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Immediate Compensation in Bite-Block Speech

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Abstract. An experiment was conducted to examine whether a bite block affects the latency and/or the quality of spoken vowels. The results suggest that vowels spoken with the bite block and vowels spoken normally were (1) of the same latency, that is, the same time elapsed between visual presentation and initiation of response; and (2) of the same quality, that is, the acoustic measures of the vowels did not differ substantially. Moreover, there was minimal evidence of improvement in either latency or quality with practice, and minimal evidence of an effect of time pressure on the quality of bite-block vowels. A detailed consideration is given to the implications of these and other findings for two recent perspectives on vowel production.

Recent evidence indicates that talkers can produce normal or near-normal vowels when the position of the jaw is fixed by a bite block [GAY and TURVEY, 1979; LINDBLOM and SUNDBERG, 1971; LINDBLOM et al., 1979; NETSELL et al., 1978]. These findings are compatible with those obtained using other techniques in which ongoing movements are perturbed unexpectedly [FOLKINS and ABBS, 1975, 1976], afferent information is disrupted [e.g. GAY and TURVEY, 1979], or lip-rounding gestures are precluded [RIORDAN, 1977]. Under these articulatory conditions, talkers show a remarkable ability to produce near-normal utterances, often with little or no practice.

These experimental manipulations change the movement capabilities, the actual movements or the afference that a talker has available to support his production of segments. In short, they have required that speech be produced under novel contextual conditions. Even so, talkers have succeeded in producing normal or near-normal speech often on their very first attempts [e.g. LINDBLOM et al., 1979].

These findings seem to falsify WICKELGREN's [1969, 1976] proposal that a language user's knowledge of a phonological segment consists of

a set of context-sensitive allophones each appropriate to one of the contexts in which the segment will occur. If this were the case, talkers could not easily produce a familiar segment in a novel context. Since evidently they can, a different explanation is called for. An interesting one is proposed by researchers who have noticed the similarity between segment production and sentence production [e.g. LINDBLOM et al., 1979] in respect to the talker's ability to generate novel instances to fit novel contextual demands. The production of novel *sentences* is explained by assuming that the talker knows a set of generative grammatical rules rather than a collection of context-sensitive instances as in WICKELGREN's view of segments. Similarly, it is possible that a talker's knowledge of segments consists of sets of organized, context-sensitive constraints on articulation, where the constraints specify the essential characteristics of the segment [e.g. FOWLER et al., 1980].

However, the conclusion that speech is generative is not yet enforced by extant bite-block studies, since they have not in fact demonstrated *immediate* compensation for the bite block even though they show vowels to be normal or near-normal from the first pitch pulse. Virtually all studies of bite-block speech use isolated vowels as utterances. In producing an isolated vowel, a talker can delay generating a sound as long as he likes. Under these conditions, a nongenerative system for vowel production could produce normal vowels from the first pitch pulse. One such system might include a specification of sensory goals for each vowel that, when reached, will ensure the appropriate vocal tract shape for the vowel. When the talker first tries to produce a vowel with a bite block, he will fail to reach the sensory targets. Having detected an error, however, he can delay generating any acoustic evidence of it, while he searches for the appropriate sensory states. On this interpretation, the capacity to produce a segment in an indefinitely large variety of ways does not really inhere in the talker's knowledge of a segment, and hence the knowledge is not generative even though it is context-sensitive.

A view of vowel production such as the foregoing may be distinguished from a view that speech is generative (e.g. LINDBLOM et al., 1979; GAY and TURVEY, 1979; FOWLER et al., 1980] by examining whether or not compensation for the bite block is temporally immediate. If the talker's knowledge of a segment is generative, then generation of a novel segment, no less than generation of a novel sentence, should be part of the normal operation of his speech production

system. Therefore, time to produce a novel bite-block vowel should be no longer than time to produce a familiar, unimpeded vowel [but see LUBKER, 1979, for a different view]. If it is not generative, then response time to produce a bite-block vowel should exceed time to produce a normal vowel. The present experiment was designed to distinguish these interpretations.

Methods

Design

Two groups of subjects were run. Both groups produced a set of vowels without the bite block followed by a set of bite-block vowels. The groups differed in the instructions they were given regarding their response times, and in the feedback they were given about response time. One group produced their responses under time pressure; the other did not. This manipulation was included to assess the quality of bite-block vowels depending on whether or not time was available to 'search' for a target shape of the vocal tract. (The confounding between order of task and bite-block versus normal conditions of production was necessary in order to manipulate the independent variable of time pressure. The confounding makes it impossible to distinguish practice effects from bite-block effects, when each group of subjects is considered independently. However, since practice effects are presumably the same for both groups of subjects, any differences between the groups in the quality of bite-block vowels may be unambiguously attributed to the variable of time pressure.)

Stimuli and Materials

The stimuli were the six vowels /i, e, a, ɔ, ʌ, u/. They were presented to subjects visually on the CRT screen of a computer terminal. The vowels were spelled 'EE', 'EH', 'AH', 'AW', 'UH', 'OO'.

The subjects' vocal responses were recorded on tape for later analysis. Reaction times collected for the purposes of providing feedback to subjects were measured with a millisecond counter interfaced to the computer.

The bite blocks were sections of wooden dowling 14 mm in height and 10 mm in diameter. These were clenched between the front teeth. This procedure differs somewhat from that of GAY and TURVEY [1979], whose subjects clenched a pair of bite blocks between their incisors. In view of the outcome of the experiment, this procedural difference could have had little effect.

Procedure

Group 1. Subjects were shown a card on which the spellings of the six vowels were listed. They were given practice reading the vowels until they were fluent. Next they were seated in front of a CRT screen. The screen was covered by opaque paper except for a slit the width of a single line of print located approximately in the center of the screen. An arrow on the paper indicated where the stimulus for each trial would appear. On each trial, a warning bell sounded, followed after 495 ms by the appearance of the screen of the vowel spelling for that trial. Subjects were instructed to read the vowel aloud as quickly as possible.

Subjects spoke their responses into two microphones. One triggered the millisecond counter and the other served to record the warning bell and vocal response on tape for later analysis. The response time measured by the millisecond counter was used for the purposes of providing feedback to the subjects in group 1. This time in milliseconds was

printed on the CRT after each trial. Response times used in the analysis of the data were measured from spectrographic displays made from the audio tape.

Trials were randomized in sets of 6, and were grouped into 5 larger sets of 18. In each set of 6 trials, each vowel was presented once. The order of the vowels within a set was random and varied over sets and subjects. Trials were sequenced so that a trial followed a subject's vocal response to the preceding trial by 2, 2.5, 3, 3.5, 4 or 4.5 s. These intertrial intervals occurred once each in a set of 6 in random order. After each 18 trials, subjects were given a 30-second break. In the bite-block series, the bite block was removed during the break. The breaks were more frequent than necessary during the series without the bite block, but were welcome during the bite-block trials.

Subjects participated in 36 practice trials without the bite block, followed by 90 more non-bite-block trials. After that, they were given a short break, during which their instructions for the bite block series were given. Subjects were told to place the bite block between their front teeth as soon as they heard a series of warning bells signaling the end of the break. They were told to produce the clearest vowels they could without slowing their response times relative to what they had been on the preceding series.

Group 2. Subjects in this group were treated almost identically to those in group 1. However, in contrast to group 1 subjects, they were not told that their response times were being measured. Nor were they given feedback about response time after each trial. Preceding the bite block series, they were told to produce the clearest vowels they could, but were not given any instructions as to reaction time.

Measures

Reaction Time. Sound spectrograms were made of the subjects' 90 trials without the bite block and their 90 bite-block trials. Each spectrogram included the warning bell and the subjects' vocal response. Response time was measured in millimeters from the onset of the warning bell to the response onset. This measure was converted to milliseconds and the 495 msec that had intervened between the warning bell and the appearance of the stimulus on the CRT was subtracted. In a few instances, the response times were longer than the 2 s that can be displayed on a single spectrogram. In these instances, the reaction time measured by the millisecond counter was substituted.

Response times were averaged separately over the normal 90 and the 90 bite-block trials. To assess practice effects, means were taken for each set of 18 trials. In addition, the subjects' first 6 trials (one instance of each of the six vowels) produced with the bite block were considered separately.

Acoustic Measures. For the purposes of the acoustic measures, the spectrograms for each subject were divided into six groups, one for each vowel. Within a group, the bite-block and normal vowels were mixed randomly. Hence scoring was blind with respect to condition (normal versus bite block), but not with respect to vowel or to subject. Measurements of the first and second formants were taken at vowel onset. As for the reaction times, averages were taken across each set of 18 trials. In addition, the first 6 bite-block trials were considered separately. Deviations between normal and bite-block formants were computed and compared against deviations predicted on the assumption that the talker made no effort to compensate for the bite block. The predictions were derived from simulations produced by the articulatory synthesizer at Haskins Laboratories by a procedure that will be described in the 'Results' section.

Perceptual Measures. To assess the relative perceptibility of bite block and normal vowels, four tapes were constructed for each of the subjects in group 1. Each tape included 48 trials, the first and last 12 of the 90 bite-block and the 90 normal vowels for a single talker. The

vowels were presented in random order with an interval between trials of 3 s. These tapes were given to a group of 11 naive subjects, who were asked to identify the vowel on each trial by circling its spelling on an answer sheet. The answer sheet offered 9 response alternatives on each trial (/i, ɪ, ɛ, a, æ, ɔ, ʌ, ʊ, u/ spelled 'ee', 'i', 'e', 'o', 'a', 'aw', 'u', 'uu', 'oo'). The order of the tapes was varied in a Latin square design with 3 subjects receiving three orders and 2 subjects receiving the fourth. The subjects' numbers of errors made to normal and bite-block vowels served as a measure of the perceptibility of bite-block relative to normal vowels produced under time pressure.

Subjects

Of the 8 subjects participating in the production experiment, 6 were undergraduates at Dartmouth College, who participated in the experiment for course credit, 1 was a graduate student, and the last was the first author. 2 of the subjects in each experimental condition were female and 2 were male. The 11 subjects participating in the perception study were undergraduates at Dartmouth College who participated for course credit.

Results

The reaction-time and acoustic measures are based on a maximum of 15 tokens per vowel per subject in each of the conditions, normal and bite block. Responses were excluded from the analysis only when they constituted clear misreadings or had been produced in less than 100 ms. This occurred rarely. Subjects in the time-pressure condition averaged 97 % accuracy, both on the normal and on the bite-block vowels. The group responding without time pressure averaged 99 % and 99.7 % on normal and bite-block vowels. The difference in accuracy between the groups probably can be attributed to the differential time pressure under which the two groups produced the vowels.

Reaction Time

Three major questions concerning reaction time are of interest. One is whether the subjects who performed under time pressure were able to follow instructions to maintain their response times during the bite-block series. An affirmative answer may be given. Subjects in this group in fact averaged 12 ms faster in the bite-block condition (408 versus 420 ms). Looking at their performance on the 18 trials preceding the bite-block series and at the first 18 trials with the bite block, again the means are close and in favor of the bite-block series (378 versus 383).

A second question concerns the relative speeds of group 1 (with time pressure) and group 2 (without time pressure). The groups did respond at different speeds, the group 1 subjects averaging 414 ms and

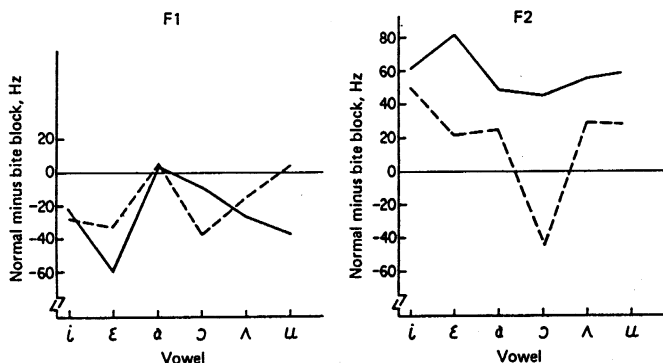


Fig. 1. Departures of formant values of bite-block vowels from those of vowels produced without the bite block, for subjects of group 1 (time pressure, —) and group 2 (no time pressure, ----).

the group 2 subjects 707 ms. This difference is statistically significant ($F[1,6] = 7.17$, $p = 0.036$). These two findings confirm that the experimental manipulations were effective in establishing two groups of subjects responding under different levels of time pressure during the bite-block trials.

A final question asks whether group 2 chose to slow down on the bite-block trials relative to the preceding series. Like the experimental group, group 2 in fact responded faster on bite-block trials than on the preceding series if the means of the two series of 90 trials are considered (670 versus 743 ms). However, comparing the last 18 normal trials against the first 18 bite-block trials provides a different picture. Group 2 subjects did slow down on bite-block trials relative to the preceding 18 trials (763 versus 680 ms). This may indicate that these subjects found it more difficult to produce vowels with a bite block than to produce them without a bite block. It remains to determine whether slowing down improved the quality of their vowels. Indeed, the response times themselves are of lesser interest than the quality of the vowels produced under the two levels of time pressure. We turn first to the acoustic measures of vowel quality.

Acoustic Measures

Figure 1 plots the deviations of acoustic measures of bite-block from normal vowels separately for group 1 and group 2 and for the first and second formants.

Separate four-way analyses of variance were performed on the measures of the first and second formants. (Vowel [i, ε, a, ɔ, ʌ, u] + 18-trial Set [1-5] × Condition [normal versus bite block] × Group [1 versus 2]). Of particular interest are the effects of the bite block (Condition), and any interaction in which it may participate with Group. A Conditions effect would indicate that the acoustic properties of the bite-block vowels differ from those of the normal vowels. (Since the effects of the bite block in raising or lowering a formant might differ for different vowels, this effect might show up instead as a Conditions × Vowel interaction.) An interaction with Group would indicate that the acoustic effects of the bite block depended on whether or not the vowels were spoken under time pressure. An effect of Sets on the bite-block trials might indicate learning. Hence an interaction of Sets and Conditions or of Sets, Conditions and Groups may be of interest.

Conditions. On the measure of F1, the Conditions effect approached statistical significance ($F[1,6] = 5.14, p = 0.06$). This near-significant outcome is due to a tendency for bite-block vowels to have a higher F1 than normal vowels (610 versus 590 Hz). As we will see, this tends to be the direction of the effect that the bite block is expected to have on a talker who does not compensate for it, but it is much smaller than the predicted magnitude of effect. The interaction between Conditions and Vowel is also significant ($F[5,30] = 3.50, p = 0.01$), but it is not particularly important, accounting for less than 0.1% of the total variance in the F1 measure. It appears to be due to the vowel /a/ having been essentially unaffected by the bite block, and /ε/ having been more affected (showing a 46-Hz rise in F1) than the remaining four vowels (range 21-25 Hz rise). Thus, subjects do show a small effect of the bite block [as suggested also in the data of LINDBLOM et al., 1979]. However, the effect is no greater for group 1 than group 2 ($F[5,30] = 2.10, p = 0.09$).

On F2, neither the effect of the bite block nor the interaction of Conditions with Vowels approached significance. Thus, although F2 tended to be lower on bite-block than on normal vowels (1,511 versus 1,549 Hz), this difference was not reliable. Nor did it interact with Group ($F[5,30] < 1$).

Sets. On F1, the effect of Sets is highly significant ($F[4,24] = 6.76, p < 0.001$). However, it accounts for little of the total variance and is

Table I. Deviation (in Hz) of bite-block from normal vowels across the five sets of 18 trials

	Set				
	1	2	3	4	5
<i>F1</i>					
Group 1	2	-38	-10	-26	-45
Group 2	-47	3	-10	-29	-11
<i>F2</i>					
Group 1	102	64	47	63	2
Group 2	-3	31	21	15	30

nonmonotonic, showing a rise from sets 1 to 3 and a slight fall thereafter. This effect interacts with Conditions and Groups ($F[4,24] = 4.61$, $p = 0.007$). As noted, an interesting interaction with Conditions would be one in which subjects show a practice effect on bite-block trials such that *F1* gradually declines, approaching its pre-bite-block value. An interaction of sets, Conditions and Groups might indicate that only one of the groups of subjects showed the learning effect. This does not describe the triple interaction in the data, however. Subjects in neither group showed a gradual decline in *F1*. The Sets effects at all levels of Groups and Conditions was nonmonotonic, and not readily interpretable.

Another way of looking at the Sets effect may be obtained by converting performance on each set to a deviation between the mean *F1* for the normally produced vowels and *F1* for the bite-block vowels. This measure is free from any Sets effects that are shared by normal and bite-block vowels. A practice effect on the bite-block trials would be manifest as an approach of the deviation scores toward zero over sets. The values are given in table I. On this measure, the second group obtains their most deviant performance on the first set. However, other than this there is no indication of a practice effect over sets. Instead, the values suggest that, as in the study of LINDBLOM et al. [1979], subjects approach normal formant values as closely on the early blocks of trials as they do on later ones. This seems to be no more nor less true for the group 2 subjects who slowed down on these initial trials than for group 1 subjects who did not.

As for *F1*, the effect of Sets on the measure of *F2* ($F[4,24] = 2.81$,

$p = 0.05$) and the triple interaction of Sets, Conditions and Groups ($F[4,24] = 4.43$, $p < 0.01$) were significant. Again the Sets effect is nonmonotonic and neither bite-block condition, that for group 1 nor for group 2, shows a practice or learning effect. Table I shows the deviation of normal and bite-block trials for the two groups on F2. On this measure, the first group obtains its most deviant score on the first set of trials; the second group obtains its least deviant score on this block.

These analyses indicate a very small, but detectable effect of the bite block on acoustic measures of the vowel. The data provide little indication of a practice effect, nor significant evidence that the subjects producing vowels under time pressure were more affected by the bite block than subjects not under time pressure.

Individual Talkers

Individual subjects produced sufficient tokens of each type of vowel ($N = 15$) under both conditions of the experiment, normal and bite block, that significance tests of bite-block effects can be performed on individuals. To that end, 12 tests were performed separately for each of the 8 subjects in the experiment, two each for the six vowels, one on the measure of F1 and one on F2. The tests compared the average F1 or F2 of the normal and bite-block vowels.

In all, then 96 t tests were performed. Performing multiple t tests is normally not an appropriate statistical procedure, because a large number of tests will overestimate the number of truly significant outcomes. (This is because the probability of making a type 1 error sums across the tests.) In the present instance, however, the unconservative outcome of these tests is unusual in being a *failure* to find significant differences – that is, in finding no effect of the bite block. Hence a group of tests that overestimates the number of significant outcomes is conservative rather than unconservative as it is ordinarily.

Our concern was to compare the number of t tests giving significant outcomes for the group 1 and group 2 subjects. Table II shows the number of significant t tests obtained by the individual subjects of the two groups. Group 1 subjects do show overall more significant tests (14 of 48 tests) than do group 2 subjects (11 of 48 tests). This difference in the number of significant tests is itself nonsignificant due to the large intergroup variability in the effect of the bite block ($t [6] = 1.71$, $p = 0.13$).

Table II. Number of significant *t* tests comparing normal and bite-block vowels on F1 and F2, listed separately for subjects in groups 1 and 2

	Group 1	Group 2
Talker 1	2	1
Talker 2	4	2
Talker 3	6	3
Talker 4	6	5
Sum	18	11

The First Six Bite-Block Vowels

We turn now to the first six vowels produced with the bite block and compare their formant values with those of the previous block of 90.

Two three-way analyses of variance were computed, one for F1 and one for F2. The analyses compared Vowel (i, ε, a, ɔ, ʌ, u) × Condition (normal versus the first six bite-block vowels) × Group (1 versus 2). On the measure of F1, only the effect of Vowels was significant ($F[5,30] = 47.2$, $p < 0.0001$) indicating, of course, that the six vowels have different F1 values. This effect accounted for 67% of the variance in the F1 measure. On F2, the effect of Vowels was again significant ($F[5,30] = 107.3$, $p < 0.0001$), accounting this time for 84% of the variance. However, the Conditions effect also reached significance ($F[1,6] = 41.2$, $p < 0.001$) owing to the bite-block vowels having a lower F2 than the normal vowels (1,480 versus 1,548 Hz). This effect did not interact with Group. Given that the effect washes out when the six trials are averaged with the remaining 12 of the first set of trials, it may indicate a rapid learning effect within the first set of 18 trials.

In sum, these analyses indicate that the first 6 bite-block vowels produced by a subject are significantly different from normal vowels in respect to F2. However, the degree of deviance is no different for subjects producing vowels under time pressure than for subjects producing them in the absence of time constraints.

Comparisons of Obtained versus Expected Effects of the Bite Block

In order to evaluate the effects of the bite block on F1 and F2, we generated a pair of predictions for each vowel. The predictions concerned the effects of the bite block on the acoustic correlates of the six vowels were a talker to make no compensatory adjustments at all.

To obtain these predicted deviations from normal F1 and F2 values we used the articulatory synthesizer at Haskins Laboratories¹. The synthesizer produces speech based on the area function of a vocal-tract analogue [MERMELSTEIN, 1973; RUBIN et al., 1979]. The vocal-tract shape can be changed by adjusting the positions of six articulators in the model including the tongue body, velum, tongue, tip, jaw, lips and hyoid bone.

Our procedure was first to generate a token of each of the vowels that was of adequate perceptual quality. Having synthesized an acceptable token of a vowel, we adjusted the position of the model's jaw to the value that it would have if a 14-mm bite block were clenched between the teeth. The vowel was then resynthesized. The difference between the initial and new values of F1 and F2 represent the changes that would occur if the talker made no effort to compensate for the bite block.

Table III provides the normal and bite-block values of F1 and F2 produced by the articulatory synthesizer. Table IV compares the predicted changes in F1 and F2 with the actual changes in the two groups of subjects. In respect to F1, the predicted effect of the bite block matches the sign of the obtained effect in five of the six comparisons with group 1, and in four of the six with group 2. In every instance but one, the obtained values were nearer zero than the predicted values, sometimes by a wide margin. The correlation between the obtained and predicted values of $\Delta F1$ is 0.73 for group 1 and 0.22 for group 2. The value for group 1 is significant ($p < 0.05$).

On F2, the predicted change in F2 matches the sign of the obtained change on four of the six vowels for the experimental group and on five of the six for group 2. In every instance the obtained values of $\Delta F2$ are closer to zero than the predicted values. The correlation between obtained and predicted values of $\Delta F2$ is 0.25 for group 1 and 0.31 for group 2.

These analyses suggest that the bite block has effects for which the talker cannot or does not compensate entirely. However, if the magnitudes as well as the signs of the predicted changes in F1 and F2 are taken seriously, they suggest that talkers go a long way toward compensation.

¹ We thank Phil Rubin for synthesizing the normal and 'bite-block' vowels on our behalf.

Table III. The values of F1 and F2 for normal and bite-block vowels as produced by an articulatory synthesizer

	Vowel					
	i	ε	a	ɔ	Λ	u
<i>F1</i>						
Normal	328	508	871	552	700	287
Bite block	701	823	792	535	754	580
<i>F2</i>						
Normal	2,238	1,844	1,243	856	1,453	814
Bite block	1,943	1,666	1,179	905	1,193	1,179

Table IV. F1 and F2: Deviations of bite-block from normal vowels as predicted by the articulatory synthesizer and as obtained by groups 1 and 2

	Vowel					
	i	ε	a	ɔ	Λ	u
<i>F1</i>						
Synthesizer	— 373	— 315	79	17	— 54	— 293
Group 1	— 21	— 60	4	— 8	— 27	— 37
Group 2	— 28	— 33	5	— 37	— 15	4
<i>F2</i>						
Synthesizer	295	178	64	— 49	260	— 365
Group 1	61	82	48	46	56	59
Group 2	51	22	26	— 45	35	32

In eight of the twelve comparisons, the obtained values of $\Delta F1$ or $\Delta F2$ for group 1 lie closer to the predicted values than those for group 2. In the remaining four comparisons, group 2 provides less evidence for compensation than the experimental group. This tendency for group 2 to show more compensation is not statistically significant according to a sign test ($p = 0.38$).

A Perceptual Measure of Vowel Quality

We will consider the outcome of the perceptual test very briefly. It seemed possible to us that measures of perceptibility would provide a better index of the quality of the bite-block vowels than acoustic measures. We reasoned that since a vowel is a category that includes a range of acoustic realizations, differences between bite-block and normally produced vowels on acoustic measures would not necessarily signify that the bite-block vowels were outside of the range of accept-

Table V. Mean number correct out of 24 (and SD) on perceptual test of normal and bite-block vowels

	Condition	
	normal	bite block
Talker 1	19.0 (2.2)	18.3 (2.5)
Talker 2	19.5 (3.2)	17.1 (3.2)
Talker 3	20.5 (2.2)	21.2 (2.0)
Talker 4	18.6 (2.7)	17.7 (3.0)

able instances of the vowel category. (It is probable that it would signify exactly this given the logic of a statistical test, but it need not have that meaning.) A more sensitive measure might be a perceiver's ability to identify the vowel as a token of the intended category.

As described in the 'Methods' section, the test was limited to the talkers of group 1. We did not extend the test to the talkers of the second group because after running the test, it did not seem to us that it had provided new information not provided by the acoustic measures.

Performance on the tests ranged from a low of 71 % to a high of 90 % correct identifications. Table V presents the performance levels for the 4 talkers and two conditions. 1 talker's bite-block vowels were slightly more identifiable than her normally produced vowels; the other 3 talkers showed small differences in the other direction, as might be expected. Performance was assessed by means of a two-way analysis of variance (Talker \times Condition [normal versus bite block]). All factors were statistically significant. The effect of Talker ($F[3,30] = 3.69$, $p = 0.02$) indicates individual differences among the talkers in the perceptibility of their vowels. The effect of Conditions ($F[1,10] = 9.68$, $p = 0.01$) indicates that overall, bite-block vowels were less identifiable than normally produced vowels. The interaction ($F[3,30] = 5.00$, $p = 0.006$) is significant because different talkers show different effects of the bite block. As noted the overall trend for bite-block vowels to be less perceptible than normal vowels was true for 3 subjects, but was reversed for the fourth. Moreover, only 1 subject of the 4 shows a substantial effect of the bite block on perceptibility.

Compatibly with the acoustic measures, bite-block vowels can be distinguished from normally produced vowels in quality. However, here as there, the quality differences are quite small. In apparent

contrast to the present findings, other researchers have tended to report no effect of the bite block on the identifiability of vowels. We suspect that the difference between their reports and our outcome is one of the relative sensitivities of the assessments of identifiability. Other assessments have been informal judgments by the investigators. Our intuitions listening to the vowels agreed with those judgments. The bite-block vowels seemed distinguishable from normally produced vowels only in sounding like an acceptable vowel produced with the teeth clenched. That is, the vowels sounded perfectly identifiable, but the presence of an obstruction was typically noticeable. However, the judgments of naive listeners indicate that the bite-block vowels do suffer slightly in intelligibility.

Discussion

The study, following others, showed substantial compensation for the imposition of novel conditions of talking. These findings support a view of segment production as generative. However, compensation was not complete, and we may ask if the minor departures from full compensation falsify a proposal that segment production is generative. They do not necessarily, since small departures from full compensation may arise for reasons that are outside the control of the system whether or not it is generative. One reason why a generative system might not show full compensation is that the bite block itself, in blocking the passage of air at the lips, may affect the acoustic signal for the vowel. Another may be that there is no way anatomically to compensate for some configurational changes made by the bite block, in particular, the opening at the lips. We are hampered in our understanding of these partial compensations because we cannot yet determine what the structural possibilities are for full compensation.

Discounting these departures from full compensation, let us consider how a generative speech system might work. Two explanations of generativity in speech production have been offered in the recent literature, one by LINDBLOM et al. [1979] and one by FOWLER et al. [1980; see also GAY and TURVEY, 1979]. LINDBLOM et al. propose that a segment is specified as a sensory goal [see also MACNEILAGE, 1970], and is paired with a set of motor commands for reaching the target. In producing a vowel, the vowel's sensory goal is translated into a

simulated set of motor commands. In conjunction with information about the context in which the segment will be realized, the simulated commands generate simulated sensory consequences. These are compared with intended sensory consequences and the difference between them specifies how the motor commands need to be adjusted in order for the intended sensory consequences to be realized. The investigators considered it essential to complicate the model by including the simulation loop in order to realize certain advantages over a scheme in which the loop is absent or in which it is replaced by an actual loop.

One advantage over a system in which the loop is absent is that the context sensitivity and generativity of segment production is captured. The speech producing system has a way of generating familiar segments in novel ways. An advantage over a system in which the loop is present, but is actual rather than simulated, is that 'errors' – that is discrepancies between intended and actual states of affairs – are not realized in articulatory activity. They occur only in the simulation prior to articulation.

A rather different proposal is offered by FOWLER et al. [1980]. This proposal differs from that of LINDBLOM et al. [1979] in attributing the generativity of vowel production to the organization of the musculature underlying speech, rather than to a set of procedures for choosing an organization. Organized constraints on muscles are effective actually by restricting what the vocal tract can do – more or less for example, as the axle and steering linkage of a car restrict what the front wheels can do.

This view is derived from the literature on motor control (see e.g. TURVEY, 1977], particularly investigations of fundamental motor skills including for example walking [e.g. GRILLNER, 1975], respiration [e.g. ZAVALISHIN and TENENBAUM, 1968] and chewing [e.g. DUBNER et al., 1979]). Generativity in skilled motor performance is characteristic of these activities as well as speech, but here it can be ascribed to the organization of the musculature underlying the activity and less to any instructions they may receive. In part this ascription is promoted by studies, particularly in the locomotion literature, in which decorticate or even spinal animals demonstrate the essential characteristics of coordinated motor performance [see GRILLNER, 1975, for a review of the literature].

In our view, the present study does not distinguish the model of LINDBLOM et al. [1979] from the proposals of FOWLER et al. [1980] and

GAY and TURVEY [1979]. LUBKER [1979] reports a study that he believes does make a distinction between the proposals, providing support for the model of LINDBLOM et al. However, we believe that this conclusions can be discounted on several grounds. First he tests a prediction, ostensibly derived from the model, that programming time for bite-block vowels will exceed that for normal vowels. As we have indicated, in our view this predication does not derive naturally from a view that speech is generative including the particular proposal of LINDBLOM et al. Moreover, if the prediction were accurate, the present study would provide apparent counterevidence to it. Next, the outcome of LUBKER's [1979] study, in fact showing a longer programming time for some bite-block vowels, is rendered uninterpretable by confoundings between levels of his major independent variables (presence or absence of bite block; choice reaction time or simple reaction time tasks) and the order in which subjects received the various levels. In particular, normal vowels invariably were produced before bite-block vowels, and the choice reaction task preceded the simple reaction time task. Since the critical measure was a comparison of the choice-simple reaction time difference for normal and bite-block vowels – by hypothesis, a rough measure of programming time – counterbalancing of the conditions is essential to avoid confounding with practice effects. Finally, the larger choice-simple reaction time difference was statistically significant only for two of the seven vowels in the experiment (as assessed from LUBKER's table IV) – the two high front vowels /i/ and /y/. Since LUBKER's measure of programming time also included execution time – that is, time to achieve the vowel's target shape of the tract once movement was initiated – and since /i/ and /y/ are most likely to be slowed in execution due to an antagonism, caused by the bite block, between lingual and mandibular muscles [see LINDBLOM and SUNDBERG, 1971], the slowing on these vowels (on the order of 30 ms for these vowels) may be a slowing in movement time, not programming. A check for this counterinterpretation would require that execution time be removed from the choice-simple reaction time difference.

In short, although the design of this study was appropriate to test the predictions that LUBKER derived from the model of LINDBLOM et al., the predictions do not seem to us to follow necessarily or even obviously from the model, and, in any case, the outcome of the study is not interpretable.