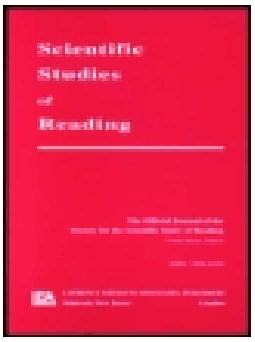

Scientific Studies of Reading

ISSN: 1088-8438 (Print) 1532-799X (Online) Journal homepage: http://www.tandfonline.com/loi/hssr20

# Individual Differences in Phonological Feedback Effects: Evidence for the Orthographic Recoding Hypothesis of Orthographic Learning

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SCIENTIFIC STUDIES OF READING
http://dx.doi.org/10.1080/10888438.2016.1258702

# Individual Differences in Phonological Feedback Effects: Evidence for the Orthographic Recoding Hypothesis of Orthographic Learning

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**ABSTRACT**

Share (1995) proposed *phonological recoding* (the translation of letters into sounds) as a self-teaching mechanism through which readers establish complete lexical representations. More recently, McKague et al. (2008) proposed a similar role for *orthographic recoding*, that is, feedback from sounds to letters, in building and refining lexical representations. We reasoned that an interaction between feedback consistency measures and spelling ability in a spelling decision experiment would lend support to this hypothesis. In a linear mixed effects logistic regression of accuracy data, this interaction was significant. Better spellers but not poorer spellers were immune to feedback effects in deciding if a word is spelled correctly, which is consistent with McKague et al.'s prediction that the impact of phonological feedback on word recognition will diminish when the orthographic representation for an item is fully specified. The study demonstrates the importance of considering individual differences when investigating the role of phonology in reading.

## Introduction

Feedback from phonology to orthography has been proposed as a basis for building orthographic representations of less-well-known words (McKague, Davis, Pratt, & Johnston, 2008). In the present study, we test this notion of "orthographic recoding." If accurate, the better spellers among skilled adult readers should be less sensitive to phonological feedback consistency than are poorer spellers when making decisions about spelling. We analyze the data collected in a spelling decision task to test the hypothesis that feedback from phonology to orthography is a tool for increasing the specificity of orthographic representations.

### *Phonological influences on orthographic processes*

Dual-route (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), connectionist (e.g., Seidenberg & McClelland, 1989), and dynamic (e.g., Van Orden & Goldinger, 1994) models of word reading all assume bidirectionality between phonological and orthographic information. The flow of information from orthography to phonology is empirically noncontroversial, but empirical support for feedback from phonology to orthography has been inconsistent. The most common method of investigating phonological feedback involves the manipulation of the *feedback consistency* of stimuli in a lexical decision or naming task. A word is considered feedback consistent if its rime body maps to only one spelling (e.g., the *elf* in *shelf* can be spelled only one way) and feedback inconsistent if its

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rime can be spelled more than one way in the language in question (e.g., the *eer* in *sneer* can also be spelled *ear, ier*, or *ere*; Stone, Vanhoy, & Van Orden, 1997). In the first study to demonstrate feedback consistency effects, Stone et al. (1997) found that responses to feedback inconsistent words in a lexical decision task were slower than responses to feedback consistent words, and accuracy to feedback consistent words was higher. To explain these findings, Stone et al. proposed that the alternative spellings activated by feedback inconsistent rimes create conflict during decision making.

Since that original study, researchers have both successfully replicated (Lacruz & Folk, 2004; Perry, 2003; Ziegler, Montant, & Jacobs, 1997) and failed to replicate (Massaro & Jesse, 2005; Peereman, Content, & Bonin, 1998) the results of Stone et al. (1997). Two recent studies that controlled extensively for factors that might confound results came to opposite conclusions. Ziegler, Petrova, and Ferrand (2008) found no evidence of a feedback consistency effect in a lexical decision task, despite controlling for both onset and rime consistency, and were able to produce feedback consistency effects with a neural network model not sensitive to feedback consistency, suggesting that presumed feedback effects are in fact attributable to other factors. Yap and Balota (2009), conversely, showed significant effects of feedback consistency in hierarchical regression analyses of a large-scale database, after controlling for more than a dozen other variables known to impact word-reading behavior. (Yap and Balota granted that it is possible that there are covariates they did not control for, but it is not clear what these might be; theirs is also the first study to examine feedback consistency effects in multisyllabic words.)

Several issues in the phonological feedback consistency literature may have prevented the field from reaching a clear consensus on the matter of feedback effects. First, all but one study (Perry, 2003) examined feedback effects at the level of the rime rather than at the individual phoneme. Categorically declaring a word "consistent" or "inconsistent" with regard to phonological feedback seems a rather blunt technique given that the individual phonemes in all words vary in their levels of feedback consistency. Vowels, in particular, can all be spelled more than one way in English (Kessler, Treiman, & Mullennix, 2008). Because research in our laboratory has utilized stimuli comprising misspelled vowels in a spelling decision task, we have a felicitous opportunity to investigate the data from that experiment for evidence of feedback effects on behavior.

In addition, the tasks used to investigate feedback effects have been exclusively lexical decision and naming. However, given that the cause of feedback effects is assumed to be activation by phonology of alternative spellings, a spelling decision task is a more direct test of the existence of these effects because participants are faced with one of the activated alternatives (assuming that the word's pronunciation is not affected by the misspelling). Researchers have also generally failed to control for individuals' differences in spelling ability in feedback consistency investigations, despite evidence that individual differences can significantly moderate cognitive processes in reading (Andrews, 2012). (An exception is Davies & Weekes, 2005, who found feedback consistency effects in children with dyslexia but not in control children.) Because we conducted assessments of individual differences in participants' spelling knowledge during the aforementioned experiment, these factors may be taken into account when examining the possibility of phonological influences on orthography.

### Orthographic recoding as a mechanism for orthographic learning

McKague et al. (2008) suggested that phonological feedback is useful *exclusively* during orthographic learning. Building on the self-teaching hypothesis (Share, 1995, 1999), which posits phonological recoding (the translation of letters into sounds) as a self-teaching mechanism through which readers establish complete lexical representations of words, McKague et al. proposed a similar role for what they termed *orthographic recoding*, that is, feedback from sounds to letters, in building and refining lexical representations.

According to the lexical quality hypothesis (Perfetti, 2007; Perfetti & Hart, 2002), the quality of individual lexical representations can vary in their degree of completeness, or specificity. Partially specified representations can include free variables in the orthographic or phonological form where uncertainty exists; vowels are often the last element of a representation to become fully specified. McKague et al. reasoned that evidence that orthographic recoding at the level of the word leads to increased orthographic knowledge would support the lexical quality hypothesis and other item-based models of reading development (Ehri, 1992, 2014; Share, 1995, 1999). Moreover, they proposed that once an orthographic representation is fully specified, phonological feedback has outlived its usefulness and feedback consistency effects should not be observed for an item in an individual who has perfect orthographic knowledge of it. They tested this hypothesis in a training study that manipulated feedback consistency in pseudowords and found moderate support for it.

Because we have spelling decision data that can be coded for feedback consistency, and individual differences data for the individuals who performed the tasks, we have the opportunity to offer complementary evidence in favor of the McKague et al. hypothesis, if it is correct. An interaction of feedback effects with spelling ability in our experiment would be consistent with the hypothesis. A brief description of the relevant methods and results from the experiment is provided next. For a discussion of the larger study and its findings, see Harris (2014).

## Methods

### *Participants*

Participants were 145 Introduction to Psychology students at the University of Pittsburgh who received class credit for their participation. All spoke English at a native or near-native level.

### *Materials*

Experimental stimuli were misspelled English words of between five and nine letters in length and were created by substituting one vowel in a word with another vowel (including *y*). Amazon Mechanical Turk workers verified that each experimental item was recognizable as a misspelling of the intended target word (e.g., that *conferm* was perceived as a misspelling of *confirm* and not *conform*). Each experimental session consisted of 40 experimental trials (misspellings) and 40 filler (correctly spelled) trials, for a total of 80 trials per participant.

The complete list of experimental stimuli used in the experiment is in Appendix A. Note that although each unseen target word was misspelled four ways, with one fourth of participants encountering each misspelling, only trials for the two phoneme-preserving misspellings were included in the present analysis. This is because previous research has demonstrated that success at spelling judgments is significantly greater when a misspelling changes the pronunciation of the word (Harris, Perfetti, & Rickles, 2014). A spelling decision task using only phoneme-preserving misspellings will thus be likelier to reveal the quality of participants' orthographic representations, because a participant who does not have a fully specified representation for a given target will be persuaded by plausible misspellings (i.e., spellings that align with their phonological knowledge), whereas a participant whose representation is fully specified will not.

#### *Offline assessment*

Each experimental session included an offline spelling assessment (Perfetti & Hart, 2002) for use as a measure of spelling ability in individual differences analyses. The assessment is adapted from Olson, Wise, Conners, Rack, and Fulker (1989) and requires participants to select only the correctly spelled words from a list of 140 items. Skill at the task is indexed by $d'$, an index of target sensitivity.

### *Procedure*

Experimental and filler stimuli were presented at the center of a computer screen in random order, using E-Prime presentation software (Schneider, Eschman, & Zuccolotto, 2002). Subjects were encouraged to respond as accurately and as quickly as possible and were informed that half the words they would see would be misspelled. They then completed a 10-trial practice block to become familiarized with the procedure. Each trial began with a white fixation cross appearing in the center of a black screen, which was replaced after 500 ms by the stimulus, also in white. Subjects were instructed to hit the *Yes* key on a serial response box if the stimulus was spelled correctly and the *No* key if it was spelled incorrectly. The stimulus remained on-screen until a response was selected, for up to 2,000 ms. The next trial, beginning with a fixation cross, began 750 ms after a response was selected. After the practice round, participants were given the opportunity to ask the experimenter any questions they might have about the procedure. The experimental session then proceeded in four blocks of 20 trials each, with participants given a chance to rest between blocks. The offline spelling assessment was administered following the experimental session.

## Results

Online and offline task performance measures are given in Table 1. Two subjects with experimental *d*' under 1.00 (indicating very poor target sensitivity) were removed from analyses, resulting in a sample size of 143. Responses with latencies less than 250 ms (1.35% of trials) were removed from analyses. Incorrect trials (7.78% of trials) were removed from latency analyses. Finally, one of the 160 items was removed from analyses due to accuracy rates below chance.

### *Examination of phonological consistency*

All misspelled stimuli were assessed for feedforward (FF) and feedback (FB) consistency. Consistency information was drawn from the report *Phoneme-Grapheme Correspondences as Cues to Spelling Improvement* (Hanna, Hanna, Hodges, & Rudorf, 1966). Grapheme–phoneme contingency was used as an index of FF consistency, that is, the percentage of instances in which the misspelled grapheme is pronounced the way it is pronounced in the stimulus (e.g., in 72.24% of occurrences of the letter *i* it is pronounced /ɪ/, so *bisiness* was assigned an FF consistency index of .7224). Phoneme–grapheme contingency was used as an index of FB consistency, that is, the percentage of instances in which the misspelled phoneme is spelled the way it is spelled in the stimulus (e.g., /ɪ/ is spelled with an *i* 68.4% of the time, so *bisiness* was assigned an FB consistency index of .6840). Consistency indices for each of the experimental stimuli are provided in Appendix B.

### *Response times*

Response times (RTs) of correct responses to misspelled words were analyzed using linear mixed-effects regression (Baayen, Davidson, & Bates, 2008) with Stata statistical software. Offline spelling *d*', FF consistency, and FB consistency were entered as fixed effects, as well as the interactions of spelling *d*' with FF and FB consistency. RTs and FF and FB consistency were log-transformed to normalize their distributions. Participants and items were entered as random effects. In Table 2, we report regression coefficients (*B*) for the fixed effects variables, which estimate the effect size (in milliseconds) of the variable, and the *z* value of the effect coefficient. As Table 2 indicates, two

**Table 1.** Online and offline performance outcomes.

| Measure | | Min | Max | M | SD |
|---|---|---|---|---|---|
| Experimental task | *d*' | 1.42 | 5.61 | 2.93 | .83 |
| | Accuracy (%) | 68.00 | 100.00 | 92.13 | .07 |
| | Response times (ms) | 527 | 1264 | 856 | 148 |
| Offline spelling assessment | *d*' | 1.06 | 2.94 | 1.90 | .39 |

*Note.* $N$ = 143 for experimental measures and $N$ = 142 for offline measure.

**Table 2.** Linear mixed-effects regression results for response times.

| Fixed Effects | B | SE | z | p |
|---|---|---|---|---|
| Spelling $d'$ | −.053 | .043 | −1.23 | .219 |
| Log FF consistency | −.028 | .015 | −1.86 | .063 |
| Log FB consistency | −.004 | .015 | −0.28 | .778 |
| Spelling $d'$ × Log FF Consistency | .013 | .007 | 1.86 | .063 |
| Spelling $d'$ × Log FB Consistency | −.002 | .007 | −0.24 | .811 |
| Constant | 6.819 | .086 | 79.12 | < .001* |
| Log restricted likelihood | 51.16 | | | |
| No. of observations | 2,236 | | | |

*Note*. FF = feedforward; FB = feedback.
*Significant *p* value.

variables predicted RTs with marginal reliability: FF consistency ($p$ = .06) and FF Consistency × Spelling $d'$ ($p$ = .06). No other variable significantly predicted RTs.

## *Accuracy*

Accuracy data to misspelled words were analyzed using logistic mixed-effects regression with Stata statistical software. Offline spelling $d'$, FF consistency, and FB consistency were entered as fixed effects, as well as the interactions of spelling $d'$ with FF and FB consistency. FF and FB consistency were log-transformed to normalize their distributions. Participants and items were entered as random effects. In Table 3, we report odds ratios for the fixed effects variables, which estimate the estimate the effect size (in ratio of the probability of answering correctly and the probability of answering incorrectly) of the variable, and the $z$ value of the odds ratio. As Table 3 indicates, the odds ratios of all of the fixed effects variables were significant. That the odds ratios are greater than one for spelling $d'$, log FB consistency, and Spelling $d'$ × Log FF consistency indicates that the likelihood of an accurate response in the presence of an increase in these variables was *greater* than the likelihood of an accurate response if their values remained the same. That the odds ratios are less than 1 for log FF consistency and Spelling $d'$ × Log FB consistency indicates that the likelihood of an accurate response in the presence of an increase in these variables was *less* than the likelihood of an accurate response if their values remained the same. That is, greater spelling ability and greater FB consistency positively impact spelling decision performance, whereas greater FF consistency negatively impacts spelling decisions.

To better understand how FB consistency interacted with spelling ability to predict accuracy, we graphed the predicted probability of a correct response for encounters with misspellings of a given FB consistency for participants with higher and lower spelling ability, according to the offline spelling $d'$ measure (Figure 1). Although this graph represents predicted values and not actual data, the linear fits of the predicted probabilities are useful for visualizing the relationship between spelling ability and sensitivity to phonological feedback. As the fitted values demonstrate, participants with spelling $d'$ greater than 2 are predicted to make, on average, spelling judgments with above 90% accuracy, regardless of the FB consistency of the misspelled phoneme. Participants with

**Table 3.** Linear mixed-effects logistic regression results for accuracy.

| Fixed Effects | OR | SE | z | p |
|---|---|---|---|---|
| Spelling $d'$ | 13.42 | 7.65 | 4.56 | < .001* |
| Log FF consistency | 0.59 | 0.15 | −2.03 | .04* |
| Log FB consistency | 1.95 | 0.52 | 2.52 | .01* |
| Spelling $d'$ × Log FF Consistency | 1.38 | 0.18 | 2.43 | .02* |
| Spelling $d'$ × Log FB Consistency | 0.72 | 0.10 | −2.35 | .02* |
| Log likelihood | −670.22 | | | |
| No. of observations | 2,466 | | | |

*Note*. FF = feedforward; FB = feedback.
*Significant *p* values.

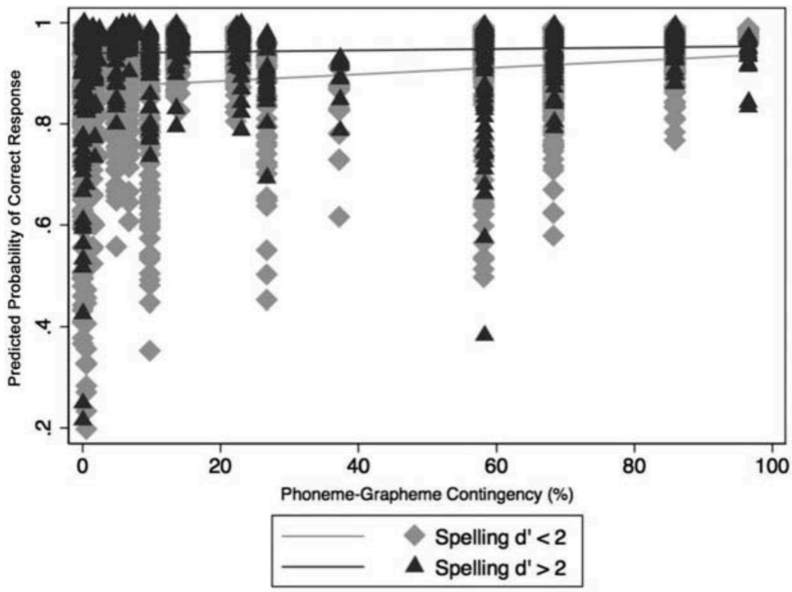


**Figure 1.** Predicted probability of correct response in spelling decision task by participant given phoneme–grapheme contingency (feedback consistency) of a misspelling. *Note*. Light gray diamonds represent participants with an offline spelling *d*' of less than 2, and dark gray triangles represent participants with an offline spelling *d*' of 2 or greater. The dark gray and light gray lines represent a linear fit of the predicted values for better spellers and poorer spellers, respectively.

spelling *d*' less than 2 are predicted to steadily increase in accuracy, from around 85% to around 90%, as FB consistency increases.

## Discussion

Our aim in the present study was to investigate data collected in a spelling decision task for evidence of orthographic recoding as a mechanism of orthographic learning. All significant results appeared in our analyses of accuracy data. We found that offline spelling ability, FF phonological consistency, and FB phonological consistency, as well as interactions of FF and FB phonological consistency with offline spelling ability, each independently affected the odds of spelling decision accuracy when included in a model with the other variables. FB consistency has been an inconsistent predictor of word reading behavior in past research; we assume that phonological feedback was significant in our model because key characteristics of our task and stimuli were optimal for detecting its effect.

That increased FF consistency decreased the odds of a correct spelling decision in our task is not surprising. Recall that our index of FF consistency invokes the percentage of instances in which the misspelled grapheme is pronounced the way it is pronounced in the experimental stimulus. Our findings indicate that if the misspelling encountered by a participant tends to suggest the correct pronunciation of the misspelled word, he or she was likelier to make a wrong decision in our task than if the misspelling tends to suggest other pronunciations. This result is consistent with Harris, Perfetti, and Rickles's (2014) finding that misspellings that suggest the correct pronunciation of a word are less likely to be detected.

Similarly, we were not surprised that increased FB consistency increased the odds of a correct spelling decision. FB effects have been hypothesized to occur when the phoneme(s) activated by a letter(s) can be spelled multiple ways, and those alternate spellings interfere with word recognition. Because a higher FB consistency measure in our study indicates there are fewer ways for the phoneme to be spelled, it stands to reason that spelling decisions were facilitated by the relative absence of interfering spellings.

The inverse relationship of the FF and FB consistency variables to one another explains the opposite impacts of their interactions with spelling ability in our task. The significant interaction of spelling ability with FB consistency is consistent with the hypothesis that feedback from phonology to orthography is instrumental in learning orthographic forms and ceases to influence reading behavior once a lexical representation becomes fully specified (McKague et al., 2008). Research in children (Bolger, Minas, Burman, & Booth, 2008; Davies & Weekes, 2005) has previously shown greater effects of FB consistency in children with reading disability relative to normally reading children, but ours is the first study using real words and their misspellings to show such an association in adults. This association in mature readers supports item-based accounts of reading development, including the lexical quality hypothesis, that hold that lexical knowledge of individual items can vary in quality apart from one's general reading level, and orthographic learning continues on a word-by-word basis even for readers of considerable overall skill.

The interaction of spelling skill with feedback effects may explain why feedback effects in past studies that did not control for individual differences have tended to be small and unreliable. The lexical quality hypothesis assumes also that orthographic knowledge varies across words as well as individuals. Accordingly feedback effects vary for an individual across words with the relative quality of the orthographic and semantic representations. In a word for which an individual has high orthographic specificity, feedback effects will be small (or, according to the orthographic recoding hypothesis of McKague et al., 2008, absent), but in a word for which an individual has high semantic specificity, feedback effects will be larger. When data are averaged across all the participants in an experiment, feedback effects may be vanishingly small.

Our finding of an association of feedback consistency effects with spelling skill is also consistent with the hypothesis that phonological feedback is used in orthographic learning and will be reduced when the orthographic representation for an item is fully specified. For a word that is well specified orthographically, phonological activation continues to occur as part of the word identification process; however, this activation is dominated by word-specific phonology so that consistency with other words is less relevant. Thus, a word such as *have* with phonology that is inconsistent with other words (e.g., *save, wave, behave*) has gained a word-specific phonology that is rapidly activated and is relatively protected from interference from words with different pronunciations. Word-specific knowledge, with both orthographic and phonological information represented precisely for a given word, defines lexical quality. The correlations with spelling skill that we observed reflect the fact that, on average, a skilled speller will have more high-quality representations among the words sampled in the experiment than a less skilled speller.

The orthographic learning mechanism that brings about these more precise representations is phonological feedback during reading. Thus, all words, regardless of the consistency of their spelling patterns, activate their word-specific phonology, and this binds to the orthographic representation of the word. The self-teaching mechanism proposed by Share (1995) is a basis for initiating an orthographic representation. Added to that initial learning process is—with experience the repeated retrieval of word-specific phonology on the basis of a word-specific spelling—a practice effect that robustly binds orthography with phonology. Research beyond the kind of correlational study we have reported here is needed to establish this hypothesis. However, evidence supports the initial stages of orthographic learning hypothesized by the self-teaching hypothesis (Bowey & Muller, 2005; Cunningham, 2006; Ricketts, Bishop, Pimperton, & Nation, 2011; Share, 1999). The hypothesis that repeated phonological retrieval from written words occurs and strengthens the orthographic-phonological binding is consistent with the effects of word frequency on word processing, including the reduced effect of consistency and regularity with more frequently encountered words (Andrews, 1982; Frost, Katz, & Bentin, 1987; Jared, McRae, & Seidenberg, 1990; Paap & Noel, 1991; Seidenberg, Waters, Barnes, & Tanenhaus, 1984). In this broader context, the contribution of the present study is the demonstration that individual differences in reading-related skills can modulate the influence that segmental phonology has on orthographic processes.

## Acknowledgments

We are grateful to Juan Zhang for help with stimulus creation, to Kimberly Muth for assistance with data collection, and to Matt Hamilton for unflagging guidance on statistical analyses. The suggestions of two anonymous reviewers also greatly improved the manuscript.

## Funding

This research was supported by NICHD grant R01HD058566-02.

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## Appendix A

**Table A1.** Unseen Targets and Experimental Stimuli Used in the Spelling Decision Task.

| Unseen Target | Experimental Stimuli |
|---|---|
| announcer | annauncer |
| | anneuncer |
| | announcir |
| | announcar |
| another | anuther |
| | anather |
| | anothur |
| | anothyr |
| betray | betrey |
| | betroy |
| | butray |
| | botray |

(*Continued*)

**Table A1.** (Continued).

| Unseen Target | Experimental Stimuli |
|---|---|
| bleachers | bleechers |
| | bleochers |
| | bleachurs |
| | bleachars |
| business | bisiness |
| | basiness |
| | businiss |
| | businass |
| certainly | cyrtainly |
| | cortainly |
| | certaenly |
| | certaonly |
| colored | culored |
| | celored |
| | colured |
| | colired |
| colorful | culorful |
| | cilorful |
| | colorfol |
| | colorfil |
| comfort | cumfort |
| | camfort |
| | comfert |
| | comfart |
| consensus | consynsus |
| | consonsus |
| | cunsensus |
| | cansensus |
| container | contayner |
| | contaoner |
| | cuntainer |
| | centainer |
| determine | deturmine |
| | detormine |
| | ditermine |
| | dotermine |
| dirtier | dertier |
| | dartier |
| | dirtiyr |
| | dirtiar |
| discover | discuver |
| | discever |
| | dyscover |
| | doscover |
| divergent | divirgent |
| | divargent |
| | dyvergent |
| | duvergent |
| diversion | divirsion |
| | divarsion |
| | dyversion |
| | doversion |
| divulge | divolge |
| | divylge |
| | devulge |
| | dovulge |
| dynamite | dinamite |
| | dunamite |
| | dynamyte |
| | dynamate |
| easily | eesily |
| | eosily |
| | easely |
| | easoly |

(*Continued*)

**Table A1.** (Continued).

| Unseen Target | Experimental Stimuli |
|---|---|
| governor | guvernor |
| | givernor |
| | govurner |
| | govirnor |
| interpret | intirpret |
| | intorpret |
| | interprypt |
| | interprat |
| language | lenguage |
| | longuage |
| | languege |
| | languoge |
| machine | machene |
| | machone |
| | mechine |
| | mychine |
| motherly | mutherly |
| | metherly |
| | mothurly |
| | motharly |
| movement | muvement |
| | mevement |
| | movemint |
| | movemont |
| movers | muvers |
| | mevers |
| | movirs |
| | movars |
| moving | muving |
| | meving |
| | movyng |
| | movung |
| mystical | mistical |
| | mostical |
| | mysticul |
| | mysticil |
| percolate | pircolate |
| | porcolate |
| | perculate |
| | percilate |
| physical | phisical |
| | phosical |
| | physycal |
| | physocal |
| prettiest | prittiest |
| | prottiest |
| | prettyest |
| | prettuest |

(*Continued*)

**Table A1.** (Continued).

| Unseen Target | Experimental Stimuli |
|---|---|
| prevail | preveil |
| | prevoil |
| | privail |
| | pruvail |
| purpose | perpose |
| | parpose |
| | purpuse |
| | purpase |
| refurbish | referbish |
| | reforbish |
| | rifurbish |
| | rofurbish |
| service | sirvice |
| | sorvice |
| | servyce |
| | servace |
| surgery | sergery |
| | sorgery |
| | surgury |
| | surgory |
| various | verious |
| | vorious |
| | varyous |
| | varuous |
| weirdest | wyirdest |
| | woirdest |
| | weirdyst |
| | weirdast |
| wonderful | wunderful |
| | wenderful |
| | wonderfol |
| | wonderfyl |
| worthless | werthless |
| | warthless |
| | worthliss |
| | worthloss |

## Appendix B

**Table B1.** FF and FB Measures of Phonological Consistency for the Four Misspellings of Each of the 40 Experimental Items in the Spelling Decision Task.

| Unseen Target | Misspelled Phoneme (IPA/ Hanna) | Correctly Spelled as | Misspelled as | FB Consistency Index | FF Consistency Index |
|---|---|---|---|---|---|
| announcer | aʊ /OU | ou | au | 5 | 4 |
| | | | eu | 5 | 5 |
| | ər /U2 + E5 | er | ir | 15 | 2 |
| | | | ar | 15 | 2 |
| another | ʌ /U3 | o | u | 6 | 9 |
| | | | a | 6 | 10 |
| | r̩ /U2 + E5 | er | ur | 15 | 1 |
| | | | yr | 15 | 1 |
| betray | eɪ /A | ay | ey | 16 | 5 |
| | | | oy | 16 | 2 |
| | ə /ə | e | u | 22 | 9 |
| | | | o | 22 | 11 |
| bleachers | iː /E | ea | ee | 16 | 3 |
| | | | eo | 16 | 2 |
| | ər /U2 + E5 | er | ur | 15 | 1 |
| | | | ar | 15 | 2 |
| business | ɪ /I3 | u | i | 22 | 7 |
| | | | a | 22 | 10 |
| | ə /ə | e | i | 22 | 7 |
| | | | a | 22 | 10 |
| certainly | ɜː/U2 + E5 | er | yr | 15 | 1 |
| | | | or | 15 | 2 |
| | ə /ə | ai | ae | 22 | 2 |
| | | | ao | 22 | 1 |
| colorful | ʌ/U3 | o | u | 6 | 9 |
| | | | i | 6 | 7 |
| | ə /ə | u | o | 22 | 11 |
| | | | i | 22 | 7 |
| comfort | ʌ /U3 | o | u | 6 | 9 |
| | | | a | 6 | 10 |
| | ər /U2 + E5 | or | er | 15 | 3 |
| | | | ar | 15 | 2 |
| consensus | e /E3 | e | y | 13 | 5 |
| | | | o | 13 | 11 |
| | ə /ə | o | u | 22 | 9 |
| | | | a | 22 | 10 |
| container | eɪ /A | ai | ay | 16 | 4 |
| | | | ao | 16 | 1 |
| | ə /ə | o | u | 22 | 9 |
| | | | e | 22 | 10 |
| covering | ʌ /U3 | o | u | 6 | 9 |
| | | | a | 6 | 10 |
| | ɪ /I3 | i | y | 22 | 5 |
| | | | u | 22 | 9 |
| determine | ɜː/U2 + E5 | er | ur | 15 | 1 |
| | | | or | 15 | 2 |
| | ə /ə | e | i | 22 | 7 |
| | | | o | 22 | 11 |
| dirtier | ɜː/U2 + E5 | ir | er | 15 | 3 |
| | | | ar | 15 | 2 |
| | ər /U2 + E5 | er | yr | 15 | 1 |
| | | | ar | 15 | 2 |

(*Continued*)

**Table B1.** (Continued).

| Unseen Target | Misspelled Phoneme (IPA/ Hanna) | Correctly Spelled as | Misspelled as | FB Consistency Index | FF Consistency Index |
|---|---|---|---|---|---|
| discover | ʌ /U3 | o | u | 6 | 9 |
| | | | e | 6 | 10 |
| | ɪ /I3 | i | y | 22 | 5 |
| | | | o | 22 | 11 |
| divergent | ɜ: /U2 + E5 | er | ir | 15 | 2 |
| | | | ar | 15 | 2 |
| | aɪ /I | i | y | 14 | 5 |
| | | | u | 14 | 9 |
| divergent | ɜ: /U2 + E5 | er | ir | 15 | 2 |
| | | | ar | 15 | 2 |
| | aɪ /I | i | y | 14 | 5 |
| | | | u | 14 | 9 |
| diversion | ɜ: /U2 + E5 | er | ir | 15 | 2 |
| | | | ar | 15 | 2 |
| | aɪ /I | i | y | 14 | 5 |
| | | | o | 14 | 11 |
| divulge | ʌ /U3 | u_e | o_e | 6 | 8 |
| | | | y_e | 6 | 2 |
| | ɪ /I3 | i | e | 22 | 10 |
| | | | o | 22 | 11 |
| dynamite | aɪ /I | y | i | 14 | 7 |
| | | | u | 14 | 9 |
| | aɪ /I | i_e | y_e | 14 | 5 |
| | | | a_e | 14 | 8 |
| easily | i: /E | ea | ee | 16 | 3 |
| | | | eo | 16 | 2 |
| | ə /ə | i | e | 22 | 10 |
| | | | o | 22 | 11 |
| governor | ʌ /U3 | o | u | 6 | 9 |
| | | | i | 6 | 7 |
| | ər /U2 + E5 | er | ur | 15 | 1 |
| | | | or | 15 | 2 |
| interpret | ɜ:/U2 + E5 | er | ir | 15 | 2 |
| | | | or | 15 | 2 |
| | ə /ə | e | y | 22 | 5 |
| | | | a | 22 | 10 |
| language | æ /A3 | a | e | 3 | 10 |
| | | | o | 3 | 11 |
| | ɪ /I3 | a | e | 22 | 10 |
| | | | o | 22 | 11 |
| lovingly | ʌ/U3 | o | u | 6 | 9 |
| | | | e | 6 | 10 |
| | ɪ /I3 | i | y | 22 | 5 |
| | | | a | 22 | 10 |
| machine | i: /E | i_e | e_e | 16 | 9 |
| | | | o_e | 16 | 8 |
| | ɪ /I3 | a | e | 22 | 10 |
| | | | y | 22 | 5 |
| motherly | ʌ /U3 | o | u | 6 | 9 |
| | | | e | 6 | 10 |
| | r̩ /U2 + E5 | er | ur | 15 | 1 |
| | | | ar | 15 | 2 |
| movement | u: /O6 | o_e | u_e | 16 | 8 |
| | | | e_e | 16 | 9 |
| | ə /ə | e | i | 22 | 7 |
| | | | o | 22 | 11 |
| mystical | ɪ /I3 | y | i | 22 | 7 |
| | | | o | 22 | 11 |
| | ə /ə | a | u | 22 | 9 |
| | | | i | 22 | 7 |

(*Continued*)

**Table B1.** (Continued).

| Unseen Target | Misspelled Phoneme (IPA/ Hanna) | Correctly Spelled as | Misspelled as | FB Consistency Index | FF Consistency Index |
|---|---|---|---|---|---|
| percolate | ɜː /U2 + E5 | er | ir | 15 | 2 |
| | | | or | 15 | 2 |
| | ə /ə | o | u | 22 | 9 |
| | | | i | 22 | 7 |
| physical | ɪ /I3 | y | i | 22 | 7 |
| | | | o | 22 | 11 |
| | ɪ /I3 | i | y | 22 | 5 |
| | | | o | 22 | 11 |
| prettiest | ɪ /I3 | e | i | 22 | 7 |
| | | | o | 22 | 11 |
| | I /E | i | y | 16 | 5 |
| | | | u | 16 | 9 |
| prevail | eɪ /A | ai | ei | 16 | 8 |
| | | | oi | 16 | 1 |
| | ɪ /I3 | e | i | 22 | 7 |
| | | | u | 22 | 9 |
| purpose | ɜː/U2 + E5 | ur | er | 15 | 3 |
| | | | ar | 15 | 2 |
| | ə /ə | o_e | u_e | 22 | 8 |
| | | | a_e | 22 | 8 |
| refurbish | ɜː/U2 + E5 | ur | er | 15 | 3 |
| | | | or | 15 | 2 |
| | I /E | e | i | 16 | 7 |
| | | | o | 16 | 11 |
| retreat | iː /E | ea | ee | 16 | 3 |
| | | | eu | 16 | 5 |
| | I /E | e | i | 16 | 7 |
| | | | o | 16 | 11 |
| service | ɜː /U2 + E5 | er | ir | 15 | 2 |
| | | | or | 15 | 2 |
| | ə /ə | i | y | 22 | 5 |
| | | | a | 22 | 10 |
| surgery | ɜː/U2 + E5 | ur | er | 15 | 3 |
| | | | or | 15 | 2 |
| | ə /ə | e | u | 22 | 9 |
| | | | o | 22 | 11 |
| various | e /A2 | a | e | 9 | 10 |
| | | | o | 9 | 11 |
| | I /E | i | y | 16 | 5 |
| | | | u | 16 | 9 |
| weirdest | ɪ /E2 | ei | yi | 8 | 0 |
| | | | oi | 8 | 1 |
| | ə /ə | e | y | 22 | 5 |
| | | | a | 22 | 10 |
| wonderful | ʌ/U3 | o | u | 6 | 9 |
| | | | e | 6 | 10 |
| | ə /ə | u | o | 22 | 11 |
| | | | y | 22 | 5 |
| worthless | ɜː/U2 + E5 | or | er | 15 | 3 |
| | | | ar | 15 | 2 |
| | ə /ə | e | i | 22 | 7 |
| | | | o | 22 | 11 |

*Note*. FF = feedforward; FB = feedback; IPA = International Phonetic Alphabet.