Is there a syllabary containing stored articulatory plans for speech production in English?

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Abstract

Three experiments with undergraduate student participants investigated whether high frequency nonword syllables of English and non-existing English syllables showed differential effects on response latency, accuracy, onset and rime duration or spectral measures of coarticulation in syllable naming tasks. Only the coarticulation data provided any support for the hypothesis that speakers store articulatory plans for high frequency syllables.

1. Introduction

The proposal that subsequent to phonological encoding speakers retrieve pre-stored commands for syllable articulation from a mental library of such commands, a "syllabary", has strong intuitive appeal. On one hand, it removes the need for models positing a string of phonemes as the output from phonological encoding (e.g. Van der Merwe, 1997) to explain how discrete phonemic segments determine the overlapping, dynamic, context-dependent properties of articulatory movements. On another, the calculation that speakers of languages such as Dutch, German and English can do approximately 80% of their talking with about 500 syllables suggests that pre-storage of articulatory commands for high frequency syllables would efficiently reduce the online computational load in speech production (Levelt, Roelofs, & Meyer, 1999). Cholin (2004) notes that the syllable is typically a significant domain for phonotactic constraints, phonological rules and stress, that naïve speakers can usually report on the number of syllables in a word while they are less accurate in identifying other phonological characteristics of utterances, and that apraxic speech impairments sometimes manifest syllabic influences. She argues that these observations support the psychological reality of the syllable in speech production, and Levelt and colleagues (e.g. Levelt et al., 1999) have incorporated the notion of a syllabary into their influential theory of speech production.

Crompton (1982) initially proposed the existence of the syllabary in a persuasive argument from slip-of-the-tongue speech error data, but laboratory-generated evidence for the syllabary has been more ambivalent. Levelt and Wheeldon (1994) reported that Dutch words ending in a high frequency (HF) syllable were produced faster than those ending in a low frequency (LF) syllable, independent of word frequency and articulatory difficulty. Syllable frequency was, however, correlated with phoneme frequency in this study, and two further experiments by Levelt and Meyer (reported in Hendricks & McQueen, 1996) failed to replicate the syllable frequency effect when phoneme frequency and other factors were controlled.

The effects of syllable frequency on response time in word naming (reading aloud) in Spanish have also been explored (Carreiras, 1993; Perea & Carreiras,1998), demonstrating the need to control for phonological, orthographic and task-related factors when investigating syllable frequency effects, but supporting the syllable as a unit of planning in production. Similar claims have been made for French (e.g. Schiller, Costa & Colomé 2002), however Spanish and French differ from languages such as Dutch, English, and German in terms of how syllables are rhythmically organised into words. This may mean that syllables play a different role in production in different languages.

Whiteside and Varley (1998) hypothesised that prestored syllable plans should result in greater coarticulation than articulatory plans computed online. Thus HF syllables should manifest shorter durations and faster transitions from consonant to vowel place of articulation than LF syllables, as well as faster response latencies as predicted by other researchers. These researchers, investigating English, only reported response latencies for monosyllabic words, confounding syllable and word frequency. Word frequency is assumed to affect response latencies in production at earlier stages than articulatory planning (Nickels, 1997). It also affects speed of receptive word processing (Marslen-Wilson, 1990), thus another possible source of Whiteside and Varley's (1998) frequency effect was the receptive component of the repetition task they used. Whiteside and Varley (1998) did not find duration/coarticulation effects associated with frequency, but materials in their two frequency sets were not matched for intrinsic duration, nor for intrinsic differences in coarticulation related to place of articulation. Varley and Whiteside (1998) did, however, report shorter durations for high frequency words.

Directly investigating syllable frequency in English, Monsell, van der Lugt and Jessiman (2002) presented

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preliminary evidence suggesting possible small effects of syllable frequency on response latency and duration in syllable naming. Materials were monosyllable nonwords that were existing English syllables or phonotactically legal but non-existing syllables of English, yielding a set of syllables likely to have been previously produced and a set not previously produced. The materials elegantly controlled for segmental and orthographic factors by re-pairing onset and coda in regularly-spelled syllable pairs (e.g. BREK KEL, BREL KEK). There were, however, no significant effects of syllable frequency on latency, duration or accuracy in this study and in two other tasks. Further planned analyses of these data are expected to yield more conclusive results (Monsell, pers. comm. June 2004).

Schweitzer and Möbius (2003) provided evidence for syllable frequency effects in a German corpus. They proposed that if speakers store auditory representations of perceived speech tokens for use as perceptual target regions in speech production (Perkell, Guenther, Lane, Matthies, Vick, & Azandipour, 2001), then speakers will have many stored exemplars for HF syllables but few or none for LF syllables. The many exemplars for HF syllables define a target region for each syllable (similar to a prestored articulatory plan, but in perceptual space). Because there are few or no stored exemplars for LF or non-existing syllables, target regions for these syllables must instead be computed from a concatenation of the target regions available for subcomponents of the syllable (segments, onsets, rimes etc.). On this basis, the authors predicted a better fit for the regression of z-scores of the durations of whole syllables against the durations of the segments comprising each syllable for LF compared with HF syllables. Investigation of the 130 syllable types occurring more than 20 times in their corpus revealed exactly this effect.

Most recently, and most positively, Cholin and colleagues (Cholin 2004; Cholin et al., 2004) demonstrated greater implicit priming in Dutch speakers for CVV and CCVV syllables when both segmental and syllabic information was available in the primes compared with segmental information alone. This is evidence for a role for syllables in production; but the effect could arise during the earlier stage of prosodification (allocation of segments to metrical frames) described in the production model of Levelt and colleagues (Levelt et al., 1999), or during subsequent retrieval from the syllabary.

Evidence for a syllabary per se was provided in a “symbol-position association learning task” (Cholin, 2004). In each block of this task, participants initially learned to associate each of 4 nonword monosyllables (2 HF, 2 LF) the position of one of four loudspeaker icons on a computer screen. Once they had learned these associations, participants were required to speak the correct syllable to a single probe loudspeaker icon appearing in one of the 4 positions. Response latency was measured by a voice key. Participants produced each of 32 items 8 times each. Piloting of this task suggested that participants’ repeated articulations of the target syllables during the learning phase eradicated any syllable frequency effects, because effects present across the first productions of each token during learning were not found in the test phase. Cholin (2004) therefore reduced the number of items to be learned/elicited to two at a time and trained participants auditorily as to the sound associated with each loudspeaker position. With the modified procedure, response latencies were faster to HF than LF syllables, and there was a trend for more errors to LF syllables. Repeating the experiment with two-syllable nonwords, manipulating frequency of the first syllable yielded similar results, but a frequency manipulation on the second syllable showed no difference between high and low-frequency syllables on latency or accuracy.

Cholin and colleagues’ procedure has the advantage of not providing information about the form of the target syllable to the participant prior to production, minimizing the potential confounds associated with orthographic and receptive word processing in the word naming and repetition tasks noted above. Interpreting response latency differences as a reflection of syllable frequency effects in production in this task, however, relies on the assumption that all items are learned to a similar criterion and that there is equivalent interference (or none) across items during the recall/production component of the task.

In the present study, our aim was to further test for syllable frequency effects in English taking into account limitations in the materials and tasks described above. *Experiment One* investigated whether syllable frequency effects could be shown in a syllable naming task for HF versus non-existing (NE) syllables given adequate experimental control for phonological and orthographic variables. Time to complete phonological encoding was matched across the HF and NE syllable sets using the DRC model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). We also hand-measured response latency from the time-amplitude waveform rather than using a voice key given the unreliability associated with this technique (Rastle & Davis, 2002). *Experiment Two* investigated whether there was evidence for durational differences in HF vs NE syllables, given the ambivalence of these findings in the careful work of Monsell and colleagues (2003). *Experiment Three* is the first we are aware of to measure spectral correlates of coarticulation in the production of HF versus NE syllables in English.

2. Experiment One

2.1. Participants

Forty-six undergraduates from Macquarie University were tested. All spoke Australian English as their first language and had normal or corrected-to-normal vision.

2.2. Stimuli

Twenty-five syllables defined by the maximal onset principle in the English CELEX database (Schreuder & Kerkman, 1987) were selected as HF syllable stimuli. They occurred in 40 or more independent word-forms and in the top 20% of syllable token frequencies, and do not exist as monosyllabic words in English. Only 25 HF syllables were selected because these exhausted the number of syllables meeting the above criteria that could be matched to phonotactically legal syllables that do not exist in English (NE syllables) on the phonological/phonetic and orthographic factors noted below. HF and NE syllables were matched on initial phoneme, number of phonemes and CV structure, vowel length, and as closely as possible on vowel height and backness. No syllable ended with a lax vowel. See Appendix for materials.

Orthographic representations required for syllable naming were based on the nonlexical rules of the DRC model. Orthographic representations for HF and NE syllables were matched on length, neighborhood size (HF: 6.72, NE: 6.96, t(24)= -0.39, p= 0.35), number of orthographic body friends (*Type*, HF: 6.96, NE: 7.76, t(24)= -0.70, p= 0.24; *Token:* HF: 29966, NE: 26796, t(24)= 0.27 p= 0.39), number of orthographic body enemies (*Type*, HF: 0.56, NE: 1.0, t(24)= -0.79, p = 0.22; *Token:* HF: 4447, NE: 3104, t(24)= 0.28 p= 0.39), and number of orthographic body neighbours (*Type*, HF: 7.52, NE: 8.76, t24 = -1.28, p=.11; *Token:* HF: 34414, NE: 29900, t(24)= 0.34 p= 0.37). The DRC model of reading aloud revealed no difference between syllable types on reading aloud latency, t(24)=-1.11, p=0.27.

Fifty six-letter ‘filler’ syllables were created. No filler syllable shared a body with any of the target syllables.

2.3. Procedure

Participants were instructed to read aloud each syllable as quickly and as accurately as possible. Syllables were presented in a different random order for each participant using the DMDX display package (Forster & Forster, 2003). Participants were given 10 practice trials before starting the main experiment.

2.4. Analysis and Results

Acoustic data were hand labeled at the onset of acoustic energy according to the criteria established in the ANDOSL database (Croot, Fletcher & Harrington, 1992). Three syllables (2 HF and 1 NE), along with their matched syllables, were removed from the analysis for producing errors greater than 50%. RTs for incorrectly produced syllables, along with RTs for their matched syllables, were also removed from the analysis.

Paired t-tests, by subjects (t1) and by items (t2), revealed no indication of an effect of syllable frequency in the RT or error data. HF syllables were produced faster and with fewer errors (528 ms, 9.16% error) than were NE syllables (534 ms, 9.99% error), but neither effect reached significance (RT: t1(45)=1.27, p>.20, t2(21)=1.08, p>.25; Error: t1(45)<1, t2(21)<1).

3. Experiment Two

3.1. Participants

Participants were 26 undergraduates from Royal Holloway, University of London with normal or corrected-to-normal vision, speaking British English as their first language.

3.2. Stimuli and Procedure

Thirty-two syllables meeting the criteria for high frequency described in Experiment 1 were selected. Each HF syllable was matched to an onset-matched (OM) and a rime-matched (RM) phonotactically legal NE syllable (creating HF/OM-NE and HF/RM-NE pairs) (see Appendix). Onset-matched NE syllables shared the initial phoneme(s) and the vowel with HF syllables (e.g., HF: /spOn/, OM-NE: /spOd/); rime-matched syllables shared the vowel and coda with HF syllables (HF: /spOn/, RM-NE: /klOn/). For each syllable, a legal orthographic representation was constructed using the rules of the DRC model; for the above examples these were SPON, SPOD, KLON. It was not possible to match on orthographic properties for this number of items and for both pair members as closely as in Experiment One. For this reason, we did not measure reaction time or error rate. The procedure was otherwise as for Experiment One.

3.3. Analysis and Results

Two trained phoneticians marked four acoustic boundaries using the ANDOSL criteria: (i) the acoustic onset of the syllable, (ii) the boundary between onset and vowel, (iii) the acoustic offset of the syllable excluding any burst release, and (iv) the acoustic offset of any syllable-final burst release. Onset duration was taken to be the interval between (i) and (ii); rime durations excluding release as the interval between (ii) and (iii), and rime durations including release as the interval between (ii) and (iv). Durations for incorrectly-pronounced items and for their matched syllables were removed from the analysis.

We tested for syllable frequency effects on onset duration by comparing onset durations of HF and OM-NE syllables. There was a significant effect of syllable frequency on onset duration, with HF syllables longer (138 ms) than OM-NE syllables (135 ms), t1(25)=2.30, p<.05, t2(31)=1.76, p=.08.

We tested for syllable frequency effects on rime duration by comparing rime durations (with and without final release) in HF versus RM-NE syllables. There was a significant effect of syllable frequency on both measures of rime duration, with HF syllables having longer rime durations (with release: 342 ms; without release: 295 ms) than RM-NE syllables (with release: 322 ms; without release: 275 ms) (with release: t1(25)=9.01, t2(31)=3.31; without release: t1(25)=8.23, t2(31)=3.36).

Further analyses revealed, however, that the significant duration effects were isolated to target-control pairs not matched on number of phonemes (e.g., the onset matched pair /tei, teis/ and the rime-matched pair /sEn, grEn/). Once these pairs were removed from the analyses (see Appendix), there was no effect of syllable frequency on onset duration (HF: 139 ms, NE: 138 ms, t2(15)<1), rime duration with release (HF: 328 ms, NE: 325 ms, t2(18)<1), or rime duration without release (HF: 250 ms, NE: 247 ms, t(18)<1).

4. Experiment Three

4.1. Participants

Participants were 37 undergraduates from Royal Holloway, University of London, similar to those in Experiment Two.

4.2. Stimuli, Hypotheses and Procedure

Twenty-two syllables meeting the criteria for high frequency described in Experiment One were selected. Eight began with a fricative; 5 contained /r/ or /w/ preceding the vowel; 4 contained a velar stop adjacent to the vowel; 5 contained an alveolar consonant adjacent to the vowel.

Hypotheses were based on the assumption that typical coarticulatory effects between segments would be amplified in HF syllables compared with phonetically matched NE syllables — if HF syllables exhibit increased coarticulation as a consequence of being produced from prestored syllable plans rather than being computed online. For the fricative-initial segments we predicted that anticipatory coarticulation with a following open vowel /A,V,@u,au,ai/ may yield lower frequency fricative noise in the HF syllable due to anticipatory opening of the vocal tract. In the /r,w/ syllables we predicted that carryover coarticulation associated with /r/ or /w/ would lower the F3 value of the following vowel more in the HF syllable than in its NE counterpart. For the syllables containing an adjacent open front vowel /A/ and velar consonant /k/, we predicted lower F2 at the vowel-consonant (or consonant-vowel) boundary in the HF syllables associated with the more posterior articulation. For the syllables containing an adjacent (post)alveolar consonant /l,n,tS,dZ/ and central or back vowel /au,V,a:,O/ we predicted raised F2 at the consonant-vowel boundary associated with increased fronting in the HF syllables.

Non-existing syllables were constructed as either onset-vowel matched or rime matched, depending on the segment of interest. For example, an onset-vowel NE syllable matched to HF /rVp/ was /rVT/ because F3 at the initial vowel boundary was the critical dependent variable in relation to the coarticulatory difference predicted for this pair. A rime-matched NE syllable /Tak/ was paired with the HF /fAk/ because F2 at vowel offset was the critical measure to evaluate coarticulatory differences between these items. Pairs were matched on the voicing of any coda consonant where the comparison of interest involved the onset and vowel in order to match on vowel duration.

Orthographic representations were constructed for each syllable. Orthographic representations for HF and NE syllables were matched as closely as possible on length, t(21)<1, and neighborhood size, t(21)<1. The procedure was as for Experiment One.

4.3. Analysis and Results

Speech data were segmented and labeled by trained phoneticians following the ANDOSL criteria using the speech analysis software EMU (Cassidy & Harrington, 1986). Formants were automatically calculated in EMU and manually corrected if necessary; mean fricative noise across the fricatives was calculated in R. All tests were one-tailed as predictions were unidirectional, and analyses were by-subjects only because of the small number of items tested for each prediction.

We excluded fricative noise values for mispronounced items and their matched syllable. Results showed evidence of lower fricative noise values for the HF syllables than for the NE syllables (t(36)=-2.23, p=.015).

In the /r,w/ items, we excluded F3 values for mispronounced items and their matched syllable. Results showed evidence of lower F3 values at the initial vowel boundary for the HF syllables (2417 Hz) than the NE syllables (2457 Hz), t(36)=-2.23, p=.016.

We analyzed F2 in velar and alveolar contexts separately, excluding F2 values for mispronounced items and their matched syllable. Results showed no evidence of an influence of syllable frequency on F2, either in the velar context or in the alveolar context. In the velar context, F2 values were slightly lower (as predicted) in the HF syllables (1756 Hz) than in the non-existent syllables (1770 Hz), but this difference did not reach significance, t(36)=-1.29, p=.10. In the alveolar context, F2 values were slightly lower (against prediction) in the HF syllable (1492 Hz) than in the non-existent syllables (1502 Hz), but again this difference was not significant, t(36)<1.

5. Discussion

5.1. Experiment One

We found no effect of syllable frequency on response latency to name well-matched HF and legal NE syllables of English. The differences between our negative finding and the positive result of Cholin (2004) may be due to different stimulus characteristics in our English compared with her Dutch materials, to uncontrolled effects in our syllable naming task despite stringent efforts to match stimuli on orthographic and phonological/phonetic properties, or they may indicate that syllable frequency effects cannot be demonstrated in English response latencies. We await with interest a final report from Monsell and colleagues, and the outcome of an attempt to replicate Cholin's Dutch results in English (Cholin, pers. comm. July 2004).

5.2. Experiment Two

This experiment also failed to support the shorter durations for HF syllables compared with NE syllables hypothesized to occue due to increased coarticulation of syllables articulated under the control of prestored articulatory plans compared with plans generated online. Again the final results of Monsell and colleagues will be valuable as their items were better matched on durational properties across each set of items than our pairs could be given our attempt to match on phonetic features pair-by-pair. The lack of control for phonetic differences in the original word materials of Whiteside and Varley (1990) and our own post-hoc recognition of the effect of the number of segments within a syllable on the duration of each segment serves the cautionary note that it is extremely difficult – perhaps impossible – to match pairs of items with different phonetic content on the intrinsic durations of their segments. The only achievable matching may require the constituent separation & re-pairing approach used by Monsell and colleagues. It also raises the question of whether the increased variability in durations of high versus low frequency syllables reported Schweitzer and Möbius (2003) may be confounded with artefactually increased durations per se in the high versus the low frequency syllables given the substantial difficulty of matching phonetically different stimuli on this measure. Schweitzer and Möbius' stimuli were 114 very frequent and 16 infrequent syllable types, with intrinsic durations of syllables in the two sets not reported.

5.3. Experiment Three

Using a different approach and different materials, in this experiment we did support two of our four predictions about the influence of the syllabary, and found a trend in the predicted direction for a third prediction. Mean fricative noise was lower in intensity before an open vowel in HF syllables than NE syllables, F3 was lower at an /r/-vowel or /w/-vowel boundary in HF syllables than NE syllables, and there was a trend for F2 to be lower at an /A/-/k/ or /k/-/A/ boundary in HF than LF syllables, reflecting the influence of posterior place of articulation of the consonant on the vowel. As far as we are aware this is the first experiment that has investigated spectral correlates of coarticulation (rather than the presumed correlate of reduced duration). The results suggest that further investigation of coarticulation may reveal differential effects of syllable frequency in production. A more direct measure of coarticulation than the acoustic analyses used in this study would be to use a physiological measure such as electropalatography as an index of tongue movement in high versus low frequency syllables.

Our results in this experiment are preliminary in the sense that further analysis of mean fricative noise close to the boundary with the vowel may give a more positive result than values reported that were calculated over the duration of the fricative; normalization of formant values may remove sufficient variability to yield more significant results in the other three comparisons; and t-tests carried out for each syllable pair may show that some contrasts are significant but lost in the overall ANOVAs reported here (or the reverse). In these analyses we pooled results to increase power, but given the variability across different items in speech production we may have lost sensitivity to differences between pairs or types of pairs in doing so. Experiments investigating rarely- or never-before-produced syllables necessarily limit the options available for dealing with variability within speaker, as multiple productions to estimate a statistically reliable mean value may actually eliminate the effect under study (as discovered by Cholin, 2004, in the pilot version of her symbol-position association learning task). Thus we, and Monsell et al. (2002) elicited one production of each syllable token per speaker, which together with known variability in articulation across items and within and across speakers may account for our difficulty in finding statistically reliable effects in our experiments.

5.4. Other candidate units of articulatory organization

If the evidence for the syllabary continues to be equivocal are there any alternatives? One is that articulatory gestures are derived from the complex concatenation of movement plans for individual phonemic segments into plans for larger units (e.g. Van der Merwe, 1997). Another is that articulatory plans are organised for units larger than the phoneme but smaller than the syllable, such as onsets, onsets-plus-vowel and rimes. These constituents can move independently of each other within speech errors (Cutler, 1988), and the articulatory gestures in onsets are stronger than those in rimes (Sussman, Bessell, Dalston, & Majors, 1997). Thirdly, speakers may store articulatory plans for units larger than syllables (e.g. bisyllabic and multisyllabic words, common phrases). Stored articulatory plans for frequently-used other-sized units instead of, or additional to, plans for syllables would account for the ambivalent findings related to syllable frequency across studies. Future experiments of this type need to consider the frequency of other units as well as syllables. Finally, psycholinguistic investigations of articulatory planning should also be carried out in the context of current models of coarticulation (Farnetani & Recasens, 1999). Although developed largely without reference to the influence of psycholinguistic variables such as word and syllable frequency, such models suggest an entirely different underlying organization for articulation than that proposed by the syllabary hypothesis.

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7. References

Carreiras, M., Alvarez, C. J., & de Vega, M. (1993). Syllable frequency and visual word recognition in Spanish. *Journal of Memory and Language, 32*, 766-780.

Cassidy, S., & Harrington, J. (1996). *EMU: an enhanced hierarchical speech database management system.* Paper presented at the 6th International Conference on Speech Science and Technology, Adelaide.

Cholin, J. (2004). *Syllables in speech production: Effects of syllable preparation and syllable frequency.* Unpublished PhD, Katholieke Universiteit Nijmegen, Nijmegen.

Cholin, J., Schiller, N. O., & Levelt, W. J. M. (2004). The preparation of syllables in speech production. *Journal of Memory and Language, 50*, 47-61.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204-256.

Crompton, A. (1982). Syllables and segments in speech production. In A. Cutler (Ed.), *Slips of the tongue and language production.* Berlin: Mouton.

Croot, K., Fletcher, J., & Harrington, J. (1992). Levels of segmentation and labelling in the Australian National Database of Spoken Language. In J. Pittam (Ed.), *Proceedings of the 4th Australian International Conference on Speech Science and Technology* (pp. 86-90). Brisbane: Australian Speech Science and Technology Association.

Cutler, A. (1988). The perfect speech error. In L. M. Hyman & C. N. Li (Eds.), *Language, speech and mind: Studies in honour of Victoria A. Fromkin* (pp. 209-223). London: Routledge.

Farnetani, E & Recasens, D (1999) Coarticulation models in recent speech production theories. In, Hardcastle, WJ & Hewlett, N (Eds) *Coarticulation: Theory, data and techniques.* Cambridge, UK: CUP

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavoiur Research Methods Instruments and Computers, 35*, 116-124.

Hendricks, H., & McQueen, J. (Eds.). (1996). *Annual Report 1995.* Nijmegen: Max Planck Institute for Psycholinguistics.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioural and Brain Sciences, 22*(1), 1-75.

Levelt, W. J. M., & Wheeldon, L. (1994). Do speakers have access to a mental syllabary? *Cognition, 50*, 239-269.

Marslen-Wilson, W. D. (1990). Activation, competition, and frequency in lexical access. In G. T. M. Altmann (Ed.), *Cognitive models of speech processing* (pp. 148-172). Cambridge MA: MIT Press.

Monsell, S., van der Lugt, A., & Jessiman, T. (2002, 9-11 April 2002). *In pursuit of the Syllabary: This Snark is a Boojum!* Paper presented at the Experimental Psychology Society Meeting, Leuven, Belgium.

Nickels, L. (1997). *Spoken word production and its breakdown in aphasia.* Hove, UK: Psychology Press.

Perea, M., & Carreiras, M. (1998). Effects of syllable frequency and syllable neighbourhood frequency in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 24*(1), 134-144.

Perkell, J., Guenther, F., Lane, H., Matthies, M., Vick, J., & Azandipour, M. (2001). Planning and auditory feedback in speech production. In B. Maassen, W. Hulstijn, R. D. Kent, H. F. M. Peters & P. H. M. M. van Lieshout (Eds.), *4th International Speech Motor Conference* (pp. 5-11). Nijmegen: Unitgeverij Vantilt, Nijmegen.

Rastle, K., & Davis, M. (2002). On the complexities of measuring naming. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 307-314.

Schiller, N. O., Costa, A., & Colomé, A. (2002). Phonological encoding of single words: In search of the lost syllable. In C. Gussenhoven & N. Warner (Eds.), *Papers in Laboratory Phonology 7* (pp. 35-59). Berlin: Mouton de Gruyter.

Schreuder, R., & Kerkman, H. (1987). On the Use of a Lexical Database in Psycholinguistic Research. In W. Meijs (Ed.), *Corpus Linguistics and Beyond: Proceedings of the 5th International Conference on English Language Research on Computerized Corpora.* Amsterdam: Rodolpi.

Schweitzer, A., & Möbius, B. (2004). Exemplar-Based Production of Prosody: Evidence from Segment and Syllable Durations. In B. Bel & I. Marlien (Eds.), *Proceedings of Speech Prosody*. Nara.

Sussman, H. M., Bessell, N., Dalston, E., & Majors, T. (1997). An investigation of stop place of articulation as a function of syllable position - A locus equation perspective. *Journal of the Acoustical Society of America, 101*(5 Part 1), 2826-2838.

Van der Merwe, A. (1997). A theoretical framework for the characterization of pathological speech sensorimotor control. In M. R. McNeil (Ed.), *Clinical management of sensorimotor speech disorders* (pp. 1-25). New York: Thieme.

Varley, R. A., & Whiteside, S. P. (1998). *Evidence of dual-route phonetic encoding from apraxia of speech: Implications for phonetic encoding models.* Paper presented at the 5th International Conference on Spoken Language Processing, Sydney, Australia.

Whiteside, S. P., & Varley, R. A. (1998). *Dual-route phonetic encoding: Some acoustic evidence.* Paper presented at the 5th International Conference on Spoken Language Processing, Sydney, Australia.

8. Appendix

Materials for Experiment One: HF syllable and matched NE syllable pairs: sEn-sEf, Ek-ES, kaun-kaum, zei-zau, fEk-fEp, Ak-Av, hAn-hAb, dZEk-dZev, sIm-sAf, tEm-tEp, lAn-lAt, kAl-kAv, kri:-kroi, fAk-fAp, flau-floi, gri:-gwi:, sVl-sVz, rVp-rVd, z@:-zo:, spOn-spOd, dZ@:-dZe:, sIg-sVg, Ob-Vb, spi:-smi:, vVl-vVn

Materials for Experiment Two:

High Frequency Syllables	Non-existing syllables	
	Onset-matched	Rime-matched
tei	teis*	tei
sEn	sEf	grEn*
v@:	v@:k*	pl@:*
t@:	t@:t*	r@:
kaun	kaut	dZaun¶
zei	zeid*	Srei*
lEk	lEb	kEk
dZEk¶	dZEg	wEk
fEk	fEg	SEk
vei	veik*	Trei*
vEnn	vEd	swEn*
ga:	ga:n*	Tra: *
hAn	hAb	slAn*
lAn	lAt	yAn
sEp	sEtS¶	wEp
sIm	sIS	mIm
tEm	tEz	wEm
kAl	kAz	yAl
kri:	kri:n*	gwi:
fAk	fAm	gAk
flau	flauk*	swau
sVl	sVz	rVl
rVp	rVd	dVp
z@:	z@:d*	br@:*
g@:	g@:s*	gl@:*
spOn	spOd	klOn
v@u	v@ud*	Sr@u*
dZ@:	dZ@:d*	dr@:*
na:	na:m*	fra: *
sIg	sItS¶	hIg
spi:	spi:t*	Twi:
vVl	vVn	tVl

KEY: * onset-matched items: coda reduces onset duration so HF/OM-NE pair removed from analysis

* rime-matched items: cluster in onset reduces rime duration so HF/RM-NE pair removed from analysis

¶ affricate durations likely to behave similarly to clusters so pairs containing affricates removed from analysis

Materials for Experiment Three

Syllable type		Set
High Frequency	Non-existing	
sAn	sAb	Fricative
sVl	sVg	Fricative
fAk	fAT	Fricative
fVN	fVd	Fricative
faun	faud	Fricative
zai	zaib	Fricative
vVl	vVd	Fricative
v@u	v@ub	Fricative
rVp	rVT	/r,w/+Vowel
kwEs	kwEtS	/r,w/+Vowel
brai	braik	/r,w/+Vowel
prIn	prId	/r,w/+Vowel
gri:	gri:g	/r,w/+Vowel
fAk	TAk	/A/+/k/
frAk	brAk	/A/+/k/
Ak	TAk	/A/+/k/
kAl	kAz	/k/+/A/
flau	flaub	(post)alveolar+Vowel
na:	na:g	(post)alveolar+Vowel
lVm	lVb	(post)alveolar+Vowel
tSa:n	tSa:b	(post)alveolar+Vowel
tSa:n	dZa:n	(post)alveolar+Vowel
pOn	vOn	Vowel+(post)alveolar