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Strategic processes in phonological recoding

by

Susan A. Vanderburg

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of**

Master of Arts

Department of Psychology

Carleton University

Ottawa, Ontario

16 May 1994

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in partial fulfilment of the requirements for
the degree of

Master of Arts

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ABSTRACT

The present research explored strategic processes in word naming. Subjects named high- and low-frequency words written in lower (e.g., house) or mixed (e.g., hOuSe) case. The effects of strategy were examined by varying the proportions of lower- and mixed-case words in the stimulus lists. Experiment 1 (25% mixed case) and Experiment 2 (50% mixed case) both resulted in commonly reported case-by-frequency interactions: low-frequency words were slowed more by mixed case than high-frequency words. Experiment 3 (75% mixed case) resulted in a non-significant case by frequency interaction. However, an analysis of all three experiments together produced a significant case-by-frequency interaction with no effects of proportion of mixed case. An analysis of errors in Experiments 1, 2, 3 and the overall analysis mirrored the naming latency case by frequency interactions. Strategic processing, though not utilized by subjects in the present study, is discussed in terms of list composition.

ACKNOWLEDGEMENT

I would like to express my gratitude to Chris Herdman for his help and guidance throughout this MA journey. He was always willing to spend that extra moment to answer my never-ending questions, even at the most inconvenient of times. I would also like to thank Jo-Anne LeFevre and John Logan for their helpful suggestions and comments. Thanks also to Andy Brook and Bill Petrusic for their challenging questions during my thesis defense. A special thank you to Tom Ryan who, at the last moment, chaired my prospectus defense.

A grateful appreciation is extended to the members of the "Herdman-LeFevre" lab who assisted at various stages of the research. Thanks in particular to Fred Lichaz, Karen Hiscock, Stephanie Greenham, Sarah Hobbs, and Greg Craig. I would also like to acknowledge the financial support provided by the Natural Sciences and Engineering Research Council.

Last, but certainly not least, I wish to express my deepest appreciation to Jeff Vanderburg, my wonderful husband, who has been with me every step of the way.

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Introduction

Cognitive psychologists interested in lexical processing study the flow of information from sensation to perception to higher cognitive processes. Of primary concern is how information is represented and accessed. A variety of models of representation and access have been proposed in the word recognition literature. Although these models describe the flow of information through the word recognition system, this flow is generally depicted as being relatively invariant in nature: The orientation of processing (strategic modulation) as information flows through the system is generally not considered.

The purpose of the present experiments was to examine if strategic modulation of phonological recoding plays a role in visual word recognition. Subjects were required to name high- and low-frequency words which were presented in either lower case (e.g., house) or mixed case (e.g., hOuSe). Strategic orienting in the word recognition system was induced by varying the proportion of mixed-case words in the stimulus lists.

Background Research: Case and Frequency

Effects of Case. Words written in mixed case disrupt the flow of information processing: Mixed-case words are most easily processed letter-by-letter, while lower-case words may be processed as whole-word units (Besner & Johnston, 1989). Visual information, such as word shape or word-specific visual patterns (WSVPs), may aid the recognition of words written in lower case (Coltheart & Freeman, 1974; Masson, 1986; Rudnicky & Kolars, 1984). Mixed case, however, disrupts the normal shape of a word and the word's visual features. Mixed-case words require longer lexical decision and naming latencies than lower-case words because mixed-case words must be processed letter-by-letter (Besner & Johnston, 1989; Besner & McCann, 1987; Chernecki, 1992; Coltheart & Freeman, 1974; Masson, 1986; Rudnicky & Kolars, 1984).

Effects of Frequency. Words labelled as high-frequency are read and spoken quite frequently, while words designated as low-frequency are encountered less frequently. Most word recognition theorists suggest that words in the lexicon are arranged by decreasing frequency, where high-frequency words are accessed

faster than low-frequency words (Becker, 1976; Besner, 1991; Besner & Johnston, 1989; Morton, 1969). In fact, many studies have shown that low-frequency words do take longer to name than high-frequency words (Besner, 1991; Besner, Coltheart, & Davelaar, 1984; Besner & McCann, 1987; Morton, 1969; Whaley, 1978).

Effects of Case and Frequency. Research on the effects of case and frequency has produced conflicting results. Using both words and nonwords in their study, Besner and McCann (1987) found a case-by-frequency interaction when they had subjects perform a naming task with 50% mixed- and 50% lower-case stimuli. Besner and McCann's interaction showed that low-frequency words were slowed more by mixed case than high-frequency words. This interaction was replicated by Chernecki (1992) using exception words instead of nonwords. In contrast, when Brown, Colombo, and Lupker (1992) attempted to replicate Besner and McCann's results with less than 25% mixed-case stimuli, they found additive effects: High-frequency words were named faster than low-frequency words and lower-case words were named faster than mixed-case words.

The inconsistency between the results of Besner and McCann and that of Brown et al. may be due to the fact that different proportions of mixed-case stimuli were used in the two sets of experiments. That is, the way in which mixed- and lower-case words of high and low frequency are processed by the word recognition system may vary depending on factors such as list composition. Therefore, one possibility is that the occurrence of interactive or additive effects between case and frequency depends upon the strategic orientation of processing. The effects of case and frequency can be explained by utilizing word recognition models.

Word Recognition Models

Word recognition models can be described as either single-route or dual-route models. In single-route models words are processed by a unitary process (or set of processes) in which pronunciations for words are usually obtained from a mental lexicon. In dual route models an addressed route serves the same function as the single route, yet, it is also accompanied by an assembly route which converts graphemes into phonemes in order to determine a word's pronunciation. As

described below, single-route models generally predict interactive effects between case and frequency despite the use of differing proportions of mixed-case (i.e., 25%, 50%, or 75% mixed-case words). In the present research, however, it is proposed that flexibility in the processing of words can be addressed using a dual-route model. Thus, dual-route models may be able to account for both interactive and additive effects between case and frequency.

Single-Route Models. Seidenberg and McClelland's (1989) Parallel Distributed Processing (PDP) model of word recognition is one example of a single-route approach. When a word is read a pattern of activation spreads across orthographic, hidden, and phonemic units. Inputs from all the incoming units are multiplied by a weight and then added together to obtain the total input going to a particular unit (Rumelhart, 1989). When the PDP model is trained using back-propagation learning procedures, the weights on the connections between the units are modified in order to reduce orthographic and phonological error scores.¹ The best performance (i.e., pronunciation) occurs when error scores are at a minimum.²

The primary difference between a PDP approach and other models of word recognition is that PDP models do not include a lexicon: Proponents of PDP models suggest that there is no area in the human brain that stores word entries per se. PDP theorists also do not use any type of rule system, only the weighted units. It is not clear how PDP models can be used to account for the effects of mixed case. In order to decode the upper and lower case letters of mixed-case words, increased back propagation (i.e., more cycles) may occur between the orthographic and hidden units. This could result in increased errors in pronunciation for mixed-case words. Seidenberg and McClelland's (1989) PDP model does account for the frequency effect: Because words of higher frequency most often produce phonological output that resembles the correct pattern of activation, they produce smaller error scores. Importantly, because PDP models are interactive systems they never predict additive effects. Thus PDP theorists should predict an interaction between case and frequency.

Another single-route approach is Morton's (1969) Logogen Model. According to Morton there are basic

units in the mental lexicon called logogens that represent all words that have been encountered. When a target word is read, the logogen system collects information about the word's features until the feature count rises above threshold. The candidates corresponding to the word are then identified and fed into a response buffer. Words which are orthographically similar to the target are co-activated, although only the first response to enter the buffer is pronounced.

Words written in mixed-case format may disrupt the amount of visual information (e.g., word shape) that reaches the logogen system, and thereby reduce the rate at which the logogens are activated. Thus, logogens corresponding to the mixed-case target would take longer to reach threshold, thereby producing longer recognition latencies.

Morton's (1969) model can also account for word frequency effects. Logogens which represent low-frequency words have high thresholds, whereas logogens corresponding to high-frequency words have lower thresholds. Because activation of a low-frequency logogen takes longer to reach its corresponding

threshold, low-frequency words are recognized more slowly than high-frequency words.

The relation between case, frequency, and logogen activation is depicted in Figure 1. As shown in Figure 1, the threshold for high-frequency words is lower than the threshold for low-frequency words. In addition, the activation rate is faster for words written in lower case than for words written in mixed case. The combination of the time needed for the logogen to be activated and the time required for the logogen to reach threshold produces the naming latency. Therefore, high-frequency lower-case words (a) will reach threshold before high-frequency mixed-case words (b), such that naming latencies will be slightly longer for high-frequency mixed-case than high-frequency lower-case words ($b - a = e$). Low-frequency lower-case words (c) will reach threshold before low-frequency mixed-case words (d): Naming latencies will be longer for low-frequency mixed-case than low-frequency lower-case words ($d - c = f$). Consequently, low-frequency words should be affected more by case than high-frequency words ($f > e$). Thus, case and frequency should always interact according to Morton's (1969) model.

Another single-route model is the Verification or Serial-Search Model (Becker, 1976; Paap, McDonald, Schvaneveldt, & Noel, 1987; Paap, Newsome, McDonald, & Schvaneveldt, 1982). This model has both sensory and lexical stores. Upon presentation, the sensory attributes of a target stimulus are stored in sensory memory. The lexical store provides the sensory store with current information about the target stimulus, additional information from past exposure to that stimulus, and access to semantic information. The activation-verification model has two main processes: feature extraction and verification.

The feature extraction process utilizes some of the sensory store's information to make available a candidate set of words which are generally consistent with the visual characteristics of the target stimulus. The verification process begins with the selection of a prototypical word from the candidate set. This prototype contains information regarding the individual features of the stimulus and how these features are organized. During each verification cycle, a candidate is checked with the visual representation in the sensory store. The stimulus word is recognized if the prototype matches the

visual code of the stimulus in sensory store. Otherwise, another candidate must be selected and the process is repeated until a successful match is made.

The verification model can also account for the effects of mixed case. The visual information extracted by the sensory store from mixed-case words is not as rich (i.e., normal word shape is destroyed) as from lower-case words. With conflicting information in the sensory store and the lexical store, accurate prototypes may be more difficult to form. In addition, the verification process may be slowed because the stored prototypes would have difficulty matching the visual representation of the target word. This would result in increased errors and increased reaction times for mixed-case words.

To account for the effect of frequency, Becker assumes that high-frequency words enter the verification process before low-frequency words. The basis for this assumption is that high-frequency words would be identified in fewer verification cycles than low-frequency words (Becker, 1976).

Becker's (1976) verification model can also account for the combined effects of case and frequency.

High-frequency words should be processed faster than low-frequency words because the verification process is ordered by frequency (i.e., high-frequency words are considered before low-frequency words). There are more verification cycles for words of lower frequency. In addition, the processing of mixed-case words may add extra time to each cycle. Thus, the number of verification cycles required, depending upon the word's frequency, plus the time added on to each cycle for deciphering mixed case may cause longer naming latencies for mixed-case words. Therefore, Becker's (1976) model predicts a case-by-frequency interaction: Low-frequency words should be slowed more than high-frequency words going from lower case to mixed case.

In summary, single-route models predict a case by frequency interaction. This prediction is made on the assumption that case and frequency influence the same process or set of processes. An alternate possibility, however, is that case and frequency affect different processes in the word recognition system. Specifically, it could be argued that case is like stimulus quality (Sternberg, 1967) in that it affects the encoding stage and not higher cognitive stages such

as those outlined above in the Logogen model and the Verification model. On this view, the word recognition system would have to "clean up" or "normalize" all mixed-case words (i.e., change the mixed-case word into lower-case format) before the word can be identified and then accessed in the lexicon. This extra time for encoding would be added onto the processing times for both high- and low-frequency mixed-case words, thus causing an additive effect.

Because either encoding or the higher cognitive processes would be affected by case, not both, single route models cannot predict both interactive and additive effects between case and frequency, only one or the other. The only model which has the flexibility in processing to explain the strategic factors which influence phonological recoding by varying list content is the dual-route model.

Dual-Route Model. Dual-route models have two processing routes which operate simultaneously: an assembly route and an addressed route. The assembly route operates at a sublexical level by converting graphemes into phonemes. When a regular word or nonword is processed via this route it is translated

using spelling-to-sound correspondence rules (Gough, 1972; Morton & Patterson, 1980; Rubenstein, Lewis, & Rubenstein, 1971). Letters and letter clusters (e.g., sh) are converted into phonemes to enable pronunciation. In general, processing along the assembly route takes longer to produce output than the addressed route because of the extra time required for translation using spelling-to-sound correspondence rules (Paap & Noel, 1991; Patterson & Coltheart, 1987).

When a regular or exception word is analyzed by the addressed route it first passes through the orthographic lexicon. The orthographic lexicon verifies that the stimulus is a word by analyzing its spelling. After the word is identified in the orthographic lexicon its pronunciation is retrieved from the phonological lexicon and produced as output.

There is neurocognitive evidence from acquired dyslexia that the word recognition system can be divided into an addressed versus an assembly route. Two forms of acquired dyslexia are phonological dyslexia and surface dyslexia. Phonological dyslexics have trouble reading nonwords, but can read words that were known before acquiring dyslexia (Beauvois &

Derouesne, 1979; Funnell, 1983; Patterson, 1982).

Proponents of the dual-route model believe that the assembly route of phonological dyslexics has been damaged and therefore they must rely almost exclusively on the addressed route for word pronunciation (Besner & Johnston, 1989; Coltheart, Curtis, & Atkins, 1992).

In contrast, surface dyslexics have difficulty reading exception words, although their reading of regular words and nonwords is not hindered (Behrmann & Bub, 1992; Marshall & Newcombe, 1973; McCarthy & Warrington, 1986; Patterson, Marshall, & Coltheart, 1985). Exception words are often misread as regular words by surface dyslexics (e.g., "have" would be read like "save"). Because the addressed route has been presumably damaged in surface dyslexic patients, processing usually proceeds via the assembly route. Single-route theories, unlike the dual-route model, cannot account for the deficits in processing caused by acquired dyslexia (Besner, 1991; Coltheart et al., 1992).

Dual-route models can account for the mixed-case effect, in which lower-case words are named faster than mixed-case words. Processing of mixed-case words from

visual feature analysis to multiletter unit identification (path 6) is difficult because multiletter unit identification is disrupted (e.g., *^H* instead of *sh*) (see Figure 2). Because mixed case interferes with the normal shape of a word and the word's visual features, mixed-case words are more efficiently processed letter-by-letter instead of as fixed units (Besner & Johnston, 1989).

Using the assembly route, the processing of mixed-case words proceeds along path 1 from visual feature analysis to letter analysis, continues via path 5 to assembled phonology, and then advances to speech production. Mixed-case words would take longer to assemble than lower-case words because twice as many letters (both the upper- and lower-case alphabet) must be considered when processing mixed-case words (Besner & Johnston, 1989).

Using the addressed route, processing of mixed-case words would progress along path 1 from visual feature analysis to letter analysis, continue on path 2 to the word identification process, proceed to path 3 to the retrieval of addressed phonology, and then continue to path 4 for speech processes. Mixed-case

words would take longer to process along the addressed route; the word identification process would be slowed because the words are distorted by mixed case. Lower-case words, however, would not be delayed in these processes thereby causing the effects of case.

Frequency has little effect on the assembly route, whereas the addressed route is frequency sensitive (Besner, 1990; Monsell, Patterson, Graham, Hughes & Milroy, 1992; Paap & Noel, 1991). High-frequency words are most efficiently processed by the addressed route because it is ordered by frequency: high-frequency words have lower thresholds, while low-frequency words have higher thresholds (Besner & Johnston, 1989).

Case by frequency interactions can be accounted for by the dual-route model. Low-frequency words are processed more slowly than high-frequency words because they have higher thresholds. The addressed and assembly routes produce output for low-frequency words at approximately the same time; thus, output for one low-frequency word may be produced from the addressed route, while the assembly route may be used for another. All mixed-case words, whether of high or low frequency, take longer to process than lower-case words

because of the extra time required to decipher the mixed case. Therefore, the combination of these effects causes a case by frequency interaction.

Case by frequency interactions can also be explained by using only the addressed route, because this route is in itself a single-route model. In this way, all high- and low-frequency words written in lower or mixed case can be processed by the addressed route. Because they have low thresholds, high-frequency words would be processed faster than low-frequency words. Mixed-case words would take longer to process than lower-case words because of the extra decoding time required. Thus, mixed-case would effect low-frequency words more than high-frequency words, causing a case by frequency interaction.

Additive effects between case and frequency can also be accounted for by the dual-route model. Additive effects would occur in situations where output from the assembly route is processed before that of the addressed route. Mixed-case words would take longer to assemble than lower-case words. In addition, because frequency has little effect on the assembly route, there would be no effects of frequency. Therefore,

when output from only the assembly route is processed, additive effects would occur between case and frequency.

There are three ways in which strategic processing may occur using the dual-route model: (1) by orientating processing to the addressed route or to the assembly route after letter analysis, (2) by deciding at output whether to produce the response generated by the addressed route or assembly route, or (3) by modulating the rate at which information flows through the word recognition system.

Present Research

One assumption of the present study was that the dual-route model can simultaneously account for both additive and interactive effects between case and frequency. As previously mentioned, the flow of information through the word recognition system is usually viewed as invariant using all word recognition models. However, the present research proposed that the dual-route model is flexible in that it can account for the strategic factors that affect phonological recoding. It was predicted that the more mixed case presented to subjects, the greater the likelihood that

processing would be oriented toward the assembly route. Thus, the frequency effect would be increasingly diminished the more the assembly route is utilized because of the lack of frequency effects using the assembly route. Therefore, additive effects should be more likely to occur as greater amounts of mixed case are presented to subjects.

The present research was designed to determine if subjects use strategic manipulation according to stimulus list composition (i.e., to see if subjects process the stimuli differently depending upon what proportion of mixed case is present in the stimulus list). In particular, in the present study it was examined whether strategic processing plays a role when subjects are presented with stimulus lists with varying proportions of mixed case. Three experiments are reported in which subjects were required to name high- and low-frequency words that were presented in either lower- or mixed-case format. Experiment 1 was designed to ascertain whether case and frequency have additive effects (Brown et al., 1992) or interactive effects (Besner and McCann, 1987) when subjects are presented with 25% mixed-case stimuli. The aim of Experiment 2

was to obtain a case by frequency interaction using 50% mixed case and replicate Besner and McCann's (1987) case-by-frequency interaction. Experiment 3 was designed to examine the effect of case and frequency when most of the stimuli (i.e., 75%) were written in mixed case.

Experiment 1: 25% mixed case

Experiment 1 was designed to determine the effects of case and frequency when the stimulus lists consisted of 25% mixed-case and 75% lower-case words. Recall that Brown et al. (1992) found additive effects using less than 25% mixed-case stimuli (i.e., about 20%) in their experiment.

Method

Subjects. Subjects consisted of 40 undergraduate students enrolled in Introductory Psychology courses at Carleton University. They participated for research credit.

Apparatus. Stimulus words were presented on a Samsung monochrome video monitor (model # SM-12SFA7) using an IBM AT-type computer equipped with a Digital I/O board. Subjects used a micro-switch to initiate trials. Naming latencies were registered on a Grason-

Stadler voice-operated relay (VOR, model # E7300A-1) using a Beyerdynamic microphone and headphone set (Sharpe model # LM6 D-48). Timing was accurate to 1 millisecond.

Design and Materials. A 2 (Case: lower, mixed) X 2 (Frequency: high, low) within-subjects design was used. Half of the stimuli were high-frequency words; half were low-frequency words. Twenty-five percent of the words were in mixed-case form.⁴ In total, 40 mixed-case words were randomly intermixed among 120 lower-case words to make a list of 160 words. Thus, four types of words were presented: 20 low-frequency lower case, 20 high-frequency lower case, 60 low-frequency mixed case, and 60 high-frequency mixed case.

All of the words were monosyllabic and ranged from three to five letters in length (Kucera & Francis, 1967). Words were closely matched on bigram frequency counts that were obtained from Mayzner and Tresslet (1965) (see Appendix A for the matched stimulus list). There were four word lists which each included a subset of 40 words (core set) that was used for the analyses. The core set was used so that a direct comparison could be made between the experiments. Within the core set

of words, high- and low-frequency words were matched as closely as possible for initial phonemes (see Appendix B). The core words list was presented to subjects in one of two sets (see Appendix C). Half the words in the first set were presented in mixed case and the other half in lower case. The second set was made up of the same words, yet from the first set the mixed-case words were in lower-case form and the lower-case words were in mixed-case form. Thus, each core set had 10 low-frequency lower-case words, 10 high-frequency lower-case words, 10 low-frequency mixed-case words, and 10 high-frequency mixed-case words. The words were presented to subjects in ascending or descending order.

Procedure. Subjects were tested individually in 25 minute sessions. After reading and signing an informed consent form, subjects read additional instructions on a computer screen. Subjects then completed 16 practice trials followed by the 160 experimental trials. Each trial was preceded by an asterisk in the middle of the computer screen. Subjects pressed a micro-switch to initiate the trial upon viewing the asterisk. After a 300-millisecond delay, a word was presented in the centre of the screen in either lower-case (i.e., house)

or mixed-case (i.e., hOuSe) format. The word remained on the screen until it was pronounced or until 2000 ms had expired. The experimenter indicated whether the subject's response was right, wrong, or invalid by entering a code into the computer.'

Results and Discussion

Set and Order Effects. A 2 (Case: lower, mixed) X 2 (Frequency: high, low) X 2 (Set: one half mixed, the other half mixed) X 2 (Order: ascending, descending) mixed ANOVA was used to analyze the mean naming latency data from the core set of words (see Appendix D). Among other effects, the analysis showed a significant set by case by frequency interaction, $F(1, 36) = 22.87$, $MSe = 24431$, $p < .001$. Upon further examination of the means, it appears that the interaction between case and frequency is only present using the core words in Set 2; such that low-frequency words were slowed more by mixed case than high-frequency words. The core words in Set 1 show additive effects between case and frequency, whereby mixed-case words were slowed more than lower-case words and low-frequency words were slowed more than high-frequency words. Thus, the low-frequency items that were presented in mixed-case form

in Set 2 seemed to have been more difficult than those low-frequency items that were presented in mixed-case in Set 1.

Analysis of Mean Naming Latencies. The primary dependent variable was pronunciation latency. The naming latency data was analyzed twice; once with means and once with medians. However, the results were quite different (see Appendices E and F). It was decided that the results from the mean analyses would be used because an analysis of the error data supported the mean naming latency findings. Thus, means were calculated using naming latencies of correctly pronounced words. A 2 (Case: lower, mixed) X 2 (Frequency: high, low) repeated measures ANOVA was used to analyze the mean naming latency data from the core set of words (see Table 1). There was a main effect of Case, $F(1, 39) = 38.9$, $MSe = 82805$, $p < .001$, such that lower-case words were pronounced faster than mixed-case words. There was also a main effect of Frequency, $F(1, 39) = 49.7$, $MSe = 70086$, $p < .001$, where high-frequency words were pronounced faster than low-frequency words. In addition, the Case X Frequency interaction was significant, $F(1, 39) = 8.34$,

MSe = 13489, $p < .01$: low-frequency words were slowed more by mixed case than high-frequency words (see Figure 3).

Error Analysis. A 2 (Case: lower, mixed) X 2 (Frequency: high, low) repeated measures analysis of the error data (see Table 2) showed a main effect of Case, $F(1, 39) = 16.04$, MSe = .26, $p < .001$: Subjects made more errors with mixed- than lower-case words (see Figure 4). There was also a main effect of Frequency, $F(1, 39) = 31.24$, MSe = .14, $p < .001$, where there were more errors on low- than high-frequency words. A Case X Frequency interaction using the error data, $F(1, 39) = 9.06$, MSe = .14, $p < .01$, concurred with the interaction using the naming latency data; thus, low-frequency words had more errors when written in mixed case than high-frequency words.

To summarize, mean naming latency in Experiment 1 showed interactive effects between case and frequency when subjects were presented with 25% mixed-case stimuli. This finding contradicts Brown et al. (1992) who found additive effects with case and frequency when they used a similar proportion of mixed-case stimuli. However, as shown in Appendix E, the analysis of median

naming latency produced additive effects between case and frequency. Thus, presenting subjects with 25% mixed case causes an interaction or additive effects, depending upon which naming latencies are analyzed: means or medians.

Experiment 2: 50% mixed case

Experiment 2 was designed to determine if presenting subjects with 50% mixed-case stimuli would cause a case by frequency interaction, as found by Besner and McCann (1987) without the inclusion of nonword stimuli. Using both words and nonwords in their study, Besner and McCann found a case-by-frequency interaction when they presented subjects with 50% mixed- and 50% lower-case stimuli. In Experiment 2 subjects were presented with 50% mixed- and 50% lower-case words.

Method

The method of Experiment 2 was almost identical to that of Experiment 1. In Experiment 2 however, 50% percent of the words were written in mixed case while the other 50% included lower-case words. Eighty mixed-case words were randomly intermixed among 80 lower-case words to produce a list of 160 words. Thus, four types

of words were presented: 40 low-frequency lower case, 40 high-frequency lower case, 40 low-frequency mixed case, and 40 high-frequency mixed case. The core set of words was used in the analysis.

Results and Discussion

Set and Order Effects. A 2 (Case: lower, mixed) X 2 (Frequency: high, low) X 2 (Set: one half mixed, the other half mixed) X 2 (Order: ascending, descending) mixed ANOVA was used to analyze the mean naming latency data from the core set of words (see Appendix G). In addition to other effects, the analysis showed a significant set by case by frequency interaction, $F(1, 36) = 20.18$, $MSe = 24988$, $p < .001$. However, as in Experiment 1, it appears that the interaction between case and frequency is only present using the core words in Set 2; such that low-frequency words were slowed more by mixed case than high-frequency words. Additive effects between case and frequency occur when the core words in Set 1 are examined; such that mixed-case words were slowed more than lower-case words and low-frequency words were slowed more than high-frequency words. Thus, as in Experiment 1, the low-frequency items that were

presented in mixed-case form in Set 2 seemed to have been more difficult than low-frequency items that were presented in mixed-case in Set 1.

Analysis of Mean Naming Latencies.

Using mean naming latencies (see Appendix H) a 2 (Case: lower, mixed) X 2 (Frequency: high, low) repeated measures ANOVA (refer to Table 1) showed a main effect of Case, $F(1, 39) = 46.2$, $MSe = 74447$, $p < .001$, such that lower-case words were pronounced faster than mixed-case words (see Figure 5). There was a main effect of Frequency, $F(1, 39) = 51.3$, $MSe = 141783$, $p < .001$, where high-frequency words were pronounced faster than low-frequency words. Most importantly, a Case X Frequency interaction, $F(1, 39) = 6.55$, $MSe = 12890$, $p < .05$, replicated Besner and McCann (1987). The interaction was also similar to that of Experiment 1, in that low-frequency words were slowed more by mixed case than high-frequency words.

Error Analysis. The pattern of errors was similar to that of Experiment 1 (refer to Table 2). In Experiment 2, a 2 (Case: lower, mixed) X 2 (Frequency: high, low) repeated measures ANOVA showed a main effect of

Case, $F(1, 39) = 10.28$, $MSe = .29$, $p < .01$, where subjects made more errors with mixed- than lower-case words (see Figure 6). There was also a main effect of Frequency, $F(1, 39) = 27.86$, $MSe = .20$, $p < .001$, where subjects made more errors with low- than high-frequency words. A Case X Frequency interaction, $F(1, 39) = 8.34$, $MSe = .24$, $p < .01$, showed that the error data was in accordance with the naming latency data: low-frequency words had more errors when written in mixed case than high-frequency words.

To summarize, an analysis of mean naming latency in Experiment 2 showed a case by frequency interaction using 50% mixed-case. This case by frequency interaction replicated that of Besner and McCann (1987). However, an analysis using medians (see Appendix I) produced additive effects between case and frequency. Thus, Besner and McCann's (1987) interaction was only replicated using mean naming latency.

Experiment 3: 75% mixed case

Experiment 3 was designed to determine the effects of case and frequency when more than half the words were written in mixed case. In this experiment, 75% of

the stimuli were presented in mixed case, while only 25% of the words appeared in lower case (This ratio was opposite to that in Experiment 1).

Method

The method used in Experiment 3 was almost identical to that of Experiments 1 and 2. In Experiment 3 however, 75% of the words were written in mixed case and the other 25% were lower-case words. Therefore, 120 mixed-case words were randomly intermixed among 40 lower-case words to produce a list of 160 words. Thus, four types of words were presented: 60 low-frequency lower case, 60 high-frequency lower case, 20 low-frequency mixed case, and 20 high-frequency mixed case. The core set of words was used in the analysis.

Results and Discussion

Set and Order Effects. A 2 (Case: lower, mixed) X 2 (Frequency: high, low) X 2 (Set: one half mixed, the other half mixed) X 2 (Order: ascending, descending) mixed ANOVA was used to analyze the mean naming latency data from the core set of words (see Appendix J). The analysis showed a significant three-way interaction between set, case, and frequency, $F(1, 36) = 18.09$,

MSe = 10589, $p < .001$. However, as in Experiments 1 and 2, the interaction is only present with the core words in Set 2: low-frequency words were slowed more by mixed case than high-frequency words. The core words in Set 1 show additive effects between case and frequency, whereby mixed-case words were slowed more than lower-case words and low-frequency words were slowed more than high-frequency words. Thus, in Experiment 3, the low-frequency items that were presented in mixed-case form in Set 2 seemed to have been more difficult than those low-frequency items that were presented in mixed-case in Set 1.

Analysis of Mean Naming Latencies.

Using mean naming latency data (see Appendix K) a 2 (Case: lower, mixed) X 2 (Frequency: high, low) repeated measures ANOVA was used to analyze the naming latency data (refer to Table 1). There was a main effect of Case, $F(1, 39) = 43.9$, MSe = 1206, $p < .001$, where lower-case words were pronounced faster than mixed-case words (see Figure 7). There was also a main effect of Frequency, $F(1, 39) = 85.3$, MSe = 901, $p < .001$, such that high-frequency words were pronounced faster than low-frequency words. The

interaction between case and frequency was nonsignificant, $F(1, 39) = 2.34$, $MSe = 918$, $p = .134$. However, the means suggest that the relationship between case and frequency in Experiment 3 was similar to that of Experiments 1 and 2: Low-frequency words were slowed more by mixed case than high-frequency words.

Error Analysis. The errors in Experiment 3 were analogous to that of Experiments 1 and 2 (refer to Table 2). In Experiment 3, a 2 (Case: lower, mixed) X 2 (Frequency: high, low) repeated measures ANOVA showed a main effect of Case, $F(1, 39) = 8.01$, $MSe = .18$, $p < .01$, where subjects made more errors with mixed- than lower-case words (see Figure 8). There was also a main effect of Frequency, $F(1, 39) = 34.20$, $MSe = .12$, $p < .001$, where subjects made more errors with low- than high-frequency words. In addition, a Case X Frequency interaction, $F(1, 39) = 5.73$, $MSe = .18$, $p < .05$, showed that low-frequency words had more errors when written in mixed case than high-frequency words.

Because there were less per cent errors in Experiment 3 (refer to Table 2) a question was posed as

to whether there was a speed-accuracy tradeoff for subjects' errors in this experiment. Therefore, the mean and median naming latencies for the errors in Experiment 3 were examined in order to determine if there was any evidence of a speed-accuracy tradeoff (see Table 3). In comparison with the naming latencies for the errors in Experiments 1 and 2, there is no clear pattern of error responding, nor any evidence of a speed-accuracy tradeoff. Thus, the relationship between the speed of the errors and subjects' lack of accuracy does not seem to have any theoretical significance.

To summarize, presenting 75% mixed-case stimuli to subjects in Experiment 3 produced a nonsignificant case by frequency interaction using the latency data. In addition, the an analysis with median naming latency (see Appendix L) produced additive effects between case and frequency. It had been predicted that the more mixed case presented to subjects, the greater the likelihood that processing would be oriented toward the assembly route. The additive effect found using the mean naming latency analysis may provide evidence for strategic processing. However, because the error data

showed a significant case by frequency interaction, it is conceivable that there may have been a type I error with the mean naming latency analysis: The hypothesis that there would be additive effects between case and frequency using 75% mixed case may have been incorrectly accepted. In order to verify if proportion of mixed case (i.e., strategic processing) indeed had a significant effect on naming latency, an overall analysis of all three experiments was conducted.

Overall Analysis

An analysis of all three experiments was completed in order to gain more statistical power and to ascertain whether the proportions of mixed case had differentially affected naming latency in Experiments 1, 2 and 3.

Results and Discussion

Analysis of Mean Naming Latencies.

Using mean naming latency a 2 (Case: lower, mixed) X 2 (Frequency: high, low) X 3 (Proportion of Mixed Case: 25%, 50%, 75%) repeated measures ANOVA was used to analyze the data from the core set of words (refer to Table 1). The overall analysis produced similar main effects as Experiments 1, 2, and 3 (see

Appendix M). A main effect of Case, $F(1, 117) = 126.5$, $MSe = 208458$, $p < .001$, showed that lower-case words were pronounced faster than mixed-case words, while a main effect of Frequency, $F(1, 117) = 166.2$, $MSe = 281233$, $p < .001$, showed that high-frequency words were pronounced faster than low-frequency words. In addition, there was a Case X Frequency interaction, $F(1, 117) = 16.92$, $MSe = 1500.90$, $p < .001$, which indicated, like those from Experiments 1, 2, and nonsignificantly in Experiment 3, that low-frequency words were slowed more by mixed case than high-frequency words (see Figure 9).

As for latencies, there was neither a main effect of Proportion, $F(2, 117) = .57$, $MSe = 32622$, $p = .57$, nor a Proportion X Case X Frequency interaction, $F(2, 117) = 1.04$, $MSe = 1501$, $p = .36$. Presenting subjects with stimulus lists of different proportions of mixed case did not differentially affect naming latencies.

Error Analysis. An analysis of the errors using the data from all three experiments was conducted to determine if there were differences in the amount of errors in the core set of stimuli when different

proportions of mixed case were presented (refer to Table 2). In all three experiments the errors were distributed as expected and are listed in descending order of average number of errors: low-frequency mixed-case words, low-frequency lower-case words, high-frequency mixed-case words, and high-frequency lower-case words.

In the overall error analysis, a 2 (Case: lower, mixed) X 2 (Frequency: high, low) X 3 (Proportion: 25% mixed, 50% mixed, 75% mixed) repeated measures ANOVA showed a main effect of Case, $F(1, 117) = 33.83$, $MSe = .24$, $p < .001$, such that subjects made more errors with mixed- than lower-case words (see Figure 10). A main effect of Frequency, $F(1, 117) = 91.99$, $MSe = .16$, $p < .001$, showed that subjects made more errors with low- than high-frequency words. There was also a Case X Frequency interaction, $F(1, 117) = 22.49$, $MSe = .19$, $p < .001$, such that low-frequency words had more errors when written in mixed case than high-frequency words. This error data was in accordance with the naming latency data.

However, there was neither a main effect of Proportion, $F(2, 117) = 1.11$, $MSe = .34$, $p = .33$ nor a

Proportion X Case X Frequency interaction, $F(2, 117) = .23$, $MSe = .19$, $p = .79$. Errors were not significantly different across experiments: Subjects made similar numbers of errors with the core set stimuli no matter which proportion of mixed case was used in the experiment.

To summarize, the overall analysis using mean naming latency showed that manipulation of the proportions of mixed-case stimuli did not produce significantly different results. In addition, this was true for the analysis using median naming latency (see Appendix N). That is, presenting subjects with stimulus lists of varying proportions of mixed-case words (i.e., 25%, 50%, or 75%) did not differentially affect naming latencies. Therefore, subjects did not strategically manipulate phonological recoding in response to the proportion of mixed-case stimuli presented. They did not orient processing to the addressed route or to the assembly route after letter analysis, nor decide at output whether to produce the response generated by the addressed route or assembly route, nor modulate the rate at which information flowed through the word recognition system. Instead,

subjects had similar response trends in each experiment as listed by increasing naming latency: high-frequency lower-case words, low-frequency lower-case words, high-frequency mixed-case words, and low-frequency mixed-case words.

General Discussion

No Strategic Processing Using Mixed Case

Contrary to what was anticipated, the present research using mean naming latencies did not show any evidence for strategic processing when subjects were presented with varying proportions of mixed-case stimuli. In contrast to Brown et al. (1992), who found main effects with case and frequency, Experiment 1 showed interactive effects using 25% mixed-case and 75% lower-case words. Experiment 2 successfully replicated Besner and McCann's (1987) case-by-frequency interaction where subjects were presented with 50% mixed-case and 50% lower-case stimuli. Though a nonsignificant case by frequency interaction occurred when subjects were presented with 75% mixed case in Experiment 3, the overall analysis showed no differences in naming latency across the experiments. In addition, the overall analysis using median naming

latencies also showed no differences across the three experiments (refer to Appendices F, I, and L), which provides more evidence that subjects did not use strategic processing. Therefore, the word recognition system did not use different strategies in response to the presentation of 25%, 50%, or 75% mixed-case items. Thus, all exposures to mixed case stimuli should result in case by frequency interactions when mean naming latencies are analyzed⁵.

According to the dual-route model, because additive effects did not occur between case and frequency using mean naming latencies, the interactive results can be explained using either both the addressed and assembly routes or solely the addressed route. The assembly route alone cannot account for interactive effects; as previously stated, the use of this route would have produced additive effects between case and frequency.

Interactions between case and frequency can be explained by the use of both routes of the dual-route model. High-frequency words were most efficiently processed by the addressed route because addressed phonology is ordered by frequency and high-frequency

words have low thresholds (Besner & Johnston, 1989). The high-frequency mixed-case words took longer to process than high-frequency lower-case words because of the extra time required to decipher mixed-case words. Low-frequency words have higher thresholds and were thereby processed slower than their high-frequency counterparts. The addressed and assembly routes produce output for low-frequency words at about the same time; thus, output for some low-frequency words was produced by the addressed route, while output from other low-frequency words was produced by the assembly route. Because the low-frequency mixed-case words had been distorted they required more processing time than low-frequency lower-case words. The above combination would have produced the interaction between case and frequency.

The previously outlined single-route models can account for interactive effects between case and frequency. Because the dual-route model's addressed route is really a single-route model, the interaction could also have been accounted for by only this route. Explained in this way, all high- and low-frequency words written in lower or mixed case were processed by

the addressed route. Because they have low thresholds, high-frequency words were processed faster than low-frequency words. Mixed-case words took longer to process than lower-case words because of the extra decoding time required. Thus, the above conditions would also have caused a case by frequency interaction.

Because the present study found no evidence for phonological recoding using mixed- and lower-case high- and low-frequency words, one might infer that varying mixed case was not a strong enough manipulation to orient processing. However, past studies using varying stimulus list compositions have evidenced strategic processing with stimuli other than mixed case.

List Composition and Phonological Recoding

The idea of selective processing is a fairly recent notion. Monsell, Patterson, Graham, Hughes, and Milroy (1992) compared naming of exception words and nonwords presented in pure blocks to the naming of these stimuli presented in randomly mixed blocks. Monsell et al. reported that subjects made fewer regularization errors with exception words when they were presented in pure blocks. As previously stated, exception words are most accurately processed by the

addressed route, while nonwords could only be processed using the assembly route. If only exception words were expected, then only the addressed route was utilized. However, if both exception words and nonwords were presented then pronunciations were produced from the addressed route and the assembly route respectively. Thus, Monsell et al. (1992) suggest that readers strategically manipulated the use of the assembly route depending upon whether or not they anticipated the presence of exception words.

Baluch and Besner (1991) also support the concept that word recognition may be affected by strategic factors. Subjects whose native language was Persian were presented with randomly combined high- and low-frequency Persian words which were or were not intermixed with nonwords. According to the dual route model of word recognition, nonwords can only be processed by the assembly route. When nonwords were included in the stimulus list, Baluch and Besner reported that processing occurred primarily using the assembly route. However, when only words were presented, Baluch and Besner postulated that the stimuli was most efficiently processed using the

addressed route. List content strategically influenced the processing of stimuli by Persian subjects.

Paap and Noel (1991) also used varying list content in their second experiment. They presented one group of subjects with half exception words and half regular words, while the other group saw only exception words. The group which received only exception words had faster naming latencies than the group who were presented with both. Paap and Noel (1991) hypothesize that the assembly route requires more processing resources than the addressed route. When subjects were presented with half exception and half regular words, both the addressed and assembly routes processed each word. However, when presented with all exception words it was not beneficial to use the assembly route because of its frequent inaccuracy with exception words. Thus, in the all exception word condition, subjects used only the addressed route. Because there was no competition of responses (i.e., to decide which pronunciation, from the addressed route or the assembly route, should be used when pronunciations are different) average naming latency for this condition was faster than that of the combination condition (Paap & Noel, 1991). Subjects

strategically manipulated the use of the assembly route depending upon stimulus list content.

Pseudohomophone naming research has also provided support for the strategic factor notion. Herdman, LeFevre, and Greenham (in press) asked subjects to name pseudohomophones (e.g., phocks) and nonpseudohomophones (e.g., snocks) when the stimulus list consisted of nonwords or both nonwords and words. They divided subjects into groups of slow and fast responders. There was no relationship between frequency and pseudohomophone naming in either condition for fast responders. In contrast, for slow responders they found that high-frequency pseudohomophones were named faster than low-frequency pseudohomophones only when words were included in the stimulus lists. Additional support for strategic processing with pseudohomophones, though in the opposite direction, was provided by Greenham, Herdman, and LeFevre (1993). Subjects were asked to name pseudohomophones and nonpseudohomophones from stimulus lists of nonwords or both nonwords and words. Fast responders were unaffected by list composition; they showed pseudohomophone-frequency effects in both conditions. However, slow responder

showed pseudohomophone-frequency effects when they were presented with only nonwords. Even though this finding is opposite to that of Herdman et al. (in press), it provides further evidence for strategic processing.

As the aforementioned studies have indicated, strategic processing mediated by stimulus list composition (i.e., including pseudohomophones, exception words, etc.) is possible. The present study, as previously described in detail, did not find any evidence for strategic processing using differential proportions of mixed-case words. Thus, naming using mixed-case stimuli should result in case by frequency interactions when means are analyzed or additive effects between case and frequency when medians are analyzed.

Future Research

The present study had predicted, using the Logogen and Verification models, that additive effects between case and frequency could provide evidence for the deciphering of mixed case solely using encoding processes. The fact that there were only interactive effects between case and frequency using mean naming latency provides support that mixed case affects the

higher cognitive processes of word recognition models (e.g., accessing the mental lexicon), not the encoding stage. Therefore, mixed case, unlike stimulus quality, does not affect encoding.

This finding has potential implications for visual information processing research. One basic assumption of vision research is that distorted or degraded images are first "cleaned up" on the retina before an image is processed (Arbib & Hanson, 1987). However, the lack of additive effects with mixed case in the present experiment provides evidence that mixed-case items are not dealt with in the same manner as items which have been degraded by poor stimulus quality. The processing of mixed-case items occurs at higher levels of processing than the encoding stage. Thus, mixed-case words (e.g., hOuSe), though semantically identical to lower-case words (e.g., house) are different enough visually that they are not seen as the same word during the encoding process. Future research should be conducted in which subjects' performance on mixed-case words could be improved through training. Then, trained subjects could be tested to see if subjects "clean up" mixed-case words (resulting in additive

effects between case and frequency) or if they still decipher mixed-case words using higher cognitive processes (i.e., resulting in case by frequency interactions). If it is possible to train individuals to process mixed-case words using encoding processes, then this may provide further support for the notion of strategic processing.

However, training individuals to read mixed-case words more efficiently may require subjects to learn whole new "dictionaries" for mixed-case words. Masson (1986) suggests that mixed case training may only aid pronunciation latencies for the trained words and not for other words written in mixed-case format. Masson conducted a series of experiments using topographically-transformed (i.e., upside-down) words written in mixed-case format. He found that rote memorization, not learning, aided the identification of inverted words. Topographically-transformed words previously presented in one mixed-case form (i.e., bOaT) had facilitated later identification, while the same words presented in an opposite topographical form (i.e., BoAt) had not aided identification. The lack of generalizability in Masson's (1986) study, however, may

have resulted solely from the subjects' difficulty with inverted words, not with mixed-case words. Further study on training using mixed-case stimuli, like previously outlined, is needed.

Another area of future interest is how phonological and surface dyslexics process mixed-case words. Results of these studies could confirm the present study's findings and provide further support for the dual-route model of word recognition. As previously stated, phonological dyslexics have difficulty reading nonwords, but can read words that were known before acquiring dyslexia. They rely almost exclusively on the addressed route for word pronunciation. Surface dyslexics, in contrast, have difficulty reading exception words, while their reading of regular words and nonwords is not hindered. Surface dyslexics must process words using the assembly route because the addressed route has been damaged.

According to the dual route model, phonological dyslexics would have no problem identifying high- and low-frequency words of lower and mixed case because they have full access to the addressed route. A case by frequency interaction should result when using

phonological dyslexics as subjects. Surface dyslexics, on the other hand, would be much slower to process these words because they must rely exclusively on the assembly route. As stated previously, the use of only the assembly route should result in additive effects between case and frequency. Single-route models should not be able to accurately account for this predicted finding because of the lack of an assembly route. If these predictions with dyslexic subjects are confirmed, then this research may provide further support for the dual-route model.

Conclusion

Strategic orienting in the word recognition system was not induced by varying the proportion of mixed-case words in the stimulus lists. Although no evidence was found for strategic processing in the present study, the manipulation of processing by stimulus list composition is well documented. Future research with special populations (e.g., trained subjects, dyslexic patients) may provide support for the notion of strategic processing using case and frequency. This prospective research may also expand support for the dual-route model.

Notes

¹Error scores represent how closely the PDP model's pattern of activation for a word approximates the actual desired output for that particular word.

²Current PDP models do not predict reaction time; they can only predict error data.

³Responses were "wrong" if subjects pronounced the word incorrectly. Responses were "invalid" if subjects coughed, sneezed, or stuttered while attempting to pronounce the word.

⁴The first letter of each mixed-case word was always a lower-case letter in order to avoid confounding the word lists with stimuli that were similar to capitalized words.

⁵When analyzing median naming latency data, all exposures to mixed case stimuli should result in additive effects between case and frequency.

Table 1

Average Naming latencies and Standard Deviations (in Brackets) for Experiments 1, 2, 3 and Overall Analysis

	Lower Case	Mixed Case
Experiment 1		
HF	619 (90.4)	646 (96.6)
LF	642 (93.5)	706 (137.1)
Experiment 2		
HF	632 (73.0)	658 (86.0)
LF	674 (97.3)	735 (122.9)
Experiment 3		
HF	626 (68.6)	655 (82.8)
LF	662 (93.9)	706 (98.4)
Overall Analysis		
HF	626 (77.5)	653 (88.0)
LF	660 (95.0)	716 (120.3)

HF = High Frequency words, LF = Low Frequency words

Table 2

Average Per Cent Errors and Standard Deviations (in Brackets) for Experiments 1, 2, 3 and Overall Analysis

	Lower Case	Mixed Case
Experiment 1		
HF	0.75 (2.67)	2.25 (4.80)
LF	2.25 (4.23)	7.25 (6.79)
Experiment 2		
HF	1.25 (3.35)	1.75 (3.85)
LF	2.75 (5.54)	7.75 (7.68)
Experiment 3		
HF	0.50 (2.21)	0.75 (2.67)
LF	2.50 (4.39)	6.00 (6.33)
Overall Analysis		
HF	0.83 (2.78)	1.58 (3.89)
LF	2.50 (4.72)	7.00 (6.93)

HF = High Frequency words, LF = Low Frequency words

Table 3

Mean and Median Errors for Experiments 1, 2, 3

	HL	HM	LL	LM
<hr/>				
Experiment 1				
Means	675	656	715	852
Medians	675	602	633	756
Experiment 2				
Means	631	827	815	751
Medians	605	785	844	721
Experiment 3				
Means	670	588	800	734
Medians	670	540	740	644

HL = High-Frequency Lower-Case Words

HM = High-Frequency Mixed-Case Words

LL = Low-Frequency Lower-Case Words

LM = Low-Frequency Mixed-Case Words

Figure 1. Conceptualization of how case and frequency interact using Morton's (1969) Logogen model.

2. 11. 11. 11. 11.

Figure 2. A Dual-Route Model of word recognition
adapted from Besner and Johnston (1989).

Figure 3. Average naming latencies (in milliseconds)
for Experiment 1.

Figure 4. Average errors (in percentage) for
Experiment 1.

Figure 5. Average naming latencies (in milliseconds)
for Experiment 2.

Figure 6. Average errors (in percentage) for
Experiment 2.

Figure 7. Average naming latencies (in milliseconds)
for Experiment 3.

Figure 8. Average errors (in percentage) for
Experiment 3.

Figure 9. Average naming latencies (in milliseconds)
for the overall analysis.

Figure 10. Average errors (in percentage) for the overall analysis.

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Appendix A
Complete Word List Matched on Bigram Frequency

LOW FREQUENCY

<u>Word</u>	<u>Freq</u>	<u>Bigram Freq</u>
chunk	1	34
weed	1	129
carve	3	45
dusk	9	32
clam	3	13
marsh	4	45
sign	11	28
brash	1	40
plank	7	39
greed	3	60
wink	7	132
pump	11	7
doom	3	130
beam	21	84
deed	8	7
sank	18	76
moss	9	74
frog	3	91
shred	3	60
sour	3	99
tint	1	63
cork	9	70
sack	8	103
dime	10	94
pan	16	75
warn	11	52
gland	9	36
rake	11	73
shed	11	34
zinc	10	29
tune	10	26
quake	2	12
dig	10	36
bud	9	95
wart	11	54
lame	2	120
meek	10	74
fold	7	41
waist	11	37
slick	7	48
blot	6	15
pest	4	86

HIGH FREQUENCY

<u>Word</u>	<u>Freq</u>	<u>Bigram Freq</u>
chair	66	47
while	680	133
short	212	51
show	287	40
club	145	9
group	390	55
date	103	38
place	571	53
block	66	32
dark	185	44
more	2216	159
page	66	18
week	275	120
best	351	122
stop	120	13
soon	199	91
fine	161	70
cost	229	114
door	312	82
made	1122	92
great	665	63
wait	94	64
dust	70	102
main	119	89
ran	134	75
park	94	45
press	127	43
foot	70	71
hope	178	30
neck	81	37
rise	102	26
judge	77	12
new	1635	48
fear	127	85
rich	74	44
east	183	124
wrong	129	73
speak	110	41
dance	90	38
sharp	72	50
rule	73	20
test	119	95

peel	3	65	pool	111	58
fake	10	81	back	967	89
smear	2	27	serve	107	22
bang	7	76	lack	110	79
float	1	28	drive	105	33
log	11	9	law	299	10
trout	4	77	close	234	77
wipe	10	110	wish	110	109
cave	9	160	wide	125	126
brink	3	69	chief	68	68
gout	2	54	poor	113	61
tong	1	64	know	683	63
shove	2	51	space	184	45
lance	3	44	clean	70	43
hare	1	162	home	547	127
wig	1	12	box	70	12
crisp	8	20	piece	129	25
lamb	7	45	role	104	40
rust	10	175	boat	72	189
inn	9	1	oil	93	1
muse	4	62	loss	86	61
flung	14	62	learn	84	67
tomb	11	57	king	88	57
tide	11	43	walk	100	44
gum	14	5	key	88	5
creep	10	31	teeth	103	32
fade	2	50	none	108	45
vain	10	50	sent	125	42
rash	1	46	farm	125	46
knit	10	25	note	127	24
glue	8	12	stay	113	19
rang	21	62	pain	88	62
tin	12	5	eye	122	4
whine	4	138	would	2714	170
blush	2	18	scene	106	15
crawl	11	35	plant	125	41

Appendix B

Core Word List Matched on Onset Sounds*

LOW FREQUENCY

Word	Freq	Bigram	Freq
1. chunk	1	34	
2. weed	1	129	
3. carve	3	45	
4. dusk	9	32	
5. clam	3	13	
6. marsh	4	45	
7. sign	11	28	
8. brash	1	40	
9. plank	7	39	
10. greed	3	60	
11. wink	7	132	
12. pump	11	7	
13. doom	3	130	
14. beam	21	84	
15. deed	8	7	
16. sank	18	76	
17. mcss	9	74	
18. frog	3	91	
19. shred	3	60	
20. sour	3	99	

HIGH FREQUENCY

Word	Freq	Bigram	Freq
1. chair	66	47	
2. while	680	133	
3. cost	229	114	
4. dark	185	44	
5. club	145	9	
6. made	1122	92	
7. slow	287	40	
8. block	66	32	
9. place	571	53	
10. group	390	55	
11. week	275	120	
12. page	66	18	
13. door	312	82	
14. best	351	122	
15. date	103	38	
16. stop	120	13	
17. more	2216	159	
18. fine	161	70	
19. short	212	51	
20. soon	199	91	

* After being divided into high- and low- frequency words, the core words were matched as closely as possible on onset phoneme.

Appendix C

Format of the Core Word List in Sets 1 and 2

SET 1:

chunk	wInK	group	bEst
weed	pUmP	cost	wEeK
carve	dOoM	place	pAgE
dusk	bEaM	club	sOoN
clam	dEeD	dark	sToP
marsh	sAnK	chair	sHoRt
sign	mOsS	while	mAdE
brash	fRoG	block	fInE
plank	sHrEd	show	dAtE
greed	sOuR	more	dOoR

SET 2:

cHuNk	wink	gRoUp	best
wEeD	pump	cOsT	week
cArVe	doom	pLaCe	page
dUsK	beam	cLuB	soon
cLaM	deed	dArK	stop
mArSh	sank	cHaIr	short
sIgN	moss	wHiLe	made
bRaSh	frog	bLoCk	fine
pLaNk	shred	sHoW	date
gReEd	sour	mOrE	door

Appendix D
Case by Frequency by Order by Set
in Experiment 1 (25% Mixed Case)

ANOVA Table**Tests of Significance**

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1452781.23	36	40355.03		
CONSTANT	68329306.34	1	68329306	1693.20	.001***
SET	33347.74	1	33347.74	.83	.369
ORDER	5432.40	1	5432.40	.13	.716
SET BY ORDER	64044.02	1	64044.02	1.59	.216
WITHIN CELLS	55849.52	36	1551.38		
CASE	82805.45	1	82805.45	53.38	.001***
SET BY CASE	26653.98	1	26653.98	17.18	.001***
ORDER BY CASE	236.92	1	236.92	.15	.698
SET BY ORDER BY CASE	188.57	1	188.57	.12	.729
WITHIN CELLS	43484.25	36	1207.90		
FREQUENCY	70086.18	1	70086.18	58.02	.001***
SET BY FREQUENCY	9028.52	1	9028.52	7.47	.010**
ORDER BY FREQUENCY	2344.73	1	2344.73	1.94	.172
SET BY ORDER BY FREQUENCY	146.11	1	146.11	.12	.730
WITHIN CELLS	38456.57	36	1068.24		
CASE BY FREQUENCY	13489.09	1	13489.09	12.63	.001***
SET BY CASE BY FREQUENCY	24430.78	1	24430.78	22.87	.001***
ORDER BY CASE BY FREQUENCY	194.26	1	194.26	.18	.672
SET BY ORDER BY CASE BY FREQUENCY	16.71	1	16.71	.02	.901

** p < .01

*** p < .001

Average Naming latencies and Standard Deviations (in Brackets)

	HL	HM	LL	LM
<hr/>				
Set 1				
Order 1	625 (48.8)	650 (47.4)	667 (57.3)	672 (49.1)
Order 2	600 (87.2)	628 (96.1)	625 (95.1)	646 (98.9)
<hr/>				
Totals	613 (68.0)	639 (71.8)	646 (76.2)	659 (74.0)

Set 2				
Order 1	594 (50.0)	624 (71.3)	619 (62.7)	732 (93.9)
Order 2	657 (142.4)	684 (146.2)	659 (140.4)	776 (221.5)
<hr/>				
Totals	626 (96.2)	654 (108.8)	639 (101.1)	754 (157.7)

HL = High-Frequency Lower-Case Words

HM = High-Frequency Mixed-Case Words

LL = Low-Frequency Lower-Case Words

LM = Low-Frequency Mixed-Case Words

Appendix E
Experiment 1 (25% Mixed Case) Analysis
Using Mean Naming Latencies

ANOVA Table

Tests of Significance						
Source of Variation	SS	DF	MS	F	Sig of F	
WITHIN CELLS	1555605.39	39	39887.32			
CONSTANT	68329306.34	1	58329306	1713.06		.001***
WITHIN CELLS	82929.00	39	2126.38			
CASE	82805.45	1	82805.45	38.94		.001***
WITHIN CELLS	55003.61	39	890.65			
FREQUENCY	70086.18	1	70086.18	49.69		.001***
WITHIN CELLS	63098.32	39	1617.91			
CASE BY FREQUENCY	13489.09	1	13489.09	8.34		.006**

Average Naming latencies and Standard Deviations (in Brackets)

	High Frequency	Low Frequency
Lower Case	619 (90.4)	642 (93.5)
Mixed Case	646 (96.6)	706 (137.1)

** p < .01
 *** p < .001

Appendix F
Experiment 1 (25% Mixed Case) Analysis
Using Median Naming Latencies

ANOVA Table

Tests of Significance					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1489613.90	39	38195.23		
CONSTANT	65004601.60	1	65004602	1701.90	.001***
WITHIN CELLS	104527.00	39	2680.18		
CASE	52562.50	1	52562.50	19.61	.001***
WITHIN CELLS	34735.27	39	890.65		
FREQUENCY	39501.23	1	39501.23	44.35	.001***
WITHIN CELLS	37563.48	39	963.17		
CASE BY FREQUENCY	2387.03	1	2387.03	2.48	.124

Average Naming latencies and Standard Deviations (in Brackets)

	High Frequency	Low Frequency
Lower Case	607 (80.7)	631 (83.3)
Mixed Case	636 (100.4)	675 (138.5)

*** p < .001

Appendix G
Case by Frequency by Order by Set
in Experiment 2 (50% Mixed Case)

2 of/de 2

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
1963-A REFERENCE MATERIAL 1010A
U.S. GOVERNMENT PRINTING OFFICE: 1963

ANOVA Table

Tests of Significance
Source of Variation
SS**DF****MS****F****Sig of F**

WITHIN CELLS	1104705.10	36	30686.25		
CONSTANT	72868818.29	1	72868818	2374.64	.001***
SET	73004.20	1	73004.20	2.38	.132
ORDER	28013.21	1	28013.21	.91	.346
SET BY ORDER	1535.74	1	1535.74	.05	.824
WITHIN CELLS	49091.05	36	1363.64		
CASE	74446.71	1	74446.71	54.59	.001***
SET BY CASE	6963.00	1	6963.00	5.11	.030*
ORDER BY CASE	1026.68	1	1026.68	.75	.391
SET BY ORDER BY CASE	5770.80	1	5770.80	4.23	.047*
WITHIN CELLS	99020.89	36	2750.58		
FREQUENCY	141782.59	1	141782.59	51.55	.001***
SET BY FREQUENCY	4140.21	1	4140.21	1.51	.228
ORDER BY FREQUENCY	4238.45	1	4238.45	1.54	.223
SET BY ORDER BY FREQUENCY	403.54	1	403.54	.15	.704
WITHIN CELLS	44565.82	36	1237.94		
CASE BY FREQUENCY	12889.90	1	12889.90	10.41	.003**
SET BY CASE BY FREQUENCY	24987.50	1	24987.50	20.18	.001***
ORDER BY CASE BY FREQUENCY	2789.73	1	2789.73	2.25	.142
SET BY ORDER BY CASE BY FREQUENCY	4373.32	1	4373.32	3.53	.068

* p < .05

** p < .01

*** p < .001

Average Naming latencies and Standard Deviations (in Brackets)

	HL	HM	LL	LM
<u>Set 1</u>				
Order 1	647 (90.0)	683 (109.4)	678 (104.2)	737 (139.2)
Order 2	659 (83.8)	697 (85.1)	741 (93.2)	728 (105.7)
Totals	653 (86.9)	690 (97.3)	710 (98.7)	733 (122.5)
<u>Set 2</u>				
Order 1	605 (56.6)	613 (51.5)	620 (72.8)	710 (76.5)
Order 2	619 (52.2)	637 (62.7)	657 (87.2)	766 (165.3)
Totals	612 (54.4)	625 (62.1)	639 (80.0)	738 (120.9)

HL = High-Frequency Lower-Case Words

HM = High-Frequency Mixed-Case Words

LL = Low-Frequency Lower-Case Words

LM = Low-Frequency Mixed-Case Words

Appendix H
Experiment 2 (50% Mixed Case) Analysis
Using Mean Naming Latencies

ANOVA Table

Tests of Significance						
Source of Variation	SS	DF	MS	F	Sig of F	
WITHIN CELLS	1207258.25	39	30955.34			
CONSTANT	72868818.29	1	72868818	2354.00		.001***
WITHIN CELLS	62851.53	39	1611.58			
CASE	74446.71	1	74446.71	46.19		.001***
WITHIN CELLS	107803.09	39	2764.18			
FREQUENCY	141782.59	1	141782.59	51.29		.001***
WITHIN CELLS	76716.38	39	1967.09			
CASE BY FREQUENCY	12889.90	1	12889.90	6.55		.014*

Average Naming latencies and Standard Deviations (in Brackets)

	High Frequency	Low Frequency
Lower Case	632 (73.1)	674 (97.3)
Mixed Case	658 (85.9)	735 (122.9)

* p < .05

*** p < .001

Appendix I
Experiment 2 (50% Mixed Case) Analysis
Using Median Naming Latencies

ANOVA TableTests of Significance

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1048599.50	39	26887.17		
CONSTANT	68985022.50	1	68985022	2565.72	.001***
WITHIN CELLS	27685.60	39	709.89		
CASE	35046.40	1	35046.40	49.37	.001***
WITHIN CELLS	35427.77	39	908.40		
FREQUENCY	73702.23	1	73702.23	81.13	.001***
WITHIN CELLS	48743.98	39	1249.85		
CASE BY FREQUENCY	1550.02	1	1550.02	1.24	.272

Average Naming latencies and Standard Deviations (in Brackets)

	High Frequency	Low Frequency
Lower Case	623 (74.7)	660 (91.1)
Mixed Case	647 (80.3)	696 (97.1)

*** p < .001

Appendix J
Case by Frequency by Order by Set
in Experiment 3 (75% Mixed Case)

ANOVA Table
Tests of Significance
Source of Variation

	SS	DF	MS	F	Sig of F
WITHIN CELLS	974449.23	36	27068.03		
CONSTANT	70115597.92	1	70115597	2590.35	.001***
SET	48219.15	1	48219.15	1.78	.190
ORDER	30046.84	1	30046.84	1.11	.299
SET BY ORDER	1142.76	1	1142.76	.04	.838
WITHIN CELLS	35655.38	36	990.43		
CASE	52991.11	1	52991.11	53.50	.001***
SET BY CASE	1159.93	1	1159.93	1.17	.286
ORDER BY CASE	6674.47	1	6674.47	6.74	.014*
SET BY ORDER BY CASE	3541.92	1	3541.92	3.58	.067
WITHIN CELLS	32659.48	36	907.21		
FREQUENCY	76869.05	1	76869.05	84.73	.001***
SET BY FREQUENCY	260.10	1	260.10	.29	.596
ORDER BY FREQUENCY	2221.59	1	2221.59	2.45	.126
SET BY ORDER BY FREQUENCY	6.40	1	6.40	.01	.934
WITHIN CELLS	21075.80	36	585.44		
CASE BY FREQUENCY	2150.62	1	2150.62	3.67	.063
SET BY CASE BY FREQUENCY	10588.52	1	10588.52	18.09	.001***
ORDER BY CASE BY FREQUENCY	1810.37	1	1810.37	3.09	.087
SET BY ORDER BY CASE BY FREQUENCY	2316.49	1	2316.49	3.96	.054

* p < .05

*** p < .001

Average Naming latencies and Standard Deviations (in Brackets)

	HL	HM	LL	LM
<u>Set 1</u>				
Order 1	647 (76.8)	695 (114.9)	691 (120.3)	750 (142.2)
Order 2	630 (85.7)	662 (88.8)	687 (111.8)	672 (93.0)
Totals	639 (81.3)	679 (101.9)	689 (116.1)	711 (117.6)
<u>Set 2</u>				
Order 1	618 (47.7)	640 (48.5)	648 (58.0)	716 (69.9)
Order 2	607 (62.4)	621 (53.7)	622 (65.0)	685 (64.8)
Totals	613 (55.1)	631 (51.1)	635 (61.5)	701 (67.4)

HL = High-Frequency Lower-Case Words

HM = High-Frequency Mixed-Case Words

LL = Low-Frequency Lower-Case Words

LM = Low-Frequency Mixed-Case Words

Appendix K
Experiment 3 (75% Mixed Case) Analysis
Using Mean Naming Latencies

ANOVA Table

Tests of Significance					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1053857.98	39	27022.00		
CONSTANT	70115597.92	1	70115598	2594.76	.001***
WITHIN CELLS	47031.70	39	1205.94		
CASE	52991.11	1	52991.11	43.94	.001***
WITHIN CELLS	35147.57	39	901.22		
FREQUENCY	76869.05	1	76869.05	85.29	.001***
WITHIN CELLS	35791.18	39	917.72		
CASE BY FREQUENCY	2150.62	1	2150.62	2.34	.134

Average Naming latencies and Standard Deviations (in Brackets)

	High Frequency	Low Frequency
Lower Case	626 (68.6)	662 (93.9)
Mixed Case	655 (82.8)	706 (98.4)

*** p < .001

Appendix L
Experiment 3 (75% Mixed Case) Analysis
Using Median Naming Latencies

ANOVA TableTests of Significance

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	946116.40	39	24259.39		
CONSTANT	66662076.10	1	66662076	2747.89	.001***
WITHIN CELLS	26671.90	39	683.89		
CASE	21529.60	1	21529.60	31.48	.001***
WITHIN CELLS	27049.27	39	693.57		
FREQUENCY	46444.22	1	46444.22	66.96	.001***
WITHIN CELLS	36815.27	39	943.98		
CASE BY FREQUENCY	133.23	1	133.23	.14	.709

Average Naming latencies and Standard Deviations (in Brackets)

	High Frequency	Low Frequency
Lower Case	618 (72.2)	650 (89.6)
Mixed Case	639 (78.7)	675 (84.6)

*** p < .001

Appendix M

Overall Analysis Using Mean Naming Latencies

ANOVA Table

Tests of Significance
Source of Variation
SS DF MS F Sig of F

WITHIN CELLS	3816721.63	117	32621.55		
CONSTANT	211276714	1	211276714	6476.60	.001***
PROPORTION	37008.45	2	18504.22	.57	.569
<hr/>					
WITHIN CELLS	192812.24	117	1647.97		
CASE	208458.34	1	208458.34	126.49	.001***
PROPORTION BY CASE	1784.92	2	892.46	.54	.583
<hr/>					
WITHIN CELLS	197954.28	117	1691.92		
FREQUENCY	281233.02	1	281233.02	166.22	.001***
PROPORTION BY FREQUENCY	7504.80	2	3752.40	2.22	.113
<hr/>					
WITHIN CELLS	175605.88	117	1500.90		
CASE BY FREQUENCY	25401.38	1	25401.38	16.92	.001***
PROPORTION BY CASE BY FREQUENCY	3128.22	2	1564.11	1.04	.356

Average Naming latencies and Standard Deviations (in Brackets)

	High Frequency	Low Frequency
<hr/>		
L. er Case	626 (77.5)	660 (95.0)
Mixed Case	653 (88.0)	716 (120.3)

*** p < .001

Appendix N

Overall Analysis Using Median Naming Latencies

ANOVA TableTests of Significance

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	3484329.80	117	29780.60		
CONSTANT	200621880	1	200621880	6736.66	.001***
PROPORTION	29820.20	2	14910.10	.50	.607
WITHIN CELLS	158884.50	117	1357.99		
CASE	105732.03	1	105732.03	77.86	.001***
PROPORTION BY CASE	3406.47	2	1703.23	1.25	.289
WITHIN CELLS	97212.33	117	830.87		
FREQUENCY	156746.41	1	156746.41	188.65	.001***
PROPORTION BY FREQUENCY	2901.27	2	1450.63	1.75	.179
WITHIN CELLS	123122.73	117	1052.33		
CASE BY FREQUENCY	3318.01	1	3318.01	3.15	.078
PROPORTION BY CASE BY FREQUENCY	752.27	2	376.13	.36	.700

Average Naming latencies and Standard Deviations (in Brackets)

	High Frequency	Low Frequency
Lower Case	616 (75.6)	647 (88.1)
Mixed Case	641 (86.4)	682 (108.7)

*** p < .001

END

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