Articulatory correlates of morpheme boundaries: preliminary evidence from intra- and inter-gestural timing in the articulation of the English past tense

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Acoustic and articulatory studies examining morpheme boundary effects have reported mixed results. Comparing the acoustic duration of segments in homophonous pairs of inflected and simple words, e.g. *frees* vs. *freeze,* [6] found that both the stem and suffix were longer in inflected words than in simple words, with a caveat: the effect was only significant for fricative-final (*-s*) words, but not stop-final (*-ed*) words. The stop-final morpheme in [6] was the English past tense, which we also investigate here. One possible explanation for the discrepancy between fricatives and stops is that the morpheme boundary effects were not captured by acoustic measurements of stop duration. We hypothesize that the effects may still be present in articulation. Other studies have shown reliable effects of morpheme boundaries on articulatory-based measures of inter-gestural timing [3, 4]. [3] examined hetero-morphemic and tauto-morphemic /pi/ sequences in Korean, looking specifically at the interval left-delimited by the midpoint of /p/ and right-delimited by the acoustic endpoint of /i/. They found greater variability (measured as standard deviation) in this interval across morphemes than within-morphemes. More recently, [4], also examining /pi/ sequences in Korean but with inter-gestural timing based solely on articulatory landmarks and using relative standard deviation (RSD) as an index of variability, reported similar findings. However, in both [3, 4], stimuli for the tauto- vs. hetero-morphemic contexts were possibly confounded with word frequency, with the mono-morphemic items (more stable) being more frequent, and did not preclude resyllabification. Thus, evidence for morpheme boundary effects on articulatory gestures remains inconclusive.

This study addresses this issue by examining intra- and inter-gestural timing in English /kt/ and /pt/ coda sequences in eight sets of word quadruples. Each quadruple crosses two conditions: morpheme boundary presence/absence and the wordhood (real/nonce) of the stem (see Table 1). We used the English past tense morpheme to induce a morpheme boundary in the bi-morphemic condition, as in [6]. Articulatory data was collected using the NDI Wave Speech Production system. Sensors were tracked on the tongue tip, tongue blade, tongue dorsum, jaw, lower and upper lips, along with reference sensors on the nasion and left/right mastoids, used to correct for head movements. Data was collected from four talkers, who produced a total of 3,729 tokens for analysis.

Table 1 sample stimuli: one set of quadruples (in shade) in their carrier phrases.

Morpheme Boundary	Mono-morphemic (no boundary)		Bi-morphemic (morpheme boundary)	
Wordhood	Real	Nonce	Real	Nonce
Example item	*A need to inspect hearts*	*A need to instect hearts*	*Anita pecked hearts*	*Anita tecked hearts*

We used the findgest algorithm in MVIEW, a Matlab-based program [7], to extract four spatio-temporal landmarks from each stop consonant in the target sequences (/pt/, /kt/): the ONSET of gestural movement, the achievement of TARGET, the RELEASE from constriction and the OFFSET of movement. These landmarks were used to delimit nine intervals, four intra-gestural intervals and five inter-gestural intervals, listed in Table 2 (also see Figure 1). We fit linear mixed effects models [1, 5] to each, assessing the effects of morpheme boundary on interval duration and interval variability (RSD). Significance was determined by comparison of nested models via likelihood ratio tests. The baseline model consisted of segment count and wordhood as fixed factors, and by-speaker and by-word random intercepts. The addition of morpheme boundary as a fixed factor significantly improved model fit to the duration of two (of nine) intervals and to the variability of one (of nine). C1 plateau duration, an intra-gestural measure, and TARGET-TO-TARGET duration, an inter-gestural measure, were both longer in the bi-morphemic condition. The ONSET-TO-TARGET interval was the only interval to show an effect of morpheme boundary on variability, being more variable in the bi-morphemic condition than the mono-morphemic condition. Additional fixed factors, cluster type (/pt/ vs. /kt/), cluster type*morpheme boundary interaction, and wordhood*morpheme boundary interaction did not improve model fit. Thus, the effects of morpheme boundary were uniform across segments as well as extreme differences in frequency, captured by the wordhood factor.

To summarize, our analysis showed that the presence of a morpheme boundary conditioned longer plateau duration (closure phase) for the pre-boundary stop consonant, irrespective of the consonant's identity or the frequency of the stem. The variability of the TARGET-TO-ONSET interval was also impacted by the morpheme boundary. These effects may follow from a common mechanism. First, we note that the TARGET-TO-TARGET interval can be decomposed into C1 plateau duration (C1 TARGET to C1 RELEASE) and the RELEASE-TO-TARGET interval. Since the RELEASE-TO-TARGET interval did not show an effect of morpheme boundary, it seems that the differences in TARGET-TO-TARGET interval can largely be attributed to variation in C1 plateau duration. Morpheme boundaries may therefore slow stem-final articulation similarly to how prosodic boundaries slow boundary-adjacent gestures [e.g. 2] except that the effect of the morpheme boundary is localized to the plateau of the preceding gesture. It is possible that morpheme-boundary based lengthening has its basis in lexical access. In bi-morphemic sequences, retrieval of the articulatory program for the second morpheme may be initiated when the final gesture of the first morpheme achieves its TARGET, facilitating a smooth transition to the second morpheme. In contrast, in mono-morphemic sequences, all gestures in the sequence belong to the same morpheme and may consequently be planned and actuated together. No additional gesture retrieval is required for a mono-morphemic word. This may also explain why the TARGET-TO-ONSET interval is more stable in the mono-morphemic condition than in the bi-morphemic condition. Variability in the onset of C2 only when C2 is a separate morpheme follows from the temporal cost of additional lexical access. On this view, prolonged plateau duration for the consonant preceding a morpheme boundary and increased variability of the TARGET-TO-ONSET interval are expected temporal consequences of morphological complexity.

Table 2 Morpheme boundary effects on duration and variability of 9 intervals based on model comparison
(1) – (4) are intra-gestural intervals; (5) – (9) are inter-gestural intervals.
NS = not significant; * = $p < 0.05$; ** = $p < 0.01$

Intervals	C1 landmark	C2 landmark	Stats (duration)	Stats (RSD)
(1) C1 gestural duration	ONSET OFFSET		NS	NS
(2) C2 gestural duration		ONSET OFFSET	NS	NS
(3) C1 plateau duration	TARGET RELEASE		*	NS
(4) C2 plateau duration		TARGET RELEASE	NS	NS
(5) ONSET TO ONSET	ONSET	ONSET	NS	NS
(6) TARGET TO ONSET	TARGET	ONSET	NS	*
(7) TARGET TO TARGET	TARGET	TARGET	**	NS
(8) RELEASE TO TARGET	RELEASE	TARGET	NS	NS
(9) OFFSET TO ONSET	OFFSET	ONSET	NS	NS

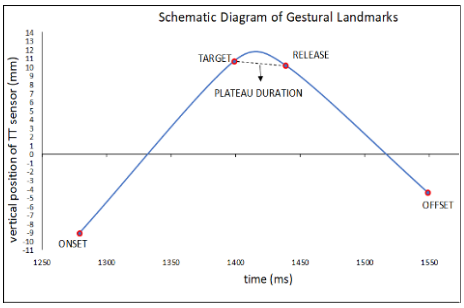

Figure 1 Schematic diagram of gestural landmarks

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