INTRA- AND INTER-SYLLABIC COORDINATION: AN ARTICULATORY STUDY OF TAIWANESE AND ENGLISH

M. Gao[a], *C. Mooshammer*[b], *C. Hagedorn*[c], *H. Nam*[b], *M. Tiede*[b,d], *Y. C. Chang*[e], *F. F. Hsieh*[e] & *L. Goldstein*[b,c]

[a]Dalarna University, Sweden; [b]Haskins Laboratories, New Haven, USA; [c]Department of Linguistics, University of Southern California, USA; [d]MIT Research Lab of Electronics, USA; [e]Graduate Institute of Linguistics, National Tsinghua University, Taiwan

mao@du.se

ABSTRACT

In this study the intra- and inter-gestural timing and coordination in English closed syllables and Taiwanese checked [1] syllables is examined. Kinematic data elicited from a repetition task reveals that the vowel is co-articulated with the onset and coda consonants to a greater extent in Taiwanese checked syllables than English closed syllables; for Taiwanese greater overlap is observed between the hetero-syllabic coda and onset consonants. The different gestural overlap patterns in Taiwanese and English are accounted for with reference to the language-specific gestural pattern.

Keywords: gestural overlap, gestural coordination, checked syllable

1. INTRODUCTION

This study aims to compare gestural timing in English closed syllables (e.g. *cop* [kɑp]) and Taiwanese checked syllables (e.g. 洽[kap˺](H)). Checked syllables are common in many Sino-Tibetan languages. They generally differ from closed syllables in English in that only one consonant (obstruent) is allowed in the coda position; the coda consonant must also either be unreleased (i.e. [p˺], [t˺], [k˺]) or a glottal stop. Such syllables are often described in the literature as 'short' (in duration), 'glottalized' or 'unreleased' [8, 10].

There have been a number of articulatory studies investigating consonant overlap patterns in English, Russian, and Korean [1, 2, 4, 9, 15, 16]. Results of these studies point towards language-specific patterns of consonant overlap. For instance, English consonants were shown to display substantial overlap [1, 2, 15], whereas Russian consonants were found to display very little overlap [9, 16]. As to English and Taiwanese, a recent study of consonant overlap in a variety of languages [14] found that consonants across syllable boundaries in Taiwanese showed less overlap than in English, based on acoustic data. However, no kinematic study has been carried out to examine the temporal relations of consonants in both the intra-syllabic and inter-syllabic positions, or to make a comparison with similar English data.

The aim of the current study is to compare closed vs. checked syllables regarding both 1) intra-syllabic coordination (the timing relations between onset and coda consonants within the same syllable), and 2) inter-syllabic coordination (the timing relations between hetero-syllabic coda and following onset consonant). Since previous studies [7, 11, 13] revealed that similar, non-identical words were more difficult to utter in sequence than identical words, the potential difference in gestural coordination patterns between identical and near-identical words is also examined.

2. METHOD

2.1. Participants

The participants in this experiment were four native Taiwanese (TW) speakers (4 male), and six native speakers of American English (AmE, 3 female and 3 male). All four TW speakers were born in Taiwan and regularly use Taiwanese for communication with their family and other Taiwanese people. From their self-report, all participants were free from any speech or hearing deficits, or respiratory infections.

2.2. Materials

All target words have the same CVC syllable structure and similar segmental components. Onset C is either /t/ or /k/ and the coda C is /p/; the V is /ɑ/ for AmE and /a/ for TW. The target words used are: *top* [tɑp], *cop* [kɑp] (AmE), and 洽, 敆[kap˺], and 答[tap˺] (TW). The words were presented as two alternating word pairs and two non-alternating control pairs in both TW and AmE:

- Taiwanese:
  答敆 [tap˺ kap˺] (H L); 洽答 [kap˺ tap˺] (H L)
  答答 [tap˺ tap˺] (H L); 敆敆 [kap˺ kap˺] (H L)
- American English:
  top cop; cop top & top top; cop cop

2.3. Procedure

Kinematic and acoustic data were collected at the physiology lab at Haskins Labs using the MIT Electromagnetic Midsagittal Articulometer (EMMA) system [12] and 3D EMA (AG500, Carstens Electronics), which use small receiver coils attached to the speech articulators to track their motion in the midsagittal plane.

A standard calibration procedure was carried out before each experiment. The data were collected from coils attached to the upper and lower lips, lower incisors, tongue tip, tongue body and tongue dorsum. Additional coils attached to the upper incisors and nasion were used to correct for head movement. The data were sampled at 500 Hz, smoothed with a 15 Hz low-pass filter, and rotated and translated to an occlusal plane reference. Acoustic data were recorded at a sampling rate of 16 kHz with a Sennheiser directional microphone at a distance from the participant's mouth of approximately 30 cm.

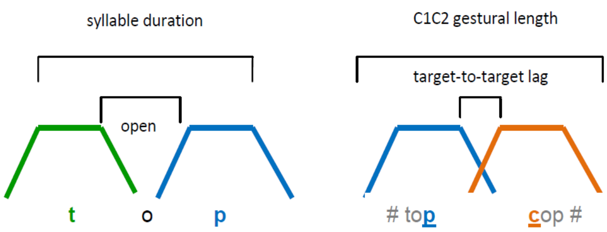
Participants were instructed to repeat each word pair for 20 seconds following a metronome beat which after 10 seconds accelerated gradually for another 10 seconds. During the practice trial, sufficient time was provided to each speaker to practice speaking in synchrony with the metronome. The starting rate was within the range of 130 to 170 beats per minute, and the metronome beats were presented to each participant through an earphone.

2.4. Measurement

The data collected from TW and AmE speakers were subjected to the same analysis. The onset of movement, the achievement of constriction, and constriction release were determined and labeled for every consonant using tangential velocity criteria applied to the trajectory of the EMMA coil closest to the articulator that forms the constriction (please refer to [3] for a detailed description of the labeling procedure). The following temporal landmarks [5] were labeled and used for subsequent computation: gesture onset (GONS), constriction plateau achievement (TONS), maximum constriction (MAX), constriction plateau offset (TOFF) and gesture offset (GOFFS).

In order to compare intra-syllabic gestural coordination between the two languages, the target plateaus for onset and coda consonants within the same syllable and the opening between these two plateaus were measured. The duration from the beginning of the first plateau to the end of the second plateau – was labeled as 'syllable duration' (see Figure 1 left).

Figure 1: Measuring intra-syllabic coordination (left) and inter-syllabic coordination (right).



In order to examine inter-syllabic gestural coordination, the temporal lag between the offset of constriction achievement for the coda C gesture (C1:TOFF) and the achievement of the C constriction (C2:TONS) in the following syllable was computed (labeled as target-to-target lag in Figure 1 right). The duration of these two gestures (GONS of C1 to GOFF of C2) was used to time-normalize the target-to-target lags. Only the inter-gestural timing within a word-pair, but not across words in successive pairs is examined in this study.

3. RESULTS

3.1. Intra-syllabic coordination

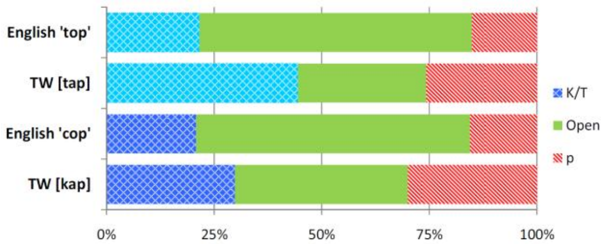
Within every target syllable, the duration of the onset and coda consonants, and the open interval (approximately corresponding to the vowel duration) were computed as normalized percentages of the duration of the sequence ('syllable duration' in Figure 1 left).

Syllable durations of control and alternating pairs were first compared. Since they were very similar, and the results of these two types of syllable are therefore pooled in the following comparison.

Figure 2 displays cross-subject averages for AmE [tɑp], [kɑp] and TW [tap˺], [kap˺]. Overall, TW syllables show much shorter open intervals, but much longer consonantal constrictions for both onset and coda consonants, than AmE syllables. It is interesting to note that the open interval in both

AmE syllables takes up more than half of the syllable duration (63.7% and 63.3%), whereas the vowel in both TW syllables takes less than half of the syllable duration.

Figure 2: Relative duration of onset, open interval and coda in TW and AmE data.



For TW, the constriction interval of onset [t] constitutes nearly half of the syllable duration in [tap˺] (44.5%), which is significantly more than for onset [k] in [kap˺] (29.8%). This pattern is not observed in AmE syllables, in which the corresponding proportion of [t] and [k] are 21.6% and 20.8% respectively. As for coda consonants, the constriction of the unreleased [p˺] in TW syllables constitutes a longer relative proportion than that of [p] in AmE syllables.

The absolute values of the constriction and open intervals vary greatly in the two languages as well. The constriction intervals of both onset and coda are significantly longer in TW, whereas the open interval is much shorter in TW than in AmE (see Table 1).

Table 1: Duration of onset and coda in TW and AmE.

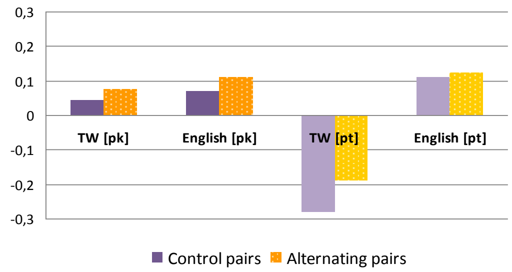
(ms)	TW	AmE
Onset C	165	68
Open (≈V)	145	205
Coda C	114	51
Total	424	324

3.2. Inter-syllabic coordination

The results of the gestural timing across syllables are displayed in Figure 3. The standardized target-to-target lags for [p#t] and [p#k] are used for comparison; a negative value means that the constriction intervals of the two gestures overlap, whereas a positive value indicates a lag between the constriction for the two gestures.

As seen in Figure 3, only the TW [pt] sequence displays an overlap between hetero-syllabic coda and onset consonants, in both the control and alternating pair. Overall, the inter-gestural coordination displays a greater lag, and a lesser degree of overlap, in alternating pairs (represented by orange bars in Figure 3) than in control pairs (purple bars) for both TW (p<0.01) and AmE (significant only for [pk], p<0.05). For the [pk] sequence, TW displays a shorter lag than AmE. Within the TW data, the [pt] sequence shows an overlap, unlike the [pk] sequence. Another pattern is observed in AmE: for alternating pairs the [pt] and [pk] lags are similar; however for control pairs the [pk] lag is considerably shorter.

Figure 3: Relative target-to-target lag in TW and AmE.



4. DISCUSSION

The results suggest that TW checked syllables differ from AmE closed syllables in terms of gestural timing both within syllable and across syllables.

Intra-syllabically, the onset C, V and coda C within a TW syllable differ from AmE in two ways. First of all, both the onset and coda C display much longer constriction intervals in TW: the temporal measurements of TW onset and unreleased coda C are more than twice as long as in AmE. Secondly, the TW data displays much shorter open interval, which takes less than half of the syllable duration. According to the C-V coupling hypothesis [6], the onset C and V exhibit in-phase relation, and the coda C and V exhibit anti-phase relation in English. If TW syllables are similar to English syllables in this regard, we may infer from the duration of open intervals that the onset and coda Cs display a greater degree of overlap with V in TW than in AmE, i.e. the vowel is co-articulated with consonants for longer interval within a Taiwanese syllable.

Inter-syllabically, the TW [pt] sequence is the only one for which an overlap in constriction intervals is observed (i.e. negative target-to-target lag). However, the target-to-target lag for [pk] in TW is shorter than in AmE, meaning that the coda C gesture (as opposed to the constriction interval) exhibits a higher degree of overlap with the onset C gesture in the following syllable in TW. These two findings are generally consistent with the previous finding regarding the longer constriction interval of TW consonants; they may potentially also be related to the unreleased nature of the coda C in TW: the greater degree of overlap may reflect a strategy to avoid audible release of the first gesture (i.e. coda C in first syllable). The significantly greater overlap for [pt] than [pk] sequences in TW may potentially be attributed to a shared articulator – the jaw. Because the formation of both [p] and [t] constriction involves the jaw movement, a possible explanation is that it is more natural and more 'economic' to articulate [p] and [t] in a near-synchronous manner. However, the same pattern was not observed for AmE, for which the [pk] sequence instead displays a marginally greater overlap than [pt] sequences.

Finally, the alternating pair was found to display less overlap than the non-alternating control pair for both [pk] and [pt] sequences and in both languages. This is consistent with previous findings of a longer lag (i.e. less overlap) between similar, non-identical words than between identical words [7, 11, 13].

5. CONCLUSION

This paper has presented a kinematic study of intra- and inter-syllabic gestural coordination in TW and AmE. The results revealed a number of systematic differences between the two languages, which lead us to the findings that consonants in TW have longer constriction duration than in AmE, and also that consonants and vowels in TW are overlapped (co-articulated) to a greater extent than in AmE, both within the same CVC syllable and across syllable boundary. The longer constriction duration is a language-specific characteristic of TW, and it can be used to account for the greater inter-syllabic overlap in TW. Additionally, we also proposed that the greater inter-syllabic overlap may be related to the unreleased coda in TW: the oral constriction of a preceding consonant is greatly overlapped with the following consonant to achieve a non-audible release. However, no effect of the speeded production rate was observed on the intra-syllabic or inter-syllabic timing relations in either language.

6. REFERENCES

[1] Browman, C.P., Goldstein, L. 1990. Tiers in articulatory phonology, with some implications for casual speech. In Kingston, J., Beckman, M.E. (eds.), *Papers in Laboratory Phonology I: Between the Grammar and Physics of Speech*. Cambridge, UK: Cambridge University Press, 341-376.

[2] Byrd, D. 1996. Influences on articulatory timing in consonant sequences. *Journal of Phonetics* 24, 209-244.

[3] Byrd, D., et al. 2008. Phrase boundary effects on the temporal kinematics of sequential tongue tip consonants. *JASA* 123(6), 4456-4465.

[4] Cho, T. 2001. Effects of morpheme boundaries on intergestural timing: Evidence from Korean. *Phonetica* 58, 129-162.

[5] Gafos, A. 2002. A grammar of gestural coordination. *Natural Language and Linguistic Theory* 20, 269-337.

[6] Goldstein, L., et al. 2006. The role of vocal tract gestural action units in understanding the evolution of phonology. In Arbib, M. (ed.), *From Action to Language: The Mirror Neuron System.* Cambridge: Cambridge University Press, 215-249.

[7] Goldstein, L., et al. 2007. Dynamic action units slip in speech production errors. *Cognition* 103(3), 386-412.

[8] Iwata, R., Sawashima, M., Hirose, H., Niimi, S. 1979. Laryngeal adjustments of Fukienese stops, initial plosives and final applosives. *Annual Bulletin of Research Institute Logopedics and Phoniatrics* 13, 61-81.

[9] Kochetov, A. 2002. *Production, Perception, and Emergent Phonotactic Patterns: A Case of Contrastive Palatalization.* London and New York: Routledge.

[10] Matthews, S., Yip, V. 1994. *Cantonese: A Comprehensive Grammar*. London and New York: Routledge.

[11] Meyer, D.E., Gordon, P.C. 1985. Speech production: motor programming of phonetic features. *Journal of Language and Memory* 24, 3-26.

[12] Perkell, J., Cohen, M., Svirsky, M., Matthies, M., Garabieta, I., Jackson, M. 1992. Electromagnetic Midsagittal Articulometer (EMMA) systems for transducing speech articulatory movements. *Journal of the Acoustical Society of America* 92, 3078-3096.

[13] Pouplier, M., Goldstein, L. 2005. Asymmetries in the perception of speech production errors. *Journal of Phonetics* 33, 47-75.

[14] Yanagawa, M. 2006. *Articulatory Timing in First and Second Language: A Cross-Linguistic Study*. Yale University Dissertation.

[15] Zsiga, E.C. 1994. Acoustic evidence for gestural overlap in consonant sequences. *Journal of Phonetics* 22, 121-140.

[16] Zsiga, E.C. 2000. Phonetic alignment constraints: Consonant overlap and palatalization in English and Russian. *Journal of Phonetics* 28, 69-102.

[1] While both terms 'closed' and 'checked' are sometimes used for English syllables such as *top*, the former term is here used for English syllables and the latter for Taiwanese syllables ending in a glottal stop or an unreleased oral stop.