단어재인에 있어서 처리단위의 적응적 변화

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Adaptive Changes in the Grain-size of Word Recognition

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요 약

The regularity effect for printed word recognition and naming depends on ambiguities between single letters (small grain-size) and their phonemic values. As a given word is repeated and becomes more familiar, letter-aggregate size (grain-size) is predicted to increase, thereby decreasing the ambiguity between spelling pattern and phonological representation and, therefore, decreasing the regularity effect. Lexical decision and naming tasks studied the effect of repetition on the regularity effect for words. The familiarity of a word form was manipulated by presenting low and high frequency words as well as by presenting half the stimuli in mixed upper- and lowercase letters (an unfamiliar form) and half in uniform case. In lexical decision, the regularity effect was initially strong for low frequency words but became null after two presentations; in naming it was also initially strong but was merely reduced (although still substantial) after three repetitions. Mixed case words were recognized and named more slowly and tended to show stronger regularity effects. The results were consistent with the primary hypothesis that familiar word forms are read faster because they are processed at a larger grain-size, which requires fewer operations to achieve lexical selection. Results are discussed in terms of a neurobiological model of word recognition based on brain imaging studies.

The experiments presented here address a hypothesis about the operative orthographic processing unit for recognizing or naming a single printed word. We propose that when a word is infrequent or unfamiliar, single graphemes are the focus of the process but that, with repeated exposures, graphemes aggregate to become larger effective units. The advantage of a small number of large grain-size units instead of many more individual grapheme units is that fewer operations are needed to effect lexical selection and, therefore, word recognition/naming will be faster. An alternative hypothesis is that the lexical selection process for familiar words is qualitatively identical to that for infrequent or unfamiliar words (both depending on the processing of single graphemes); only the speed of the process decreases with experience.

In order to assess the hypothesis about changes in the grain-size of processing, we utilize the regularity effect. The regularity effect is the term given to the difference in response latencies between regularly spelled words such as *flop* and "irregularly spelled" words such as *deaf.* The latter are words whose spellings are pronounced in a way that is both inconsistent and less usual compared to other words (the word *leaf* illustrates the more usual pronunciation of the vowel digraph). A regular word (e.g., *flop*) whose spelling is consistently pronounced in only one way is recognized faster in print, all other things being equal (Plaut, McClelland, Seidenberg, and Patterson, 1996; Van Orden, Pennington, and Stone, 1990). The regularity effect is rarely found for high frequency words whether the task is lexical decision or naming (but see Jared, 1997, for an exception in the naming task). Although it is nearly always found for low frequency words in the naming task, it is sometimes not found in lexical decision task. The regularity effect is central to the experiments presented here because, when it is found, it can be taken as evidence that individual letters are being processed (instead of larger grain-size aggregates). Conversely, the absence of a regularity effect can be taken to mean that letters in the word are not processed as independent units (with a proviso discussed below). Thus, we predict that as a reader becomes more familiar with a word in print, any regularity effect that existed earlier will be attenuated or eliminated, demonstrating that repeated experience with a word increases its effective grain-size for lexical access. This interpretation depends not only on the assumption that the recognition or naming process depends on analyzing individual letters but also that the process maps these letters into their phonological counterparts (Hino and Lupker, 2000; Frost, Katz, and Bentin, 1987). For example, consider the irregular word *pint.* A reader may be slowed in recognizing that word (relative to regular words) if phonology is part of the process. This is because a letter-by-letter translation into phonology will produce all the pronunciations for each letter including the incorrect pronunciation for the vowel (the one that would make the word rhyme with *mint*) as well as its correct pronunciation. This will delay lexical selection when it depends on matching the phonemes that were translated from print to the reader's lexical phonological representation of *pint* (e.g., Seidenberg, Waters, Barnes, & Tannenhaus, 1984). The same mechanism explains the regularity effect in word naming (Glushko, 1979). For an irregular word, additional time will be needed to find its correct phonological representation in the lexicon, slowing its pronunciation. However, after many exposures to such a word it may become familiar enough which, in terms of our hypothesis, means that the effective grain-size for lexical access becomes larger than the single grapheme.The number of graphemes in the larger grain-size aggregate must be large enough to obviate any ambiguity of the resultant phonology. For the word *pint*, that aggregate must contain the entire four letters of the word in order for it to be pronounced correctly; smaller subsets such as *pin-* or *–int* will still produce the more common pronunciation, the one that rhymes with *mint*. However, the larger effective grain-size need not be equal, necessarily, to the whole word. Phonologically unambiguous subword units may occur particularly for multisyllabic words, such as the three units in the word *ex-peri-ment*. But for a word of any complexity, whether one syllable or multisyllabic, the grain-size of its aggregates need be only large enough to avoid ambiguities of phonology. These larger units of orthography may map onto units of any size: phonological consonant clusters, open syllables, closed syllables, multisyllabic units, and whole phonological words. In this paper, we do not differentiate among these several possible manifestations of larger grain-size. Our proposal that the grain-size of processing changes with experience is supported, in part, by the frequency-regularity interaction discussed above and in part by recent neurobiological data. Brain imaging data from several laboratories, including our own, indicate that two distinct brain circuits are involved in word recognition. The data suggest that one circuit carries a slow, apparently effortful process of word recognition that is responsible for the recognition of unfamiliar printed forms. The other is a later-developing fast system that processes familiar printed words. The two systems involve two posterior circuits in the left hemisphere (LH). The slow acting system is a dorsal circuit, located in the temporo-parietal lobes, that includes the angular and supramarginal gyri. The fast recognition system is a ventral circuit, located in the occipito-temporal lobes. A variety of technologies have contributed to these results, including fMRI, PET and ERP. We have proposed a theory of word recognition based on the neurobiological data in which lexical selection occurs via the ventral circuit if that circuit has received information appropriate to it and, if it has not, via the dorsal circuit. If both have circuit-appropriate information, then the ventral circuit process will dominate lexical selection because of its faster speed. The two circuits correspond loosely to the two routes of classical dual route theory in which printed words can be recognized either by a slow process of letter to sound decoding or by a rapid process in which the printed word directly activates the word's meaning (Paap, Noel, & Johansen, 1992; Coltheart, 1978).

Both the neurobiological and dual route theories propose that the slow process involves grapheme-to-phoneme conversion. However, we propose that the second process, rapid word recognition, may typically involve phonology, contrary to dual route theory. We suggest that lexical selection, whether in the slow circuit or the fast circuit is a selection from a lexicon which has parallel phonologic and orthographic components and that activation of a word's meaning will typically be accompanied by the activation of its phonological representation as well. We expand on this proposal in the Discussion section but not here as it is not the central topic of the present experiments. These are focussed on the issue of the grain-size of the orthographic unit used for lexical selection and not on the processing that occurs subsequently.

Experiment 1

Experiment 1 was a lexical decision experiment designed to evaluate the hypothesis that the word recognition process will change to adopt a larger grain-size as the reader increasingly acquires experience with an individual printed word. Before that experience has been acquired, small grain-size processing will dominate and, therefore, grapheme-phoneme correspondences will be produced as part of the lexical selection process. Along with the correct grapheme-phoneme correspondences, incorrect (and, therefore, competing) phonemes will be produced. These incorrect phonemes will slow lexical selection which, for unfamiliar words, requires the synthesis of the collection of phonemes into cohesive higher-order phonological form suitable for searching the reader's phonological lexicon. Therefore, a regularity effect should be found for such small grain-size aggregates. However, after repeated experience, the regularity effect should disappear due to the absence of any competing phonemes in the larger grain-size aggregates. In Experiment 1, all participants received four repeated blocks of the same list of words and nonwords. Half of the words had irregular and half regular spelling-to-sound correspondences. In addition, one group of participants saw the stimulus items in mixed case, an orthographic form that was novel to them. Items that have a novel orthographic appearance (as when printed in an unfamiliar font) should be consolidated more slowly. However, eventually, even these should be recognized as quickly as items that were originally more familiar. Mixed case items (words and nonwords) appeared in alternating lower- and uppercase letters (e.g., mInT). The initial letter was always lowercase.

Method

Subjects. Seventy-six undergraduate students at the University of Connecticut participated in the experiment for course credits. All participants reported that they had at least corrected-to-normal vision. Each subject was randomly assigned to one of two counterbalanced groups, resulting in 38 subjects per group.

Materials. Eight-eight words and the same number of nonwords were created to construct the stimulus list. Half of words were high frequency (5548±5788.96, tokens per 17.1 million, from the CELEX database, Baayen, Piepenbrock & van Rijn, 1993), and the other half were low frequency words (145.5±96.47). The words in each frequency group were further divided into half regular words and half irregular words. The length and average frequency of regular and irregular words were matched. The frequency of these four subgroups were: 5521±4750.03 for high frequency regular words; 5575±6827.89 for high frequency irregular words; 145±91.30 for low frequency regular words; 146±101.62 for low frequency irregular words. Two stimulus lists, with the same words and nonwords in each list, were created in order to investigate the effect of mixing case. Half the stimuli in each list were printed in mixed case and half in normal (i.e., uniform) case. Mixed case words began with a lowercase letter and alternated the case between successive letters (e.g., bEaCh). Uniform case words were printed all in lowercase letters. The two lists differed in that words that were mixed case in one list were composed in uniform case in the other. Nonwords were orthographically legal and pronounceable and were created by changing one letter of a real word that was not one of the word stimuli. Half of the nonwords were also printed in mixed case and half in uniform case. An additional 16 words and nonwords were created as the practice stimuli. The stimuli for Experiment 1 are listed in the appendix.

Procedure. The presentation of stimuli and data recording were done by the experiment software, E-prime. Participants sat in front of a computer monitor, at a viewing distance of about 60 cm. Stimuli were presented in the center of the monitor screen and remained on until the subject responded. The stimuli were presented as white characters on the dark background of the screen. The intertrial interval was 1 sec. Participants were told that the stimuli they saw in the first block would be repeated three more times for a total of four blocks. Participants were required to decide the lexicality of each letter string as quickly and as accurately as possible. Subjects pressed one of two telegraph keys to indicate a word or nonword decision. Subjects were given a short break after each block, and an experimenter sat beside the subject throughout the experiment.

Results

Response latencies less than 100ms and more than 1900ms were discarded as outliers. These outliers composed of less than 0.5% of all responses. For the reaction time (RT) analysis, trials on which an error occurred were also discarded. In the analysis of variance (ANOVA), there was no interaction between the counterbalanced lists and the other independent variables (all Fs < 1), enabling us to combine the data of the two subgroups. The ANOVA was a 2 x 2 x 2 x 4 (Frequency x Case x Regularity x Block) within-subject design, and was conducted with subjects as the error term (see discussion of relative values of subject and items analyses by Raaijmakers, Schrijnemakers, & Gremmen, 1999). All main effects were statistically significant, $F(1, 75) = 358.10$, $MSE = 1861166.51$, $p < .0001$, for Frequency; $F(1,75) = 109.15$, $MSE = 613019.11$, $p < .0001$, for Case; $F(1, 75) = 16.07$, $MSE = 46982.35$, $p < .001$, for Regularity; and $F(3, 225) = 13.48$, $MSE = 211562.29$, $p < .001$, for Block. Importantly, each of the two-way interactions between Block and the other variables were all statistically significant, $F(3, 225) = 10.76$, $MSE = 32810.49$, $p < .001$, for the interaction between Block and Case; $F(3, 225) = 9.61$, $MSE = 26470.81$, $p < .001$, for the interaction between Block and Frequency and, finally, $F(3, 225) = 6.25$, $MSE = 17689.81$, $p < .001$, for the interaction between Blockand Regularity.

The overall pattern of response latencies shows that the effects of the lexical variables were reduced as the number of repetitions increased. The three-way interaction, Block x Frequency x Regularity, was statistically significant, $F(3, 225) = 7.58$, $p < .001$, $MSE = 21647.28$. The effects of Frequency and Regularity seen in the first block were nulled by the fourth block.

Half the nonwords were presented to participants in uniform case and half in mixed case. A 2 x 2 (Case x Block) ANOVA was conducted for nonwords in order to investigate the effects of lettercase and repetition. Mean RT for uniform case nonwords was 693ms and for mixed case, 714ms. For all nonwords, mean RT decreased over blocks from 771ms to 653; the difference between mixed and uniform case nonwords decreased over blocks. The main effects of both Case and Block were statistically significant, $F(1, 75) = 61.51$, $MSE = 306991.74$, $p <.001$, and $F(3,225) = 49.30$, $MSE = 61520.07$, $p < .001$, respectively. The two-way interaction was also significant, $F(3, 225) = 9.10$, $MSE =7477.66$, $p <.001$.

Analyses of errors that paralleled the analyses for response latencies were also conducted. For words, the average error rate (which included outliers) was 7%. The pattern of error rates was similar to the one for response latencies, although none of two-way interactions reached statistical significance. All variables had statistically significant main effects, $F(1, 75) = 235.57$, $MSE = 3.6512$, $p < .0001$, for Frequency, $F(1,75) = 38.65$, $MSE = 0.4237$, $p < .0001$, for Case, $F(1, 75) = 7.93$, $MSE = .08741$, $p < .01$, for Regularity, and $F(3, 225) = 2.$, $MSE = .0163084$, $p < .05$, for Block. Importantly, the three-way interaction of Block x Frequency x Regularity was also significant, $F(3, 225) = 7.98$, $MSE = .03709$, $p < .001$. It paralleled the three-way interaction for RT in that differences that between regular and irregular low frequency words became negligible by Block 3. For nonwords, the error analysis showed a mean error rate of 8%. Only the main effect of Blocks was significant, $F(3,225) = 4.85$, $MSE = .01804$, $p < .01$. However, unlike the consistent decrease in errors over trials that was observed for words, for nonwords errors followed a slightly curvilinear pattern: 10%, 7%, 7%, and 9%, over blocks 1 to 4.

Discussion

Although low frequency irregular words showed an initial processing inferiority, after only two repetitions they were recognized no more slowly than regular words (Figure 1). Consistent with our hypothesis, the convergence of irregular and regular word recognition times with increasing experience suggests that both kinds of words were processed at a larger grain-size, a grain-size in which the letter-phoneme inconsistencies of irregular words were no longer relevant. Because our stimuli were short in length (four to six letters), it is tempting to speculate that this larger grain-size equaled the whole word. In fact, for many of our words, incorrect phonology can be avoided only by knowing the whole word.

Notwithstanding the marked disadvantage for mixed case, there was no regularity effect for high frequency mixed case words. This latter result is somewhat at odds with the regularity effect on high frequency mixed case words found by Herdman, Chernecki, and Norris (1999) who used a naming paradigm. Perhaps the difference between Experiment 1 and Herdmann et al. is due to the paradigm difference. The regularity effect (i.e., small grain-size processing) may be more characteristic in naming than in lexical decision because (1) the naming task obviously recruits the brain's speech processing structures for articulation which (2) may result in the persistence of the initial phonological representations used when a word was unfamiliar. The use of phonological representations in itself would not require phoneme sized processing – those phonological representations could in principle be syllabic or multisyllabic in size. But the lexical selection of unfamiliar words will initially be dominated by grapheme-phoneme codes and the greater activation of phonological circuitry may make this coding more resistant to extinction. Small grain-size coding persists in naming because it is stronger there than it is in lexical decision.

Behavioral data indicate the likelihood that the naming paradigm is, in fact, characterized by greater phonological processing than lexical decision, although the issue of grain-size, per se, has not been raised previously. The neurobiological data concur in that areas of cortex associated with speech (such as Brodmann's area 44) are strongly coactive with processing in the dorsal circuit. This suggests that the naming task, because it necessarily involves activation of cortical speech areas, will preferentially favor the dorsal circuit which the evidence suggests supports small grain-size processing. Therefore, if a printed word is unfamiliar and therefore is initially processed by the dorsal circuit, that processing will persist longer under a naming paradigm than under lexical decision.

Experiment 2

As discussed above, small grain-size processing for unfamiliar words should predominate in naming (as opposed to lexical decision) which should result in a greater regularity effect under repetitions. Although, typically, a regularity effect is found in the naming paradigm for only low frequency words, Herdman et al. (1999) found an effect for high frequency words also when the words were printed in mixed case. As usual, they found no effect on high frequency words printed in uniform case. Presumably, for mixed case words, the regularity effect occurred when words were high frequency because case mixing slowed the aggregation of graphemes into units of larger grain-size. This experiment changed the lexical task from the lexical decision to the naming.

Method

Experiment 2 parallels Experiment 1 in design. It has the same 88 words as those in Experiment 1 and, as in Experiment 1, they are repeated in four consecutive blocks.

Subjects. Forty-four undergraduate students at the University of Connecticut participated in the experiment for course credits. All participants reported that they had at least corrected-to-normal vision. Each subject was quasi-randomly assigned to one of two counterbalanced groups, resulting in 22 subjects per group.

Materials. Eight-eight words, the same as those in Experiment 1, comprised the stimulus list: 22 high frequency regular words, 22 high frequency irregular words, 22 low frequency regular, and 22 low frequency irregular words. Two stimulus lists, with the same words in each list, were created in order to investigate the effect of mixing case. Half the stimuli within a condition in a given list were printed in mixed case and half in uniform case. Mixed case words began with a lowercase letter and alternated the case between successive letters (e.g., bEaCh). Uniform case words were printed in all lowercase letters. The two lists differed in that words that were mixed case in one list were composed in uniform case in the other and vice versa.

Procedure. The presentation of stimuli and data recording were done by the Windows version of the experiment software, E-prime. Participants sat in front of a computer monitor, at a viewing distance of about 60 cm. Stimuli were presented in the center of the monitor screen and remained on until the subject responded. The stimuli were presented as white characters on the dark background of the screen. The intertrial interval was 1 sec. An additional 16 words were presented for practice. Participants were told that the stimuli they saw in the first block after practice would be repeated three more times for a total of four blocks. Participants were required to speak the word as quickly as possible. Subjects were given a short break after each block of about 30 seconds; an experimenter sat beside the subject throughout experiment.

Results

Response latencies less than 100ms and more than 1900ms were discarded as outliers. These outliers composed of less than 0.5% of all responses. An additional 2.2% of responses were classified as errors (stammers, incorrect pronunciations, etc.). For the reaction time (RT) analysis, trials on which an error occurred were discarded. The ANOVA was a 2 x 2 x 2 x 2 x 4 (List x Frequency x Case x Regularity x Block) with all but List repeated measures factors. There were two marginally significant four-way interactions involving counterbalanced lists. A third four-way interaction with list was more strongly significant (Frequency X Case X Regularity X List), $F(1,42) = 30.33$, $p < .0001$, $MSE = 89169.02$. Inspection of the means for this interaction indicated that RTs were particularly long for low frequency, regular words in List 1, for Block 2,. However, with that exception, the pattern of responding in that block was otherwise consistent with List 2. The data aggregated across both lists can, therefore, be assessed without important distortion. All main effects were statistically significant. For Frequency, $F(1, 42) = 231.99$, $p < .0001$, $MSE = 514859.02$; for Case, $F(1,42) = 32.32$, $p < .0001$, $MSE = 37538.72$; for Regularity, $F(1, 42) = 53.32$, $p < .001$, $MSE = 126950.77$; and, for Block, $F(3, 126) = 33.86$, $p < .001$, $MSE = 134466.79$. Also significant were the two-way interactions between Case and Regularity, $F(1, 42) = 18.69$, $MSE= 10956.10$, $p < .0001$, and Frequency by Regularity, $F(1, 42) = 32.57$, $MSE = 43688.64$, $p < .0001$.

Importantly, each of the two-way interactions between Block and the other variables were all statistically significant. For the interaction between Block and Case, $F(3, 126) = 9.46$, $MSE = 5849.96$, $p < .001$; for the interaction between Block and Frequency, $F(3, 126) = 20.31$, $MSE = 13977.51$, $p < .001$; and for the interaction between Block and Regularity, $F(3, 126) = 5.55$, $MSE = 4120.07$, $p < .002$. Finally, the three-way interaction for Block by Case by Regularity was significant, $F(3,42) = 4.70$, $MSE = 2939.44$, $p < .004$.

Although the interaction for Block x Case x Frequency x Regularity was not significant (and, in fact, its mean square was small), there was a priori interest in testing for an initial regularity effect on high frequency words. Herdman et al. (1999) had found such an effect on high frequency words, i.e., slower naming times for irregular words compared to regular, but only when they had been printed in mixed case; no regularity effect was found for uniform case. For the present mixed case data, there was an 18ms difference between regular and irregular high frequency words in block 1 that was significant by a paired t-test, $t(43) = 2.33$, $p = .024$. However, this same comparison for uniform case words was small, 3ms, and nonsignificant. In contrast to high frequency words, the regularity effect in block 1 for low frequency words was substantial, as can be seen in Figure 2. For mixed case, the difference was 67ms, $p < .0001$, and for uniform case it was smaller, 27ms, but still strongly significant, $p < .0006$. By block 4, there was no significant regularity effect for high frequency words. But, for low frequency words, significant (although reduced) regularity effects still obtained for mixed case ($p < .01$) and for uniform case ($p < .01$).

Discussion

The results are substantially in agreement with the neurobiological theory's predictions that small grain-size processing would persist in the naming paradigm. For low frequency words, the regularity effect persisted and was still significant at the fourth exposure in contrast to lexical decision, where the effect was null by the third exposure. The effect of mixed case was also effective in creating conditions for maintaining small grain-size; for low frequency words, mixed case stimuli displayed a larger regularity effect. There were no regularity effects for high frequency words except for a weak effect on the first presentation for mixed case words.

General Discussion

Recent brain imaging data indicate that the brain processes involved in word recognition change as a reader becomes more familiar with a given word (Pugh et al., 2000a). As we discussed in the introduction, two key brain circuits appear to be responsible for the difference between the slow, effortful, decoding of unfamiliar words and the rapid recognition of familiar words. These two cortical circuits are located, respectively, in the temporo-parietal (dorsal) and the occipito-temporal (ventral). Although it is clear from the imaging data that each circuit has its own domain of operation (e.g., familiar versus unfamiliar words, skilled versus unskilled word recognition, etc.), the imaging studies have not addressed differences between the domains in their operative informationcodes.

We proposed, from a processing aspect, that the shift from dorsal to ventral processing with repeated experience can be described in terms of the cognitive information code that each domain processes, viz., a shift in the grain-size of processing. Unfamiliar words are decoded by the dorsal circuit which utilizes grapheme-to-phoneme correspondences and other normative information relevant to single letters and small letter clusters. As words become more familiar through increased exposure, the ventral system forms recognition templates based on aggregates of larger numbers of letters. The data in the present paper support this interpretation. With increasing experience, the regularity effect either disappeared (in the lexical decision task) or was attenuated (in the naming task). Because the regularity effect is, necessarily, caused by small grain-size processing (i.e., caused by ambiguity in grapheme-phoneme correspondence), its nullification or attenuation is likely evidence of processing at larger grain-size.

If grain-size increases with exposure to a word, it is natural to ask whether there are limits on the maximum grain-size that can be achieved. The whole word may be the largest effective grain-size, typically, because multi-word combinations occur infrequently. When they do occur, they may become "lexicalized" and represent a single lexical address. As examples, consider phrases like, "kick-the-bucket" or "large Coke". These printed word forms may become recognized, after a sufficient number of experiences, via a multi-word template.

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