# Supplementary Material for:
## Chunking of phonological units in speech sequencing

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### S.1 Effects of syllable position on speech motor learning

We conducted two additional sets of analyses to test for effects of syllable position (syllable-initial [onset] clusters vs. syllable-final [coda] clusters) as such effects are suggested by some theories of speech production (see, e.g., Browman & Goldstein, 1988, 1995; Byrd, 1995, 1996; Keating, Wright, & Zhang, 1999; Byrd, Lee, Riggs, & Adams, 2005; Bohland, Bullock & Guenther, 2010).

*S.1.1. Evidence of learning for practiced syllables.*

Our first set of analyses was aimed at examining performance improvements over the course of the practice blocks on day one. We conducted an ANOVA (with syllable sequence type [native CC vs. non-native CC], syllable position [onset vs. coda], and time (first five trials vs. last five trials) as within-subjects factors) on the mean percentage of *sequencing errors* during the practice blocks (on day 1). Figure S1 shows of the mean percentage of *sequencing errors* for each sequence type (native CC vs. non-native CC) as a function of syllable position (onset vs. coda) and time (first five trials vs. last five trials).

The ANOVA revealed a significant main effect of sequence type [$F(1,10) = 109.938$, $p < 0.001$, $\eta^2 = 0.917$], such that speakers produced fewer errors while executing the *native CC* syllables ($M = 3.0$, $SD = 5.1$) compared to the *non-native CC* syllables ($M = 44.0$, $SD = 19.9$). there was also a main effect of time, such that speakers produced more errors during the first five trials (on day 1; $M = 29.6$, $SD = 28.1$) compared to the last five trials (on day 1; $M = 15.79$, $SD = 20.66$). The interaction effect between time and sequence type approached significance [$F(1,10) = 3.836$, $p = 0.079$, $\eta^2 = 0.277$]. To tease apart the interaction, difference scores were computed by subtracting the mean sequencing error rates averaged across the first five and last five trials for each sequence type. A post-hoc LSD *t*-test performed on these difference scores indicated that they were marginally significantly larger for the *non-native CC* syllables [$M = 18.1$, $SD = 21.4$] compared to the *native CC* syllables [$M = 6.1$, $SD = 5.9$; $t(10) = -1.930$, $p = 0.079$].

Critically, however, the main effect of syllable position [$F(1,10) = 2.518$, $p = 0.144$, $\eta^2 = 0.201$] did not reach statistical significance. In addition, none of the interaction effects involving syllable position were significant: syllable position × time [$F(1,10) = .457$, $p = 0.514$, $\eta^2 = 0.044$]; syllable position × sequence type [$F(1,10) = 2.758$, $p = 0.128$, $\eta^2 = 0.216$]; syllable position × time × sequence type [$F(1,10) = .444$, $p = 0.520$, $\eta^2 = 0.043$].

*S.1.2. Generalization of learning to novel syllables.*

Our second set of analyses were designed to examine the specificity of the motor sequence learning that occurred for syllables containing non-native onset and coda clusters during the practice blocks. We conducted separate ANOVAs (with syllable sequence type [practiced CCVCC vs. practiced CC vs. practiced CVC vs. novel CCVCC] and syllable position [onset vs. coda] as within-subjects factors) on the mean percentage of sequencing errors and the mean percentage of total errors (sequencing and non-sequencing) for the first five trials of the test session (to minimize practice effects during the test phase). Figure S2 shows boxplots of the mean percentage of *sequencing errors* (see main text for details) for the first five utterances of each syllable type as a function of syllable position (onset vs. coda). The ANOVA showed a significant main effect of sequence type [$F(3,30) = 3.306$, $p = 0.033$, $\eta^2 = 0.248$]. Post-hoc *t*-tests revealed that the mean sequencing error rates for the *practiced CCVCC* syllables [$M = 30.4$, $SD = 42.7$] were significantly lower than the *novel CCVCC* [$M = 52.2$, $SD = 29.2$; $t(10) = -3.425$, $p = 0.006$] syllables and marginally lower than *practiced CC* [$M = 42.7$, $SD = 22.2$; $t(10) = -2.218$, $p = 0.051$] and *practiced CVC* [$M = 44.5$, $SD = 25.4$; $t(10) = -1.985$, $p = 0.075$] syllables. While sequencing error rates for the *practiced CC* syllables were not significantly lower than the *practiced CVC* [$t(10) = -0.281$, $p = 0.785$], they were significantly lower than the *novel CCVCC* [$t(10) = -2.345$, $p = 0.041$] syllables, suggesting some minor improvement from practicing the CC portion of the CCVCC syllables but less improvement than practicing the whole syllable. The *practiced CVC* and *novel CCVCC* error rates were not significantly different from each other [$t(10) = -1.376$, $p = 0.199$]. The effect of syllable position was marginally significant [$F(1,30) = 4.787$, $p = 0.054$, $\eta^2 = 0.324$], such that more errors occurred during the execution of coda clusters ($M$=30.3; $SD$=25.2) compared to onset clusters [$M$=21.7; $SD$=17.3]. The interaction did not reach statistical significance [$F(3,30) = 1.087$, $p = 0.369$, $\eta^2 = 0.098$].

Figure S3 shows boxplots of the mean percentage of *total errors* (sequencing and non-sequencing) for the first five utterances of each syllable type as a function of syllable position (onset vs. coda). The ANOVA showed a highly significant main effect of sequence type [$F(3,30) = 4.636$, $p = 0.009$, $\eta^2 = 0.317$]. Post-hoc LSD paired *t*-tests showed that the mean error rates for the *practiced CCVCC* syllables [M = 46.3, SD = 25.1] were significantly lower than the *practiced CC* [M = 59.5, SD = 22.2; $t(10) = -2.498$, $p = 0.032$], *practiced CVC* [M = 65.4, SD = 26.4; $t(10) = -2.003$, $p = 0.043$] and *novel CCVCC* [M = 66.8, SD = 23.9; $t(10) = -3.190$, $p = 0.010$] syllables. The mean error rates for the *practiced CC* syllables were not significantly lower than either the *practiced CVC* [$t(10) = -0.643$, $p = 0.535$] or *novel CCVCC* [$t(10) = -1.638$, $p = 0.132$] syllables. The *practiced CVC* and *novel CCVCC* error rates were not significantly different from each other

[$t(10) = -0.420$, $p = 0.683$]. There was no significant effect of syllable position [$F(1,30) = 4.787$, $p = 0.054$, $\eta^2 = 0.324$] or interaction [$F(3,30) = 0.631$, $p = 0.600$, $\eta^2 = 0.059$].

Although previous kinematic studies have consistently found effects of syllable position on the spatial and temporal production of *native-language* consonant sequences (Browman & Goldstein, 1988; Byrd, 1995; Keating, Wright, & Zhang, 1999; Byrd, Lee, Riggs, & Adams, 2005), no clear effects emerged in the current experiment. It is important to note, however, that we measured motor learning using perceptual/transcription methods and simple acoustic measures of utterance duration. However, these measures provide a limited window on potential articulatory differences between onsets and codas since they cannot capture movement characteristics among cluster elements (such as inter-gestural timing), and how those characteristics may vary as a function of syllable position and motor practice. Furthermore, the model of speech sequencing presented in Figure 2 of the main article is agnostic to this distinction, largely because the current findings cannot fully illuminate this issue since a given cluster was always used as an onset or always used as a coda in our experiment. We plan to investigate this issue in future experiments.

## Supplementary References


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**Figures for Supplementary Material**

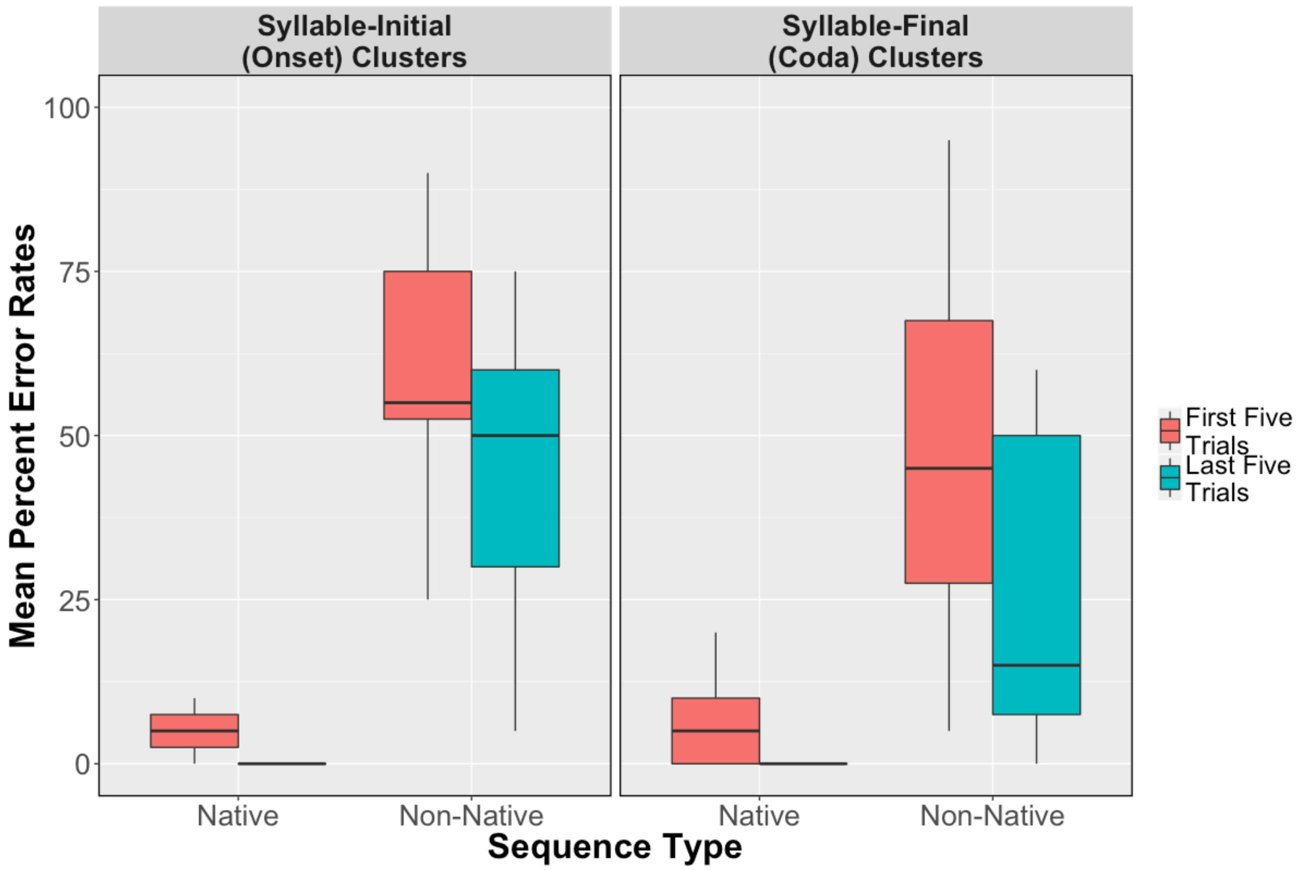


**Figure S1:** Boxplots of the mean percentage of *sequencing errors* for the first and last five utterances of each syllable type (on Day 1) as a function of sequence type (native CC vs. non-native CC) and syllable position (onset vs. coda).

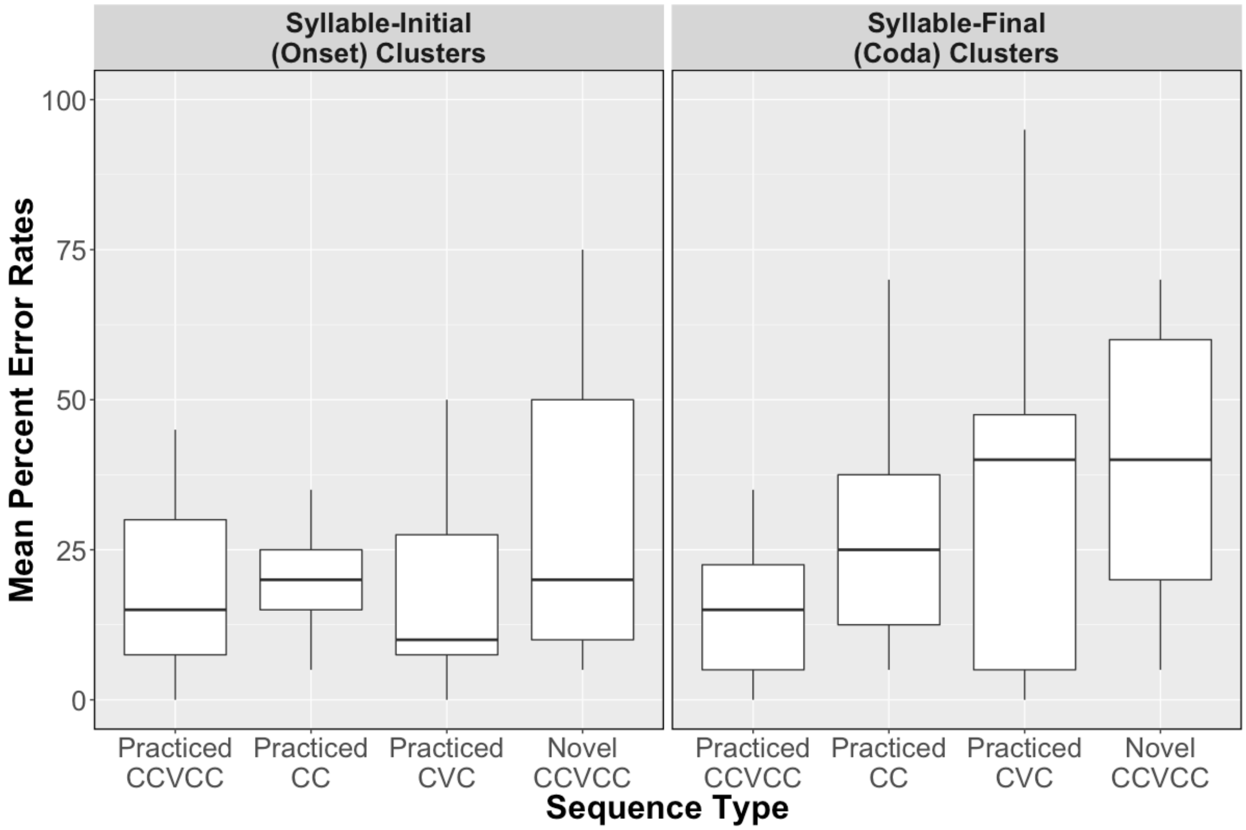


**Figure S2:** Boxplots of the mean percentage of *sequencing errors* for the first five utterances of each syllable type as a function of syllable position (onset vs. coda).

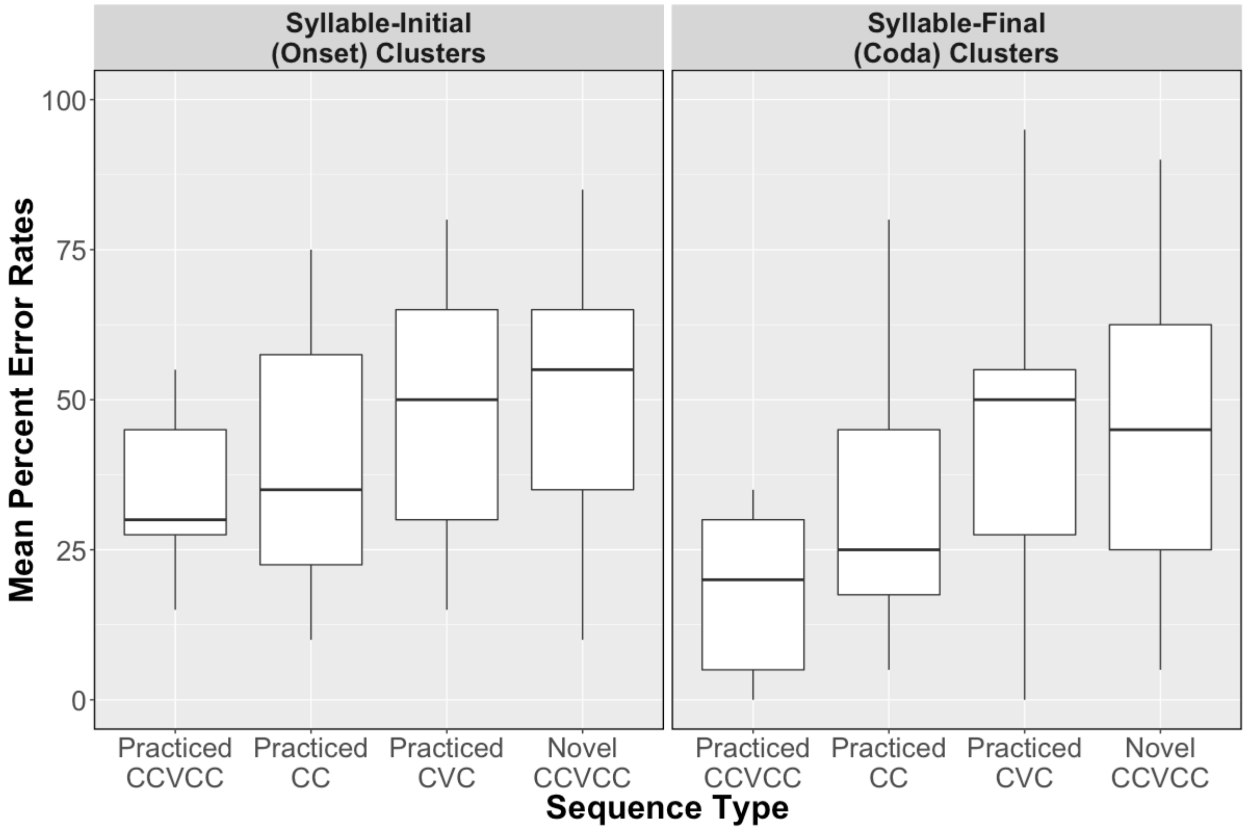


**Figure S3:** Boxplots of the mean percentage of *total errors* (sequencing and non-sequencing) for the first five utterances of each syllable type as a function of syllable position (onset vs. coda).