



Holistic and Analytical Processing: Reaction Time in Recognizing High- and Low-Frequency Words

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Abstract

Investigating cognitive processes has taken various routes in word recognition studies; however, in recent years, considerable attention has been paid to two major word-recognition mechanisms: holistic and analytical processing. Taking these two mechanisms as complementary solutions, this study examined the case-alteration effect as a variable in word recognition. To this end, 80 English words, some of high-frequency and some low-frequency, were selected as stimuli. Non-words were generated as control stimuli. All were presented in lowercase, uppercase, and mixed-case. Results show that participants used the holistic mechanism to recognize high- and low-frequency words and analytical processing to recognize low-frequency non-words. Both high- and low-frequency words were sensitive to case alteration. Results are compatible with the dual-route model of word recognition.

Key words: Analytical processing, holistic processing, lexical processing

Introduction

Word recognition is believed to be the initial stage and foundation of any reading activity on which later processes depend. Word recognition encompasses accessing information stored in memory. For instance, the visual word recognition process involves receiving information about the spoken form and, subsequently, the meaning of the word through its printed form. False or inefficient word recognition may result in ineffective reading.

The oldest inquiry in relationship to word recognition processes is believed to have been made by Cattell (1886). In modern times, word recognition research has attracted the attention of psycholinguists because words are minimal units having various modes of analysis, including orthography, phonology, semantics, and syntax, and involving various processing, such as automatic vs. attentional. Therefore, despite the importance of individuals' higher-level processing of clauses, sentences, and paragraphs, many studies have focused on the processing of words as basic units of language.

Language teachers try to improve the reading ability of their learners. To this end, in alphabetic languages, visual word recognition has become an area of investigation for psycholinguists. One dilemma has been whether word formation can

be based solely on abstract letter units, known as serial processing, or also on other sources, such as word global shape, known as parallel processing. This is an important issue with implications for teaching reading and spelling (Besner, 1983).

Despite previous studies showing that the word recognition and identification process uses word shape as its starting point (Cattell, 1886), many currently believe that words initially are constructed based on component letters (see analytical models, such as the search model, Forster, 1976; multiple read-out model, Grainger & Jacobs, 1996; interactive-activation model, McClelland & Rumelhart, 1981; activation-verification model, Paap, Newsome, McDonald, & Schvaneveldt, 1982).

An important issue related to both automaticity in decoding and the discussion of serial-parallel processing in word recognition is the size of the perceptual unit used by the reader. It is believed that by being more adept at decoding and reaching automaticity in performing the task, one increases the size of the unit of perception. Hence, it can be inferred that beginner and less-skillful readers who have not achieved automaticity have smaller units of perception and use serial processing in recognizing words. In comparison, skilled readers, who can decode automatically, have larger perceptual units and take advantage of parallel processing. This hypothesis is supported by several studies, including that of Samuels, LaBerge and Bremer (1978), which indicated that if one becomes more adept at decoding and more automatic at task performance, one's perception of unit size will expand. Therefore, it has been accepted that novice readers who are non-automatic at decoding will have smaller units of perception and serial processing, and comparatively skilled readers, who are more automatic at decoding, will have larger perceptual units and parallel processing.

Acceptance of the assumption that the word is the basic element in language processing and recognition has stimulated a key question about human brain function: How is previously stored information regarding an input pattern organized and retrieved? As Foster (1992) noted, because words can make structured patterns, lexical processing is well-suited to empirical and theoretical investigations.

Based on particular experiments, three main models of word processing have been proposed and developed. In general, one could not say that any model is complete by itself and explains the whole word-recognition process. To clarify, each model will be reviewed briefly.

Word Shape Model

The word shape model states that words are recognized as complete units. It is the oldest model of word recognition, and it considers words as unique patterns instead of the sum of their letter parts. According to some scholars, patterns of ascending, descending, and neutral characters are the information used for word recognition. Some word patterns are identifiable as an image because the reader has seen the pattern many times before. Cattell (1886) found an interesting effect, now called the word superiority effect. He exposed participants to letter and word stimuli for short periods (5–10 m) and found that subjects recognized words more accurately than letters. He concluded that participants more accurately recognized words after short exposure because words are units and their recognition is easier.

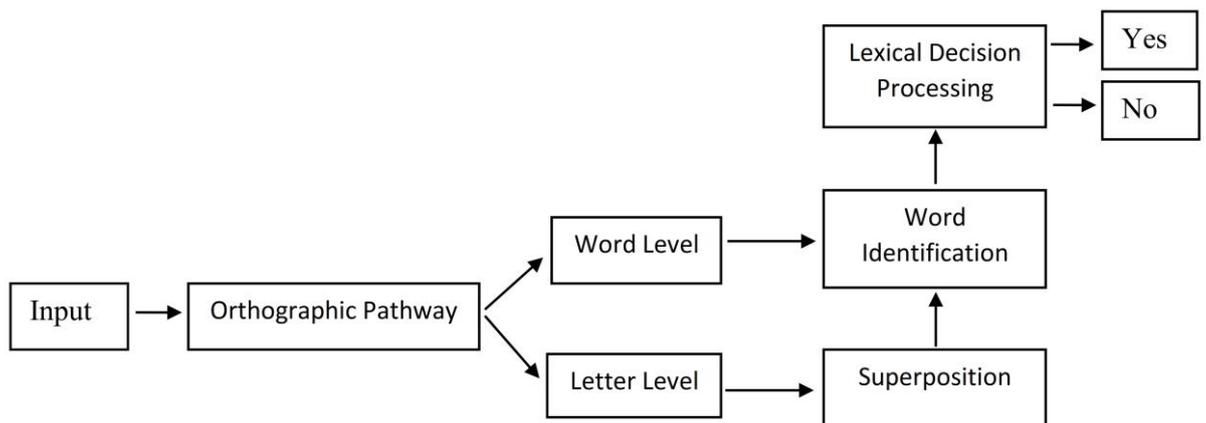


Figure 1. Processes involved in the lexical decision task, according to the holistically biased hybrid model (adapted from Allen, Wallace, & Weber, 1995, p. 3)

The second significant finding of the word shape model is that lowercase text can be read faster than uppercase text. Woodworth (1938) was the first investigator to note this, but it is supported by later studies, including those by Smith (1969) and Fisher (1975).

Perhaps the most inclusive, holistic word-recognition model is the holistically biased hybrid model proposed by Allen et al. (1995), which is composed of two levels in which words are constructed through either letter-level codes, such as analytical models, or word-level codes, in which the fundamental unit of analysis is an entire word's spatial-frequency pattern. In their models, Allen and Emerson (1991) and Allen et al. (1995) noted that high-frequency words could be determined quickly by the word-level route if familiarity and format were kept constant, whereas, material in an unfamiliar format led to use of the letter-level route. Hence, the word-level route is not capable of being used to accept or reject words or non-words in a lexical-decision activity. See Figure 1.

Serial Processing Model

Currently, the assumption that words are made of series of letters is supported by a group of studies and scholars using analytical models (including the search model, Forster, 1976; the multiple read-out models, Grainger & Jacobs, 1996). Common to these models is the idea that information about visual form probably is lost early in the process of word recognition through separating the special visual form of a letter from the process. Other scholars believe in the significant role of supra-letter features, such as word shape, in visual word recognition (Allen et al., 1995; Healy & Cunningham, 1992; Healy, Oliver, & McNamara, 1987). The two main serially based word-recognition models are as follows.

Dual-route Model

The dual-route model (DRC) is proposed mainly by Coltheart, Rastle, Perry, Langdon, & Zeigler (2001). In terms of processing polysyllabic word, DRC postulates two processes, holistic and analytical, and assumes that these two processes work in parallel, meaning that learners use two routes in parallel to process words and non-words, with neither route preceding or following the other. In addition, the DRC

model predicts use of the holistic, or lexical, route for high-frequency words and use of the analytical, or non-lexical, route for low-frequency words and non-words. The DRC model assumes that if more words are encountered, the lexical route will be used, and if more non-words are encountered, the non-lexical route will be used.

Interactive Activation Model

According to the interactive activation (IA) model, words are manifested as a set of orthographic features that are contained within their letters. When a string of letters is presented, representations of words orthographically similar to input are activated. Lateral inhibition between word units that share features results in their inhibition; hence, the strongest overcomes its competitors. An important aspect of the IA model is its letter position coding scheme, in which the process for every letter takes place independently within its own channel, and letters are tagged to their position in the perceived word. In the IA model, the word *judge* is very similar to the transposed-letter, non-word *jugde* and to the non-word *junpe*, all of which have three out of five letters in common. However, intuition informs readers that *judge* is more similar to the non-word *jugde* than to the non-word *junpe*.

Parallel Letter Recognition Model

The parallel letter recognition model has attracted the attention of most psychologists and is believed to be the most comprehensive model, the main idea of which is that there is simultaneous recognition of letters within a word and that in this recognition process, letter shape and position information is used to conceive the word. For instance, the reader observes the word *work*, and operates on letters simultaneously. The first step in processing is recognition of the features of individual letters, such as horizontal lines, diagonal lines, and curves. After that, these recognized features are sent to the letter-detector level, on which every letter in the word is determined simultaneously with other letters from similar words. In the final step, the activation made in the letter level is fed to and analyzed in word-detector level.

Significance of the Study

This study aims to identify the global process involved in word recognition, including identifying explanations for the nature of word processing in second languages and determining an appropriate approach to teaching vocabulary. Research results could provide solutions for both lexical processing models and teaching vocabulary.

Statement of the Problem and Research Questions

This study intends to investigate two main processes involved in lexical decisions. Particularly, it examines students' use of analytical/non-lexical or holistic/lexical routes in word recognition. To investigate the processes involved in lexical decisions, a case-alteration comparison was developed. To this end, the researchers formulated the following two questions.



RQ1: Are the same mechanisms used for high- and low-frequency words in lexical decision tasks by EFL learners?

RQ2: Do EFL learners use analytical or holistic processing in recognizing words and non-words?

Method

Participants

The 40 study participants were 23 male and 17 female university undergraduate students of English. Participants were adults from 22–27 years and students of English language teaching. All were all in their final year of the undergraduate program and were proficient students. The group was homogenous.

Materials

The study used 300 words and non-words as stimuli. Based on results of previous studies, which suggested that high- and low-frequency words yielded different results, both high- and low-frequency words were included in stimuli, 40 of each, including two-, three-, four-, and five-syllable words of each frequency type. One-syllable words were not included because they act differently and their inclusion would hamper results. The study used four types of stimuli: 1) lowercase words, for example, *student*; 2) uppercase of words, for example, *STUDENT*; 3) mixed-case words, for example, *sTuDeNT*; 4) non-words, which were used as control stimuli. Non-words were generated by inverting two letters of each stimulus, for example, *redcue* from *reduce*. Units generated by inverting high-frequency words are called high-frequency non-words, and those generated by inverting low-frequency words are called low-frequency non-words. In all, 80 English words in lowercase, 80 in uppercase, 80 in mixed case, and 60 non-words were used.

Procedures

Stimuli were displayed one at a time in lower-, upper- and mixed-cases in the center of a computer monitor using MRTS, software developed to measure reaction time. Participants were instructed to press “P” on the keyboard for “positive”, or word, stimuli and “W” for “negative”, or a non-word, stimuli. Reaction Time (RT) was measured in milliseconds from the onset of stimulus to when the participant pressed a key. The experiment was run in three sessions of approximately 20 minutes each. Each student acted individually under researcher supervision. The inter-trial interval was 1 second. Stimulus presentation was randomized, so high- and low-frequency words and non-words were presented randomly in 3 groups of 100 stimuli each.

Results

Case Alteration Data Analysis

Table 1 presents the mean RT for all participants in lexical decision tasks. High frequency, mixed-case words have the highest mean and high-frequency, lowercase words the lowest. As shown in Table 2, there are significant differences among RTs of participants in the three groups. The p-values of the t-test for comparing high-

frequency, uppercase, lowercase and mixed-case words are less than 0.05. As the mean of the RT for lowercase is less than that for uppercase and mixed-case words, it can be concluded that participants used holistic processing for high-frequency words. In other words, shape modification resulted in significant RT differences among groups.

Table 1. Mean reaction times of high-frequency words

Group	N	Mean	Std
High-frequency lowercase	40	1.106	0.147
High-frequency uppercase	40	1.332	0.218
High-frequency mixed-case	40	1.515	0.268

Table 2. Two-by-two comparison of mean reaction times (t-test) of high-frequency words

Pair	Std. Error Mean	t	df	Sig. (2-tailed)
Lowercase vs. upper case	0.039	-5.729	39	0.000
Uppercase vs. mixed case	0.037	-4.843	39	0.000
Lowercase vs. mixed case	0.038	-10.598	39	0.000

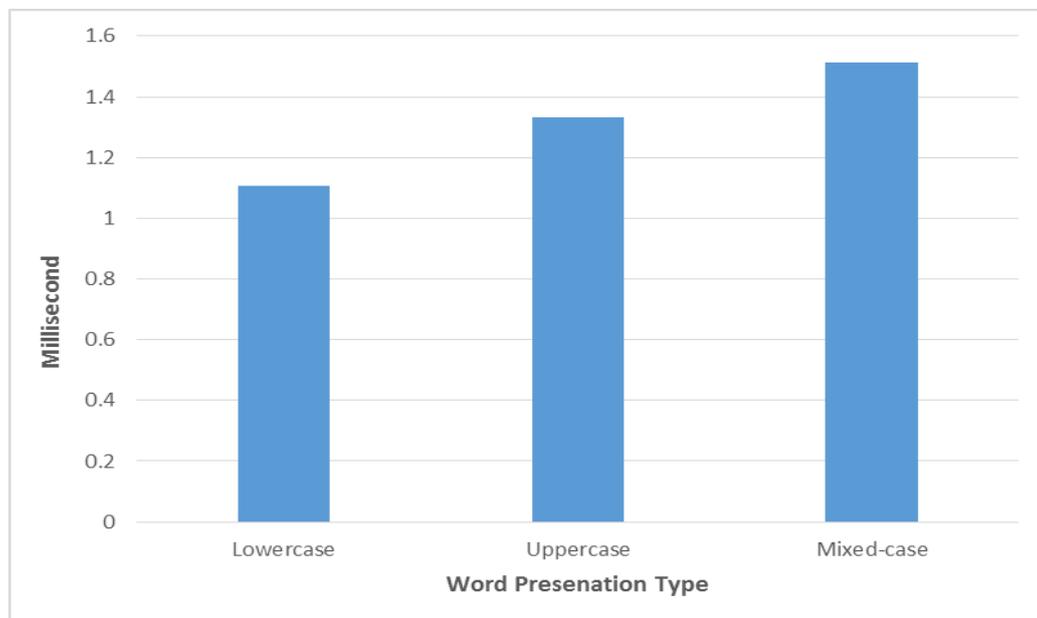


Figure 2. RT for high-frequency words in lowercase, uppercase, mixed-case

As is clear from Tables 1 and 2 and Figure 2, analysis of participants' RTs for all three types of case for high-frequency words shows that they did not apply the



analytical, or non-lexical, mechanism in word recognition, but used holistic processing, since they recognized the familiar, lowercase format more quickly than the unfamiliar, uppercase and mixed-case formats.

Table 3. Mean RTs of low-frequency words in three cases

Group	N	Mean	Std.
Low-frequency words in lowercase	40	1.353	0.256
Low-frequency words in uppercase	40	1.512	0.235
Low frequency words in mixed-case	40	1.757	0.296

Table 4. Two-by-two comparison of mean (t-test) reaction times for low-frequency words in three cases

Pair	Std. Error Mean	t	df	Sig. (2-tailed)
Lowercase vs. uppercase	0.031	-5.09	39	0.000
Uppercase vs. mixed-case	0.052	-4.61	39	0.000
Lowercase vs. mixed-case	0.054	-7.34	39	0.000

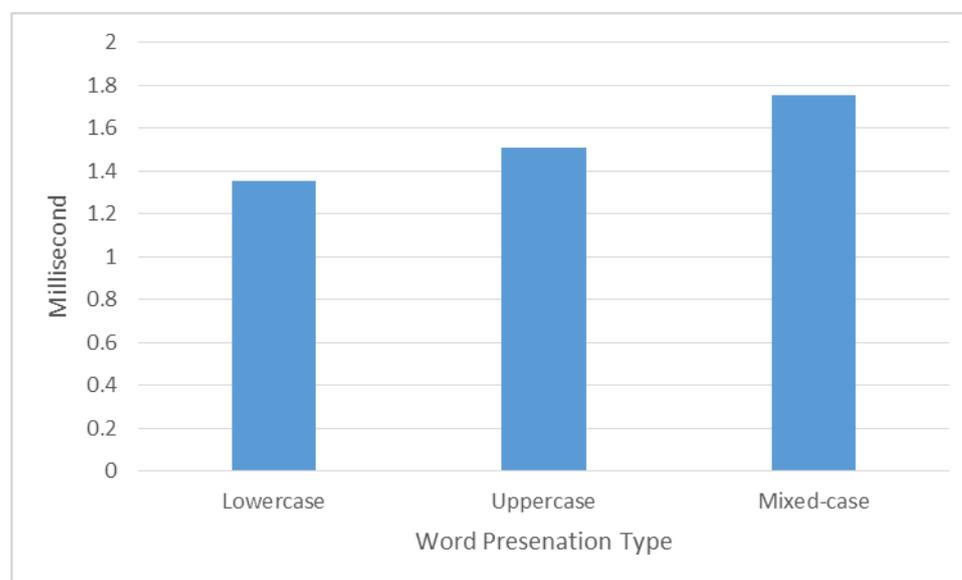


Figure 3. RT for low-frequency words in lowercase, uppercase, mixed-case

For low-frequency words, the same trend prevails. As familiarity of the stimuli decreases, RT increases. Based on comparison of means in Table 3 and Figure 3 and the significant p-value in Table 4, it can be concluded that participants preferred holistic processing for low-frequency word recognition. To better understand the problem, a follow-up comparison was made between words and non-words.

Word and Non-word Analysis

As mentioned, 60 non-words were created by inverting letters of English words, with 30 of these non-words related to high-frequency words and 30 to low-frequency words. Participants' RTs in terms of words and non-words were compared. Tables 5 and 6 present descriptive and statistical information regarding high-frequency words and non-words.

Table 5. Mean of RTs of high-frequency words and non-words

Group	N	Mean
High-frequency words	40	1.05
High-frequency non-words	40	1.08

Table 6. Two-by-two comparison of means (t-test) of high-frequency words and non-words

Pair	Std. Error Mean	t	df	Sig. (2-tailed)
Words vs. non-words	0.36	-0.769	39	0.447

Results show no significant difference in RT between high-frequency words and non-words. In addition, all non-words were recognized as words by participants. As the sequence of letters in words and non-words differed, by applying analytical processing, participants could detect non-words. So, it can be concluded that participants applied holistic processing to recognize non-words.

The same analyses were done for low-frequency words and non-words, and results show significant differences between word and non-word RTs in the low-frequency group. It took less time to reject non-words than to recognize words. Tables 7 and 8 present descriptive and inferential statistics regarding low-frequency words and non-words. Figure 4 summarizes the same statistics.

Table 7. Mean of RTs of low frequency words and non-words

Group	N	Mean
Low-frequency words	40	1.31
Low-frequency non-words	40	1.15

Table 8. Two-by-two comparison of means (t-test) of low-frequency words and non-words

Pair	Std. Error Mean	t	df	Sig. (2-tailed)
Words vs. non-words	0.30	5.278	39	0.000

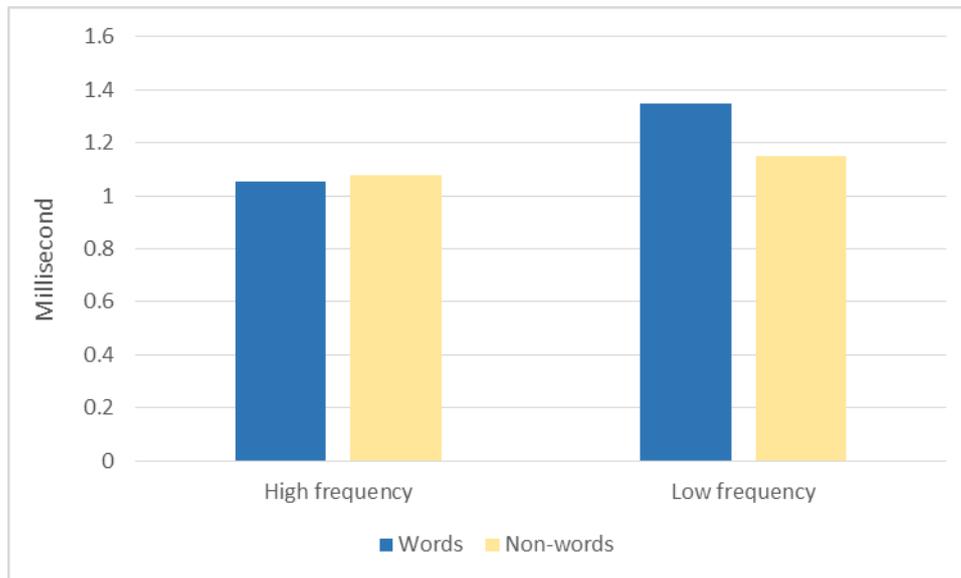


Figure 4. RT for high-frequency and low-frequency words and non-words

Discussion and Conclusion

The purpose of this experiment was to investigate holistic and analytical processing in word recognition. Three word formats were presented: lowercase, uppercase, and mixed-case. The hypothesis behind this experiment is that if stimuli are presented in a similar format with minimal differences in word-shape information or minimal distortion of the visual pattern, participants will not depend on word information or visual familiarity for recognition relative to standard lowercase print, which may affect high- and low-frequency words differently.

Results reveal significant differences among the three cases used to present stimuli. These findings are in agreement with holistic processing theory. Thus, it can be concluded that if participants adopted the analytical route to word recognition, there would be no significant differences between the RTs of lowercase, uppercase and mixed-case stimuli formats. In analytical word recognition, readers of English move from left to right, step-by-step, first activating the first letter of each word and then activating all candidate letters step-by-step, until all competitors are exceeded and the target word recognized. In such a process, presentation in uppercase, lowercase, or mixed-case makes no difference, as letter “a” and “A” activate the same node in the mental lexicon. As a result, letter strings such as *abcdefg* and *ABCDEFGG* are activated and recognized in the same RTs.

From a holistic perspective, because participants are more familiar with lowercase, RTs for lowercase are shorter than for uppercase and mixed-case, and as the findings show, there are significant differences among the three cases. Thus, it can be concluded that participants used holistic processing in word recognition.

A similar argument can be made for both low- and high-frequency words. Participants’ RTs in the lower-case category differ significantly from uppercase and mixed-case RTs. This finding fails to support the principles of the dual-route cascade model and the multi-trace memory model, which suggest holistic route processing for high-frequency words and the analytical route for low-frequency words. If participants

used the holistic route for high- and low-frequency words, their RTs for lowercase would differ significantly from those for uppercase and mixed-case, which is the case in this study.

In-depth examination of RTs for words vs. non-words was of great help in understanding the analysis. Scrutiny indicated that high-frequency non-words were conceived as words by all participants, and that participants used holistic processing. Subjects judged low-frequency non-words as non-words. The time needed to reject non-words was significantly less than the time needed to make a decision on words, which, again, proves the application of analytical processing to low-frequency words.

As mentioned, non-words were created by transposing letters in words while preserving the word's shape, so participants could consider word shape during non-word recognition if they preferred using holistic processing. Since participants recognized all high-frequency non-words as English words, it can be concluded that they used holistic processing in non-word recognition. Because the general shape of a non-word was like that of its word counterpart, participants could depend on word shape in non-word recognition. Had they applied analytical processing, they would have found non-words as non-English words, because in analytical, or lexical, processing, participants moved from left to right in a step-by-step process to match letter strings with strings stored in their lexicon.

Finally, it can be concluded that if participants used holistic processing, they should recognize non-words as words, because word shape was not changed. As the sequence of letters in words and non-words differed, had participants applied analytical processing, they would have detected non-words, since in analytical word recognition, they moved letter-by-letter from left to right, which is the analytical processing paradigm. Considering this, results show that for high- frequency non-words, participants employed holistic processing in word recognition. Result of most previous studies have suggested that for high-frequency words, participants used the holistic, or non-lexical, route, and for low-frequency and non-words, they applied analytical processing. Results of the current study are in line with those of previous studies (Cattell 1986, 1985; Allen et al., 1995; Healy & Cunningham, 1992; Healy et al., 1987) and are compatible with results of studies suggesting that words are detected through analytical, or lexical, processing (Gough, 1972).

Unlike high-frequency non-words, low-frequency non-words were recognized as non-words by participants, who were able to reject them because they used analytical processing to recognize low-frequency words and non-words.

It can be argued that rejecting non-words is easier and faster than rejecting words. To confirm words, participants applied the first letter, either by absolute or relative position coding, thus activating all words starting with that letter in their lexicon. To limit the scope of activated words, they added the next letter to the first. This process was continued until a string was accepted or rejected. In the case of non-words, as deformations (distortion) were made in the second and the third letters, the time required to recognize non-words was expected to be less than that for words because participants could reject the stimuli easily based on the first three or four letters of any string. For instance, if the stimulus was ABCDEFGH (7 letters) and it was deformed as ACBDEFGH, participants could reject it as a non-word when reaching the ACB stage without moving further. However, to confirm words, participants had to accept the stimuli as a word by using all letter clusters. Therefore, time needed to detect words was more than that needed to reject non-words.



Results regarding high-frequency word recognition are in line with the word-shape paradigm. As results suggest, participants used the holistic route to recognize high- and low-frequency words. In contrast, they used analytical processing to recognize low-frequency non-words, a result not compatible with the word-shape paradigm.

Pedagogical Implications

Results of this experiment are useful in teaching vocabulary. Understanding processes and mechanisms that students use in word recognition helps to select appropriate methods for teaching vocabulary. In terms of high- and low-frequency words, to which study participants applied holistic processing, students can benefit from instruction in applying morphological rules, such as suffixes and prefixes. So, students should be taught these rules formally to help them understand the meanings of complex words.

Another important pedagogical implication of this research is that results can be used to help students distinguish between orthographically similar words—those with similar shapes, which sometimes confuse students—by applying the analytical process and by understanding the internal structures of both words.

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