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Large grain instruction and phonological awareness skill influence rime sensitivity, processing speed, and early decoding skill in adult L2 learners

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Abstract

Linguistic knowledge, cognitive ability, and instruction influence how adults acquire a second orthography yet it remains unclear how different forms of instruction influence grain size sensitivity and subsequent decoding skill and speed. Thirty-seven monolingual, literate English-speaking adults were trained on a novel artificial orthography given initial instruction that directed attention to either large or small grain size units (i.e., words or letters). We examined how initial instruction influenced processing speed (i.e., reaction time (RT)) and sensitivity to different orthographic grain sizes (i.e., rimes and letters). Directing attention to large grain size units during initial instruction resulted in higher accuracy for rimes, whereas directing attention to smaller grain size units resulted in slower RTs across all measures. Additionally, phonological awareness skill modulated early learning effects, compensating for the limitations of the initial instruction provided. Collectively, these findings suggest that when adults are learning to read a second orthography, consideration should be given to how initial instruction directs attention to different grain sizes and inherent phonological awareness ability.

Learning to read an alphabetic orthography requires learning alphabetic rules; however the manner by which these rules are learned differ with age and instruction (Bitan and Karni, 2003, 2004; Bitan, Manor, Morocz, and Karni, 2005; Brooks and Miller, 1979; Farrington-Flint Wood, Canobi, and Faulkner, 2004; Foorman, Francis, Fletcher, Schatschneider, and Mehta, 1998; Van Orden, Stone and Pennington, 1990; Walton, 1995; Walton, Walton, and Felton, 2001). For literate adults learning to read a second orthography, existing linguistic knowledge, cognitive skill, and educational experience influence learning (Detey and Nespoulous, 2008; Erlam, 2005; Hamada and Koda, 2008, 2011; Koda, 1997, 1999; Laufer, 1997; Muljani, Koda, and Moates, 1998; Skehan, 1989; Sparks, Patton, Ganschow, and Humbach, 2009, 2012; Tong, Irby, Lara-Alecio, and Mathes, 2010). Previous investigations focusing on adult acquisition of a new orthography revealed that different forms of grain size instruction influence learning (Bitan and Karni, 2003, 2004; Bitan, Manor, Morocz, and Karni, 2005; Brooks and Miller, 1979). Orthographic acquisition is facilitated by sensitivity

to multiple grain sizes, including rimes (vowel and subsequent consonants) (Ziegler and Goswami, 2005). Rime recognition facilitates decoding speed and accuracy, yet it remains unclear how grain size instruction generalizes to rimes. It is also unclear if phonological awareness skill is important for second orthographic learning, but phonetic coding skills have been shown to influence second oral language learning (Skehan, 1989). Use of artificial orthographies reduced the influence of previously learned linguistic and orthographic experience that could confound learning outcomes (Bitan and Karni, 2003, 2004; Bitan, Manor, Morocz, and Karni, 2005; Brooks and Miller, 1979). The current study also utilized an artificial orthography to reduce the influence of reading and language experience on learning outcomes and to allow direct comparisons of two different instruction methods. We gave instruction that emphasized either a large or small grain size to determine if decoding speed and accuracy is enhanced for a rime-based alphabetic orthographic system. We also aimed to determine if phonological awareness skill influenced the acquisition of a new orthography. The results from this study extend previous research on second language learning by scrutinizing the influence of instruction method and phonological awareness skill in the acquisition of a second orthography.

Learning a second alphabetic orthography requires learning new grapheme-phoneme correspondences and the form of instruction provided influences decoding speed and accuracy (Bitan and Karni, 2003, 2004; Bitan, Manor, Morocz, and Karni, 2005; Brooks and Miller, 1979). Instruction that emphasized large grain units resulted in faster reading of new words written in an artificial orthography (Brooks and Miller, 1979). Instruction that emphasized small grain units, i.e., letters, resulted in slower reading of new words (Brooks and Miller, 1979) and slower performance on a letter task (Nokes and Ash, 2010). Adults given small grain instruction achieved higher accuracy on letter knowledge with better generalization to novel words compared to those given large grain instruction; however RT (reaction time) was faster for words given large grain instruction (Bitan and Karni, 2003). When grapheme-phoneme correspondence rules were simplified and training included additional exposures to words, large grain instruction also facilitated letter skill, but only for some of the adults given large grain instruction (Bitan and Karni, 2004). These results collectively demonstrated that large grain instruction better facilitated rapid word recognition and higher accuracy for larger grain patterns, and small grain instruction facilitated better knowledge of letter-sound correspondences, but these studies did not consider outcomes in terms of both RT and accuracy for multiple orthographic grain sizes, such as letters compared to rimes.

Fluent decoding involves rapid recognition of familiar and novel words. New learners sensitive to multiple grain sizes have an advantage when learning a new alphabetic orthography (Ziegler and Goswami, 2005). In an orthographic system that includes many rime families, such as English, rapid decoding is further enhanced when rimes can be accurately and quickly recognized. For example, speed and accuracy of word recognition improves when rime analogies (e.g., cat/hat, found/round) can be made. This is especially the case in an inconsistent orthography, like English, because some words cannot be decoded accurately based on letter-by-letter correspondences (e.g., night/light) (Goswami, 1999; Goswami and Bryant, 1990). In fact, letter-by-letter correspondences may result in frequent errors, whereas recognition of larger orthographic patterns, such as rimes, promotes

higher word reading accuracy. When learning to decode consistent orthographies, like German, learning rime patterns (e.g., Land/Strand, Hund/Mund) will improve the speed of decoding because untrained/unknown words will be more quickly decoded when rimes are familiar. Therefore, skilled word recognition for both types of alphabetic orthographies is facilitated by quick and accurate identification of larger patterns, including rimes. Despite previous research showing the influence of grain size instruction on second orthographic learning in adults (Bitan and Karni, 2003, 2004; Bitan, Manor, Morocz, and Karni, 2005; Brooks and Miller, 1979), how grain size instruction generalizes to rimes remains unknown.

Second oral language learning is influenced phonetic coding skill (Skehan, 1989), but it is unknown if second orthographic learning is influenced by phonological awareness skill. Phonetic coding is the ability to perceive non-native phonemic boundaries and requires sensitivity to small grain features. In contrast, phonological awareness refers to sensitivity to the smallest units of sound that make up words in the oral language, the ability to represent this information in short-term memory, and the ability to quickly access this information from long-term memory for sound blending during decoding (Wagner and Torgesen, 1987). Reading acquisition requires mapping between the oral and written systems and phonology plays an important role in this mapping process, especially with sensitivity to small grain structures (Goswami and Bryant, 1990). While it is well established that phonological awareness influences orthographic learning in children (Ball and Blachman, 1991; Bradley and Bryant, 1983; Wagner and Torgesen, 1987), it is unclear if this skill influences second orthographic learning in adults. Given the influence of phonetic coding skills for development of a second oral language in adults (Skehan, 1989) and the role of phonology in mapping between letters and phonemes, phonological awareness skill should influence the acquisition of a second alphabetic orthography in adult learners.

Learning to decode a new orthography is influenced by the method of instruction. Instruction can emphasize specific grain sizes in order to direct attention and promote sensitivity to targeted grain sizes. In the current study, monolingual literate adults were trained to decode an artificial alphabetic orthography that placed strong emphasis on rime structure. We hypothesized that when attention was directed to large grain structures; there would be better sensitivity to rimes as measured by higher accuracy. Recognition of larger patterns, such as rimes, should facilitate faster decoding and attention to smaller structures should result in slower decoding, therefore we predicted faster RTs given large grain instruction and slower RTs given small grain instruction. We further predicted that when attention was directed to small grain structures, sensitivity to letters would be enhanced and accuracy for letter-sound matching would be higher. However, because the artificial orthography used here emphasized rime structures, measurable differences in accuracy for letter-sound matching may be reduced. The second aim was to determine if phonological awareness skill influenced second orthographic learning. Phonological awareness plays a role in early development of readings skill and phonetic decoding is critical for second oral language acquisition. We hypothesized that since phonetic coding influences second oral language learning and both phonetic coding and phonological awareness require high sensitivity to small grain structures, accuracy of word recognition in the new orthography would be better for learners with higher phonological awareness skill.

Method

Design

Two separate forms of initial instruction were included to emphasize either large or small grain size as the between-subjects variable. We examined the effect of initial instruction on accuracy and RT (for correct trials) on a cross-modal word matching task following training on three separate days (within-subjects variable), as well as cross-modal matching tasks across two different orthographic grain sizes (i.e., smaller: letters, and larger: rimes) as the within-subjects variable at Day 3. Finally, we examined whether the relationship between phonological awareness skill and accuracy on cross-modal word matching depended on method of instruction and point in learning (i.e., Day 1, Day 2, and Day 3).

Participants

Thirty-seven adults participated in the study. All participants were monolingual English speaking participants who were also literate only in English. Participants were assigned to one of two instruction groups. Pre-testing performance ensured that groups were matched in reading and phonological skill. The small grain instruction group ($n=18$: 4 males, 14 females) had a mean age of 21.6 years (range 19–25 years). The large grain instruction group ($n=19$: 5 males, 14 females) had a mean age of 23.1 years (range 18–31 years).

Participants were recruited from Northwestern University and the nearby community using posters and fliers in accordance with IRB requirements. Participants were given questionnaires to insure that they met the following criteria: (1) native monolingual English speaker, (2) right-handed, (3) normal hearing and vision, (4) no neurological disease or psychiatric disorders, (5) not taking medication affecting the central nervous system, and (6) no learning disability.

Procedure

Participants completed four sessions. The initial session included standardized testing. The remaining three sessions included computer training and testing on the artificial orthography. All three training sessions included a cross-modal word matching test of trained words. The third training session (Day 3) also included a cross-modal matching test of rimes (larger grain) and letters (smaller grain). For all training and tests, participants sat in a quiet room approximately 24 inches from a 24-inch flat screen monitor and wore headphones.

Pre-testing

Standardized assessments were administered in order to match phonological awareness, reading skill, and visual working memory across the instruction groups. There were no significant differences between groups for average standardized testing scores on reading ability (*TOWRE* Sight Word Efficiency): ($F(1,35) = 1.125, p > .30$), phonological awareness skill (*CTOPPE* Elision and Segmenting Words): Elision ($F(1,35) = 0.678, p > .42$), Segmenting Words ($F(1,35) = 1.145, p > .29$), and visual working memory (*WJIII* Picture Recognition): ($F(1,35) = 0.025, p > .88$) (see Table 1). Phonological awareness measures were also correlated with learning outcomes as part of the second aim of the study.

Standardized measures included: Sight Word Efficiency from the *Test of Word Reading Efficiency* (TOWRE) (Torgesen, Wagner, and Rashotte, 1999). Two subtests from the *Comprehensive Test of Phonological Processing* (CTOPP) were administered: Elision and Segmenting Words (Wagner, Torgesen, and Rashotte, 1999). Elision and Segmenting Words were included because each measure involves different methods of grain size manipulation. Elision requires phonological manipulation at smaller and larger grain sizes. For Elision, participants delete single phones from words and then synthesize the remaining sounds into other words. For example, delete /n/ from “snail” (correct response is “sail”). In contrast, Segmenting Words requires manipulation only at the smallest phonological grain size (i.e., phones). For this measure, participants must break a given word into separate phonemes. For example, the correct response for the word “graduate” is /g/ + /t/ + /æ/ + /dg/ + ...etc. Elision therefore requires a two-step process involving deletion of a small grain followed by synthesis of small grain into larger grain, whereas Segmenting Words requires is a one-step process involving breaking a large grain unit (word) into small grain components (phones). A subtest from *Woodcock-Johnson III Tests of Cognitive Abilities* (Woodcock, McGrew, and Mather, 2001) was given to independently assess visual working memory: Picture Recognition.

Stimuli

In order to use an alphabetic orthographic script with minimal resemblance to English, a Klingon-like script was created. Klingon is an artificial language created by linguist Marc Okrand for the *Star Trek* television and movie franchise in 1984. Klingon has its own distinctive orthography and the version that inspired the graphemes in the current study were based on the font created by Mark Shoulson (<http://www.kli.org/tlh/pIqaD.html>). Prior to the experiment, the Klingon-like graphemes were evaluated by seven adults (different participants from the rest of the study). To evaluate the graphemes, participants were presented with each individual grapheme on a computer screen for three seconds. An inter-stimulus-interval (ISI) of three additional seconds followed each presentation during which the participants were instructed to identify or label any of the graphemes that looked like an English letter. After eliminating the graphemes that were identified as looking like English letters by two or more participants, there were 21 graphemes left. Nineteen of these graphemes were then randomly assigned to correspond to 19 phonemes (four vowels, 15 consonants) (for examples of the artificial graphemes, see Appendix 1).

Artificial words were created based on English words that have a similar spelling and rhyme. For example, the words “gasp, grasp, and clasp” all have the same spelling and rime, /-æsp/. Four groups of English words were selected controlling for word frequency and orthographic neighborhood density (Grainger, 1990). All of the words in these sets were matched on word frequencies and neighborhood density (Baayen, Piepenbrock, and Van Rijn, 1993). Additionally, the word sets were selected because the rimes had two possible pronunciations (such as clasp, grasp, and wasp). In order to create pseudowords for the artificial orthography, four groups of pseudowords were created based on the English word sets so that the original rimes of the English word sets were maintained. We created two sets of pseudowords with a CVCC (consonant-vowel-consonant-consonant) structure and two sets with a CCVC (consonant-consonant-vowel-consonant) structure. Even though the real

word families that the pseudowords were based on had two possible pronunciations, for this experiment, only one possible pronunciation was trained, making the artificial orthography consistent. From each word group, 32 artificial words were created following English phonotactic rules (see Table 2). The four rime groups were created with different vowels, /ə, o, i, æ/, and different final consonants, /-d, -n, -f, -p/. Examples of words include “blood, droad, pload”; “forn, jorn, lorn”; “bleaf, dreaf, pleaf”; and “fasp, jasp, nasp” (for all artificial words written with the artificial graphemes, see Appendix 1). Bigram frequency (phonotactic probability) was matched between the word groups (Medler and Binder, 2005; Vitevitch and Luce, 2004). Sixteen words were selected for training so that every grapheme was trained at least once and no more than six times. The other 16 words were used for testing generalization.

Auditory stimuli were recorded in a sound proof booth and digitally processed using WaveLab 4 software. All stimuli were spoken by the same female speaker (F0 approximately 190Hz) with a similar loudness level. An attempt was made to control the duration of spoken words and phonemes, however due to the manner of articulation and coarticulation, there is some variability in timing (mean word length: 609ms (range 410–900); mean phoneme length: 410ms (range 150–700)).

Instruction

Training was provided for three days. Each day of training included initial instruction (which differed for each group) following by exposure to training words and tests (see Figure 1a). Exposure to training words and tests were exactly the same for both instruction groups so the only difference between the groups is the nature of the initial instruction. Three days was considered necessary because in earlier pilot studies, adult participants failed to demonstrate adequate accuracy (>80%) on the cross-modal word matching task for trained words unless they had completed three days of training (one day of training resulted in an average accuracy <75%; two days of training resulted in a range of accuracy from 66–88%). Given three days, all adult participants were 85% or higher on the cross-modal word matching task for trained words.

After participants were divided into two groups, participants in each group were given only one form of initial instruction that each focused on different grain sizes: large or small (see Figure 1b and 1c). The initial instruction was provided at the beginning of each training session.

The initial large grain instruction directed explicit attention to the largest grain size for the stimuli being trained (whole words). As such, initial large grain instruction involved the single presentation of each of the 16 training words (see Figure 1b). Each word was presented only once. Words were presented visually in black text and accompanied by an auditory presentation of the corresponding spoken word. Visual word duration was 4500ms with the auditory presentation of the word beginning 1500ms after the visual presentation. Each word presentation was followed by a fixation lasting 2500ms. Pseudo-randomized order was used to minimize the occurrence of similar graphemes or rimes being presented in direct sequence. Participants were told to remember as much as they could.

The initial small grain instruction directed explicit attention to the smallest grain size, (letters/phones). As such, initial small grain instruction involved a single presentation of each of the 19 single letters, one letter at a time (see Figure 1c). Each letter was presented once. Letters were presented in a randomized order. Letters were presented visually in black text and accompanied by an auditory presentation of the corresponding phone. Letters were presented visually for 2700ms with the initiation of the auditory phone beginning 1000ms after visual presentation. The duration for the letter exposures was selected because it falls within the range of previous studies that also utilized timed letter instruction training (Bitan and Karni, 2003; Bishop, 1964; Knaflle and Legenza, 1978). Participants were told to remember as much as they could.

Following the initial instruction on all three training days, all participants were presented with a passive exposure to all 16 training words (Trained Words Exposure). During this word exposure, each training word was presented 7 times in pseudorandomized order. Therefore, all participants (regardless of the initial instruction) saw each training word seven times during this portion of training. In order to direct attention to large versus small grain size, the participants given initial large grain instruction also saw the training-words during the initial instruction component of training, whereas the participants given initial small grain instruction saw each of the letters instead of words. The format of the word exposure trials was exactly the same as the initial large grain instruction format (see Figure 1b). Passive exposure was utilized because we postulated that initial form instruction that emphasized either letters or words would be adequate to draw explicit attention to different grain sizes and allow us to measure generalization effects that occurred following word exposures. Directions prior to word exposures and testing were the same for both instruction groups.

Test Measures

Test measures included forced choice cross-modal matching judgments for trained words, rimes, and letters. Each trial consisted of a visual presentation (word or letter) followed by an auditory presentation (word or letter). Participants were instructed to determine if the visual and auditory word/letter presentations matched using the keyboard. Participants could respond as soon as they heard the auditory stimulus and had a total of 1950ms before the next trial began (see Figure 1d). Accuracy and RT were logged. For the cross-modal rime matching task, novel pseudowords were used, and matches and foils all had the same initial letters, requiring participants to make judgments based on the rime component of the word (the last 2–3 letters). The cross-modal letter matching task involved presentations of letters and phonemes. Foils included phonemes for other graphemes in the study (vowels for vowels and consonants for consonants).

Following the Trained Words Exposure on the first and second day, the only test given was the cross-modal word matching task for trained words. Following training on the third day, all cross-modal matching tasks were given (trained words, rimes, and letters).

Statistical Analysis

Mixed model ANOVAs (separately for accuracy and RT) were used to determine effects of instruction group (large or small) and day (1, 2, and 3) on the test of trained words. Post-hoc t-tests were done to further determine differences between groups when a significant group effect was found. One-way ANOVAs (separately for accuracy and RT) were used to determine group effects for rimes and letters on Day 3. ANOVAs for accuracy and RT were repeated, partialing for reading skill, phonological awareness (the average of the two administered *CTOPP* subtests), or visual working memory. Partial correlations for phonological awareness measures (*CTOPP* Elision and Segmenting Words) were calculated for each instruction group. In order to assess the individual contributions of Elision and Segmenting Words separately, we entered each of the variables into a stepwise multiple regression model using accuracy on the cross-modal matching task for trained words on days 1, 2, and 3 as the dependent variable. We entered Elision or Segmenting Words on the first step and the remaining phonological awareness variable entered on the second step. These analyses were done separately for each instruction group and for each day. Because this analysis determines the influence of each variable while controlling for the other, the results reveal the unique influence of each measure on learning outcomes for each instruction group. Correlations were repeated, partialing for reading skill or visual working memory. An additional regression analysis was done to determine if performance on Sight Word Efficiency (*TOWRE*) explained unique variance in learning for either instruction group.

Analysis of group differences in accuracy on the cross-modal matching test for trained words across three days of training includes one family of tests. In order to control for family-wise error rate, we assigned a type I error rate (alpha) of 0.05 and controlled for family-wise errors using Bonferroni correction. The same procedure was used for analysis of group differences in RT on the cross-modal test for trained words across three days of training, which was considered another family of tests. Partial correlations of the phonological awareness measures with accuracy on the cross-modal matching test for trained words across three days of training was treated at four families: one for each measure (Elision, Segmenting Words) and for each group (large or small).

Results

Accuracy

Both instruction groups demonstrated improvement in accuracy over the course of the three days on the cross-modal word matching task (trained words) as demonstrated by a significant effect of day ($F(1,35) = 52.974, p < .001$) (see Figure 2). Effect of day was still significant after partialing for reading skill ($F(1,35) = 39.359, p < .001$), phonological awareness ($F(1,35) = 52.316, p < .001$), and visual working memory ($F(1,35) = 40.129, p < .001$). For accuracy, there was not a significant interaction between day and group. Table 3 shows the mean percent accuracies for each instruction group across three days of training.

Accuracy for the larger grain size as measured by the cross-modal rime matching task revealed a significant effect of group ($F(1,35) = 5.074, p < .05$) (see Figure 3). Effect of

group was still significant after partialing for reading skill ($F(1,35) = 4.238, p < .05$) and visual working memory ($F(1,35) = 4.931, p < .05$), but not phonological awareness. When each phonological measure was partialled separately, there were trends towards significance (Elision: ($F(1,35) = 3.664, p < .07$); SW: ($F(1,35) = 3.362, p < .08$). There was no significant difference between groups for accuracy on the smaller grain size as measured by letter matching. Higher accuracy on the cross-modal rime matching task was found for the large grain instruction group. This finding is consistent with our prediction that directing attention to the largest grain size fosters generalization to other larger orthographic patterns.

Reaction Time

All instruction groups demonstrated faster RT over the course of the three days on the cross-modal word matching task (trained words) as demonstrated by a significant effect of day ($F(1,35) = 81.174, p < .001$) (see Figure 4). Effect of day was still significant after partialing for phonological awareness ($F(1,35) = 41.863, p < .001$) and visual working memory ($F(1,35) = 38.274, p < .001$), but not reading skill. There was a significant interaction between day and group ($F(1,35) = 5.062, p < .05$) and a significant effect of group ($F(1,35) = 12.847, p < .001$) with the large grain instruction group showing faster RT than the small grain instruction group on day 2 ($F(1,35) = 11.561, p < .002$) and day 3 ($F(1,35) = 14.837, p < .001$). Interaction between day and group was still significant after partialing for reading skill ($F(1,35) = 7.275, p < .05$), phonological awareness ($F(1,35) = 5.485, p < .05$), and visual working memory ($F(1,35) = 4.912, p < .05$), effect of group for day 2 was still significant after partialing for reading skill ($F(1,35) = 11.375, p < .002$), phonological awareness ($F(1,35) = 6.853, p < .003$), and visual working memory ($F(1,35) = 9.639, p < .005$) and effect of group for day 3 was still significant after partialing for reading skill ($F(1,35) = 19.330, p < .001$), phonological awareness ($F(1,35) = 9.883, p < .001$), and visual working memory ($F(1,35) = 14.469, p < .001$). These results are consistent with our prediction that large grain instruction would facilitate a faster processing speed.

RT for the cross-modal matching tasks for the larger and smaller grain sizes revealed significant group effects for rime matching ($F(1,35) = 7.487, p < .05$) and letter matching ($F(3,35) = 21.367, p < .001$). Effect of group for rime matching was still significant after partialing for reading skill ($F(1,35) = 6.846, p < .05$), phonological awareness ($F(1,35) = 3.751, p < .035$), and visual working memory ($F(1,35) = 7.313, p < .05$). Effect of group for letter matching was still significant after partialing for reading skill ($F(3,35) = 22.235, p < .001$), phonological awareness ($F(1,35) = 10.410, p < .001$), and visual working memory ($F(3,35) = 21.508, p < .001$). For both rime and letter matching, the small grain instruction group had slower average RT (see Figure 5). These results are consistent with our predictions that small grain instruction would show slower RT for rimes due to more explicit analysis of letters, and large grain instruction would show more rapid processing of letter combinations, such as rimes, due to greater attention of larger grain patterns.

Phonological Ability

We found that Elision explained unique variance for the small grain instruction group on day 1 (entered at step 1: $r = .57, p < .05$; entered at step 2: $r = .67, p < .01$) and on day 2 (entered at step 2: $r = .61, p < .05$), whereas Segmenting Words explained unique variance for the

large grain instruction group on day 1 (entered at step 1: $r = .73, p < .001$; entered at step 2: $r = .68, p < .01$), day 2 (entered at step 1: $r = .63, p < .01$; entered at step 2: $r = .56, p < .05$), and day 3 (entered at step 1: $r = .62, p < .01$; entered at step 2: $r = .62, p < .01$) (see Table 4).

For the small grain instruction group, the effects for Elision for day 1 remained significant after partialing for reading skill (reading skill entered at step 1; Elision entered at step 2: $r = .59, p < .05$; entered at step 3: $r = .75, p < .005$), as well as for day 2 (reading skill entered at step 1; Elision entered at step 2: $r = .53, p < .05$; Elision entered at step 3: $r = .67, p < .05$). Effects for day 1 also remained significant after partialing for visual working memory (visual working memory entered at step 1; Elision entered at step 2: $r = .59, p < .05$; Elision entered at step 3: $r = .76, p < .005$), as well as for day 2 (visual working memory entered at step 1; Elision entered at step 2: $r = .57, p < .05$; Elision entered at step 3: $r = .73, p < .05$).

For the large grain instruction group, the effects for Segmenting Words (SW) for day 1 remained significant after partialing for reading skill (reading skill entered at step 1; SW entered at step 2: $r = .87, p < .001$; entered at step 3: $r = .82, p < .001$), as well as for day 2 (reading skill entered at step 1; SW entered at step 2: $r = .73, p < .005$; entered at step 3: $r = .65, p < .01$), and day 3 (reading skill entered at step 1; SW entered at step 2: $r = .71, p < .05$; entered at step 3: $r = .71, p < .05$). Effects for day 1 also remained significant after partialing for visual working memory (visual working memory entered at step 1; SW entered at step 2: $r = .72, p < .001$; SW entered at step 3: $r = .68, p < .05$), as well as for day 2 (visual working memory entered at step 1; SW entered at step 2: $r = .60, p < .05$; SW entered at step 3: $r = .53, p < .05$), and day 3 (visual working memory entered at step 1; SW entered at step 2: $r = .68, p < .05$; entered at step 3: $r = .68, p < .05$).

Discussion

The first aim of this study was to determine if attention to large or small grain size structures resulted in differences in accuracy and speed for rimes versus letters. Adults were expected have sensitivity to multiple grain sizes given their English experience, but we predicted that attention to specific grain sizes would result in differences on accuracy and RT. We expected that large grain instruction would result in higher accuracy on rimes and faster RTs, but that small grain instruction would result in higher accuracy on letters. We found that large grain instruction resulted in the highest accuracy for rimes, but small grain instruction resulted in the slowest RTs across all learning measures. The second aim was to determine if phonological awareness skill influences second orthographic learning. We expected that learners with higher phonological awareness skill would achieve higher accuracy on word decoding. We found that high skill in Elision facilitated learning given small grain instruction, but high skill in Segmenting Words facilitated learning large grain instruction.

The current results support and extend findings of previous studies of effects of grain size instruction on second language orthographic learning by demonstrating that large grain instruction generalizes to rimes and results in faster processing. Large grain instruction resulted in faster word reading (Brooks and Miller, 1979) and small grain instruction resulted in better learning of letter-sound associations (Bitan and Karni, 2003). The current results are consistent with these previous findings and further demonstrate that large grain

instruction resulted in higher accuracy for rimes. Further, we demonstrated that small grain instruction lead to slower RT not only for words, but for letters and rimes as well. Because conscious analysis of details resulted in slower RT for decoding (Brooks and Miller, 1979) and letter matching (Nokes and Ash, 2010), we hypothesize that the small grain instruction provided here resulted in a slower processing speed due to greater conscious analysis of small grain features regardless of the grain size being measured.

We found that phonological awareness skill influences new orthographic learning, but individual differences in skill resulted in different outcomes following larger versus small grain instruction. Two phonological awareness measures (Elision and Segmenting Words) were examined to determine how they influence learning. We found that skill on Elision, which requires synthesis of small grain into large grain, is positively correlated with learning for adults given small grain instruction. Conversely, skill on Segmenting Words, which requires breaking large grain into small grain, is positively correlated with learning for adults given large grain instruction. These effects suggest that phonological awareness skill may compensate for the limitations of the instruction provided when initial instruction is only focusing on a specific grain size. High skill in Segmenting Words facilitated compensation when instruction focused on large grain structures because the adults were already highly skilled at breaking up larger structures. High skill in Elision facilitated compensation when instruction focused on small grain because the adults were already highly skilled at manipulating and synthesizing small into large grain structures. These results provide preliminary evidence that different phonological skills may differentially influence second orthographic learning in adults depending on the form of instruction provided, at least for the early stages of training. Future investigation should examine the role of phonological awareness in the acquisition of second natural orthographies in early learning and long-term outcomes.

The current results also address previously unanswered questions from previous findings. It was unclear why some of the participants in the Bitan and Karni study (2004) failed to master letter-sound correspondences given large grain instruction even when adequate exposure was provided. The current study demonstrated that individual differences in phonological awareness skill influenced outcomes depending on the form of instruction provided. The participants in the Bitan and Karni (2004) study who failed to learn letter-sound correspondences following large grain instruction may have had lower skill on Segmenting Words. These participants in the Bitan and Karni study (2004) were fluent in Hebrew, an opaque orthography, and may not have had the same level of phonological awareness as those with English experience, such as those in the current study. Because the current findings demonstrate that skill on Segmenting Words influences early decoding skill, we predict that phoneme awareness skill (as measured with Segmenting Words) would influence acquisition of small grain skill, including letter-sound knowledge, when instruction focused on large grain structures. Such effects would be consistent with those reported by Bitan and Karni study (2004).

Although the adults given small grain instruction were significantly slower on the letter matching task compared to large grain instruction, they did not achieve higher accuracies. Previous investigations of reading instruction methods suggest that direct alphabetic

instruction facilitates learning of letter-sound associations in adults learning a new orthography (Bitan and Karni, 2003), so we expected that letter matching accuracy would be better given small grain instruction. It is possible that in our study there were ceiling effects for letter knowledge before the third training day, as mean accuracy levels for all instruction groups was near 90%. Perhaps the small grain instruction group exhibited superior letter knowledge earlier in training, but this could not be examined with the current experimental design.

Orthographic structure, including consistency in the orthographic to phonological mappings and the importance of rime families, likely influenced learning outcomes observed. Our artificial words were based on English rhyme families that had two possible pronunciations, but we only trained one pronunciation, making our artificial orthography consistent. Given that we utilized a consistent artificial orthography, the results may not generalize to an inconsistent orthographic system, like English, and further investigation is warranted. While it is possible that an inconsistent orthography may have resulted in different effects from those reported here, we suggest that large grain instruction would also be advantageous for inconsistent alphabetic orthographies as long as training included adequate exposure to commonly occurring rime patterns. Adequate exposures may be especially important for inconsistent orthographies because decoding in these systems cannot rely solely on letter-by-letter decoding. Because our orthography included four rime families, it was more efficient to learn rimes than letters. Large grain instruction was therefore more informative given the structure of the orthography used here. In contrast, an alphabetic orthography with less commonly occurring rime patterns may not benefit from large grain instruction to the same degree. Instruction should emphasize the critical features of the orthography being trained and the grain size(s) most important to the new orthography should be targeted, especially in the early stages of training. Consistent orthographies that naturally emphasize smaller grain sizes may prove to be better trained given small grain instruction. Orthographies that map at a larger grain size, like Chinese, may benefit more from large grain instruction.

The current results reflect learning outcomes for learning a second orthography given preexisting knowledge and experience reading in English and these effects relate to usage-based views of language and literacy learning (Tomasello, 2003). Usage-based views propose that the acquisition of language follows from multiple exposures to linguistic structures and subsequent pattern-finding. Linguistic exposure and pattern-finding behaviors facilitates recognition of the complexities of a dynamic system (Tomasello, 2003). Since L1 experience influences L2 acquisition (Detey and Nespoulous, 2008; Sparks, et al., 2009, 2012; Tong et al., 2010), exposure to English likely influenced new pattern learning in the trained artificial orthography. In fact, L1 experience has been shown to influence attention to specific features of L2, especially when linguistic features are similar in both languages (Hamada and Koda, 2008, 2011; Koda, 1997; Koda, 1999; Laufer, 1997; Muljani et al., 1998). In the current study, the new orthography was consistent, alphabetic, and heavily emphasized rimes. English is an inconsistent alphabetic orthography that also has many rime families. Adults experienced with English should have a well-developed sensitivity to multiple grain sizes, including rimes. Therefore, the advantage observed for adults given the large grain instruction for rimes and RT may be due to the participants' experience with the relatively opaque mapping between orthography and phonology in English as well as a high

familiarity with rime families. It is possible that participants with different L1 experiences would show relative benefits under small grain instruction, such as adults who have mastered a transparent writing system like Korean or adults with less familiarity with rime patterns.

The current results provide evidence that initial instruction focusing on letters or words results in differences in the sensitivity to various grain sizes, but this study did not include an initial instruction that specifically focused on rimes. For young children, instruction that emphasizes rimes leads to accurate decoding for novel words (Wise et al., 1990) and fosters the emergence of a reading strategy utilizing rime analogies (Peterson and Haines, 1992). Because of the importance of learning to manage both large and small grain sizes, Goswami (1999) argues that instruction should emphasize both large and small grain sizes by including instruction on phoneme correspondences, onset-rime segmentation, and rime analogy. Because the orthography utilized in this study included words from rime families, learning the rimes was highly important for decoding quickly and accurately. While Goswami's position is that rime instruction is beneficial to children learning to read their first orthography, we suggest that the adults in the current study would have also benefitted from instruction that emphasized rime structures. We propose that if initial instruction emphasized rimes, then accuracy for rimes would have been even higher than the adults given initial large grain instruction. Additionally, if faster processing speed is facilitated by attention to larger grain sizes then rime instruction may promote faster RTs compared to small grain instruction but slower RTs compared to large grain instruction.

The measure used in the current study involved a cross-modal matching task which may tap into a combination of L2 visual memory skills and L1 grain size sensitivity; however we believe that these effects would not confound the current findings due to pre-testing controls. Pre-testing results showed no significant group differences on visual working memory or phonological awareness (which taps into L1 grain size sensitivity). While visual working memory influences the ability to acquire visual recognition of L2 graphemes (Harrington and Sawyer, 1992), the groups here were matched on this ability. Further, when analyses were rerun partialing for visual working memory, the effects for group differences remained significant. L1 grain size sensitivity was, in part, measured by the phonological awareness measures and revealed no group differences. While L1 grain size sensitivity may influence performance on the L2 cross modal matching, comparable skills across groups reduce the possibility that any differences in this skill (or in visual) would be responsible for current group differences. Further, when analyses were rerun partialing for phonological awareness skill, group effects for RT remained significant. In contrast, group difference for accuracy on rime matching did not maintain a significant level after partialing for phonological awareness, although it was trending towards significance when each phonological awareness measure was partialled separately. This effect suggests that phonological awareness does influence acquisition of sensitivity to larger grain sizes, in this case rimes, regardless of the grain size targeted in instruction. This finding further extends our results demonstrating the influence of phonological awareness for adults learning a new orthography and suggests that phonological awareness may mediate development of grain size sensitivity but does not appear to influence processing speed.

The authors acknowledge that the artificial orthography utilized here was structurally simple and included only a small set of training and generalization words. Learning to recognize trained words and rimes required only a simple abstraction on the basis of a limited number of words. It remains unclear to what extent these findings are ecologically valid. This design allowed us to address clear questions regarding how grain size instruction influences learning orthographic patterns. We also demonstrated the influence of phonological awareness in new orthographic learning. These findings improve our understanding of the influence of instruction and phonological skill on second orthographic learning.

Importantly, this study opens new avenues of research that can address acquisition of more complex orthographic features such as what would occur in natural second language learning. While the demands of the large grain size instruction and the rime matching task are similar, we do not believe this gave an advantage to the large grain instruction group. First, both groups were given multiple exposures to the training words. Secondly, the instruction was passive and did not require participants to respond. In contrast, the task required participants to perform differently by matching visual and auditory forms of the artificial words. Any possible advantage on the cross-modal matching task for the large grain instruction should be minimal because both groups were similarly exposed to whole words and the large grain instruction group did not have practice at a word level (or rime level) task prior to testing.

As a form of control, the artificial orthography utilized in this study did not include semantic elements. Similarly, previous studies of second orthography learning also chose not to have semantic associations as part of their artificial orthography (Bitan and Karni, 2003, 2004; Bitan, Manor, Morocz, and Karni, 2005). We acknowledge that semantics and the ability to make semantic associations play critical roles in literacy acquisition. Our rationale to not include semantics in our design was to have a small finite set of words and rime families in order to test the theory that grain size emphasis in instruction would lead to differences in accuracy for rimes and letters. We believe that adding meaning to the artificial words could have given our participants an alternative approaches to learning, making interpretation of outcomes less clear. In a more natural learning experience, semantics would likely influence learning and may either mitigate or exaggerate the outcomes seen here. For example, semantic associations may help when grain size mapping is insufficiently learned.

In conclusion, the current study provides evidence that initial instruction that emphasizes different grain sizes influences processing speed and sensitivity to rimes for adults learning a second, novel orthography. Small grain instruction emphasizes explicit attention to the smallest grain size, resulting in slower processing but high accuracy for letters. Large grain instruction emphasizes greater attention to larger grain size units and promotes attention to rimes, resulting in faster processing and higher accuracy for rimes. The current results also demonstrate that phonological awareness skill is important for adults learning a new orthography. We found that individual differences in phonological skill (Elision and Segmenting Words) interact with the form of initial instruction and differentially influence early learning outcomes. Future investigations should consider the role of grain size in instruction and the role of phonological awareness when more complex orthographic

systems and/or natural languages are being trained to literate adults learning a second language.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Design of Instruction Methods. (a) Training was provided for three days and involved instruction, exposure to training words, and tests. Participants were given only one form of initial instruction: large or small grain instruction. Each participant got the same form of instruction at the beginning of each training session; (b) Large grain instruction involved a single presentation of each of the 16 training words, each whole-word visually presented and paired with the pronunciation; (c) Small grain instruction involved a single presentation of each of the 19 single letters, each letter presented visually and then paired with the pronunciation; (d) Test measures for trained words, rimes, and letters included forced choice cross-modal matching judgments.

Figure 2.

Both groups demonstrated significant improvement in accuracy over the course of the three days on the cross-modal word matching task (trained words) as demonstrated by a significant effect of day.

Figure 3.

Analysis of accuracy for large and small grain instruction reveals a significant effect of group ($p < 0.05$) for matching rimes with initial large grain instruction achieving higher accuracies than those given initial small grain instruction. There was no significant difference between instruction groups for matching letters.

Figure 4.

Both instruction groups demonstrated faster RTs over the course of the three days on the cross-modal word matching task (trained words) as demonstrated by a significant effect of day. There was also a significant interaction between day and group and a significant effect of group with the large grain instruction group showing faster RT than the small grain instruction group on day 2 and day 3.

Figure 5.

RT for the cross-modal rime matching task revealed a significant effect of group ($p < 0.05$) with slower average RT for the small grain instruction group. There was also a significant group effect ($p < 0.001$) for RT on the cross-modal letter matching task with slower average RT for the small grain instruction group.

Table 1

Average standardized testing scores on reading ability (TOWRE Sight Word Efficiency), phonological skill (CTOPP Elision and Segmenting Words), and visual working memory (WJIII Picture Recognition) for the 2 instruction groups (large and small) reveals no significant group differences.

	Instruction Groups		Effect of Group	
	Large	Small	F	sig.
TOWRE Sight Word Efficiency ⁺	105 (9.5)	108 (7.5)	1.125	$p > .30$
CTOPP Elision [*]	11.0 (0.8)	10.8 (1.2)	0.678	$p > .42$
CTOPP Segmenting Words [*]	12.7 (1.9)	11.7 (1.2)	0.292	$p > .29$
WJIII Picture Recognition ⁺	99 (2)	104 (4)	0.025	$p > .88$

Notes: All scores are standardized and group averages are followed by the standard deviation in parentheses.

⁺ TOWRE and WJIII subtests provide standard scores with a mean of 100 and a standard deviation of 15.

^{*} CTOPP subtests provide standardized scaled scores with a mean of 10 and standard deviation of 3.

Table 2

All artificial words for the four rime groups including trained words (top 4 rows) and novel words for the rime test (bottom 4 rows).

	CCVC /ɒd/	CCVC /ɪf/	CVCC /æsp/	CVCC /ɔrn/
Trained Words	bload /blɒd/	pleaf /plɪf/	nasp /næsp/	forɪn /fɔrn/
	droad /drɒd/	speaf /spɪf/	shasp /ʃæsp/	jɔrn /dʒɔrn/
	stoad /stɒd/	shreaf /ʃrɪf/	sasp /sæsp/	lɔrn /lɔrn/
	smoad /smɒd/	gleaf /glɪf/	zasp /zæsp/	vɔrn /vɔrn/
Novel Words	pload /plɒd/	bleaf /blɪf/	fasp /fæsp/	nɔrn /nɔrn/
	spoad /spɒd/	dreaf /drɪf/	jasp /dʒæsp/	ʃɔrn /ʃɔrn/
	shroad /ʃrɒd/	steaf /stɪf/	lasp /læsp/	sɔrn /sɔrn/
	gload /glɒd/	smeaf /smɪf/	vasp /væsp/	zɔrn /zɔrn/

Note. // delimits phonetic symbols.

Table 3

Mean percent accuracies and RT (ms) for each instruction group (large and small) on the cross-modal word matching task across three days of training (standard error in parentheses).

Accuracy	Day 1	Day 2	Day 3
Large	73.1 (3.6)	83.4 (1.7)	88.6 (1.4)
Small	72.4 (2.6)	81.8 (2.8)	87.9 (1.8)
Reaction Time	Day 1	Day 2	Day 3
Large	1000 (30)	837 (33)	741 (38)
Small	1103 (55)	1013 (60)	948 (46)

Table 4

Partial correlations for phonological awareness measures (*CTOPP* Elision and Segmenting Words) for each instruction group (large and small) across the three days of training. In order to assess the unique contributions of Elision and Segmenting Words, we entered each of the variables into a stepwise multiple regression model using accuracy on the cross-modal matching task for trained words on days 1, 2, and 3 as the dependent variable. Elision accounts for unique variance in the small grain instruction group, whereas Segmenting Words accounts for unique variance in the large grain instruction group.

	Step: Measure	Day1	Day2	Day3
Large	1: Elision	0.38	0.43	0.14
	2: Segmenting Words	0.68 *	0.56 *	0.62 *
	1: Segmenting Words	0.73 *	0.63 *	0.62 *
	2: Elision	0.15	0.25	-0.14
Small	1: Elision	0.57 *	0.51	0.34
	2: Segmenting Words	-0.45	-0.40	-0.47
	1: Segmenting Words	-0.14	-0.13	-0.29
	2: Elision	0.67 *	0.61 *	0.50

Note:

*
p<.05 corrected