LANGUAGE AND COGNITIVE PROCESSES
2007, 22 (1), 58–82
Psychology Press
Taylor & Francis Group

Word frequency modulates the Basic Orthographic Syllabic Structure (BOSS) effect in English polysyllable word recognition

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Do native readers segment polysyllabic words based on orthographic/morphological criteria or phonological criteria? Research by Taft (1979, 2001) argues in support of the former, as readers were faster in split-word lexical decision tasks when the words were segmented by orthographic/morphological principles based on Basic Orthographic Syllable Structure (or BOSS) units than when they were phonologically segmented following the Maximum Onset Principle (MOP). However, a BOSS-based preference has been difficult to replicate. The present research examined three factors potentially modulating a BOSS-based segmentation preference: whether a given BOSS unit is or is not present in other words, reading experience, and word frequency. The results showed that across higher and lower ability readers, and across words with shared or unique BOSSes, a BOSS preference was reliably obtained in low but not in high frequency words. Thus, word frequency appears to modulate the segmentation strategy of polysyllabic English words.

The question of how complex, polysyllabic words are segmented and represented in the lexicon is of increasing interest in reading research. Several studies suggest that sublexical units such as syllables are relevant functional units affecting word recognition. For example, in speakers of Spanish, words with low syllable frequency are slower to recognise than words with higher syllable frequency (Álvarez, Carreiras, & Taft, 2001; Carreiras, Álvarez, & de Vega, 1993; Conrad & Jacobs, 2004; Perea &

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A version of this article was presented at the annual meeting of the American Psychological Society, Atlanta, 2003. We thank Kenneth Forster and an anonymous reviewer for their helpful criticism and comments on an earlier version of the present paper.

http://www.psypress.com/lcp DOI: 10.1080/01690960500372717

Carreiras, 1998; see Carreiras & Grainger, 2004, for discussion). What is unclear is whether word syllabification in reading relies on primarily visual (Prinzmetal, Treiman, & Rho, 1986), phonological (Grainger & Ferrand, 1996), or orthotactic/morphographic characteristics (Taft, 1979).

Several studies have addressed this issue by comparing the relative speed of processing polysyllabic words that are segmented on the basis of phonological syllabification principles, such as the Maximum Onset Principle (MOP) vs. on the basis of orthotactic/morphological considerations, such as the Basic Orthographic Syllable Structure (BOSS) proposed by Taft (1979). The Maximum Onset Principle holds that syllables in word onsets are to include as many consonants as are allowed in the syllable structure of the language and as can occur at the beginning of a word in the language (Kahn, 1976). Thus, syllabification according to the MOP produces the greatest possible number of onsets within a word. By contrast, syllabification according to BOSS units, defined as units in which the first syllable of a word contains 'as many consonants following the first vowel of the word as orthotactic factors will allow without disrupting the morphological structure of that word' (Taft, 1979, p. 24) makes use of a Maximal Coda strategy. For example, a BOSS-based analysis of the word SPIDER would consider the initial syllable as SPID whereas a MOP analysis would segment the word as SPI+DER.

Several experimental methods were developed by Taft to test the psychological reality of the BOSS. These include lexical decision tasks (LDT) in which syllables compatible with a MOP or a BOSS analysis are either separated by a space (Taft, 1979, Exp. 1), or are presented in different cases (upper vs. lower) (Taft, 1979, Exp. 2), or where the syllable in a nonword is the BOSS of a real word (e.g., the SPID from SPIDER is presented in the nonword SPIDAL) (Taft, 1986). Yet another technique (used in Taft, 1987) involves priming a target word with its BOSS (e.g., SPIDER is primed by SPID). A BOSS segmentation advantage has been argued on the basis of findings of faster decision times to words that are separated, cued by case, or primed according to BOSS-based criteria than phonological segmentation criteria.

Evidence for a BOSS advantage has primarily come from Taft's own laboratory. Other researchers have generally not been able to replicate the results. For example, Lima and Pollatsek (1983, Exp. 1), using a split-word lexical decision task (LDT), did not obtain a significantly faster response for words divided by the rule of BOSS than that for words divided by phonological structure. Katz and Baldasare (1983), using a lexical decision task in which stimuli were divided by a diagonal slash, also failed to obtain a BOSS advantage. Using a primed LDT, Lima and Pollatsek (1983, Exps. 2

and 3) found that subjects did not respond faster to target words primed by BOSS letter strings than to letter strings based on phonological structure (see also Jordan, 1986). Taken together, these studies seriously damage Taft's claim of a BOSS effect.

To address the failure to replicate issue, Taft (2001) suggested that variations in participants' reading ability may account for the inconsistent findings observed across laboratories. Since most of the participants used in Taft's studies were advanced honors students and graduate students whereas those in others' studies tended to be students taking lower level courses, Taft (2001) argued that higher language ability may be needed to obtain a BOSS preference. When subjects are recruited from an undergraduate subject pool, they are likely to include both good and poor readers; thus, Taft reasoned, the weaker BOSS preference of poor readers might counteract the BOSS preference of good readers in the sample. In support of this notion, Taft (2001) found a significant correlation between a BOSS preference and reading comprehension ability. Further, in a direct comparison of good vs. poor adult readers on a split word lexical decision task, he found a significant BOSS preference among good readers but a phonological segmentation preference among poor readers (Taft, 2001).

Taft (2001) further proposed that when different words share the same BOSS, this weakens a BOSS effect. Using the term 'morphemic cue presence' to refer to whether a BOSS was shared by several words, Taft argued that words possessing a BOSS found in more than one word (e.g., the BOSS 'ACT' found in ACTOR, ACTIVE) would not show a BOSS advantage because the shared BOSS would activate other candidates with the same BOSS which would, in turn, influence recognition. In Experiment 3 of his split-word LDT study (Taft, 2001), a BOSS preference was indeed only revealed in words without shared BOSSes (e.g., ANKLE).

Whereas differences in reading experience or the presence of a shared vs. unique BOSS may account for some of the discrepancies noted across studies, we suggest that an additional variable, word frequency, may be an even more critical determinant of segmentation preferences. Frequency has not been controlled in previous studies of segmentation preference despite being one of the most robust variables known to influence word recognition (see Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Frost, 1998; Monsell, 1991, for discussion).

Given that low frequency words are thought to be more likely influenced by sublexical processes than high frequency words, it is reasonable to hypothesise that if BOSS units are psychologically real, their effect on processing may be more evident for low frequency words. Other sublexical effects such as the regularity effect (e.g., Paap & Noel, 1991; Seidenberg,

1985) and the consistency effect (e.g., Andrews, 1982) are indeed reported more often for low than for high frequency words (see Jared, 2002, for a more detailed discussion). Certain syllable level effects also have been reported to occur more often for low than high frequency words (Álvarez et al., 2001; Carreiras et al., 1993; Conrad & Jacobs, 2004; Perea & Carreiras, 1998).

To address whether word frequency differences may underlie the presence or absence of a BOSS advantage in previous studies, we first examined the word frequency of stimuli from all previously published word segmentation studies of the BOSS effect. A summary of these studies and the mean word frequency values of the stimuli used, based on norms from Kučera and Francis (1967) and Francis & Kučera (1982), is provided in Table 1. As can be seen, studies that obtained a BOSS preference, in fact, tended to have a lower average word frequency than those that did not.

For example, using a split-word LDT, Taft (2001, Exp. 3) reported a BOSS advantage for words without shared BOSSes. However, as can be seen from Table 1, words without shared BOSSes in this study had lower frequency values as compared to those with shared BOSSes (10 vs. 46 per million, respectively). Whereas a larger BOSS advantage was reported for words with short vowels than for words with long vowels (Taft, 2002, Exp. 1), here again word frequency was lower in the former case than in the latter (58 vs. 81 per million, respectively). Similarly, in studies that used a primed LDT paradigm, the average word frequency of stimuli in experiments revealing a BOSS preference (e.g., Lima & Pollatsek, 1983, Exp. 3, inflected stimuli; Taft, 1987, Exp. 4) tended to be lower (e.g., 13 and 22 per million, respectively) than that for studies that did not show a BOSS preference (e.g., 59 per million in Jordan, 1986; 25 and 26 per million in Lima & Pollatsek, 1983, Exp. 2, Exp. 3 with monomorphemic stimuli).

In Taft (1987, Exp. 1), stimuli showing a significant BOSS advantage in primed LDT had a higher average word frequency than that characterising studies that did not find a BOSS advantage (Lima & Pollatsek, 1983, Exp. 2 and Exp. 3, with monomorphemic stimuli); however, the effect size of the BOSS advantage in Taft (1987, Exp. 1) was still smaller than that of Taft (1987, Exp. 4), which used lower word frequency stimuli (the effect sizes were .32 vs. .61, respectively). Thus, one possible cause of different findings across studies may have been differences in word frequency.

Finally, a study by Chateau and Jared (2000) is of relevance to the interpretation of reading ability-related effects in word recognition. These researchers found that readers who had low print-exposure showed a larger word frequency effect in lexical decision than did high print-exposure readers. Low print-exposure readers also showed a stronger neighbourhood

TABLE 1
Summary of studies examing BOSS advantages

Author(s)	*Task*	*BOSS effect*	*Effect size*	*Mean stimulus frequency*
Taft (1979, Exp.2)	Split-word LDT (change case)	18 ms	$f = .19$	25[b]
Lima & Pollatsek (1983, Exp.l)	Split-word LDT (with spaces)	N.S.	N/A	25[b]
Katz & Baldasare (1983, Exp.2)	Split-word LDT (with slash)	N.S.	N/A	25[b]
Taft (2001, Exp.l)	Split-word LDT (with spaces)	N.S.	$f = .04$	20[a]
Taft (2001, Exp.2)	Split-word LDT (with spaces)	N.S.	N/A	50[a]
Taft (2001, Exp.3, with morphemic cue, good readers)	Split-word LDT (with spaces)	N.S.	N/A	46[a]
Taft (2001, Exp.3, without morphemic cue, good readers)	Split-word LDT (with spaces)	27 ms	$f = .29$	10[a]
Taft (2002, Exp.l, long vowel condition)	Split-word LDT (with spaces)	N.S.	$f = .08$	81[a]
Taft (2002, Exp.l, short vowel condition)	Split-word LDT (with spaces)	26 ms	$f = .19$	58[a]
Jordan (1986)	LDT (priming)	N.S.	N/A	59[a]
Lima & Pollatsek (1983, Exp.2)	LDT (priming)	N.S.	N/A	25[b]
Lima & Pollatsek (1983, Exp.3, monomorphemic stimuli)	LDT (priming)	N.S.	N/A	26[b]
Lima & Pollatsek (1983, Exp.3, inflected stimuli)	LDT (priming)	37 ms	$f = .50$	22[bc]
Taft (1987, Exp.l)	LDT (priming)	45 ms	$f = .32$	30[a]
Taft (1987, Exp.4)	LDT (priming)	37 ms	$f = .61$	13[a]
Taft (1987, Exp.3)	Naming (priming)	50 ms	$f = .27$	30[a]
Taft (1987, Exp.2)	Beginning Judgement Task	63 ms	$f = .36$	30[a]

Note. [a]Based on Francis and Kučera (1982) with the unit of 'per million appearance'. [b]Based on Kučera and Francis (1967) with the unit of 'per million appearance'.[c]The original mean frequency should be 26 per million, however, there were 2 out of 50 words had the word frequency more than twice of the frequency range (14–46) authors claimed and we adjusted the mean frequency excluding these two words. N/A in the effect size column mean no *F* reported due to insignificant results and the effect size thus could not be calculated.

size effect in LDT for low frequency words than they did for high frequency words. Based on these findings, one might expect that poor readers would show a greater effect of orthographic processing than good readers, especially for low frequency words. The BOSS advantage, if there is any, might thus be present for low frequency words even among low reading ability readers to the extent that BOSS-based segmentation relies on orthographic/morphological word knowledge.

THE PRESENT STUDY

Three experiments using a split-word LDT procedure, as was used by Taft (2001), were conducted to examine factors influencing segmentation strategy (BOSS-based vs. MOP-based) of polysyllabic English words.

Experiment 1 systematically manipulated word frequency, segmentation type, and presence/absence of shared BOSSes. If word frequency plays a role in influencing word recognition processes, we expected that it would interact with segmentation type. Specifically, we expected that a BOSS preference would be restricted to low frequency words. Furthermore, if word frequency also underlies the effect attributed to the shared/ unshared BOSS variable in Taft (2001, Exp. 3), we expected to obtain a BOSS preference for low frequency words with or without a shared BOSS.

Experiment 2 was conducted to replicate the findings of Exp. 1 using a new set of stimuli. As in Exp. 1, performance was examined as a function of word frequency, segmentation type, and shared/unshared BOSS. However, segmentation type in this experiment included a BOSS + 1 analysis (e.g., SPIDE + R) in addition to the BOSS and the MOP conditions. By comparing participants' responses to BOSS-based, MOP-based, and BOSS + 1-based analyses, we were able to examine whether the expected BOSS advantage in Experiment 1 may have been due simply to there being one more letter in the left part of the segmentation in the BOSS relative to the MOP analysis. If we still obtained a BOSS advantage restricted to low frequency words with the new set of stimuli used in this experiment, the results would strengthen support of our hypothesis that word frequency modulates the BOSS effect.

Experiment 3 manipulated reading ability in addition to word frequency, segmentation type (BOSS vs. MOP), and presence/absence of a shared BOSS using the same stimuli as were used in Exp. 1. If, as Taft (2001) proposed, reading ability affects segmentation strategy, we should get a similar pattern of results as Taft's (2001), with better readers showing a BOSS-based, Maximum Coda preference but poorer readers showing a Maximum Onset preference in segmenting words, particularly for words without a shared BOSS. However, if word frequency modulates segmentation strategy, a

BOSS-effect should be present only for low frequency words. Further, if the effect of word frequency overrides that of reading ability and/or shared/unshared BOSS, we would expect a BOSS preference in low frequency words for both better and poorer reading ability groups, across the shared/unshared BOSS variable.

EXPERIMENT 1

This experiment sought to test the relative contribution of word frequency and unique vs. shared BOSSes as potential determinants of a BOSS-based segmentation preference in native readers of English on a split word lexical decision task.

Method

Participants. Thirty-six male and female undergraduates recruited from an upper level Psychology of Language course at a large southwestern U.S. university participated in the experiment. All were fluent readers of English with normal or corrected-to-normal vision.

Design and stimuli. The design was a 2(Word Frequency) × 2(Shared/Unshared BOSS) × 2(Segmentation Type) within-subjects factorial, with a total of 8 conditions.

Sixty-four English words were selected as the stimuli. These included 16 sets of four words matched, to the extent possible, in number of letters and number of syllables and sharing the same final two or three letters (see Appendix A for a list of the stimuli). Each stimulus set contained two high frequency and two low frequency words, and each of these contained words with or without a shared BOSS. High frequency words averaged 243 per million and low frequency words averaged 11 per million (Francis & Kučera, 1982). There was no significant frequency difference between words with a shared BOSS vs. those without a shared BOSS ($ts < 1$ for high frequency words and low frequency words). A set of 64 pseudowords was created by replacing consonants or vowels from real words to fit the requirement of the lexical decision task.

Apparatus and procedure. The experiment was administered on personal computers. Stimuli were presented individually in the centre of a VGA-adapted, 72 Hz, display. E-Prime (Psychological Software Tools, 2002) was used for controlling experimental procedures and data handling. Participants received ten practice trials with correctness feedback. No feedback was given on the experimental trials.

On each trial, a cross, used as a fixation point, was presented at the centre of the monitor and was displayed for 500 ms. Then, a target letter string, which subtended a visual arc of approximately 1.2 degrees, was presented at the centre of the screen and remained there until the onset of the participant's response. The target contained a space that divided the word according to either a Maximum Onset Principle or a BOSS-based analysis. The presentation of a Maximum Onset Principle or a BOSS-based analysis for each target was counterbalanced among subjects.

Participants, tested individually, were to decide whether or not the target letter string, disregarding the space, was a real English word. They were to signal a 'yes' or 'no' response by pressing one of two assigned keys on the keyboard as quickly and as accurately as possible. Timing of the reaction time (RT) started from presentation of the target letter string until a button press response was made.

Each participant received a randomly arranged sequence of stimuli containing 128 target letter strings. A 1000 ms blank screen was shown between trials. A rest was given after every 32 trials. The entire procedure took approximately 20 minutes per participant.

Results

The data for one set of four stimuli were removed on discovery after the experiment that the space inside the words had been misplaced. In calculating the mean RT of correct responses for each condition per participant, those trials with RTs less than 200 ms or with two SD above the mean of the condition to which the trials belonged were discarded, as were invalid and incorrect responses. These cutoffs led to the rejection of 2.4% of the observations. The accuracy and recomputed mean correct RTs are shown in Table 2.

Two three-way analyses of variance were conducted on the accuracy data and the correct RT scores, one analysing the data by subjects (F_1) and the other by items (F_2).

Reaction time analysis. There was a significant main effect of Word frequency, $F_1(1, 35) = 57.65$, $p < .001$, $F_2(1, 56) = 18.92$, $p < .001$, showing that high frequency words were responded to significantly faster than low frequency words (mean response latencies were 638 ms vs. 725 ms, respectively). The factor of Shared/Unshared BOSS was significant in the analysis by subjects, $F_1(1, 35) = 14.19$, $p < .01$, $F_2(1, 56) < 1$, and showed that words with a shared BOSS were responded to faster than words without a shared BOSS (670 ms vs. 694 ms, respectively).

Segmentation type was not significant, $F_1(1,35) = 2.57$, $p > .05$, $F_2(1, 56) = 2.44$, $p > .05$. However, the interaction between Word frequency and

TABLE 2
Mean accuracy (%) and reaction times (ms) in Experiment 1

	High frequency				*Low frequency*			
	Shared BOSS		*Unshared BOSS*		*Shared BOSS*		*Unshared BOSS*	
	MOP OR DER	BOSS ORD ER	MOP UN DER	BOSS UND ER	MOP RI DER	BOSS RID ER	MOP EL DER	BOS ELD ER
RT	633	628	645	645	723	695	762	721
Accuracy	97.42	98.16	97.42	98.81	93.20	89.9S	85.96	88.89

Note. MOP = Max Onset Principle; BOSS = Basic Orthographic Syllabic Structure.

Segmentation type was significant when analysed by subjects,[1] $F_1(1, 35) = 5.38$, $p < .05$, $F_2(1, 56) = 1.80$, $p = .18$. The simple main effect suggested that, as expected, the segmentation type effect was found for low frequency words (where responses to BOSS-based segmentation were 34 ms faster than those to MOP-based segmentation, $F_1(1, 70) = 6.57$, $p < .05$, $F_2(1, 56) = 4.22$, $p < .05$), but not for high frequency words: the mean difference here was 3 ms, $F_1(1, 70) < 1$, $F_2(1, 56) < 1$. No other significant interactions were found.

Accuracy analysis. There was a significant main effect of Word frequency, $F_1(1, 35) = 103.58$, $p < .001$, $F_2(1, 56) = 5.36$, $p < .05$, showing that high frequency words were responded to more accurately than low frequency words (97.95% vs. 89.51%, respectively). The factor of Shared/Unshared BOSS was found to be significant only when analysed by subjects, $F_1(1, 35) = 4.91$, $p < .05$, $F_2(1, 56) < 1$, and showed that words with a shared BOSS were responded to more accurately than words without a shared BOSS (94.69% vs. 92.77%, respectively). An interaction between Word Frequency and Shared/Unshared BOSS, significant when analysed by subjects, $F_1(1, 35) = 6.50$, $p < .05$, $F_2(1, 56) < 1$, indicated that the greater accuracy of words with shared BOSSes over that for words without shared BOSSes was restricted to low frequency words. Segmentation type was not significant, $F_1(1, 35) < 1$, $F_2(1, 56) < 1$ nor were there other significant effects.

Discussion

As hypothesised, an advantage of BOSS-based over MOP-based segmentation was found for low frequency words; there was no difference in responses to high frequency words. This finding is consistent with our observation that where a BOSS effect has previously been reported in the literature, the stimuli were typically of lower frequency. Further, contrary to Taft's previous results, we did not obtain an interaction between segmentation type and the variable of shared/unshared BOSS. Instead, our results suggest that variations in word frequency (rather than whether a BOSS unit is shared or unique) contributed to whether a BOSS effect was obtained or not.

[1] As Ratcliff (1993) indicated, different cutoff outliers may result in different patterns of results. Since several outcomes in the present study which used a cutoff of 2 SD were only significant by subjects, we also conducted two other analyses, one using a cutoff of values above 3 SD and the other of values above 1500 ms (Experiment 1 and 3) or 2000 ms (Experiment 2, due to longer RTs after adding BOSS+1 segmentation). In all cases, the lower cutoff was always values below 200 ms. Basically, the three ways of analysing the data did not produce different results; where differences were obtained, they are noted in the footnotes below. In Experiment 1, the only difference was in the interaction between frequency and segmentation type when analysed by items: whereas our 2 SD cutoff did not produce a significant interaction, the 3 SD cutoff revealed a significant interaction, $F_2(1, 56) = 4.92$, $p < .05$, and the 1500 ms cutoff also showed a marginally significant interaction, $F_2(1, 56) = 3.25$, $p = .07$.

EXPERIMENT 2

In this experiment we sought to determine whether the BOSS advantage for low frequency words found in the previous experiment will generalise across a new set of stimuli and participants. In addition, we sought to test two alternative accounts of the BOSS effect.

One alternative account is that the results do not reflect a BOSS-based processing advantage so much as a possible processing disadvantage for an analysis based on MOP under the split-word presentation conditions used in this study.[2] That is, introducing a space may for some reason be more disruptive to an analysis based on MOP rather than one based on BOSS. According to this view, polysyllabic words are normally segmented according to the MOP, but the stimulus presentation conditions interfere with normal MOP-based segmentation. Thus, finding a MOP-disadvantage here would provide evidence for a MOP effect. To test this account, an additional control segmentation condition is needed to determine whether the obtained response differences in Experiment 1 were due to a BOSS advantage (i.e., faster processing than control segmentation) or to a MOP disadvantage (i.e., slower processing than control segmentation).

The second alternative account tested here is that a BOSS advantage is an artifact of the fact that BOSS-based segmentation results in one more letter in the left part of the segmented word compared to a MOP-based segmentation. These two possibilities were tested by introducing a third segmentation type condition, BOSS + 1, besides a BOSS- and a MOP-based segmentation.

Previous studies in which a third segmentation condition was included have shown that BOSS- and MOP-based segmentation are both generally preferred over the third condition (BOSS + 1 or MOP-1). For example, Taft (1987) found that BOSS-based word divisions (e.g., THUND of THUNDER) presented an advantage over BOSS + 1 divisions (e.g., THUNDE) and MOP-based divisions (e.g., THUN). Lima and Pollatsek (1983) found that BOSS primes and MOP primes were both responded to faster than BOSS + 1 primes in English lexical decision. In Dutch, Knuijt and Assink (1997) found that lexical decision latencies for BOSS primes were equivalent to those to MOP primes and MOP-1 primes (e.g., THUN or THU of THUNDER) but were faster than those to BOSS + 1 primes (THUNDE).

The present lexical decision experiment factorially manipulated word frequency, shared/unshared BOSS, and three levels of segmentation type. If the critical results from our previous experiment are reliable, we should find a BOSS-based advantage restricted to low frequency words (regardless of whether the words share a BOSS with other words). If the results are better

[2] This possibility was suggested to us by one of the reviewers, Kenneth Forster.

described in terms of a MOP-disadvantage, we would expect that responses to words segmented by a MOP-based analysis would be slower than to BOSS and BOSS + 1 segmented words. Finally, if the faster responses to words segmented by BOSS-based analysis were due to the fact that they have one more letter in the left part of the segmented words, the fastest responses should be for words segmented by a BOSS + 1 analysis since this condition includes one more letter in the left part of segmented words.

Method

Participants. A new set of 30 college students participated in the experiment. Participants were recruited from an introductory psychology subject pool at a large southwestern U.S. university. All were fluent native readers of English with normal or corrected-to-normal vision.

Design and stimuli. The design was a 2(Word Frequency) × 2(Shared/Unshared BOSS) × 3(Segmentation Type) within-subjects factorial, with a total of 12 conditions.

A new set of 96 English words were selected as the stimuli. These included 24 sets of four words matched, to the extent possible, in number of letters and number of syllables and sharing the same final two or three letters (see Appendix B for a list of the stimuli). Each stimulus set contained two high frequency and two low frequency words, and each of these contained words with or without a shared BOSS. High frequency words averaged 148 per million and low frequency words averaged 14 per million (Francis & Kučera, 1982). There was no significant frequency difference between words with vs. without shared BOSSes (ts < 1 for high frequency words and low frequency words). A set of 96 pseudowords was created by replacing consonants or vowels from real words to fit the requirement of the lexical decision task.

Apparatus and procedure. The apparatus and procedure in Experiment 2 were the same as in Experiment 1 except that, on each trial, the target letter string was separated by a space according to either a Maximum Onset, a BOSS, or a BOSS + 1 analysis and was presented at the centre of the screen. Each participant received a randomly arranged sequence of stimuli containing 192 target letter strings. For the set of 96 word trials, there were 32 words segmented by a Maximum Onset analysis, 32 by a BOSS analysis, and 32 by a BOSS + 1 analysis. The presentation of a Maximum Onset Principle, a BOSS, or a BOSS + 1 based analysis for each target word was counterbalanced among subjects.

Results

In calculating the mean RT of correct responses for each condition per participant, those trials with RTs less than 200 ms or with two SD above the mean of the condition to which the trials belonged were discarded, as were invalid and incorrect responses. These cutoffs led to the rejection of 3.3% of the observations. The accuracy and recomputed mean correct RTs are shown in Table 3.

Two three-way analyses of variance were conducted on the accuracy data and the correct RT scores, one analysing the data by subjects (F_1) and the other by items (F_2).

Reaction time analysis. There was a significant main effect of Word frequency, $F_1(1, 29) = 58.33$, $p < .001$, $F_2(1, 92) = 17.79$, $p < .001$, showing that high frequency words were responded to significantly faster than low frequency words (mean response latencies were 816 ms vs. 945 ms, respectively). The factor of Shared/Unshared BOSS was not found to be significant, $F_1(1, 29) < 1$, $F_2(1, 92) = 1.65$, $p > .05$.

Segmentation type was significant, $F_1(2, 58) = 5.40$, $p < .01$, $F_2(2, 184) = 4.11$, $p < .05$. The interaction between Word frequency and Segmentation type was also significant when analysed by subjects, as found in Exp. 1, $F_1(2, 58) = 3.35$, $p < .05$, $F_2(2, 184) < 1$.[3] The simple main effect suggested that, as expected, the segmentation type effect was revealed for low frequency words, $F_1(2, 116) = 8.25$, $p < .001$, $F_2(2, 184) = 4.42$, $p < .05$, but not for high frequency words, $F_1(2, 116) < 1$, $F_2(2, 184) < 1$. Further analysis of this effect for low frequency words showed that responses to BOSS-based segmentation ($M = 894$ ms) were significantly faster than those to MOP-based segmentation ($M = 953$ ms), $t_1(29) = 2.59$, $p < .05$, $t_2(47) = 1.70$, $p = .09$. Responses to BOSS-based segmentation were also significantly faster than those to BOSS+1-based segmentation ($M = 989$ ms), $t_1(29) = 2.98$, $p < .01$, $t_2(47) = 2.15$, $p < .05$. However, responses to MOP-based segmentation were not significantly different from those to BOSS+1-based segmentation, $t_1(29) = 1.24$, $p > .05$, $t_2(47) = 1.10$, $p > .05$. No other significant interactions were found.

[3] Whereas our 2 SD cutoff only yielded a significant interaction between frequency and segmentation type when the data were analysed by subjects, the 3 SD cutoff revealed a marginally significant interaction only in by-subject analysis, $F_1(2, 58) = 3.01$, $p = .056$, $F_2(2, 184) = 1.08$, $p > .05$, as did the 2000 ms cutoff, $F_1(2, 58) = 3.03$, $p = .054$, $F_2(2, 184) < 1$. We applied 2000 ms instead of 1500 ms as the cutoffs in Experiment 2 because the response time increased after we added the BOSS+1 condition.

TABLE 3
Mean accuracy (%) and reaction times (ms) in Experiment 2

	High frequency						*Low frequency*					
	Shared BOSS			*Unshared BOSS*			*Shared BOSS*			*Unshared BOSS*		
	MOP OR DER	BOSS ORD ER	BOSS+1 ORDE R	MOP UN DER	BOSS UND ER	BOSS+1 UNDE R	MOP RI DER	BOSS RID ER	BOSS+1 RIDE R	MOP EL DER	BOSS ELD ER	BOSS+1 ELDE R
RT	813	812	833	797	810	832	926	876	994	979	912	984
Accuracy	96.25	97.50	97.08	95.83	97.50	96.67	87.08	90.83	85.83	86.67	86.67	87.50

Note. MOP = Max Onset Principle; BOSS = Basic Orthographic Syllabic Structure.

Accuracy analysis. There was a significant main effect of Word frequency, $F_1(1, 29) = 91.05$, $p < .001$, $F_2(1, 92) = 10.89$, $p < .01$, showing that high frequency words were responded to more accurately than low frequency words (96.81% vs. 87.43%, respectively). The factor of Segmentation type was not significant, $F_1(2, 58) = 1.11$, $p > .1$, $F_2(2, 184) < 1$. No other main effects or interactions were found to be significant, $F\text{s} < 1$.

Discussion

The critical result of Experiment 1, namely, a BOSS-based lexical decision advantage in response latency for low but not high frequency words, was replicated in Experiment 2, indicating that the results in our previous experiment did not arise from some artifact of stimulus selection. As in Experiment 1, there was no interaction between segmentation type and shared/unshared BOSS in Experiment 2, suggesting that the presence or absence of a shared BOSS does not modulate whether a BOSS-preference is obtained. Further, our finding that BOSS-based segmentation produced faster response times not only as compared with MOP-based segmentation but also as compared with BOSS + 1 segmentation suggests that the obtained BOSS advantage was not simply the result of having one more letter in the left part of the segmented words. Finally, the fact that responses to words segmented by MOP-based analysis were not slower than those segmented by a BOSS + 1 analysis suggests that a MOP-disadvantage explanation is not valid in the present study.

Results from both our experiments point to a BOSS-based preference in lexical decision response latency restricted to low frequency words.

EXPERIMENT 3

Thus far we have demonstrated a consistent BOSS advantage for low frequency words across two different stimulus sets and two different samples of participants. In the final experiment, we directly address the possibility that segmentation preferences interact with individual differences in reading ability, as proposed by Taft (2001). Participants in this experiment were subdivided into higher and lower reading ability on the basis of their SAT verbal scores. If Taft's reading ability proposal has merit, only higher ability subjects should show a BOSS preference; however, if the BOSS preference is influenced by word frequency regardless of reading ability, we should obtain an overall BOSS preference over the Maximum onset strategy for segmentation of low frequency words.

Method

Participants. Seventy-four college students, subdivided into higher and lower reading ability groups, participated in the experiment. Those with SAT verbal scores higher than 650 ($M = 694$) were classified as being of higher reading ability ($N = 37$), whereas those with SAT verbal scores lower than 580 ($M = 531$) were classified as the lower ability group ($N = 37$). Participants were recruited from an introductory psychology subject pool at a large southwestern U.S. university. All were fluent native readers of English with normal or corrected-to-normal vision.

Design and stimuli. The design and the stimuli were the same as in Experiment 1 except for the additional between-subjects factor of reading ability (higher vs. lower).

Apparatus and procedure. The apparatus and the procedure in Experiment 3 were the same as in Experiment 1.

Results

As in Experiment 1, the data for one set of 4 stimuli were removed from the analysis after it was discovered that the space inside the words had been misplaced. In calculating the mean RT of correct responses per condition per participant, those trials with RTs less than 200 ms (reflecting possible anticipation effects) or responses that were 2 SD above the mean of the condition to which the trials belonged were discarded. These cutoffs led to the rejection of 3.2% of observations. The accuracy and recomputed mean correct RTs are shown in Table 4.

The RT and accuracy data were analysed in a four-way ANOVA with one between- subjects factor (Reading Ability Group) and three within-subjects factors (Word Frequency, Shared/Unshared BOSS, and Segmentation Type). The data were analysed by subjects (F_1) and by items (F_2).

Reaction time analysis. There was a main effect of Word Frequency, $F_1(1, 72) = 146.65$, $p < .001$, $F_2(1, 56) = 16.41$, $p < .001$, showing that high frequency words were responded to significantly faster than low frequency words (668 ms vs. 758 ms, respectively). The factor of Shared/Unshared BOSS was also found to be significant when analysed by subjects, $F_1(1, 72) = 15.11$, $p < .001$, $F_2(1, 56) = 1.13$, $p > .05$, and showed that words with a shared BOSS were responded to faster than words without a shared BOSS (697 ms vs. 728 ms, respectively). Segmentation type was also found to be

TABLE 4
Mean accuracy (%) and reaction times (ms) in Experiment 3

Reading ability		*High frequency*				*Low frequency*			
		Shared BOSS		*Unshared BOSS*		*Shared BOSS*		*Unshared BOSS*	
		MOP OR DER	BOSS ORD ER	MOP UN DER	BOSS UND ER	MOP RI DER	BOSS RID ER	MOP EL DER	BOSS ELD ER
Higher	RT	626	625	667	656	697	708	764	695
	Accuracy	98.21	98.89	97.15	95.13	87.79	94.79	86.82	87.45
Lower	RT	678	678	703	709	799	767	834	800
	Accuracy	99.32	98.94	97.49	97.20	92.76	92.62	85.67	86.53

Note. MOP = Max Onset Principle; BOSS = Basic Orthographic Syllabic Structure.

significant when analysed by subjects,[4] $F_1(1, 72) = 6.64$, $p < .05$, $F_2(1, 56) = 2.28$, $p > .05$, indicating that words segmented by a Maximum Onset Principle ($M = 721$ ms) were responded to more slowly than words segmented by a BOSS ($M = 705$ ms).

As in Experiment 1, an interaction between word frequency and segmentation type was significant when analysed by subjects, $F_1(1, 72) = 6.33$, $p < .05$; it was near significant when analysed by items,[5] $F_1(1, 56) = 3.33$, $p = .07$. The simple main effect indicated that the BOSS advantage was restricted to low frequency words (mean difference in RT to BOSS-segmented vs. MOP-segmented words was 31 ms, $F_1(1, 144) = 12.96$, $p < .001$, $F_2(1, 56) = 5.56$, $p < .05$; for high frequency words the mean difference was 2 ms, $F_1(1, 144) < 1$, $F_2(1, 56) < 1$). Thus, as in our previous experiments, the BOSS effect was only revealed in low frequency words.

A significant main effect of Reading ability, $F_1(1, 72) = 5.43$, $p < .05$, $F_2(1, 56) = 13.94$, $p < .001$, showed that the higher ability group responded significantly faster than the lower ability group (680 ms vs. 746 ms, respectively). Another interaction, Word frequency by Reading ability, was also found when the data were analysed by subjects,[6] $F_1(1, 72) = 5.61$, $p < .05$, $F_2(1, 56) < 1$. The interaction came from the fact that the reading ability effect was larger for low frequency words—the mean difference between higher and lower reading ability groups was 84 ms, $F_1(1, 144) = 8.16$, $p < .01$, $F_2(1, 56) = 8.85$, $p < .01$, than for high frequency words—the mean difference was 48 ms, $F_1(1, 144) = 2.73$, $p > .05$, $F_2(1, 56) = 5.32$, $p < .05$.

The three-way interaction of Segmentation type, Word frequency, and Reading ability was not significant, $F_1(1, 72) < 1$, $F_2(1, 56) < 1$. This indicates that reading ability did not differentially influence segmentation preference. No other interactions were found.

Accuracy analysis. There was a main effect of Word frequency, $F_1(1, 72) = 160.41$, $p < .001$, $F_2(1, 56) = 7.88$, $p < .01$, showing that high frequency words were responded to more correctly than low frequency words (97.80% vs. 89.30%, respectively). The factor of Shared/Unshared BOSS was also

[4] For the analysis by items, whereas our 2 SD cutoff and the 1500 ms cutoff did not yield a segmentation type main effect, F_2 (1, 56) = 2.49, $p > .05$, the 3 SD cutoff did, $F_2(1, 56) = 4.65$, $p < .05$.

[5] Whereas our 2 SD cutoff only yielded a marginally significant interaction between frequency and segmentation type when the data were analysed by items, the 3 SD cutoff revealed a significant interaction, $F_2(1, 56) = 4.25$, $p < .05$, as did the 1500 ms cutoff, $F_2(1, 56) = 5.67$, $p < .05$.

[6] Whereas our 2 SD cutoff did not yield a significant interaction between frequency and reading ability group when the data were analysed by items, the 1500 ms cutoff did yield a significant interaction, $F_1(1, 56) = 4.43$, $p < .05$, but the 3 SD cutoff did not reveal a significant interaction, $F_2(1, 56) < 1$.

found to be significant when analysed by subjects, $F_1(1, 72) = 36.54$, $p < .001$, $F_2(1, 56) = 1.67$, $p > .05$, and showed that words with shared BOSSes (M = 95.42%) were responded to significantly more accurately than words without shared BOSSes ($M = 91.68\%$). Segmentation type was not significant, $F_1(1, 72) = 1.47$, $p > .05$, $F_2(1, 56) < 1$. The main effect of Reading ability was also not significant, $F_1(1, 72) < 1$, $F_2(1, 56) = 1.40$, $p > .05$.

The three way interaction of Segmentation type, Reading ability, and Shared/Unshared BOSS was significant, $F_1(1, 72) = 4.73$, $p < .05$, $F_2(1, 56) = 4.02$, $p < .05$, reflecting that the segmentation type effect (i.e., the BOSS advantage) was only revealed in words with shared BOSSes among better readers: mean difference = 3.84%, $F_1(1, 144) = 9.56$, $p < .01$, $F_2(1, 56) = 6.58$, $p < .05$. No other interactions were found.

Discussion

Our finding of an interaction between segmentation type and word frequency replicates that found in Experiment 1 and Experiment 2 and suggests that word frequency is the critical determinant of the presence of a BOSS effect. The reason that Taft obtained a BOSS advantage over MOP but this was not found in other laboratories might, thus, be due to the use of stimuli differing in the range of word frequency used.

With respect to the variable of reading ability, an interaction between reading ability and word frequency suggested that the difference in reaction time performance between individuals with high and low reading ability was greater for low than high frequency words. However, no support was found for Taft's (2001) contention that a BOSS advantage is more evident among high ability readers, as there was no interaction between reading ability and segmentation type in the reaction time analysis.

GENERAL DISCUSSION

Whereas Taft (2001) suggested that a BOSS advantage is limited to readers of high ability and to words without shared BOSSes, we found no support for either of these variables. Instead, our results suggest that word frequency is what modulates the BOSS effect. In three different experiments with different sets of stimuli and across readers of differing ability, we found a segmentation preference favouring a BOSS analysis for low frequency words only. A BOSS-based effect confined to low frequency words is a novel finding but not altogether surprising, given that research in word recognition has found that the processing of low frequency words may rely more on sublexical processes (e.g., Andrews, 1982; Paap & Noel, 1991; Seidenberg, 1985).

Although we obtained an overall effect of reading ability (in Experiment 3), this factor primarily influenced the overall speed of lexical decision. In contrast to Taft (2001), we found no interaction between reading ability and segmentation type. In line with Chateau and Jared's (2000) finding that poorer readers showed a larger frequency effect and neighbourhood size effect for low frequency words than good readers, our data similarly suggest that a BOSS advantage shows up in low frequency words even for poor readers.

One methodological difference in the operationalisation of reading ability between our study and that of Taft (2001) should be acknowledged. In our study (Exp. 2) the criterion used to determine reading ability (SAT verbal scores) was different from that used by Taft (a more direct measure of reading ability). Although the difference in mean SAT verbal score between our higher and lower ability groups (i.e., 164) was larger than one and a half the population standard deviation, the mean of our lower ability readers (531) was still higher than the population mean of the SAT (i.e., 500). Thus, our lower ability readers could, arguably, still be better than normal readers. This may be why our lower ability group still showed a BOSS preference when making lexical decisions to low frequency words. Thus, the question remains open whether lower ability readers as defined by other, perhaps more stringent, measures of reading ability would still make use of a BOSS-based principle in recognising low frequency words.

Although we demonstrated the importance of the BOSS structure in English in the present study, it is possible that it may not emerge in orthographies with clear syllable boundaries (e.g., Spanish and Dutch) in which syllable units are presumed to be based on phonological structure (Álvarez, Carreiras, & Perea, 2004; Knuijt & Assink, 1997). Álvarez, Taft, and Carreiras (1998) found that Spanish readers preferred a Maximum Onset analysis whereas English good readers preferred a BOSS analysis when homographs in English and Spanish were directly compared using a split-word LDT. Álvarez et al. (2004) also obtained an advantage of phonologically based syllable structure with the primed LDT. Besides, Perea and Carreiras (1998) and Álvarez et al. (2001) demonstrated syllable frequency effects on both LDT and naming tasks in Spanish and Conrad and Jacobs (2004) replicated these effects in German. In other orthographies with clear syllable boundaries such as Dutch, Knuijt and Assink (1997) failed to find a BOSS advantage on a primed naming task and the split-word LDT.

Studies with bilinguals also provide evidence of different processing strategies in different language users. Taft (2002) compared segmentation preferences of two different non-native English speakers: Japanese, a syllable-based orthography, and Chinese, an orthography with ambiguous syllable boundaries, which could be identified as orthographic, phonological, and morphemic boundaries. Japanese speakers were found to show a Maximum Onset Preference for English split word lexical decision while Chinese speakers showed no preference (Taft, 2002). Chen, Vaid, and Choi

(2004) compared Spanish-English bilinguals and English monolinguals on English stimuli using a split-word LDT and found that whereas the English monolinguals showed a BOSS advantage for low frequency English words, the bilinguals preferred a Maximum Onset analysis, at least for low frequency English words with shared BOSSes. A subsequent study showed that Spanish-English bilinguals showed a MOP preference for low frequency words when tested in Spanish as well, and that two other bilingual groups, Hindi-English, and Kannada-English, did not show a BOSS or MOP preference for English words (Vaid, Chen, Martinez, & Rao, 2004). Taken together, these data suggest that, in some cases, characteristics of the first language may influence segmentation preferences in the second language (English). However, since there are very few cross-linguistic and bilingual studies to date, more research comparing native and non-native users of different orthographies is clearly needed.

It is important to note that while our data with English support Taft's (1979) BOSS proposal in suggesting that the syllable unit in English can be based on orthographic and morphological structure, they do not preclude a phonological basis for syllable representation in reading English polysyllable words. The experimental design in the present study permits conclusions only about the relative reliance on a BOSS vs. a Maximum Onset strategy for word segmentation. It is possible that readers make use of aspects of the spoken phonological structure in lexical processing, as suggested by theories such as the universal phonology principle (Perfetti & Zhang, 1995) or strong phonology theory (Frost, 1998). However, what our results do suggest is that reading models, whether dual route (e.g., Coltheart et al., 2001) or connectionist (e.g., Seidenberg & McClelland, 1989), should take into account syllabic representations based on orthographic and morphemic information as well as phonological information. As suggested by Álvarez et al. (2004), a model such as the bimodal interactive activation model (Grainger & Ferrand, 1994, 1996) with sublexical units at the syllable level, as proposed by Ferrand, Segui, and Grainger (1996), may be more appropriate to account for the present results, although the nature of this sublexical syllable unit might turn out to differ across different orthographies.

In summary, in the present research we systematically manipulated word frequency in addition to reader ability and shared/unshared BOSS applying a split-word lexical decision task. An interaction between word frequency and segmentation type was obtained with a reliable BOSS preference demonstrated for low frequency words only. Our results showed a BOSS advantage in lexical access for low frequency words regardless of reading ability.

The primary significance of our findings is that they establish that word frequency appears to modulate word segmentation preferences. Further research on word segmentation preferences is needed to delineate the parameters of this effect (e.g., whether only certain kinds of low frequency words are more likely to show a segmentation preference) and to explore how the observed differences in segmentation preferences interact with other differences, such as type of writing system, and native vs. non-native reader status.

Manuscript received August 2004
Revised manuscript received September 2005
First published online May 2006

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APPENDIX A
Stimuli used in Experiment 1 and Experiment 3

High frequency word		*Low frequency word*	
Shared BOSS	*Unshared BOSS*	*Shared BOSS*	*Unshared BOSS*
gi/v/en	se/v/en	ha/v/en	o/v/cn
or/d/er	un/d/er	ri/d/er	el/d/er
cen/t/ral	seve/r/al	figu/r/al	late/r/al
natu/r/al	fede/r/al	spi/r/al	lite/r/al
la/t/er	wa/t/er	vo/t/er	li/t/er
lo/w/er	po/w/er	se/w/er	to/w/er
cer/t/ain	cap/t/ain	sus/t/ain	cur/t/ain
lo/v/e	fi/v/e	ca/v/e	hi/v/e
li/v/e	ga/v/e	do/v/e	ri/v/e
na/t/ure	fu/t/ure	ma/t/ure	pos/t/ure
acti/v/ity	oppor/t/unity	actua/l/ity	eligibi/l/ity
cen/t/er	bet/t/er	hun/t/er	but/t/er
par/t/y	coun/t/y	sal/t/y	trea/t/y
pres/s/ure	mea/s/ure	clo/s/ure	lei/s/ure
sup/p/ort	re/p/ort	ex/p/ort	rap/p/ort
sim/p/le	cou/p/le	tri/p/le	tip/p/le

Note. The first slash denotes the position of the segmentation following MOP analysis and the second slash denotes the BOSS analysis.

APPENDIX B
Stimuli used in Experiment 2

High frequency word		Low frequency word	
Shared BOSS	*Unshared BOSS*	*Shared BOSS*	*Unshared BOSS*
ac/t/i/on	func/t/i/on	dic/t/i/on	tui/t/i/on
ba/s/i/s	cri/s/i/s	mime/s/i/s	the/s/i/s
buil/d/i/ng	mor/n/i/ng	pen/d/i/ng	dar/l/i/ng
chil/d/r/en	kit/ch/e/n	broa/d/e/n	sud/d/e/n
col/l/e/ge	advan/t/a/ge	car/r/i/age	pilgri/m/a/ge
cor/n/e/r	din/n/e/r	tur/n/e/r	ban/n/e/r
de/g/r/ee	cof/f/e/e	trus/t/e/e	ru/p/e/e
direc/t/o/r	charac/t/e/r	reac/t/o/r	banis/t/e/r
edi/t/o/r	shel/t/e/r	visi/t/o/r	clus/t/e/r
ef/f/e/ct	pro/j*/e/ct	sus/p/e/ct	in/j/e/ct
fac/t/o/r	chap/t/e/r	ou/t/e/r	hols/t/e/r
gover/n/o/r	man/n/e/r	hol/d/e/r	soo/n/e/r
le/g/a/l	fis/c/a/l	fo/c/a/l	feu/d/a/l
mar/r/i/age	ave/r/a/ge	cove/r/a/ge	beve/r/a/ge
mil/l/i/on	sea/s/o/n	fis/s/i/on	crim/s/o/n
mo/d/e/l	ho/t/e/l	mo/t/e/l	vo/w/e/l
offi/c/e/r	daugh/t/e/r	produ/c/e/r	slaugh/t/e/r
pa/p/e/r	dan/g/e/r	hel/p/e/r	fin/g/e/r
pic/t/u/re	proce/d/u/re	ges/t/u/re	aper/t/u/re
presi/d/e/nt	diffe/r/e/nt	confi/d/e/nt	cohe/r/e/nt
sec/t/i/on	ques/t/i/on	frac/t/i/on	fric/t/i/on
techni/c/a/l	hospi/t/a/l	cyni/c/a/l	mari/t/a/l
va/l/u/e	is/s/u/e	sta/t/u/e	res/c/u/e
wri/t/e/r	num/b/e/r	car/t/e/r	lum/b/e/r

Note. The first slash denotes the position of the segmentation following MOP analysis, the second slash denotes the BOSS analysis, and the third slash denotes the BOSS+1 analysis.