reaction times for orthographically primed words. Finally, reaction times for transparently primed words will be about 80ms faster than reaction times for opaquely primed words.

At the student-level, eighth graders are expected to respond about 146ms faster than fifth graders, and, even though it is not a significant effect, for each standard deviation a student scores above the mean on comprehension predicted reaction times are reduced by 23ms.

As mentioned above, better comprehenders benefit more from morphological priming than their less skilled peers do, such that for each standard deviation a student scores above the mean on comprehension, their reaction times are 19ms faster than expected for morphologically primed words. On the other hand, poor comprehenders benefit more from the transparency of the prime, such that for each standard deviation below the mean a student scores on comprehension, their reaction times are 21ms faster than expected for transparently primed words.

The significant main effects in Model 2 support the findings of previous studies, as well as the findings of Model 1. In addition to the findings of Model 1, this model demonstrates a main effect of transparency, once again demonstrating that students benefit more from transparent morphological information than opaque morphological information.

The absence of a main effect of skill level on reaction times, however, is unexpected but most likely due to interactions involving comprehension.. While high skilled students receive more of a benefit from morphological priming, low skilled students receive more of a benefit from transparent priming, such that overall neither skill level appears to receive significantly more benefit than the other. In Model 1, only prime type was considered (averaged across transparency), so the results provided no opportunity to show low comprehenders' advantage on transparently primed words.

Relatedly, the interactions provide new insight into why explicit studies of morphological skill often find that reading skill is differently related to morphologically opaque words vs.

morphologically transparent words. When a prime-target pair is morphologically primed and opaque, skilled readers are at an advantage because they are able to make better use of the morphology, while poor readers struggle because they are particularly disadvantaged by the opacity. However when a prime-target pair is morphologically primed and transparent, less skilled readers are no longer handicapped by opacity.

General Discussion

In this study I accomplished three tasks. First, I investigated whether there was a morphological priming effect. Second, I examined whether the morphological priming effect was particularly strong for skilled readers. And finally, I investigated the interactions between word-level and student-level qualities. The results of these three areas of inquiry not only supported the findings of other studies, but also provided new insight into students' metalinguistic processing during word reading.

In regards to replicating the morphological priming effect found by others (e.g. Giraud, 2001; McCutchen, et al., 2009), both of the models presented in this study supported the previous findings that morphological primes predict faster target reaction times than either orthographic or control primes. These findings are meaningful because the implicit nature of the task design facilitates examination of the role of morphology in real-time reading.

The majority of research in this field utilizes explicit measures of morphological awareness, which examine morphological awareness in isolation from authentic reading tasks. As a result it has been difficult to rule out the possibility that the correlation between morphological skill and reading ability are simply caused by an artifact of explicit morphological task paradigms rather than variance in attention to morphology. The findings of this study and

others like it, however, provide evidence that the morphological information contained in many words does have a role in how successful students are at authentic reading activities.

In addition to supporting the findings of other studies of implicit morphological sensitivity, the present research also clarifies some discrepancies between previous findings. Previous research has reported mixed findings regarding whether or not morphological priming has different salience for high and low skill readers. That is, Giraudo (2001) found that while there is a significant morphological priming effect for typically developing students, the effect was not significant for dyslexic students. This pattern of morphological information by reading ability interaction has also been demonstrated in explicit studies (e.g. Carlisle, 1995, 2000; Deacon & Kirby, 2004; Mahoney, et al., 2000; McBride-Chang, et al., 2008, McCutchen, et al., 2008; Singson, Mahoney, & Mann, 2000; Windsor, 2000). However, McCutchen, et al. (2009) found no interaction between reading skill and morphological priming.

In Model 1 of the present study, no prime type by reading skill interaction was found, which seemed to support McCutchen, et al.'s (2009) findings. However, when transparency was entered into Model 2 as a word-level characteristic, the prime type by reading ability interaction found by Giraudo (2001) was replicated. In the past, the prime type by skill interactions have been found when the high group is typically developing students and the low group is dyslexic students. In the present study, the interaction was found typically developing students, some of whom struggle more than their peers with reading. As such, the results presented here extend the applicability of the studies they replicate.

A morphology by skill interaction matters because it supports the idea that stronger readers differ from weaker readers, in part, because they are better at accessing the

morphological structure of words. In other words, since skilled readers show a particularly strong advantage over their less skilled peers on morphologically primed words (more so than the advantage they have over their peers on any other words), it follows that these skilled readers, above and beyond any other advantages they have, are more sensitive to the morphological structures in words while they are reading.

Finally, the significant morphology by skill and transparency by skill interaction provide new insight into the results of studies of explicit morphological knowledge. Others have suggested that since the morphology by skill interaction is consistently situated primarily within opaque words, the skill differences can be attributed to disparities in phonological processing rather than morphological processing (Windsor, 2000). However the results presented here show that while less skilled readers are disadvantaged by opacity (indicating a shortcoming in phonological processing), they are also at a relative disadvantage, compared to their more skilled peers, at using morphology regardless of transparency or opacity (indicating a shortcoming in morphological processing).

While it was not an explicit goal of the study, both Model 1 and Model 2 offer evidence that the effects reported here and in other implicit morphological studies are not unduly influenced by a few special items. The three versions of the task, randomly assigned to each student, each contained a different set of prime-target pairings such that if a few sets of words on one version were particularly salient to students, the other versions would not have those words and student performance between versions would vary. By using an HLM approach, I was able to consider the effects associated with the word lists (assigned at the student level) while controlling for variables of the individual words (assigned at the word level). The results of both models showed no significant differences in student performance based on which version they

saw, indicating that the effects reported in this study, and others, are stable, regardless of the specific words students are reading.

Limitations and Future Directions

Of course, there are several questions that this study leaves unanswered. First, less skilled readers seem to suffer the consequences of two related problems. Firstly, as this study demonstrates, weak readers are less sensitive to morphological information than their more skilled counterparts. Secondly, McCutchen & Logan's (2011) findings suggest that weak readers are not using the morphological information they do pick up as strategically as high skill readers do. Future research should explore both facets of this problem by examining how students come to be sensitive to morphology as well as the mechanisms by which that morphological sensitivity is leveraged into positive literacy outcomes.

Additionally, the present study utilized a relatively authentic word reading task (compared to masked priming and word completion tasks, Giraudo (2001) and Feldman, et al. (2002) respectively) to assess implicit morphological sensitivity. Still, a task that can capture students' morphological sensitivity during other types of reading activities (e.g. vocabulary acquisition and passage reading) has yet to be designed. Thus another way to move this line of research forward would be to consider whether skilled readers remain more sensitive than their less skilled peers when they are tackling other types of reading activities.

Finally, given the growing demographic of English Language Learners (ELL) in American classrooms, it is imperative that future research investigate the ways that bilingual students are different from or similar to monolingual English speakers when it comes to leveraging English morphology during authentic reading tasks. As Kieffer and Lesaux (2007)

point out, morphology could be a powerful tool among students whose first language includes English cognates (e.g. Spanish). However we have little information about whether ELL students are inherently sensitive to morphology while reading, and if so whether or not they are negatively impacted by opacity in the way that less skilled monolingual readers are.

In short, it is fairly clear that skilled readers are making better use of morphological information than their less skilled peers during real-time word reading. However the mechanisms that underlie that advantage, and how less skilled readers might develop them, remains a topic for inquiry.

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Table 1. *Prime lists across three versions*

Target Word	Prime Word		
	Version 1	Version 2	Version 3
Assume	Assumption	<i>Assignment</i>	Fiction
Write	Wrote	<i>Wrist</i>	Plum
Pain	<i>Painter</i>	Mold	Painful
Add	Precise	Addition	<i>Address</i>
Trick	<i>Trickle</i>	Manhood	Tricked
Expand	Expansion	<i>Expend</i>	Dusk
Bleed	<i>Blessed</i>	Minor	Bled
Center	<i>Century</i>	Palm	Central
Glory	Bandit	Glorify	<i>Glossary</i>
Win	Salad	Winner	<i>Windy</i>
Harm	Harmed	<i>Harmony</i>	Foul
Choose	Diary	<i>Chose</i>	<i>Goose</i>
Score	Scoring	<i>Scorn</i>	Vault
Miss	Rank	Missed	<i>Missle</i>
Muscle	Muscular	<i>Mustache</i>	Trap
Fair	<i>Fairy</i>	Tool	Fairly
Sing	Singer	<i>Singular</i>	Tack
Fall	Fell	<i>Full</i>	Whip
Pump	Ticket	Pumped	<i>Pumpkin</i>
Cave	Trip	Cavities	<i>Calves</i>
Fertile	<i>Futile</i>	Hush	Fertility
Plan	Orbit	Planner	<i>Planet</i>
Sick	Sickly	<i>Sickle</i>	Demand
Dead	Construct	<i>Death</i>	<i>Dear</i>
Hum	Humming	<i>Humble</i>	Bake
Hide	Boot	Hidden	<i>Hitched</i>
Speak	<i>Spear</i>	Horror	Spoke
Wife	<i>Wires</i>	Roam	Wives
Bus	<i>Bustling</i>	Tick	Buses
Pick	<i>Pickles</i>	Effort	Picky

Note. Bolded words are morphological primes, italicized words are orthographic primes, and words in regular font are control primes.

Table 2. *Summary of results for Model 1*

Fixed Effects	<i>Coeff</i>	<i>(SE)</i>	<i>t</i>
Adjusted mean Reaction Time	857.82	19.96	42.98 ***
Version 1 Effect	-28.65	22.35	-1.28
Version 2 Effect	19.50	21.77	0.90
Student Grade Level	133.54	20.57	6.49 ***
Reading Comprehension	-25.75	10.42	-2.47 *
Morph Priming v. Control Priming	-78.07	12.92	-6.04 ***
Morph x Comprehension	-2.39	8.60	-0.28
Morph x Grade	-30.80	17.26	-1.79
Orth Priming v. Control Priming	-15.98	12.92	-1.24
Ortho x Comprehension	16.18	8.60	1.88
Ortho x Grade	<0.001	17.26	<0.001
Target Word Frequency Effect	-11.56	0.78	-14.90 ***
Random Effects	<i>Var</i>	<i>(SD)</i>	χ^2
Between Students	18429.14	135.75	1747.52 ***
Within Students (Residual)	100146	316.46	

Note. Version is dummy coded such that Version 3 is the reference group. Prime is dummy coded such that Control Prime is the reference group. Grade is dummy coded (1=Grade 5 and 0=grade 8). Reading Comprehension is in z-scores by grade, and Target Word Frequency is grand mean centered. * $p < .05$, ** $p < .01$, *** $p < .001$

Table 3. *Summary of results for Model 2*

Fixed Effects	<i>Coeff</i>	<i>(SE)</i>	<i>t</i>
Adjusted mean Reaction Time	872.40	20.86	41.81 ***
Version 1 Effect	-2.33	22.52	-0.10
Version 2 Effect	31.26	21.93	1.43
Student Grade Level	145.74	21.79	6.69 ***
Reading Comprehension	-17.95	10.98	-1.64
Morph Priming v. Orth Priming	-66.64	12.54	-5.32 ***
Morph x Comprehension	-18.61	8.31	-2.24 *
Morph x Grade	-29.84	16.74	-1.78
Transparent Priming v. Opaque Priming	-79.94	12.59	-6.35 ***
Transp x Comprehension	20.60	8.31	2.48 *
Transp x Grade	-26.06	16.74	-1.56
Target Word Frequency Effect	-12.32	0.94	-13.06 ***
Random Effects	<i>Var</i>	<i>(SD)</i>	χ^2
Between Students	17300.53	131.53	1254.22 ***
Within Students (Residual)	92586.61	304.28	

Note. Version is dummy coded such that Version 3 is the reference group. Prime is dummy coded (M = 1, O = 0). Grade is dummy coded (1=Grade 5 and 0=grade 8). Transparency is dummy coded (T = 1, O = 0). Reading Comprehension is in z-scores by grade, and Target Word Frequency is grand mean centered. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 1. Reaction Times by Reading Skill, Prime Type, and Transparency

