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THE TIME COURSE OF LEXICAL ACTIVATION: SEQUENTIAL CONSTRAINT, CO-ARTICULATORY PREVIEW AND ADDITIONAL PROCESSING TIME

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ABSTRACT

Three experiments are reported that examine the manner in which lexical information unfolding over time modulates lexical activation. Three word lengths (one, two and three or more syllables) were used to manipulate the degree of constraint afforded the word-final target phoneme. An additional manipulation (developed in Experiment 1) permits a measure of changes in activation given additional processing time where a silent interval is introduced prior to the target phoneme. The silent interval facilitates phoneme monitoring reaction time and provides a sensitive measure of the time course of lexical activation. Experiment 2 manipulates degree of activation via mismatching segments and shows that information subsequent to the mismatch is utilized to modulate activation in a manner dependent on word length and the availability of additional processing time. Experiment 3 examines the time course of co-articulatory effects as a function of word length and processing time. Taken together, the results show a dynamic use of information over time where information across the extent of a word contributes to lexical activation. Complimentary to this, activation of lexical representations is not statically tied to acoustic-phonetic input but benefits from additional processing time.

1. INTRODUCTION

Spoken language differs fundamentally from visual language in its explicit distribution of information over time. This explicit distribution of information over time is manifest in a number of ways. For a given word, the degree of constraint available in a left-to-right fashion for a given segment is linked to the receipt of the sequence of segments, a sequence that is temporally distributed. Lexical constraint differs across lexical items in a way that is related to word length- the longer the word, the more information is available from the speech signal to specify lexical identity. Although information is received in a left-to-right fashion, the consequences of this aspect of lexical constraint is bi-directional - subsequent segments can serve to supplement faulty or ambiguous information in previous segments and in doing so, provide a continuous source of evidence for a lexical representation. Past research has provided strong evidence for this claim and its associated claim of graded activation based on similarity of features [1] [2]. The temporal dimension of activation is presumed to be a processing characteristic that is responsible for the graceful recovery of activation given erroneous hypotheses and for increasing levels of commitment to a lexical hypothesis (as indexed by activation). These experiments investigate the functional properties of spoken word recognition in permitting flexible use of information over time that require no special significance to a particular portion of a word. [1] [3]. As implied by graded activation, information throughout a word's extent can modulate activation. One consequence is that activation can fluctuate throughout a word's extent; downstream information in the signal can influence both the time course and final activation of a lexical representation. A related issue that has only recently begun to be investigated is the contribution of time to the activation of a word. This approach has focused on changes in lexical activation subsequent to the offset of a stimulus. This research suggests that lexical activation is not statically linked to the cessation of acoustic-phonetic input but can continue to accrue following its offset [4]. Rather, as our experiments show, activation can wax and wane over time in the absence of additional input.

2. EXPERIMENT 1

Experiment 1 was designed to develop a modification of the phoneme monitoring paradigm that permits additional processing time prior to a phoneme target. In this experiment, target segments occurred in word-final position and an interval of silence (0ms, 50ms, 150ms, 300ms) was inserted prior to the onset of the target segment. Table 1 reports phoneme monitoring reaction time from the onset of frication.

Table 1. Phoneme monitoring reaction time as a function of delay. Experiment 1.

TARGET DELAY	0	50	150	300
	505	473	443	384

As can be seen in Table 1, phoneme monitoring reaction time decreased as the temporal delay increased. We attribute this effect to an expectation for the target segment that increases with additional processing time. Specifically, the temporal dimension of activation tracked in the delayed phoneme identification paradigm is presumed to be a processing characteristic that is responsible for the graceful recovery of activation given erroneous hypotheses and for increasing levels of commitment to a lexical hypothesis (as indexed by activation). This is consistent with a functional property of spoken word recognition in permitting flexible use of information over time that assigns no special significance to a particular portion of a word.

3. EXPERIMENT 2

Experiment 2 was designed to extend the results of Experiment 1. We focused on some inter-related properties that govern spoken word activation. Relative degree of activation was manipulated two ways: 1) by decreasing the similarity between the input and a lexical representation and 2) by manipulating properties of the lexical items themselves. The similarity manipulation was accomplished by including a condition with an initial mismatching segment (derived non-words) and lexical properties were manipulated by including short (one syllable), medium (two syllable) and long (three or more syllables) words. Similar to Experiment 1, we examined the consequence of additional processing time for both of these dimensions of lexical activation using the phoneme monitoring delay manipulation. Final phoneme targets were preceded by 0 (no delay), 150ms or 300ms of inserted silence. The stimuli are illustrated in Table 2.

Table 2. Experiment 2 sample stimuli.

	Word	Nonword
Short	bus	Dus
Medium	chorus	Gorus
Long	ridiculous	Lidiculous

Phoneme monitoring reaction times are shown in Table 3 as a function of stimulus type (short, medium or long words), similarity (word and derived nonword) and target delay (0, 150 or 300).

Table 3. Phoneme monitoring reaction time as a function of word length, delay and carrier (word or nonword). Experiment 2.

	WORD			NONWORD		
LENGTH	0	150	300	0	150	300
SHORT	622	595	577	646	645	613
MED	541	493	444	597	546	519
LONG	434	390	387	499	428	412

The stimulus length manipulation was effective- at the 0ms delay, phoneme monitoring reaction time decreased as lexical length increased. Also evident was an effect of temporal delay in that all word types showed a decrease in reaction time given additional processing time afforded by the delay manipulation. Finally, word carriers showed faster reaction times than their nonword counterparts.

The utility of the additional processing time afforded by the delay differed across the three word types. Table 4 shows the advantage afforded by the 150 ms delay (0-150) and any additional advantage found for the 300 ms delay (150-300) for each word type. The final columns display the total advantage across the two delay conditions. The delay advantage is shown separately for words and derived nonwords. Although the total processing time advantage was comparable for the medium and long words, the time course of the delay advantage differed across word type. Medium and short words showed a large and comparable advantage with each delay indicating that the advantage for additional processing time continued beyond the 150 ms window. In contrast, long words showed a processing time advantage only within the 150ms window and showed no further advantage given the 300 ms delay. Finally, the total processing time advantage was smaller for short compared to the other word lengths. The pattern of results indicates that even for words where the final segment is completely determined by the preceding lexical context, additional processing time affords an advantage in processing.

Table 4. Phoneme Monitoring Delay Advantage. Experiment 2.

WORD

LENGTH	0~150	150~300	TOTAL
SHORT	27	18	33
MEDIUM	48	49	76
LONG	44	3	87

DERIVED NONWORD

LENGTH	0~150	150~300	TOTAL
SHORT	1	32	83
MEDIUM	51	27	128
LONG	71	16	63

The influence of processing time and lexical constraint is seen in the derived nonwords -- they showed an initial delay advantage that increased with word length. During the initial 150 ms prior to the target, the constraint provided by the longer word types was more effective in compensating for the decreased activation resulting from the mismatching segment. Subsequent processing time did not provide much additional benefit. This pattern contrasts with the short words where additional processing time was beneficial only at the longer delay. Medium words showed a pattern intermediate between these two extremes.

Table 5 highlights the waxing and waning of lexical effects given additional processing time for each word length.

Table 5. Lexical advantage as a function of word length and delay. Experiment 2.

WORD LENGTH	0	150	300
SHORT	24	50	36
MEDIUM	56	53	75
LONG	65	38	25

As is shown in Table 5, the initial lexical effect (0ms delay) is smaller for short stimuli relative to medium and long words. For long words, what functions to facilitate reaction time at the 0 delay condition? One obvious possibility is that the final phoneme is completely determined by the preceding sequence of segments (the target is subsequent to the "uniqueness point"). However, a lexical effect is still evident even after the delay. This suggests that the initial facilitation found for long words is not simply because of the sequential constraint available from lexical properties (e.g. given RIDICULOU_, there exists only a single lexically consistent phoneme). Rather, this view suggests that activation of a lexical representation is not statically tied to incoming information but unfolds over time. For the long words, the additional processing time diminishes the influence of the mismatching initial-segment in the carrier nonword- by 300 ms subsequent to the penultimate segment, the word and nonword stimuli function as more equivalent stimuli. The additional processing time afforded by the delay is also effective for the short and medium words where a maximum lexical advantage is found at either 150 ms (short words) or 300 ms (medium words). The increase in the lexical effect given additional processing time for short and medium words similarly suggests that lexical constraint provided by the sequential input of speech is not the only operating factor. For these word lengths, the final segment is only marginally constrained by the preceding segments (medium stimuli) or permits a very wide range of possible endings that form a word (short stimuli).

4. EXPERIMENT 3

The results of Experiment 2 suggest that lexical activation is a dynamic system that changes given additional processing time, even in the absence of additional acoustic-phonetic input. In Experiment 3, we focus on one possible source of the processing time effects, specifically, co-articulatory information prior to the final segment. Previous experiments have investigated the influence of co-articulation by demonstrating the consequences of conflicting cues for fricative place of articulation where vowel formant transitions were consistent or inconsistent with the fricative noise [5]. Inconsistent stimuli consisted of a vowel originally produced with a "sh" combined with the frication for an unambiguous "s". In general, these results show that subjects took longer to make a phonetic decision in the mismatch condition even though the inconsistent cues in the fricative noise and the vowel portion were not consciously detectable.

Co-articulatory information provides a vehicle to examine the consequences of both anticipatory and temporal processes in spoken word recognition. Our approach was to track the time course of co-articulatory effects across different categories of word lengths by examining mismatching co-articulatory effects. In Experiment 3, a set of one (e.g. miss), two (e.g. compass) and three syllable (e.g. reminisce) words were used all ending in /s/. A set of 'sh' nonword stimuli were recorded along with the three sets of words ending in /s/ in which the final /s/ is replaced with 'sh'. A mismatch condition was created by combining the initial portion of each 'sh' stimulus with the final /s/ from its 's' counterpart. A match condition was created from two recordings of the word stimuli. Similar to Experiments 1 and 2, an additional condition included a 300 ms period of silence prior to the target. Phoneme monitoring responses for the final segment /s/ are reported beginning at the onset of the frication. Phoneme monitoring reaction times are presented in Table 6 for the no delay condition and in Table 7 for the delay condition. The final column in each table shows the mismatch effect for each word type.

Table 6. Phoneme monitoring reaction time for matching and co-articulatory mismatch stimuli as a function of word length for the no delay condition. Experiment 3.

NO DELAY

WORD LENGTH	MATCH	MISMATCH	EFFECT
SHORT	568	592	24
MEDIUM	568	617	49
LONG	504	545	41

In the no delay condition, medium and long word lengths showed comparable mismatch effects while the short words showed a reduced effect. This suggests that for longer words, co-articulatory information is available more readily available.

Table 7. Phoneme monitoring reaction time for matching and co-articulatory mismatch stimuli as a function of word length for the no delay condition. Experiment 3.

DELAY

WORD LENGTH	MATCH	MISMATCH	EFFECT
SHORT	414	482	68
MEDIUM	375	423	48
LONG	388	403	15

In contrast, Table 7 shows a more robust influence of co-articulatory information only after additional processing (300 ms delay) for short words. This suggests a later time course for the consequences of co-articulatory information than for longer words. Thus, similar to the consequences of segmental mismatches found in Experiment 2, effects of subcategorical mismatch shows a different time course across the different word lengths.

5. DISCUSSION

One major finding of the experiments is that the extra processing time available in the delay conditions resulted in facilitated processing. The time course of the facilitation varied across word length but all words, including long words where the final phoneme was completely determined, showed benefits. Experiment 2 demonstrated that activation levels fluctuate over time in a way that serves to maximize activation levels given mismatching information. For long words, the evidence subsequent to the mismatch functioned to render words and derived nonwords almost equivalent given 300 ms additional processing time. Finally, a similar influence of additional processing time was evident for co-articulatory information. Mismatch effects for short words were enhanced given additional processing time. In contrast, long words showed immediate robust effects of co-articulatory information that diminished over time. Taken together, the results show a dynamic use of information over time where information across the extent of a word contributes to lexical activation. Complimentary to this, activation of lexical representations is not statically tied to acoustic-phonetic input but benefits from continued processing time.

6. ACKNOWLEDGMENTS

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