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A dissociation between orthographic awareness and spelling production

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ABSTRACT
In this study, two nonword spelling and two orthographic awareness experiments were used to examine people's production and awareness of sound–spelling relationships. The results of the nonword spelling experiments suggest that, in general, people use phoneme–grapheme sized relationships when spelling nonwords. Alternatively, the results of the orthographic awareness experiments suggest that, under some circumstances, people can use larger sized sound–spelling relationships when judging how frequently subsyllabic relationships occur. Together the results suggest that there is a dissociation between sound–spelling production and sound–spelling awareness tasks, and the size of the sound–spelling relationships that people use varies under different tasks and task conditions.

Production and awareness of spelling are two core components of spelling ability. They allow people to write and proofread text. Although intricately linked, the two components are not identical. This can be seen most obviously from young children's spelling. When young children spell, they often use simple single-letter, single-sound transcriptions for words, even when more orthographically typical responses exist (e.g., Treiman, 1993). Similar comparisons with adults are more difficult because adults produce many fewer errors when proofreading and writing. This may be one reason why there is much less data in this area than similar areas, such as reading. However, for a better understanding of adult spelling ability, a systematic study of the relationship between spelling awareness and production is necessary.

According to the dual route model of spelling (e.g., Ellis, 1982, 1984; Kreiner, 1992), one of the differences between nonword spelling and orthographic awareness is that nonword spelling requires the ability to segment larger syllabic sounds into smaller sound segments and then apply phonology to orthography translation rules on each smaller segment. If people segment syllables when spelling nonwords, then the size of those segments is important, for at least two reasons. First, the size of the segments provides a constraint on the sound–spelling relationships that people use to spell nonwords. If, for example, people segment syllables into an onset-rime structure, then it would be expected that nonword spelling would be influenced by the frequency of the relationships based on those units. Alternatively, if people segment syllables into phonemes, then the relationships used would be based on phoneme–grapheme units. Second, the way in which syllables are segmented affects how the complexity of the sound–spelling domain should be measured. If people predominantly use phoneme–grapheme relationships when spelling, then factors determining the complexity of the sound–spelling relationship would need to be measured at the phoneme–grapheme level. Alternatively, if people use larger sound–spelling relationships (e.g., rime–body), then complexity would need to be measured at the larger level.

In terms of small sized relationships, Kreiner (1992) found evidence suggesting that people are sensitive to phoneme–grapheme sized sound–spelling relationships when spelling. In Experiment 2 of his study, he measured the amount of time it took people to spell words aloud. The results indicated that people were faster at spelling words that had phoneme–grapheme relationships that could be spelled in only a few ways, compared to words that had phoneme–grapheme relationships that could be spelled in many ways. This finding suggests that the inconsistency of phoneme–grapheme relationships is an important factor in spelling aloud tasks. In terms of larger sized sound–spelling relationships, Nation (1997) found that children were more likely to correctly spell words with many rime neighbors than words with few rime neighbors. She argued that this meant that children are able to use relationships larger than the phoneme–grapheme size when spelling nonwords.

Apart from data from spelling production tasks, data from orthographic awareness tasks (e.g., Cassar & Treiman, 1997; Siegel, Share, & Geva, 1995) have also been used to help understand processes that underlie spelling and orthographic development. Two types of orthographic awareness tasks that have been used are the orthographic choice task and the auditory–orthographic choice task. In the orthographic choice task, people are presented with a list of nonword pairs and asked to choose one item from each nonword pair based on a word likeness criterion. The auditory–orthographic choice task is identical to the orthographic choice task except that a nonword is presented auditorily before the presentation of each orthographic pair. An interesting aspect of the results from the orthographic and auditory–orthographic choice tasks is that they are not always the same as those found in spelling production tasks. Cassar and Treiman (1997), for instance, noted that children's awareness of doubling constraints in medial and final letter positions differed from error patterns found in spelling production. In their orthographic choice experiment, the children exhibited a similar level of accuracy when judging whether a letter could be doubled in a medial or a final position. Conversely, in a number of previous spelling studies (Stage & Wagner, 1992; Treiman, Berch, & Weatherston, 1993) children tended to have more difficulty spelling medial than final letters. Such a pattern suggests the existence of a difference between the levels of children's orthographic awareness and spelling production.

Although a number of results from orthographic awareness and spelling tasks were reported individually, no study with adults systematically investigated the similarities and differences between the two types of tasks. Finding such differences would suggest that component processes involved in spelling may differ critically, depending on whether participants produce spellings or merely judge their legality. Furthermore, if people are aware of common sound–spelling relationships but do not use them when spelling, it suggests that processes related to more than simple relationship complexity cause spelling to be more difficult than reading. In this case, it suggests that there are certain difficulties associated with the production of spelling that are not associated with sound–spelling awareness.

The main objective of the following experiments was to examine two interrelated factors: orthographic awareness and people's production of sound–spelling relationships. Here we assume, based on child and adult spelling data (see Treiman, 1993, for a review of child spelling data, and Kreiner, 1992, for some adult spelling data), that smaller sound–spelling units tend to be easier to spell than larger ones and that the difficulty of task conditions can modulate the extent to which people produce orthographically typical answers compared to simply the most frequent sound–spelling correspondences (see Brown & Deavers, 1999, for a task condition manipulation in reading). We also assume that people's orthographic awareness is not necessarily the same as their ability to produce sound–spelling relationships (or to read; see Siegel et al., 1995, for a dissociation of these two variables with dyslexics and normal readers). Note that orthographic awareness and spelling production are unlikely to be completely independent in literate adults, however, or people would produce nonword spellings with common sound–spelling relationships but orthographically atypical sequences (e.g., *cwac*). Thus, it is assumed that in spelling and orthographic awareness tasks the integration of knowledge involving both sound–spelling relationships and orthographic awareness must occur.

Four experiments were used to allow these two factors to be investigated on a continuum. In the first experiment, participants were asked to spell a list of nonwords. In the second experiment, participants spelled the same nonwords, but the task conditions were changed by deliberately asking the participants to try and produce the statistically most common sound–spelling patterns they knew. The idea of the first two experiments was to examine the type of sound–spelling relationships people use when spelling nonwords, and to see whether those relationships can be strategically biased by changing task conditions. The third and fourth experiments examined people's awareness of sound–spelling relationships using two orthographic awareness tasks. In the third experiment an auditory–orthographic choice task was used. The fourth experiment was identical to the third except that an orthographic choice task was used. In the third and fourth experiments, we assume that the correspondences that people use may be biased by sound–spelling relationships rather than only orthographic patterns (particularly when participants are asked to judge orthographic patterns based on sound criteria). Here, if people's orthographic awareness and ability to produce sound–spelling relationships never converges (i.e., if people's orthographic awareness units are bigger than those that they used to spell), then we would expect that incorporating smaller units of spelling–sound knowledge when performing such tasks would reduce people's potential use of larger orthographic units. Together, the idea is that neither spelling nor orthographic awareness tasks tap processes that are completely independent of each other, and thus that each task allows a different view on the processes discussed here.

EXAMINING SOUND–SPELLING RELATIONSHIPS WITH NONWORDS

Before we describe the experiments, it is useful to detail the methodology we used for examining the results from the nonword spelling experiments. Perhaps the biggest problem with examining the results of nonword spelling experiments is that the answers people can give for any given stimuli are often fairly unconstrained. That is, given a single nonword phonology, many answers can be given. Note that this problem essentially mirrors that found when examining nonword reading. In that task, people may give answers based on single grapheme–phoneme relationships (regularity), answers based on body–rime relationships (consistency), a combination of the two, or some other form (see Andrews & Scarratt, 1998, for a discussion). Thus, we need some way of examining nonword answers so that underlying processes can be examined.

One potential method for analyzing the results is to examine the distribution of answers based on different sound segmentations that can be used. Let us assume that the phoneme is the smallest form of segmentation. If the largest unit into which people can segment sound is the phoneme, then we would expect the simplest form of phoneme–grapheme spellings to be given. Take the nonword /jaɪt/ as an example. When broken into its individual phonemes, it is /j/, /aɪ/, /t/. If the most frequent set of phoneme–grapheme correspondences is applied to these, then the relationships are /j/ → j, /aɪ/ → i.e, /t/ → t. If the letters are assembled into a contiguous string, they form the nonword *jite*. Thus, based on phoneme–grapheme frequency, this is the most common spelling that would be expected. Of course, on the basis of individual phoneme–grapheme relationships, some words are also spelled with the /aɪ/ → igh relationship. If the phonemes people spell nonwords with are susceptible to probabilistic influence, then some of the answers would also be likely to be written as *jight*. It would still be expected that *jite* would be more common than *jight*, however. The idea here is that if people spell nonwords using the most common graphemes, it suggests that phoneme–grapheme sized sound–spelling relationships are important.

Let us now assume that people can process larger units of sound than the phoneme and that these larger units also influence people's spelling. The rime appears to be a relevant unit in people's speech perception (e.g., Treiman & Danis, 1988), and therefore seems a reasonable choice as a possible larger unit that people use when spelling. Here /jaɪt/ would be broken into /j/ and /aɪt/. The most common orthography that corresponds to /aɪt/ is *-ight* (e.g., *fight*). If people use these larger relationships, then the distribution of answers that they give would be expected to differ compared to the distribution if only phoneme–grapheme relationships are used. Here, it would be expected that *jight* would be given as an answer, even though the /aɪ/ → *igh* relationship is a relatively uncommon spelling pattern, in terms of phoneme–grapheme relationships. In this case, because the *-ight* body is more common than *-ite*, it may influence the nonword spellings that people use. Thus, if the distribution of answers was such that *jight* was commonly given, then it would suggest that not only phoneme–grapheme relationships play a role in people's nonword spelling, but that the rime plays an important role, too.

In summary, the idea behind the analysis of the nonwords reported here is to group the answers based on statistical categories derived a priori from database statistics. Examining the distribution of responses based on these groups may then allow some insight into the process that people use when spelling.

EXPERIMENT 1: FAST SPELLING

The objective of this experiment was to examine the type of subsyllabic relationships that people use when spelling nonwords. One method of examining these relationships is to choose nonwords that have alternative spellings that can be manipulated on a dimension of interest, as discussed above. Using such a technique, seven groups were chosen to examine the subsyllabic units that people use in nonword spelling. They can be broken into two main subsets; grain size and morphological subsets. The purpose of the two subsets is the same: that is, to examine the size of the subsyllabic units that people use to spell nonwords (i.e., which units are smaller than the syllable people use when spelling nonwords). However, because the relationships between the individual groups within each subset is slightly different, we describe and analyze the results from the two subsets separately.

In terms of the items of the grain size subset, four different groups were used. The first three groups all used a high–low phoneme–grapheme contingency[1] (PGC) manipulation. That is, the nonwords were chosen such that two expected spelling groups for the nonwords would be given for any given stimuli. The expected spelling groups were chosen from previously derived database statistics, with the high PGC group always containing the most common vowel spelling unless that spelling would have resulted in an orthographic body that did not exist. When that happened, the next most common vowel was selected. Further constraints on these stimuli choices are documented here. Where possible, the phoneme–grapheme relationships were taken from Barry and Seymour (1988) and Hanna, Hanna, Hodges, and Rudorf (1966). Relationships that were not in those databases were simply counted from the monosyllabic CELEX database. For example, the phoneme examined in the nonword /tʃəʊp/ was /əʊ/. Therefore, the two most common spellings expected were *chope* (most common) and *choap* (second most common). The idea is that if people are sensitive to phoneme–grapheme frequency, then it would be expected that more spellings would be given where higher frequency relationships are used than where lower frequency relationships are used. That is, *chope* would be given more often than *choap*. Note that the PGC counts we used were sensitive to whether a vowel phoneme occurred at the end of a word. This was done by considering the same vowel different when it occurred at the end of a word and when it occurred in

Table 1. *Summary of design*

Gram-size groups			
		Phoneme–grapheme contingency	
Example	Difference in body neighbors	High	Low
/tʃəʊp/	High	*chope*	*choap*
/tʃɔːn/	Medium	*chorn*	*chawn*
/jaɪt/	Low	*jite*	*jight*
High frequency neighbor control group			
/pɑʊn/(down)		*paun*	*pown*
Morphological groups			
		Complexity	
	Type	Simple	Complex
/gænd/	Doublet	*gand*	*ganned*
/sɒmpt/	Three consonant	*sompt*	*somped*
/vækt/	Digraph	*vact*	*vacked*

Note: Italicized items are examples.

the middle of a word. Thus, the /eɪ/ in *late* was considered to be different to the /eɪ/ in *pay*. We did this because middle vowel spellings and end vowel spelling often have very different distributions in terms of sound–spelling relationships.

Across the three groups, the high PGC spelling groups differed with respect to difference in orthographic body neighbors (dBN).[2] Here we refer to orthographic body neighborhood (BN) as the count of all words that share the same letters, excluding the initial consonants, as the target nonword (e.g., the *-ite* in *bite*). We refer to dBN as the BN count of one word minus the BN count of another (e.g., the dBN count of *bite* and *flight* would be the number of times *-ite* occurs minus the number of times *-ight* occurs). With respect to the dBN variable, one of the groups used a high dBN count, the second group a medium dBN count, and the third group a low dBN count. Thus within each of the groups there was a PGC manipulation, and across the three groups there was dBN manipulation. The idea of the design was to allow the effect of both smaller (phoneme based) and larger (rime based) sound–spelling relationships to be examined. This design can be seen in Table 1. Here, if people use larger units when spelling and if the frequency distribution of those units differs from that of the smaller units, then it would be expected that the number of times high PGC nonwords are given would be modulated by the frequency of the larger units. Thus, if a high frequency phoneme–grapheme relationship is contained within a low frequency word body and if people are susceptible to larger units, then it would be expected that the number of times a high frequency phoneme–grapheme relationship is given would be less than when a high frequency phoneme–grapheme relationship is contained in a high frequency word body.

An example of this design can be seen from the nonwords /tʃəʊp/, /plɔːn/, and /jaɪt/. First take /tʃəʊp/. The two most common body spellings for the nonword /tʃəʊp/ are *-ope* and *-oap*, with -ope occurring more often than *-oap*. Thus, the most commonly expected spelling would be *chope*, based on both phoneme and rime sized segmentations. Alternatively, the two most common bodies for /plɔːn/ are *-orn* and *-awn*, both of which occur at similar frequencies (*-or* is the most common vowel spelling). Thus, when people spell the phoneme /ɔː/, they should not be influenced by larger sized units, because the frequency is matched. Thus, if larger units do not play a role, the ratio calculated from the number of times *plorn* is used as a spelling compared to *plawn* would be similar to the ratio calculated from the number of times *chope* is given compared to *choap*. Alternatively, if larger units do play a role, then the ratio between *plorn* and *plawn* would be less than between *chope* and *choap*, because *chope* would be the dominant spelling based on both sizes of measures, rather than only the phoneme–grapheme sized measure. Finally, take the nonword /jaɪt/. Here, the most common vowel spelling, *-i.e*, occurs in a body that is less frequent than a body that contains the less common vowel spelling *-igh*. Thus, if larger units play a role in spelling, the ratio calculated from the number of times *jite* (the nonword with the most common vowel spelling) is given compared to *jight* (the nonword with the most common orthographic body) would be expected to be less than either the intermediate group (*plorn* vs. *plawn*) or the group in which both the body and vowel were of the highest frequency (*chope* vs. *choap*).

A final (fourth) group was used as a control group to examine whether people tended to make an analogy with the spellings of high frequency words of a similar sound, as measured by phonological neighbors (e.g., Peereman & Content, 1997; Vitovich & Luce, 1998), rather than use common sound–spelling relationships. For each nonword in that group, the two most likely spelling groups were chosen such that one represented a high PGC spelling whereas the other represented a low PGC spelling. The low PGC spelling had a high frequency (CELEX frequency > 5000; Baayen, Piepenbrock, & van Rijn, 1993) phonemic neighbor, however. If the results of the previous groups are confounded with this variable, then such a comparison should show an advantage for words with high-frequency neighbors. An example of this is the nonword /pɑʊn/. There are two typical spellings that would be expected for this nonword based on PGC: *pown* and *poun*. If people typically use high PGC correspondences, then they would spell the nonword *poun*. Alternatively, if they are influenced by a high frequency neighbor, then they would spell the nonword *pown*. This is because the high frequency neighbor *down* has a much higher frequency than any words that end in /ɑʊn/.

The purpose of the morphological groups was the same as for the grain size groups. That is, these groups were used to examine the size of the sound–spelling relationships that people use when spelling. However, instead of examining whether people use rime–body or phoneme–grapheme relationships when spelling, we examined whether they use morphologically complex or simple patterns. Three main types of comparison were used. These were the effect of morphological complexity on doublet (*-nned* vs. *-nd*), digraph (*-cked* vs. *-ct*), and three-consonant (*-mped* vs. *-mpt*) spellings. Note that we use the term *digraph* because in that group, participants may potentially spell the nonwords with a *-ck* digraph. Thus, the idea was to examine whether people use *-ed*, rather than a single consonant, at the end of nonword spellings. Note that the idea behind the groups was identical. Three groups were used simply to allow generalizability of the results over different nonword types in case idiosyncratic (unknown) aspects of morphology affected the results. Note that, unlike the previous comparisons, where larger units were manipulated in low, medium, and high groups, the comparisons used with each of these groups is simply based on a dichotomous comparison between the number of times morphologically simple and morphologically complex answers are given. These morphological groups allow an even more extreme comparison than was the case in the previous groups. This is because, even in the group with the largest dissociation between PGC and dBN, the difference between the most common and the next most common orthographic body is still relatively small. Alternatively, in the morphological comparisons, it is possible to find large units in which there are extremely large differences between the most common phoneme–grapheme sequence and the larger unit spelling (e.g., *-mpt* vs. *-mped*).

The idea behind the comparisons is that if people only use small-sized (i.e., phoneme–grapheme) relationships, then the morphologically simple answers have the higher frequency sound–spelling relationships. Alternatively, if people use larger sized sound–spelling relationships, then the morphologically complex answers have the higher frequency sound–spelling relationships. Take the digraph words as an example. All of these words end in /kt/, which is why they potentially can be spelled as digraphs. If the two phonemes /kt/ are analyzed in terms of single phoneme–grapheme relationships, then the most frequent relationships are /k/ → c and /t/ → t. Thus, putting them together gives a morphologically simple answer: *-ct*. However, if the larger units of sound are examined (in this example, two phonemes), then a different pattern is the most frequent: /kt/ → *cked* is more common than /kt/ → *ct*. The same pattern holds true for the nonwords used in the other two groups. That is, the application of the most frequent phoneme–grapheme relationships, which are single-phoneme single-letter translations for all of the nonwords in those two groups, leads to a morphologically simple answer. Application of the most frequent larger units leads to a morphologically complex answer. An example of this in the two consonant group is the nonword /gænd/. The two likely alternative spellings for this nonword are *gand* and *ganned*. In terms of single phoneme–grapheme relationships, the individual phoneme–grapheme correspondences in the word *gand* (/g/ → *g*, /æ/ → *a*, /n/ → *n*, /d/ → *d*) occur more often than *ganned* /g/ → *g*, /æ/ → *a*, /n/ → *nn*, /d/ → *ed*). However, if sound–spelling relationships larger than a single phoneme are taken into consideration, then the correspondences in *-anned* occur more often than those in *-and*. An example of this in the three consonant group is the nonword /sɒmpt/. The two likely spellings for this nonword are *sompt* and *somped*. In terms of single phoneme–grapheme relationships, the individual phoneme–grapheme correspondences in the word *sompt* (/s/ → *s*, /ɒ/ → *o*, /m/ → *m*, /p/ → *p*, /t/ → *t*) occur more often than those in *somped* (/s/ → *s*, /ɒ/ → *o*, /m/ → *m*, /p/ → *p*, /t/ → *ed*). However, if sound–spelling relationships larger than a single phoneme are taken into consideration, then the correspondences in *-omped* occur more often than in *-ompt*.

Our assumption behind the morphological comparisons is therefore that if the most dominant spelling is based on single phoneme–grapheme sized units, then it means that morphologically simple answers should be given. As the size of the phonology–orthography relationships that people use becomes larger (i.e., when sound–spelling patterns greater than a single phoneme are examined), however, the relative frequency of the mappings in the morphologically simple and complex words changes such that the frequency of the sound–spelling units in the morphologically simple patterns becomes less when compared to the frequency in the morphologically complex patterns. Therefore, if people use sound–spelling relationships based on sound units larger than the phoneme, it would be expected that morphologically complex answers would be used. As a result, the number of times morphologically simple answers are given compared to the number of times morphologically complex answers are given gives some insight into the size of the sound–spelling units that people use.

Participants

Nineteen students from a first year psychology course at Macquarie University participated in the experiment in return for course credit.

Stimuli

One hundred and fifty-five nonwords were selected. The nonwords were chosen such that two typical responses would be given. The nonwords could be split into seven groups based on the two subsets described earlier. The groups were all manipulated along a dimension of interest. These dimensions were designed to examine the grain size of subsyllabic relationships used in spelling. The idea is that if two potential spellings for a nonword exist and a variable is important in predicting potential spellings, then people should be biased by that variable when writing the spelling of the nonword, as discussed above.

The groups were as follows: (a) high dBN; (b) medium dBN; (c) low dBN; (d) high frequency phonemic neighbors; (e) morphologically complex doublet versus morphologically simple spelling (doublet); (f) morphologically complex versus morphologically simple three-consonant spelling (three consonant); and (g) morphologically complex digraph versus morphologically simple spelling (digraph).

In the high dBN group we used 57 nonwords that were selected such that each had two plausible alternative nonword spellings. One of the spellings contained a phoneme–grapheme relationship that had the highest PGC relationship except when using that relationship would have led to a nonextant body. When that happened, the next most common relationship was used. The other nonword contained a grapheme that was representative of a spelling with the next lower PGC relationship. A further constraint was that the nonword with the highest PGC relationship also had a higher frequency body than the other nonword.

In the medium dBN group, 24 nonwords were used. They were selected on the basis that the two most obvious spelling groups, based on database statistics of phoneme–grapheme contingencies, had similar BN counts but different PGC relationships. This protocol was designed to examine whether an effect of PGC would remain after other larger relationships were controlled.

In the low dBN group, 20 nonwords were used. They were selected on the basis that the two alternative spelling groups contained high and low dBN counts. The PGC relationships were reversed, however. The group with the high BN count had a lower frequency PGC relationship than the group with the low BN count.

In the high frequency phonemic neighbors group, 20 nonwords were used. They were selected on the basis that one of the potential answers had a very high frequency neighbor (CELEX frequency over 5,000). That is, the high frequency neighbor had the same phonology, except for a single phoneme, as a high frequency word. In the other group, the nonwords were chosen such that they consisted of high PGC relationships.

In the doublet group, 14 nonwords were used. They were selected on the basis that the two most obvious spelling groups had either a morphologically complex spelling (e.g., *-nned*) or morphologically simple spelling (e.g., *-nd*), and the nonwords ended with two consonants that could potentially be spelled with single-phoneme single-letter correspondences.

In the three consonant group, 10 nonwords were used. They were selected on the basis that the two most obvious spelling groups had either a morphologically complex (e.g., *-mped*) or morphologically simple spelling (e.g., *-mpt*) and the nonwords ended with three consonants that could potentially be spelled with single-phoneme single-letter correspondences.

In the digraph group, 10 nonwords were used. They were selected on the basis that the two most obvious spelling groups had either a morphologically complex coda that could be spelled with a digraph (e.g., *-cked*) or morphologically simple spelling (e.g., *-ct*).

Procedure

Participants were tested individually. The nonwords were read aloud by one of the authors, a native speaker of Australian English. This method of presentation was used after a test trial had shown that recording the nonwords and playing them through headphones caused a higher phoneme-confusion (error) rate. The nonwords were read aloud such that participants had no break between finishing the writing of one nonword and beginning the writing of the next. The order of the list was randomized for each participant. Participants were asked to "write the first reasonable nonword spelling that comes to mind." The participants would occasionally interrupt the experimenter when they did not hear a nonword properly. When this happened, the experimenter read the nonword aloud again.

Results and discussion

Responses that were neither of the two initial pairs under examination (listed in the Appendix) were excluded from the analysis. This meant that counts for only two spelling patterns were available for each item. If answers were given that were different from one of the initial pairs on a phoneme that was not manipulated, the difference was ignored. For example, the two expected answers for the nonword /kliː/ were *clee* and *clea*. Thus, the differing phoneme–grapheme relationship that was examined used the /iː/ phoneme. The response *klee* was given four times by participants. Instead of discarding those responses because they did not exactly match one of the initial pairs, they were entered into the analysis as if the nonword had been spelled *clee*. Similarly, on the morphological comparisons, spelling patterns that differed from those predicted were accepted as long as they still represented a morphologically complex or morphologically simple spelling of the nonword. For instance, the two expected answers for the nonword /vækt/ were *vact* and *vacked*. Three participants wrote *vakt* as their answer, however. Those answers were considered morphologically simple. Using these criteria, 24.3% of the data were excluded from the analysis. The excluded data consisted of a variety of more idiosyncratic spelling patterns and incorrect sound perceptions, with no obvious patterns predominating. For the remaining responses, each of the two spellings for each nonword was changed into a percentage, depending on how many times it occurred compared to the alternative spelling. For example, out of the 20 responses for the nonword /kliː/, the two expected spellings, *clea* and *clee*, were given 1 and 14 times, respectively. Changing the results of the two expected spellings into percentages while ignoring the five responses that were neither of the two items meant that *clea* was given 6.66% and *clee* 93.33% of the time. Responses to individual items appear in the Appendix. Two nonwords, /miːf/ and /lɔːs/, were excluded from the analysis because there were no responses that were one of the two most common predicted pairs (*meaf* and *mief*; *lorce* and *lauce*). Mean overall results appear in Table 2.

The results were examined in the following way. For the grain size groups, first the relationship between PGC contingency and dBN was examined. This was done using a one-way analysis of variance (ANOVA) on the responses in the high, medium, and low dBN groups, using the high PGC response counts for each group.[3] The idea of the test was to examine whether differences in dBN affected the number of times people would give spelling patterns with high-contingency PGC relationships. Second, three t tests were used to examine whether PGC affected the results of each group separately. This was done by comparing the number of responses using a high PGC spelling with the number of responses using a low PGC spelling. Finally, a t test was performed on the high frequency phonological neighbor group to examine the number of common PGC responses that were given compared to the number of high frequency neighbor analogies. The idea of that comparison was to see if participants simply chose a spelling that corresponded to a high frequency neighbor. If they did, then an advantage should be found for high frequency neighbor spellings over high frequency PGC spellings. The morphological groups were examined in a

Table 2. *Mean percentage results of the seven groups in the four experiments*

	Exp. 1	Exp. 2	Exp. 3	Exp. 4
dBN				
High				
High PGC	72****	70****	61****	65****
Low PGC	$28^{\dagger\dagger\dagger\dagger}$	$30^{\dagger\dagger\dagger\dagger}$	$39^{\dagger\dagger\dagger\dagger}$	$35^{\dagger\dagger\dagger\dagger}$
Medium				
High PGC	69****	72****	62***	52
Low PGC	$31^{\dagger\dagger\dagger\dagger}$	$28^{\dagger\dagger\dagger\dagger}$	$38^{\dagger\dagger\dagger}$	48
Low				
High PGC	63	59	53	44
Low PGC	$37^{\dagger}$	$41^{\dagger}$	47	$56^{\dagger}$
PN control				
High PGC	71****	82****	82****	63
High-frequency PN	$29^{\dagger\dagger\dagger\dagger}$	$18^{\dagger\dagger\dagger\dagger}$	$18^{\dagger\dagger\dagger\dagger}$	$37^{\dagger\dagger\dagger\dagger}$
Morphological group				
Doublet				
Simple (-nd)	92****	82****	67****	32**
Complex (-nned)	$8^{\dagger\dagger\dagger\dagger}$	$18^{\dagger\dagger\dagger\dagger}$	33	68^{++++}
Triple consonant				
Simple (-mpt)	74****	64****	65***	16****
Complex (-mped)	$26^{\dagger\dagger\dagger\dagger}$	$36^{\dagger}$	35	$84^{\dagger\dagger\dagger\dagger}$
Digraph				
Simple (-ct)	61	50	36***	8****
Complex (-cked)	$39^{\dagger}$	50	64	$92^{\dagger\dagger\dagger\dagger}$

Note: Significance scores reflect differences between response probabilities within each group: by items, ****$p < .001$, ***$p < .005$, **$p < .01$; by participants, $^{\dagger\dagger\dagger\dagger}p < .0001$, $^{\dagger\dagger\dagger}p < .005$, $^{\dagger}p < .05$, dBN, difference in body neighbors; PGC, phoneme–grapheme contingency; PN, phonological neighbors.

way very similar to that for the grain size groups. First, a one-way ANOVA examining differences between the three groups was used to examine whether nonwords of different morphological types cause a difference in the number of morphologically simple or complex responses. The idea was to see whether people were simply aware that some nonwords can be spelled with morphologically complex spellings, or whether the generation of morphologically complex spellings was also related to the constraints of the different nonword types. Second, three individual *t* tests were performed on each of the groups separately. The idea of those tests was to examine the extent to which people produced morphologically simple or complex answers in each of the groups.

In terms of the grain size groups, the one-way ANOVA exhibited a weak dBN effect that was significant by participants but not by items. $F_p(2, 36) = 11.75$, $p < .001$; $F_i < 1$. This appeared to be caused by participants using high frequency body spellings more often in the low dBN group. That can be seen from the three individual phoneme–grapheme comparisons. In the low dBN group, there was only a weak effect of PGC that did not reach significance by items, $t_p(18) = 2.59$, $p < .05$; $t_i(18) = 1.65$, $p = .12$. Conversely, both the high and medium dBN groups produced a strong PGC effect: high dBN; $t_p(18) = 12.87$, $p < .001$; $t_i(56) = 5.16$, $p < .001$; medium dBN: $t_p(18) = 6.75$, $p < .001$; $t_i(22) = 2.86$, $p < .01$. Thus, although participants typically used high PGC spellings for the nonwords, when there was a potential trade-off between a spelling with a high frequency body and a low frequency PGC relationship or a spelling with a low frequency body and a high frequency PGC relationship (i.e., the nonwords in the low dBN group), occasionally, the spelling with the high frequency body and low frequency grapheme would be used. These results were unlikely to be strongly influenced by high frequency phonemic neighbors, as high-frequency PGC answers were given more often than high frequency word analogy answers, $t_p(18) = 10.16$, $p < .001$; $t_i(19) = 2.69$, $p < 05$.

In terms of the morphological groups, a one-way ANOVA was significant by participants and items, $F_p(2, 36) = 9.42$, $p < .005$; $F_i(2, 31) = 12.42$, $p < .001$. Thus, it appeared that participants did not simply use a strategy based on morphological complexity alone when producing those spellings. Rather, the differences suggested that participants used morphological constraints differently on different stimuli types. Three planned comparisons showed that participants preferred to give morphologically simple answers in all of the groups. These effects were significant by participants and items in all comparisons except for the items analysis in the diagraph group: doublet: $t_p(18) = 16.4$, $p < .001$; $t_i(13) = 17.47$, $p < .001$; three consonant: $t_p(18) = 4.04$, $p < .005$; $t_i(9) = 5.07$, $p < .005$; digraph: $t_p(18) = 2.35$, $p < .05$; $t_i(9) = 1.65$, $p = .13$.

Overall, there were two main aspects of interest in the results. First, in terms of the grain size groups, participants exhibited a strong preference to give spellings using high PGC relationships. Although this preference was weakly modulated by dBN, the majority of answers used high PGC relationships, even in the low dBN group, where using high PGC relationships also meant using nonwords with low body frequencies. Similarly, the results suggested that there was a PGC effect in the medium dBN group, even though the dBN between the low and high PGC groups was effectively zero. If there was no PGC effect, then the probability of high and low PGC spellings would have been at chance. Second, in terms of the morphological groups, participants did not appear to use certain forms of morphologically complex spellings or larger sound–spelling relationships when spelling, even when there was statistical pressure to do so. For example, the *-umpt* and the *-ect* sequences of letters are very uncommon in English in terms of statistical occurrence. Yet participants rarely produced *-umpt* and only occasionally produced *-ecked*. Similarly, in terms of doublets, *-unned* occurs more frequently than *-und*. The responses given by the participants were strongly biased toward the morphologically simple spelling, however. The results therefore suggest that the participants did not often use larger sound–spelling relationships when spelling nonwords. This was so even when the smaller sound–spelling relationships led to a very infrequent translation in terms of larger sound–spelling relationships.

EXPERIMENT 2: SLOW NONWORD SPELLING

The first experiment suggested that people typically spell nonwords in a way that does not appear to often involve statistically common, larger sound–spelling relationships. However, in the previous experiment, the tempo at which the words were read aloud was quite fast. That is, participants were never encouraged to try and spell the nonwords using the most frequent correspondences. Rather, they were simply asked to write "the first reasonable spelling that comes to mind." The objective of the second experiment was to examine whether people can spell nonwords in a more statistically probable fashion, in terms of larger sound–spelling relationships, when specifically asked to do so.

Participants

Seventeen students from Macquarie University participated in the experiment in return for course credit. They were drawn from the same pool as those in Experiment 1.

Procedure and stimuli

The procedure was identical to that of the first experiment except for two changes. First, instead of participants being told to write the first reasonable nonword spelling that comes to mind, they were specifically asked to write the most wordlike spelling, based on English sound–spelling relationships, that they could. Second, the experimenter deliberately left a small gap between the time when the participants wrote down each nonword and the reading of the next.

Results and discussion

Based on the same criteria as in the first experiment, responses that did not fall into one of two patterns initially determined for each nonword were excluded from the analysis. This affected 24.1% of the data. Those spellings consisted of a variety of more idiosyncratic spelling patterns, with no obvious pattern predominating. The remaining counts were changed into a percentage response for each pair. Responses to individual items are listed in the Appendix. The mean overall results appear in Table 2.

In terms of the grain-size groups, an ANOVA performed on the three dBN groups was significant by participants but not items, $F_p(2, 32) = 13.92$, $p < .001$; $F_i(2, 98) = 1.36$, $p = ns$. This appeared to be caused by participants using high frequency body spellings more often in the low dBN group. That can be seen from the three tests that examined the effect of PGC. In the low dBN group, a weak effect of PGC was found that was only significant by participants, $t_p(16) = 2.29$, $p < .05$; $t_i(19) = 1.10$, $p = ns$. Conversely, in the medium and high dBN groups, a strong effect of PGC was found: high dBN: $t_p(16) = 10.51$, $p < .001$; $t_i(56) = 5.33$, $p < .001$; medium dBN: $t_p(16) = 8.38$, $p < .001$; $t_i(23) = 4.09$, $p < .001$. Thus, participants were less likely to give high PGC answers (and hence, more likely to give high BN answers) when the frequency of the orthographic body was high. The results were unlikely to be strongly influenced by high frequency phonemic neighbors, as participants typically gave high PGC answers rather than high frequency word analogies, $t_p(16) = 16.38$, $p < .001$; $t_i(19) = 6.69$, $p < .001$.

In terms of the morphological groups, an ANOVA performed on the three groups was significant, $F_p(2, 30) = 10.37$, $p < .001$; $F_i(2, 31) = 9.72$, $p < .005$. That suggests that participants were not simply applying morphological constraints based only on a single complex/simple criterion. Rather, they were applying constraints differently in each of the three groups. That can be seen from the three planned comparisons. There were significantly more morphologically simple answers given than morphologically complex answers in both the doublet and three consonant group: doublet: $t_p(16) = 8.05$, $p < .001$; $t_i(13) = 7.12$, $p < .001$; three consonant: $t_p(16) = 2.83$, $p < .05$; $t_i(9) = 1.98$, $p = .079$. There was no significant difference in the number of morphologically simple and complex answers given in the digraph group, however, both *t*s < 1.

The results of this experiment were similar to those found in Experiment 1. Despite participants being asked to spell the nonwords with the most wordlike spellings they could, they still spelled the majority of nonwords in a way that appeared to suggest the usage of phoneme–grapheme sized relationships. In terms of absolute values, however, there was a slightly larger number of responses given that would suggest that participants were occasionally using larger sound–spelling relationships, at least in the morphological groups. In those comparisons, the morphologically complex words were given slightly more often than the previous experiment. In particular, the number of times the morphologically simple versus morphologically complex digraph answers were given (*-ct* and *-cked*) was similar rather than biased toward morphologically simple answers and the number of times morphologically simple answers were given in the three consonant group was only marginally significant by items. Note, however, that morphologically simple forms were still used predominantly in both the doublet and three consonant groups. That suggests that even in conditions where participants are asked to use the most wordlike translations they can, they still predominantly prefer to use smaller sound–spelling relationships.

EXPERIMENT 3: AUDITORY–ORTHOGRAPHY CHOICE

The first two experiments suggest that, when spelling nonwords, people do not appear to be affected by a number of statistical constraints to do with larger sized subsyllabic relationships in the sound–spelling mapping. That is, people tend to spell nonwords using small phoneme–grapheme relationships. A question that might be asked about such a finding is whether people are aware of larger unit constraints at all. That is, because, when spelling nonwords, people do not appear to frequently use the statistically most common larger sound–spelling correspondences for a number of nonword types, it may be possible that they are not sensitive to such constraints at all. One potential way of changing the task conditions that might cause the effect of these constraints to differ is to simply present potential spellings and ask people to choose those that are the most wordlike, rather than getting them to produce the spellings. The idea here is that if sound–spelling production tasks are more difficult than sound–spelling awareness tasks and if the difficulty of the task constrains the size of the sound–spelling relationships that are used, then the constraints on the size of the sound–spelling relationships used may be relaxed in sound–spelling awareness tasks. That is, participants may be able to use larger sound–spelling relationships in these tasks.

The main objective of the following experiment was to examine whether people are aware of potential statistical constraints that they do not produce when spelling. To do this, an auditory–orthographic choice task was used (Cassar & Treiman, 1997; Siegel et al., 1995). In such a task, a nonword is presented auditorily and two alternative spellings are presented visually that are potential spellings of the nonword. If the results of this task deviate from those found in the previous nonword spelling experiments, this would suggest that there are differences between producing spelling and deciding whether spelling patterns are wordlike.

Participants

Sixteen students from Macquarie University participated in the experiment in return for course credit. They were drawn from the same pool as those in Experiment 1.

Stimuli

The stimuli used were the same nonwords as those used in the two spelling experiments. In addition, for each nonword, two alternative spellings were chosen. These spellings were based on the same manipulations used in the previous spelling experiments.

Procedure

In terms of materials, each nonword was read from a randomized list by a trained linguist who had a standard Australian accent. These nonwords were recorded in a professional recording studio, digitized, and saved using a sampling rate of 22050 Hz.

In terms of the task, participants were seated 50 cm in front of an IBM compatible computer. They were given verbal instructions about task. This included the fact that sound–spelling relationships occur at different frequencies in English and that they should choose the orthographic string that had the sound–spelling correspondences that occurred the most frequently in English, with respect to the auditorily presented nonword. Participants were specifically asked to respond as quickly and accurately as possible to each stimuli. Ten practice items were presented before the 155 experimental trials. The order of the experimental trials was randomized for each participant.

Each experimental trial began with a 1500-ms presentation of a fixation mark (*) that was centered in the middle of the screen. After the 1500 ms had elapsed, the nonword was played through Boston Acoustics speakers. One second later (including the duration of the nonword), the two orthographic choices appeared on the screen. These remained until a response was given. Participants gave a response by pressing one of two keys ("a" and ";"), depending on whether they thought the left or right nonword contained the sound–spelling correspondences most typical of English. Thus, for the nonword /jaɪt/, participants would first hear the nonword /jaɪt/. They would then see "jite jight" displayed in the middle of the screen. The two nonwords then remained on the screen until the participant had responded. The nonwords were presented in lower case letters using a standard IBM PC DOS font.

Two counterbalanced groups were used in the study. In one of the groups, one of the nonwords in the pair fell on the left side (and the other on the right side). In the other counterbalanced group, the order of the pairs was reversed.

Results

The results of each nonword pair were changed into percentages. The mean results appear in Table 2. Individual item statistics appear in the Appendix.

In terms of the grain size manipulations, an ANOVA performed on the three dBN groups was significant by participants, $F_p(2, 30) = 4.96$, $p < .05$, but not by items, $F_i(2, 98) = 1.43$, $p = ns$. That weak main effect appeared to be caused by participants giving fewer high PGC answers (and hence more high BN answers) in the low dBN group. That can be seen from the three t tests. In the low dBN group, no significant effect of PGC was found, $t_p(15) = 1.65$, $p = ns$; $t_i(23) < 1$. Conversely, in the high and medium dBN groups, a strong effect was found: high dBN: $t_p(15) = 4.49$, $p < .001$; $t_i(56) = 4.09$, $p < .001$; medium dBN: $t_p(15) = 3.72$, $p < .005$; $t_i(22) = 3.59$, $p < .005$. Those results were unlikely to have been strongly influenced by high frequency neighbors, as participants more often gave high PGC answers than high-frequency word analogies: $t_p(15) = 13.45$, $p < .001$; $t_i(19) = 6.42$, $p < .001$.

In terms of the morphological comparisons, an ANOVA performed on the three groups was significant by participants and items, $F_p(2, 30) = 13.54$, $p < .005$; $F_i(2, 34) = 20.87$, $p < .001$. Three t tests showed a significant advantage for morphologically simple answers in the doublet and three-consonant groups, although only by items: doublet: $t_p(15) = 19.3$, $p = 0.73$; $t_i(13) = 4.73$, $p < .001$; three consonant: $t_p(15) = 1.53$, $p > .1$; $t_i(9) = 3.97$, $p < .005$. However, the reverse pattern was found in the digraph group, $t_p(15) < 1$, $t_i(9) = 3.85$, $p < .005$.

The overall pattern of results was similar to the previous experiment. However, in terms of absolute differences, there was a slightly greater tendency for participants to use larger sound–spelling correspondences. That pattern was found in both the grain-size and morphological groups, with the comparisons in some of the morphological groups failing to reach significance by participants and a trend in the digraph group for morphologically complex responses to be chosen more often than morphologically simple responses. Overall, however, participants still preferred to use smaller sound–spelling relationships, compared to larger sound–spelling relationships, when choosing nonwords with sound–spelling correspondences most common in English.

EXPERIMENT 4: ORTHOGRAPHIC CHOICE

The third experiment used an auditory-orthographic choice task to examine whether people could choose the most common sound–spelling patterns in nonwords. However, in that experiment, the sound of the nonword was played auditorily and participants were asked to choose nonwords based on sound–spelling relationships that occur in English. It is conceivable that playing the sound and deliberately asking participants to use the sound–spelling relationships of English biases them to use sound–spelling correspondences that they would not necessarily use if they had simply been asked to determine wordlikeness. That is, the task conditions may have constrained the correspondences that were used. In this experiment, the task conditions of the orthographic choice task were changed in two ways. First, the sound of the nonword was not played, and second, participants were simply asked to choose the nonword that appeared to be the most wordlike.

Participants

Eighteen students from Macquarie University participated in the experiment in return for course credit. All came from the same pool as Experiment 1.

Stimuli

The nonword pairs used in Experiement 3 were used.

Procedure

The procedure was the same as Experiment 3, except for two changes. First, the two orthographic choices appeared directly after the fixation spot. Second, participants were instructed to choose the spelling that appeared the most wordlike of the two choices.

Results and discussion

The results of each item pair were changed into percentages. The mean results for each group appear in Table 2. Individual items appear in the Appendix.

In terms of the grain size results, there was a significant dBN effect, $F_p(2, 34) = 14.33$, $p < .001$; $F_i(2, 98) = 6.78$, $p < .005$. Unlike the previous experiments, however, the three *t* tests showed that high contingency phoneme–grapheme relationships were chosen less often or a similar number of times in the medium and low dBN groups: high dBN: $t_p(17) = 8.25$, $p < .001$; $t_i(56) = 4.98$, $p < .001$; medium dBN: both *t*s < 1; low dBN: $t_p(17) = 2.17$, $p < .05$; $t_i(23) < 1$. Indeed, in the medium dBN group, where the frequencies of the two orthographic bodies were balanced, no effect of PGC was found. Thus, smaller sound–spelling relationships did not appear to predict participants' responses when making wordlikeness judgments. Furthermore, the low dBN group showed the reverse pattern as the spelling experiments. High frequency body spellings were chosen more often than high frequency phoneme–grapheme spellings. That result was only significant by participants, however. Note that we did not test the high-frequency neighbor group here as, without the sound of the nonword, many of the comparisons do not allow sound–spelling constraints to be examined. In this case, people's typical pronunciations of the orthographic patterns may be different from the nonwords being examined in the previous experiments (e.g., *sork* vs. *surk* for /sɜːk/).

The morphological groups displayed a different pattern to the previous experiments. Although there was a main effect showing that differences existed between the three groups, $F_p(2, 34) = 14.48$, $p < .001$; $F_i(2, 31) = 13.66$, $p < .001$, in all of the groups, participants preferred to choose morphologically complex patterns as the most wordlike: doublet: $t_p(17) = 4.18$, $p < .005$; $t_i(13) = 4.36$, $p < .005$; three consonant: $t_p(17) = 5.55$, $p < .001$; $t_i(9) -17.95$, $p < .001$; digraph: $t_p(17) = 9.87$, $p < .001$; $t_i(9) = 21.79$, $p < .001$.

Overall, the results were different to those found in the previous auditory–orthographic choice experiment. In general, the effect of PGC was reduced. Instead, larger sound–spelling relationships began to play a role. In the medium dBN group, for instance, the number of responses given for the two nonword groups was very similar. Thus, in nonword pairs where dBN was effectively zero, there appeared to be little effect of PGC. Similarly, the results of the low dBN group went in the reverse direction of the two spelling experiments, although the *t* test was not significant by items. The morphologically complex groups showed a similar pattern to that in the grain size groups, with participants biased to give the morphologically complex answer as being the most wordlike. This was again the opposite of the spelling results in both the doublet (*-nned* vs. *-nd*) and three-consonant (*-mpt* vs. *-mped*) groups. In addition, the percentage of times a digraph was given in nonwords with the /kt/ correspondence was much higher than in any of the three previous experiments, with participants almost always choosing the morphologically complex nonwords. The results therefore provide evidence that people can use sound–spelling relationships larger than single phoneme–grapheme relationships when determining wordlikeness.

OVERALL TASK COMPARISONS

Apart from the results of the experiments individually, it is useful to examine the experiments together. Overall, the four experiments showed a consecutive "widening" of the sound–spelling correspondences that people used. That is, the size of the sound–spelling correspondences increased across the four experiments. The smallest correspondences appeared to be used in the fast spelling task (Experiment 1), followed by the slow spelling experiment (Experiment 2), then the auditory–orthographic choice task (Experiment 3), and finally the orthographic choice task (Experiment 4). This can be seen by examining the five groups that all examined one particular unit size or morphological type (medium dBN, low dBN, and the three morphological groups; note that the high dBN group is not used, since any decrease in PGC usage may have simply been offset by a greater usage of high BN patterns). In the medium dBN group, the two spelling experiments produced the largest effect of PGC, followed by the auditory–orthographic choice task and then the orthographic choice task (69, 72, 62, and 52%, respectively). The low dBN group showed a similar pattern. The mean number of high frequency phoneme–grapheme words given was 63, 59, 53, and 44% for the fast spelling, slow spelling, auditory–orthographic choice, and orthographic choice tasks, respectively. The doublet and the three consonant groups showed a similar pattern: the proportion of morphologically simple answers decreased in the same order, indicating an increased usage of sound–spelling relationships larger than the phoneme–grapheme relationship: doublet: Exp. 1, Exp. 2, Exp. 3, Exp. 4, 92%, 82%, 67%, 32%; three consonant: Exp. 1, Exp. 2, Exp. 3, Exp. 4, 74%, 64%, 65%, 16%. However, the auditory–orthographic choice task and slow spelling experiment produced a similar result on the three-consonant group. Finally, the *-ck* digraph group also showed a similar decrease, where people were less likely to use the morphologically simple forms across the four experiments (Exp. 1, Exp. 2, Exp. 3, Exp. 4: 61%, 50%, 36%, 8%).

Overall, then, the five groups showed a similar pattern. The largest effect of PGC was found in the fast spelling task. That group was closely followed by the slow spelling task. This effect was reduced somewhat in the auditory–orthographic choice task and markedly reduced in the orthographic choice task. The orthographic choice task appeared to capture the effect of larger, statistically more commonly occurring correspondences. Note that this conclusion is based on the assumption that larger sound–spelling relationships reduce PGC effects and increases dBN effects and, similarly, larger sound–spelling relationships allow the statistically more common (in terms of larger units) morphologically complex patterns to be accessed. This trend was extremely strong when examined statistically. The results from an ANOVA conducted on only the items from the five groups specified here showed that there were significant differences in terms of small or large unit-size usage across experiments, $F(3, 225) = 45.17$, $p < .001$. More important, there was an extremely strong linear decrease in small-unit reportage across the experiments, $F(1, 75) = 61.14$, $p < .001$. To further examine this pattern, we examined mean reportage differences from each of the individual comparisons that can be made by comparing item means in the individual experiments (i.e., Exp. 1 vs. Exp. 2, Exp. 1 vs. Exp. 3, Exp. 1 vs. Exp. 4, Exp. 2 vs. Exp. 3, etc.). Every single one of the nine possible comparisons was significant to at least the .05 level.

NULL EFFECTS AND GUESSING

A concern that could be raised about the results was that in the low dBN group, no significant differences were found by items in the experiment. Thus, the results are open to interpretation that participants were simply guessing in those groups and that the pattern does not reflect a choice between different types of information that produce a similar result. However, it is possible to examine whether the participants were simply guessing using a cross-task correlation. If the participants were simply guessing in the tasks, there should be no correlation between the individual items of the different tasks. Alternatively, if the results were due to PGC and dBN effects being of a similar strength, then the results

Table 3. *Cross-correlation matrix of responses to the low dBN items across the four experiments*

	Exp. 1	Exp. 2	Exp. 3	Exp. 4
Exp. 1	1			
Exp. 2	0.81**	1		
Exp. 3	0.33	0.46*	1	
Exp. 4	–0.1	0.05	0.81**	1
N	19	20	20	20

**p* < .05; ***p* < .001.

across the tasks should still be correlated because the same items were used. To examine this question, a correlation using the items of the low dBN group over the four experiments was performed. Those results are summarized in Table 3.

As can be seen from the table, despite differences in tasks, the two choice tasks correlated very strongly, as did the two spelling tasks. The strength of the cross-task correlations suggests that people were not simply guessing in the tasks; rather, the results represent a manipulation whereby neither of the two variables in the trade-off were strong enough to cause the difference in the results to be significantly different. If people were simply guessing, such strong correlations would be highly unlikely.

GENERAL DISCUSSION

The main objective of this study was to examine the nature of the subsyllabic sound–spelling correspondences that people produce and are aware of. To do this, four experiments were conducted examining people's awareness and production of sound–spelling relationships. Understanding differences between the production and awareness of these relationships is important, as spelling ability draws upon both spelling awareness (e.g., proofreading) and spelling production (e.g., writing).

Experiments 1 and 2 examined the subsyllabic sound–spelling relationships that people use in nonword spelling. This was done by examining people's spelling of nonwords in a situation in which the two most likely potential spellings were manipulated on a dimension of interest. Thus, the idea was that if a variable is important, the nonword responses should be influenced by that variable. For instance, if PGC is important (as was found), people would be more likely to spell nonwords using high PGC correspondences than low PGC correspondences. If this variable is not important, no effect should be found. In the first experiment, participants were simply asked to write down nonword responses. In the second experiment, participants were specifically asked to write down nonwords using the most common sound–spelling translations that they could access. The idea of the two experiments was to examine people's nonword spelling under different task conditions. Overall, the results suggested that while people used sound–spelling correspondences larger than phoneme–grapheme relationships in the second experiment more often than the first, they typically used small phoneme–grapheme–sized relationships when spelling the majority of nonwords in both experiments.

In Experiments 3 and 4, people's awareness of subsyllabic sound–spelling relationships was examined. This was done using an auditory–orthographic choice task and an orthographic choice task. The idea of the experiments was to examine sound–spelling awareness rather than spelling production. In the auditory–orthographic choice task, where the sound of a nonword was played and participants chose a response that had the most common sound–spelling relationships, participants typically chose patterns that had the highest PGC relationships. Alternatively, on the orthographic choice task, where participants chose the most wordlike nonword of a pair, they typically chose the orthographic patterns that had the most common larger sound–spelling relationships.

Taken together, the results of the nonword spelling and orthographic awareness tasks suggest that people's awareness of common subsyllabic relationships is different than suggested by the patterns that they produce in nonword spelling tasks. In Experiment 4, people typically chose the statistically most common nonwords in terms of larger sound–spelling relationships, even though such nonword spellings were only infrequently given in the spelling tasks. Furthermore, the difference between the two orthographic choice experiments suggests that the amount of biasing that occurred, in terms of the size of the subsyllabic relationships used by participants, was much greater than the amount of biasing that occurred in the two nonword spelling experiments. In the choice tasks, participants used both small and large sound–spelling relationships, depending on the task-specific conditions of the experiment, whereas in the spelling tasks, they only infrequently used large sound–spelling relationships.

Overall, the four experiments suggest that there are factors other than complexity differences that make the production of spelling more difficult than the awareness of sound–spelling relationships. If there were only a difference of complexity, then the dissociation between the awareness and the production of spelling should not have occurred. This is because, in terms of only complexity, knowing what a typical spelling is should not be more difficult than producing it. In this case, people require access to common subsyllabic sound–spelling relationships in the two orthographic choice tasks to determine what is wordlike, and in the spelling tasks, they require access to common subsyllabic relationships to produce a wordlike spelling. However, the spelling tasks require that this information be explicitly produced, whereas the orthographic choice tasks do not. The production of this information may therefore be one factor causing the usage of the larger sound–spelling relationships to be less frequent compared to the orthographic choice tasks. Note that these conclusions are based on the results of experiments that only used nonwords. The extent to which nonword spelling and orthographic awareness tasks correlate with other tasks designed to examine spelling ability, such as letter identification (e.g., Kreiner, 1992), spelling speed (e.g., Kreiner, 1992), and spelling errors in long, low frequency words with irregular spellings (e.g., Kreiner, 1992; Holmes & Carruthers, 1998), remains undetermined.

One potential reason why the results of the orthographic choice tasks and the spelling tasks were different is that the production of spelling may involve a sound segmentation process that may be so difficult that it constrains the potential set of correspondences with which people spell nonwords. That is, the difficulty of the task may limit people such that they tend to use the simplest form of subsyllabic sound–spelling translation. Such translation rules may not be the most common, according to sound-print statistics, but are influenced by a whole range of factors. For instance, it was already found that such segmentation processes influence adult's simple phoneme counting tasks (Treiman & Cassar, 1996). There is also a large amount of developmental data relating to this issue (e.g., Muter, Hulme, Snowling, & Taylor, 1998). Alternatively, if the nonwords are presented as a two-alternative forced choice task, then people may be able to take advantage of the letters to help with segmentation by simply reading the nonwords. In this case, if they read the nonwords before they choose between the different spellings, they may be able to use that knowledge to help determine the appropriate subsyllabic units to use.

In conclusion, this study examined the subsyllabic sound–spelling relationships that people use in spelling awareness and production tasks. Across four experiments, it was found that the size of the subsyllabic sound–spelling relationships varied, starting from predominantly phoneme–grapheme sized relationships in nonword spelling tasks and moving to larger sound–spelling relationships in orthographic awareness tasks. Those results suggest that, when spelling, there are restrictions on the size of the sound–spelling correspondences that people use. They therefore provide a useful constraint on our understanding of the processes that underlie spelling production and sound–spelling awareness.

APPENDIX

Individual item pairs, percentage responses, and item statistics for stimuli used in the four experiments

Group	Pron	Alt 1	Alt 2	N 1	BN 1	N 2	BN 2	Ex 1 (%) Res 1	Ex 2 (%) Res 1	Ex 3 (%) Res 1	Ex 4 (%) Res 1	Ex 1 (%) Res 2	Ex 2 (%) Res 2	Ex 3 (%) Res 2	Ex 4 (%) Res 2
High dBN	kliː	clee	clea	4	21	4	7	95	88	64	61	5	13	36	39
	gɛlt	gelt	gealt	10	10	1	1	100	100	91	67	0	0	9	33
	weɪnt	waint	weint	6	6	1	1	100	100	100	83	0	0	0	17
	tʃəʊp	chope	choap	4	13	2	1	94	94	55	28	6	6	45	72
	lɔːt	lort	lourt	12	8	1	1	100	100	73	61	0	0	27	39
	vɔːd	vord	voard	5	6	2	2	100	92	64	56	0	8	36	44
	pleːm	plame	plaim	7	12	4	3	33	36	55	44	67	64	45	56
	dreːm	drame	draim	4	12	1	3	36	33	55	94	64	67	45	6
	rɒlt	rolt	ralt	10	6	6	4	100	100	82	72	0	0	18	28
	plɔːk	plork	plawk	1	6	1	3	100	92	73	61	0	8	27	39
	fɛnt	fent	feant	16	13	4	2	100	100	100	78	0	0	0	22
	spəʊb	spobe	spoab	3	4	0	0	94	100	55	83	6	0	45	17
	dɜːb	durb	derb	2	2	3	2	31	33	36	61	69	67	64	39
	gruːn	groon	grune	5	10	2	5	94	71	64	56	6	29	36	44
	drəʊ	drow	droe	8	28	1	9	43	30	27	89	57	70	73	11
	slɛə	slare	slair	11	20	3	8	18	31	27	56	82	69	73	44
	sɪtʃ	sitch	sich	6	11	5	2	82	93	91	100	18	7	9	0
	tʃɒʊt	chout	chowt	2	17	1	0	92	71	45	72	8	29	55	28
	prʊd	prood	prould	3	11	0	3	100	100	91	39	0	0	9	61
	tɔːd	tord	tawd	12	6	1	1	100	73	45	39	0	27	55	61
	fruːp	froop	frupe	2	12	1	2	71	67	64	67	29	33	36	33
	peɪf	pafe	paif	8	3	5	1	71	43	45	33	29	57	55	67
	gleɪt	glate	glait	6	18	1	6	75	62	55	44	25	38	45	56
	flʌm	flum	flumb	5	16	2	5	100	100	64	11	0	0	36	89
	θɑːk	thark	tharc	2	12	0	3	100	100	91	100	0	0	9	0
	bliːm	bleam	bleem	4	11	2	3	29	45	55	67	71	55	45	33

slɛk	sleck	slek	5	9	3	1	44	69	82	94	56	31	18	6
sniː	snee	snea	1	21	0	7	94	94	73	61	6	6	27	39
mːtʃ	meach	meech	5	10	2	5	14	17	36	72	86	83	64	28
fliːk	fleak	fleek	4	16	4	10	6	19	27	72	94	81	73	28
wɛg	weg	wegg	14	7	0	1	100	94	64	78	0	6	36	22
reɪnt	raint	reint	15	6	2	1	100	100	91	78	0	0	9	22
gruːd	grood	grewd	2	11	1	2	91	90	64	61	9	10	36	39
stuːm	stoom	steum	4	9	2	1	100	100	82	94	0	0	18	6
blɪk	blick	blic	7	23	2	3	100	100	91	89	0	0	9	11
nɪf	niff	nif	4	11	5	1	33	81	45	83	67	19	55	17
θɪl	thill	thil	3	27	5	2	53	71	82	100	47	29	18	0
skaɪm	scime	scyme	1	11	0	2	93	70	27	44	7	30	73	56
flaɪp	flipe	flype	1	8	0	1	100	82	55	67	0	18	45	33
grɪtʃ	gritch	grich	0	11	0	2	83	88	91	94	17	13	9	6
drəʊk	droke	droak	4	13	1	4	78	88	55	67	22	12	45	33
trɒk	trock	troc	5	19	3	4	100	100	73	100	0	0	27	0
stɒd	stod	stodd	4	16	1	2	100	94	82	61	0	6	18	39
pruːp	proop	prupe	3	12	3	2	79	71	64	44	21	29	36	56
druːk	drook	druke	4	12	2	3	71	43	45	11	29	57	55	89
bləʊnz	blones	bloans	3	14	1	4	38	67	36	56	63	33	64	44
grəʊm	grome	groam	4	8	3	3	27	54	45	39	73	46	55	61
pləʊm	plome	ploam	1	8	0	3	75	83	27	39	25	17	73	61
tʃeɪd	chade	chaid	4	13	3	9	69	40	55	61	31	60	45	39
briːl	breal	breel	3	12	2	10	33	25	55	56	67	75	45	44
tʃiʊl	cheal	cheel	2	12	5	10	6	23	73	89	94	77	27	11
keɪf	kafe	kaif	1	3	2	1	93	73	36	50	7	27	64	50
zeɪt	zate	zait	10	18	3	6	59	43	45	61	41	57	55	39
θiːt	theat	theet	4	18	3	11	5	41	45	78	95	59	55	22
niːtʃ	neach	neech	5	10	2	5	11	25	55	72	89	75	45	28
nəʊk	noke	noak	11	13	2	4	94	87	55	17	6	13	45	83
pəʊd	pode	poad	13	9	6	6	88	7	55	61	13	93	45	39
druːb	droob	drube	2	2	2	1	60	63	55	28	40	38	45	72
wɛsk	wesk	whesk	2	1	4	1	95	94	55	72	5	6	45	28

APPENDIX (*cont.*)

Group	Pron	Alt 1	Alt 2	N 1	BN 1	N 2	BN 2	Ex 1 (%) Res 1	Ex 2 (%) Res 1	Ex 3 (%) Res 1	Ex 4 (%) Res 1	Ex 1 (%) Res 2	Ex 2 (%) Res 2	Ex 3 (%) Res 2	Ex 4 (%) Res 2
Medium dBN	frɑʊl	froul	phroul	0	3	0	3	0	100	91	78	100	0	9	22
	tʃɔːn	chorn	chawn	3	11	5	12	77	67	55	44	23	33	45	56
	kʌdʒ	cudge	kudge	4	9	5	9	50	59	55	83	50	41	45	17
	nɒlf	nolf	knolf	1	2	2	2	82	71	45	17	18	29	55	83
	tʃiːn	chean	cheen	4	9	3	9	88	88	55	72	13	13	45	28
	θɜːl	thurl	thirl	3	5	1	5	80	100	73	72	20	0	27	28
	wʌsk	wusk	whusk	1	6	6	6	100	100	73	50	0	0	27	50
	plɔːn	plorn	plawn	2	11	0	12	79	46	45	33	21	54	55	67
	vɔːk	vork	valk	5	6	5	6	100	100	64	44	0	0	36	56
	duːθ	dooth	duth	1	2	2	3	100	100	82	67	0	0	18	33
	θɜːn	thurn	thern	3	4	2	5	21	19	45	56	79	81	55	44
	dɜːs	durse	derse	3	3	4	3	29	56	45	44	71	44	55	56
	blɔːt	blort	blought	1	9	1	8	80	73	73	17	20	27	27	83
	tɑːf	tarf	taff	4	5	5	4	93	86	100	56	7	14	0	44
	θɔːk	thork	thalk	2	6	1	6	100	100	82	44	0	0	18	56
	lɔːs	lorce	lauce	2	1	1	1	X	100	55	33	X	0	45	67
	glɔː	glore	glaw	6	20	3	21	67	62	55	67	33	38	45	33
	dɜːtʃ	durch	dirch	2	2	2	2	54	27	45	11	46	73	55	89
	gɜːn	gurn	gern	3	4	2	5	44	36	64	61	56	64	36	39
	riːʃ	reash	reesh	0	0	2	1	0	25	64	72	100	75	36	28
	tʃiːb	churb	chirb	1	0	2	2	92	85	36	61	8	15	64	39
	nɜːtʃ	nurch	nirch	1	2	1	2	91	75	73	56	9	25	27	44
Low dBN	zeɪn	zane	zain	11	13	8	21	82	76	73	56	18	24	27	44
	mɜlθ	melth	mealth	1	0	2	3	100	100	45	28	0	0	55	72
	dɪmf	dimf	dymph	2	0	2	2	100	83	27	6	0	17	73	94
	tʃɔːl	chorl	chall	4	1	3	15	67	0	45	67	33	100	55	33
	tɜːt	turt	tirt	9	3	6	7	87	92	64	50	13	8	36	50

	skəʊf	skofe	skoaf	0	0	0	2	100	100	82	44	0	0	18	56
	teɪn	tane	tain	21	13	12	21	24	56	45	44	76	44	55	56
	karɪt	crite	cright	4	13	3	17	88	82	36	17	13	18	64	83
	nɜːk	nurk	nirk	4	3	4	6	80	50	55	50	20	50	45	50
	tiːp	teap	teep	12	5	11	14	11	18	73	78	89	82	27	22
	rɜlθ	relth	realth	0	0	2	3	67	33	27	11	33	67	73	89
	ɡliːd	glead	gleed	3	14	4	21	6	14	36	61	94	86	64	39
	nɑːs	narse	nass	3	3	10	12	82	90	100	83	18	10	0	17
	miːf	meaf	mief	6	3	3	5	X	100	100	94	X	0	0	6
	sɔːnt	sornt	saunt	0	0	9	8	13	7	0	0	88	93	100	100
	jaɪt	jite	jight	8	13	10	17	81	80	45	61	19	20	55	39
	leɪl	lale	lail	18	15	15	19	11	29	27	22	89	71	73	78
	speɪl	spale	spail	8	15	3	19	28	6	64	56	72	94	36	44
	tʃəʊt	chote	choat	4	9	1	11	80	79	45	22	20	21	55	78
	zəʊt	zote	zoat	7	9	4	11	93	79	64	39	7	21	36	61
HFPN control group															
HFPN															
have	bæv	bav	bave	9	2	17	17	83	100	91	6	17	0	9	94
rich	fitʃ	fitch	fich	9	11	2	2	84	93	100	89	16	7	0	11
rich	slɪtʃ	slitch	slich	4	11	2	2	83	81	100	89	17	19	0	11
could	dʒʊd	jood	jould	6	11	3	3	100	80	82	22	0	20	18	78
there	ɡɛə	gair	gere	6	8	6	7	0	88	73	61	100	13	27	39
if	zɪf	ziff	zif	5	11	1	1	42	88	82	89	58	13	18	11
go	ɡəʊ	clow	clo	13	28	1	17	33	45	45	94	67	55	55	6
are	sɑː	sar	sare	19	14	21	20	100	93	100	11	0	7	0	89
they	tʃeɪ	chay	chey	7	33	4	8	100	79	82	56	0	21	18	44
he	bliː	blee	ble	6	21	3	8	100	100	100	94	0	0	0	6
for	vɔː	vore	vor	13	21	8	6	17	50	45	94	83	50	55	6
when	wɛp	wep	whep	9	6	6	6	95	94	73	44	5	6	27	56
down	paʊn	poun	pown	5	1	7	17	76	100	91	56	24	0	9	44
first	lɜːst	lurst	lirst	4	4	1	2	92	88	91	89	8	13	9	11

APPENDIX (*cont.*)

Group	Pron	Alt 1	Alt 2	N 1	BN 1	N 2	BN 2	Ex 1 (%) Res 1	Ex 2 (%) Res 1	Ex 3 (%) Res 1	Ex 4 (%) Res 1	Ex 1 (%) Res 2	Ex 2 (%) Res 2	Ex 3 (%) Res 2	Ex 4 (%) Res 2
much	rʌtʃ	rutch	ruch	5	5	6	2	74	81	100	94	26	19	0	6
here	kɪə	kear	kere	12	19	3	7	0	50	82	78	100	50	18	22
work	sɜːk	surk	sork	9	3	9	6	100	100	100	56	0	0	0	44
said	gɛd	ged	gaid	14	15	9	9	100	100	91	11	0	0	9	89
small	spɔːl	sporl	spall	4	1	5	15	43	29	18	39	57	71	82	61
young	fʌŋ	fung	foung	9	14	4	1	100	100	91	78	0	0	9	22
Doublet	gænd	gand	ganned	8	13	8	10	100	94	55	33	0	6	45	67
	dʒɪnd	jind	jinned	9	9	6	10	81	82	55	39	19	18	45	61
	mʌnd	mund	munned	3	1	4	5	100	100	64	56	0	0	36	44
	vɒnd	vond	vonned	5	5	2	2	100	100	73	33	0	0	27	67
	pɛld	peld	pelled	8	5	9	10	79	50	64	22	21	50	36	78
	vɪld	vild	villed	6	4	6	18	78	81	45	56	22	19	55	44
	dænd	dand	danned	8	13	13	10	94	79	73	17	6	21	27	83
	nɒft	noft	noffed	2	4	1	2	100	82	82	22	0	18	18	78
	nɑːd	nard	narred	9	10	6	9	100	100	82	33	0	0	18	67
	dɜːd	durd	durred	3	3	3	6	100	100	73	44	0	0	27	56
	fɒpt	fopt	fopped	5	1	8	20	82	75	55	11	18	25	45	89
	mɪpt	mipt	mipped	4	1	10	21	89	65	64	11	11	35	36	89
	bæpt	bapt	bapped	3	2	10	21	100	87	55	17	0	13	45	83
	gɒft	goft	goffed	5	4	4	2	88	53	91	50	12	47	9	50
3 Cons	sɒmpt	sompt	somped	0	1	3	3	89	88	82	22	11	13	18	78
	mʌlpt	mulpt	mulped	1	1	3	2	67	56	55	22	33	44	45	78
	rɪmpt	rimpt	rimped	0	0	5	7	74	76	64	11	26	24	36	89
	næmpt	nampt	namped	0	0	5	11	78	88	64	22	22	12	36	78
	sʌmpt	sumpt	sumped	1	0	7	12	79	76	45	22	21	24	55	78
	pɛnst	penst	pensed	0	0	4	3	65	33	64	17	35	67	36	83
	dɪlpt	dilpt	dilped	0	0	1	0	89	41	82	17	11	59	18	83

	rænst	ranst	ranced	1	1	4	5	38	38	64	11	63	63	36	89
	wʌmpt	wumpt	wumped	0	0	6	12	83	94	55	6	17	6	54	94
	dɪnst	dinst	dinced	1	0	4	2	78	53	73	11	22	47	27	89
Digraph	vækt	vact	vacked	5	6	7	18	82	69	36	11	18	31	64	89
	mɪkt	mict	micked	6	1	9	12	38	42	55	11	62	58	45	89
	blʌkt	bluct	blucked	1	1	4	11	47	33	18	0	53	67	82	100
	zækt	zact	zacked	3	6	7	18	69	53	27	17	31	47	73	83
	blɪkt	blict	blicked	0	1	5	12	20	36	45	11	80	64	55	89
	ɡrʌkt	gruct	grucked	1	1	0	11	73	64	45	17	27	36	55	83
	ɡækt	gact	gacked	4	6	8	18	69	50	45	6	31	50	55	94
	bɒkt	boct	bocked	5	0	11	16	77	58	36	0	23	42	64	100
	fɛkt	fect	fecked	5	1	4	7	87	57	27	6	13	43	73	94
	nʌkt	nuct	nucked	1	1	9	11	50	38	27	6	50	62	73	94

Note: Pron, pronunciation; Alt, orthographic alternative; N, neighbors; BN, body neighbors; Ex, experiment; Res, results; HFPN, high-frequency phonological neighbor; Cons, consonant; X, excluded value.

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NOTES

1. Phoneme–grapheme contingency is calculated by dividing the number of times a grapheme occurs with a particular phoneme by the number of times the phoneme occurs with all graphemes (Barry & Seymour, 1988). A high phoneme–grapheme contingency value therefore represents a grapheme that occurs commonly with a phoneme, whereas a low value represents a grapheme that is only rarely associated with a phoneme.
2. We use dBN rather than rime to body consistency for convenience. The stimuli were chosen such that both measures caused a similar pattern in terms of the overall statistical means for each of the groups examined.
3. Due to the initial data analysis procedure, the low PGC values were the mirror of the high PGC values, so it makes no difference whether the ANOVA is performed on the low PGC or the high PGC values. The same is true for the simple–complex morphology ANOVA performed on the morphological groups described next. Performing the ANOVA on the percentage of times that morphologically simple answers were given gives the same result as performing the ANOVA on the percentage of times that morphologically complex answers were given.

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