EFFECTS OF BITE-BLOCK AND LOUD SPEECH ON TONGUE HEIGHT IN THE PRODUCTION OF GERMAN VOWELS

O.-S. Bohn*, J. E. Flege, P. A. Dagenais*** and S. G. Fletcher****

*English Dept., Kiel University, Germany; ** Dept. Biocommunication, U. Alabama Birmingham, U.S.A; ***Dept. Speech Pathology and Audiology, U. South Alabama, Mobile, U. S. A.

ABSTRACT

Compensatory tongue positioning in vowel production was examined in two conditions of lower-than-normal jaw positions (bite-block speech and loud speech), and compared to a "normal" speech condition. Tongue-palate distances in multiple productions of the German vowels /i, I, u, U, y, Y/ were measured using glossometry. The tongue compensated for the lower jaw positions in both perturbation conditions. Jaw lowering in bite-block and in loud speech did not much affect the degree of precision in tongue positioning.

1. INTRODUCTION

Comparisons of normal and perturbed speech may help understand important aspects of speech motor control. Over the past twenty years, a research paradigm has become established which addresses issues such as invariance in the control of speech gestures, adaptive abilities of the speech motor system, and the role of feedback through experiments in which normal production patterns are disrupted. By examining the behavior of unperturbed articulators, the acoustic output, and/or the intelligibility of perturbed speech, studies employing this paradigm have aimed at determining if, how, and how successfully talkers reorganize articulatory gestures.

Probably the majority of perturbation studies examined the acoustic properties of vowels produced with and without the mandible being fixed in positions that required talkers to reorganize tongue gestures in order to produce intended vowel qualities. These studies have generally shown that adults [7, 8] and children [2] compensate remarkably well for a fixed jaw even before auditory feedback can occur. The small number of articulatory studies that examined tongue shapes for bite-block vowels [4, 6, 11] indicate that intended acoustic output in bite-block speech is achieved through selective compensation, i.e., by preserving "cavity configuration(s) at points of maximum constriction" [6]. Although previous research on bite-block vowels has contributed importantly to the construction and refinement of models of speech motor control, this line of research has not made it clear whether talkers aim to achieve invariance in the acoustic, perceptual, or articulatory domain.

The recently renewed interest in speech produced with loud vocal effort [9, 10] is to some extent motivated by a desire to determine the nature of talkers' "goals" or "targets". Loud speech is similar to bite-block speech in that the jaw assumes lower-than-normal positions which, however, are not artificially induced but "natural". In the only detailed study of articulatory consequences of loud speech, Schulman [9] found that the upper lip compensates for the lowered jaw in bilabial stop production, demonstrating that motor equivalence for bilabial closure occurs in both the "natural bite block condition" [9] and its artificial counterpart [1].

However, the acoustic properties of vowels produced with loud vocal effort, which have been examined in a number of studies (summarized in [10]), suggest that the analogy between loud and bite-block speech does not extend to vowel production, for the frequencies of F_1 and F_0 (but not usually the upper formants) are much higher in loud than in normal speech. The increase in F_1 for shouted vowels led Traunmüller [10] to hypothesize that the tongue does not compensate for lower jaw positions in loud speech.

The present study, which compared tongue-palate distances for normal, bite-block, and loud vowels, was primarily motivated by the fact that only very few studies have presented direct evidence (as opposed to inferences from the acoustic output) concerning compensatory tongue positioning in bite-block vowels [4, 6, 11], and by the complete lack of published data on tongue shapes in loud vowels. Bite-block and loud vowels were compared to normal vowels to determine if and how the tongue would compensate for an artificially and a naturally lowered jaw. This study also examined variability in tongue positioning for normal, bite-block, and loud vowels. Because most earlier studies [6, 11] used x-ray techniques, which preclude detailed analyses of token-to-token variability, very little evidence exists concerning this aspect of motor control precision for the tongue in perturbed speech (but see [4]).

2. METHODS

2.1 Subject, Material, Procedure

A male native speaker of German (age: 35 years) produced 12 tokens each of the German vowels /i, I, u, U, y, Y/ in the carrier phrase <u>ob er /bVp/ habe</u> (blocked on vowel). The vowels were produced in three conditions. In the normal (NO) condition jaw movement was unperturbed and vocal effort was conversational (64 dB SPL). In the bite-block (BB) condition the talker's jaw was fixed in a lower-than-normal position for non-low vowels. An acrylic bite block, held between the right premolars, provided an interincisal distance of 21 mm. In the loud (LO) condition the talker produced the vowels with loud vocal effort (84 dB SPL).

Tongue-palate distances were measured using glossometry. This opto-electronic device for measuring and displaying tongue positions below the hard palate has been described previously (see [5] and references therein). Briefly, the glossometer makes use of four sensor assemblies mounted on a thin acrylic pseudopalate. Each assembly contains an LED and a phototransistor. The assemblies are positioned equidistantly along the palatal vault and are oriented perpendicularly to the occlusal plane. Sensor 1 is located just posterior of the alveolar ridge, and sensor 4 just anterior of the juncture of the hard and soft palates. Infrared light emitted from the LED is reflected from the tongue's surface, detected by the phototransistor and transduced to a voltage level. The detected voltage is approximately proportional to the inverse square of the distance of the tongue from the sensor assembly.

2.2 Data Analysis

Tongue-palate distances for tokens 2-11 for each vowel in the three conditions were measured at that point within the acoustic vowel interval that best represented the endpoint of tongue movement for each token. Endpoints were selected by visual inspection of the time-varying distance traces, which were displayed together with RMS intensity on a high-resolution graphics terminal.

Articulatory compensation with respect to tongue positioning below the hard palate was considered (by way of definition)

-complete if the average unsigned tongue-palate distance at the four sensor locations differed by less than 1.0 mm for NO vs. BB or LO productions of a given vowel; [1]

-selective if the mean tongue-palate distances in BB or LO productions at sensor locations that are near the acoustically critical maximum constriction for a given vowel were within the range of the standard deviation (SD) associated with the mean for the NO tokens at those sensor locations;

-partial if the tongue compensated for the lowered jaw, but did not compensate completely or selectively.

Overshoot and *undershoot* refer to <u>partial compensation with higher-</u>

1 Reasons for selecting this criterion to determine tongue shape overlap are given in [5].

than-normal and lower-than-normal tongue positions, respectively. Finally, in *zero compensation* the tongue does not compensate for the lowered jaw in BB and LO speech. Variability in tongue positioning was assessed in terms of the SDs associated with the multiple productions of NO, BB, and LO vowels.

3. RESULTS

3.1 Tongue Positions

The most important result was that in the production of all six vowels, the tongue compensated for the lower-than-normal jaw position in both BB and LO speech. However, the tongue was lower in LO than BB speech at all four sensor locations for five vowels, suggesting that the tongue did not compensate as much for jaw lowering in the "natural" as in the artificial BB condition. The exception was /Y/ with overlapping tongue configurations in the BB and LO conditions.
Complete compensation by the tongue for jaw perturbation was observed in only two instances: For /i/ in the LO and for /U/ in the BB condition. Compensation was selective for /i/ in the BB condition, for /I/ in the BB and LO conditions, and for /y/ in the BB condition.
Partial compensation (undershoot) was observed for /y, Y, u, U/ in the LO and /Y/ in the BB condition. Undershoot relative to NO tongue positions, which increased monotonically from anterior to posterior sensor locations, was small for /Y/, medium for /y/ and /U/, and large for /u/. Surprisingly, undershoot for /u/ and /U/ in the LO condition was largest at sensor 4, which is located close to the acoustically critical maximum constriction for these back vowels at the velum. Results for perturbed /u/-productions differed from all other results in that undershoot in LO speech contrasted with overshoot (at the posterior sensors) in BB speech.

3.2 Variability of Tongue Positioning

The most important result concerning variability of tongue positioning in the three conditions was that perturbed vowels were not produced with uniformly more or uniformly less precise tongue gestures than NO vowels. The SDs associated with the multiple productions of the six vowels averaged 0.84 mm in the NO, 0.93 mm in the BB, and 0.77 mm in the LO condition. Tongue positioning for /i, I, y, Y/ was slightly more variable in the BB than the NO condition (SDs were 0.1 - 0.2 mm larger), but variability did not differ for /u, U/ across these conditions. Token-to-token variability was slightly larger in the LO than the NO condition for /i, I, U/ (SDs were 0.1 - 0.2 mm larger), did not differ for /Y/, and decreased for /u/ and /Y/ (by 0.3 mm and 0.6 mm, respectively).
The most conspicuous result was that for all vowels and all conditions, SDs increased monotonically from anterior to posterior sensor locations. This front-to-back increase in variability was observed irrespective of whether the acoustically critical maximum constriction was in the prepalatal (/i, I/), palatal (/y, Y/), or velar (/u, U/) region. It may be of some interest to note that tongue positioning for each of the nominally tense vowels /i, y, u/ was *more* variable than for its nominally lax counterpart (/I, Y, U/) in all three conditions.

4. DISCUSSION

The single-subject experiment reported here showed that the tongue compensated for a lowered jaw in both BB and LO speech, and that both conditions of jaw perturbation did not importantly affect the precision of motor control for the tongue.
Results of previous BB studies led to the expectation that articulatory compensation by the tongue in BB speech would be selective or complete. The present results for four (i, I, y, U/) of the six vowels examined conformed to this expectation. However, tongue positions for /Y, u/ in BB speech did not overlap with NO tongue positions or maintain NO tongue-palate distances near the acoustically critical maximum constriction. Preliminary acoustic analyses of the vowels examined in the present study indicated that partial compensation for /Y/ (undershoot) and /u/ (overshoot) did not result in changes in acoustic output that one might expect given the differences between NO and BB

tongue positions below the hard palate. This suggests that compensation for the lowered jaw in the BB production of /Y, u/ may have occurred in an area of the vocal tract not registered by the glossometer.
The hypothesis being tested for LO vowels was that the tongue would not compensate for the "natural bite block". This hypothesis, which Traunmüller [10] based on the acoustic properties (increase in F1) of LO vowels, was not supported. The present experiment showed that compensation by the tongue for a lowered jaw in LO speech may be partial (y, Y, u, U/), selective (/I/), or even complete (/i/). This suggests that motor programming in *both* LO and BB speech involves reorganization of tongue positioning to achieve precisely defined articulatory goals that are not necessarily (as for /i/ in LO speech) the same as in NO speech. The lower tongue positions in LO than in NO speech for four of the six vowels examined may have been effected to increase F1, so that the perceptually important distance between F1 and the increased F0 in LO speech would be maintained for a given vowel irrespective of vocal effort (see [10]).
Degree of precision in tongue positioning did not differ much across the three conditions. The SDs associated with multiple productions of NO (0.84 mm), BB (0.93 mm), and LO (0.77 mm) vowels were of approximately the same magnitude as the mean SD for the complete set of NO German vowels (0.78 mm [3]), the complete set of NO English vowels (0.81 mm [5]), and five Spanish and English vowels spoken normally (0.76 mm) and with a BB (0.80) [4]. These earlier studies suggested that neither vowel inventory size [4] nor mechanisms used to differentiate large vowel inventories [3] affect variability of tongue positioning. The present results corroborate and extend Flege's [4] BB study by showing that both artificial and natural jaw perturbation need not importantly affect degree of precision in tongue positioning.
(Research supported by grant NS20963-04 from the U.S. National Institutes of Health to the second author)

5. REFERENCES

[1] ABBS, J., GRACCO, V. & COLE, K. (1984), "Sensorimotor contributions to the coordination of multicomponent behaviors: Evidence from recent studies of speech movement control", *J. Motor Behavior, 16*, 195-231.
[2] BAUM, S. & KATZ, W. (1988), "Acoustic analysis of compensatory articulation in children." *J. Acoustical Society of America, 84*, 1662-1668.
[3] BOHN, O., FLEGE, J., DAGENAIS, P. & FLETCHER, S. (1991), "Differenzierung und Variabilität der Zungenpositionen bei der Artikulation deutscher Vokale", *Forum Phoneticum* (in press).
[4] FLEGE, J. (1989), "Differences in inventory size affect the location but not the precision of tongue positioning in vowel production", *Language & Speech, 32*, 123-147.
[5] FLEGE, J., FLETCHER, S., McCUTCHEON, M. & SMITH, S. (1986), "The physiological specification of American English vowels", *Language & Speech, 29*, 361-388.
[6] GAY, T., LINDBLOM, B. & LUBKER, J. (1981), "Production of bite-block vowels: Acoustic equivalence by selective compensation", *J. Acoustical Society of America, 69*, 802-810.
[7] LINDBLOM, B., LUBKER, J. & GAY, T. (1979), "Formant frequencies of some fixed-mandible vowels and a model of speech motor programming by predictive simulation", *J. Phonetics, 7*, 147-161.
[8] LINDBLOM, B. & SUNDBERG, J. (1971), "Acoustical consequences of lip, tongue, jaw, and larynx movement", *J. Acoustical Society of America, 50*, 1166-1179.
[9] SCHULMAN, R. (1989), "Articulatory dynamics of loud and normal speech", *J. Acoustical Society of America, 85*, 295-312.
[10] TRAUNMÜLLER, H. (1988), "Paralinguistic variation and invariance in the characteristic frequencies of vowels", *Phonetica, 45*, 1-29.
[11] TYE, N., ZIMMERMANN, G. & KELSO, J. (1983), "'Compensatory articulation' in hearing impaired speakers: A cinefluorographic study", *J. Phonetics, 11*, 101-115.