Motor Equivalence in the Production of /ʃ/

Joseph S. Perkell, Melanie L. Matthies* and Majid Zandipour

Speech Communication Group, Research Laboratory of Electronics, M.I.T., Cambridge, Massachusetts 02139,
*also Department of Communication Disorders, Boston University, Boston, Massachusetts 02215

Abstract: To explore the idea that speech motor goals are acoustic targets, upper lip protrusion and tongue blade fronting were examined in the sibilant /ʃ/ for evidence of motor equivalence in 8 speakers of American English. Positive correlations across multiple repetitions of /ʃ/ (i.e., motor equivalence) would occur if the upper lip compensated with more protrusion when the tongue blade was further forward and vice versa. This motor equivalence would serve to maintain an adequate front cavity volume, thus enhancing the acoustic stability of /ʃ/ and assuring good acoustic separation from /s/. It was hypothesized that motor equivalence would be found among acoustically less canonical tokens, as elicited in a "clear+fast" speaking condition (used in addition to a normal condition). Acoustic spectral analyses indicated excellent separation between the two sibilants, even in the clear+fast condition. Four subjects showed some significant positive correlations of tongue-blade and upper lip displacements. When there was a difference between conditions in how canonical the tokens were, the motor equivalent tokens were less canonical. There were no significant negative correlations. There were relatively few motor equivalence findings, perhaps because some speakers use saturation (quantal) effects, which could also enhance acoustic stability.

INTRODUCTION

We hypothesize that speech motor control is based on a planned acoustic trajectory that passes through sequences of phoneme-specific acoustic goal regions. If the control of speech movements is based on acoustic goal regions, speakers might utilize mechanisms that enhance speech sound contrasts by sharpening boundaries (reducing overlap) between the goal regions of sounds that are adjacent to one another in acoustic space. One such mechanism is compensatory covariation, or "motor equivalence". When two articulators contribute to producing an acoustic cue and the planned movement of one of the articulators might make the actual acoustic trajectory miss the goal region for the cue, a compensatory, "motor equivalent" adjustment is planned in the movement of the other articulator to help keep the acoustic trajectory within the goal region. Furthermore, due to economy of effort, the compensation would be limited to an amount that makes the acoustic trajectory from one segment to the next pass through the edge of the goal region that is nearest to goal region of the next sound. Thus, we would expect to observe such compensatory covariation mainly among tokens near an edge of the goal region, i.e., the least canonical tokens.

METHODS

We have found motor equivalence for the vowel /u/ (1, 2) and the liquid /r/ (3); the purpose of this study is to look for the same kind of effect in a consonant sound that is also produced with the actions of two independently controllable articulators, /ʃ/. We recorded the acoustic signal and the midsagittal-plane movements of points on the tongue blade and lips (4). Eight adult speakers of American English pronounced multiple repetitions of utterances of the form "a ___ again", where ___ was "shed", "she", "said" and "see". There were approximately 30 repetitions of each utterance in each condition; they were interspersed with other utterances and were arranged in random order. We attempted to create less canonical subsets of tokens by manipulating speaking condition—using a "clear+fast" condition in addition to a "normal" one. We reasoned that the requirement for speed would induce some blurring of the contrast with /s/ and the clarity requirement would keep the tokens within the /ʃ/ region. Thus we expected the clear+fast tokens to be less canonical, near the boundary between the acoustic goal regions of /ʃ/ and /s/.

Mid-consonant transducer locations were extracted from the movement signals, and values of mid-consonant spectral median were calculated from the acoustic signal. For each subject and each of the four sets of utterances (containing "shed" or "she" in each condition), separate Pearson product moment correlations were calculated for matched pairs of values of the x coordinate of the tongue blade transducer (fronting) and the x coordinate of the
upper lip transducer (protrusion). Mean values of the spectral median were compared between conditions for each word with t-tests.

RESULTS

Four of the eight subjects had significant (p ≤ .05) positive correlations of tongue blade fronting and upper lip protrusion for /f/ (indicating motor equivalence) in at least one of the four word × condition sets. One subject showed motor equivalence for both words in both conditions, with negligible differences between conditions in mean values of the spectral median. Among the other three subjects, a total of four data sets were produced with motor equivalence. All four sets were in the normal condition, which turned out to have acoustically less canonical tokens of /f/ than those in the clear+fast condition (p ≤ .05). There were no significant negative correlations. Overall, there were significant correlations indicating motor equivalence in 28% of all possible cases.

DISCUSSION AND CONCLUSIONS

The results support the motor equivalence hypothesis, but only weakly. One reason for the general paucity of significant correlations may be that lip rounding for /f/ is a "secondary articulation" (5), and is not very pronounced. Findings of individual differences in the use of motor equivalence for /f/ may be related to whether or not speakers use a "saturation effect" (2) with the primary articulation to help sharpen the /s-/f/ distinction. It has been shown that /s/ may be produced with the tongue tip contacting the lower incisors (6). To produce a /f/, the tongue blade is positioned so that a sub-lingual space is created between the tongue tip and the floor of the mouth, causing a quantal increase in the size of the front cavity and lowering of the spectral center of gravity (in relation to /s/). Thus, with continuous movement of the tongue blade forward along the palate from the position for /f/, the volume of the cavity anterior to the constriction decreases continuously and then suddenly "saturates" at zero when the tongue tip contacts the lower incisors. It may be that only some speakers use this saturation effect to stabilize the /s-/f/ distinction. Those speakers would not need to use motor equivalence because the saturation effect creates a sufficiently sharp boundary between /s/ and /f/. The subjects who do show motor equivalence for /f/ may not consistently produce /s/ with the tongue tip touching the lower incisors. Without the use of motor equivalence, their boundary between /s/ and /f/ would be more graded, so they could employ motor equivalence in producing /f/ to help sharpen the boundary. This hypothesis could be tested by measuring contact between the tongue tip and lower incisors during a motor equivalence experiment. Further resolution of this issue may also depend on some additional methodological improvements. A "fast" condition may elicit "less canonical" tokens better than the clear+fast condition, and additional acoustic measures may be used to refine the assessment of the extent to which the tokens are canonical.

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REFERENCES