BITE-LOCK SPEECH IN THE ABSENCE OF ORAL SENSIBILITY

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INTRODUCTION

Bite-block experiments have been a popular means of investigating the articulatory system's compensatory abilities, especially regarding the speed with which compensation is achieved and the necessity for various forms of feedback. Lindblom, Luker and Gay /4/ reported for isolated vowels almost perfect articulatory compensation for the presence of a 22 mm bite-block, even when formant measurements were made at the first glottal pulse. The question of whether production of bite-block vowels suffers when the bite-block condition was combined with anesthesia of the oral mucosa; the latter also produced distortion, but only when sensory deprivation also included temporo-mandibular nerve-block. The results of these two experiments were interpreted by Perkell /5/ /6/ /7/ as demonstrating the motor system's dependency on afferent information to mark out an articulatory configuration in the course of the paradigm, with auditory information being substituted when the bite-block condition is introduced. Various studies have shown that under this condition, auditory information can be used to compensate for the absence of oral afferent information bilaterally following surgical treatment for trigeminal neuralgia.

SUBJECT

Three years prior to the experiment reported here the patient (male, aged 29, native German speaker with some Bavarian dialectal influence) suffered closed-head trauma and whiplash injury to the cervical cord in a sporting accident. For about the first month afterwards he was only capable of monosyllabic speech but subsequently his articulatory abilities recovered rapidly, being essentially normal six months after the accident. Substantial sensory deficits for the oral region were observed immediately after the accident, with no signs of subsequent improvement. Immediately prior to the experiment we examined the patient's oral sensibility in detail. In all speech structures where detailed testing was possible, namely lower and upper lip, tongue tip and blade, and mucosa of the oral cavity, thresholds for light touch, two-point discrimination, temperature and vibrotactile perception were raised substantially as to be unmeasurable with our custom-developed equipment for assessment of oral sensibility. No forms at all could be recognised in a 12-form test of oral afferents. Less formal testing techniques also revealed substantial no longer being present in the temporal region. As far as the speech system is concerned, the only deficits of our patient were thus probably more severe than those of Linke's patient /7/ and still more than those of the relevant to the upper lip condition /1/. It is perhaps also subjects the sensory deficits of our patient were thus considerably reduced. Under this condition, the patient was described as being characterized by laryngealized, low intensity phonation. The precise values were: /i/ F1 390 Hz, F2 2005 Hz
/u/ F1 421 Hz, F2 1152 Hz

PROCEDURE

We endeavoured to replicate the procedure followed in /4/ /6/ /7/, regarding vowels produced, mode of elicitation and size of bite-block (although we restricted our investigation to bite-block, i.e. 22 mm). The patient was asked to produce nine responses (at three amplitudes of three of the six German vowels /i/, /u/ and /a/ under the following conditions and in the following order:

1. Initial unperturbed (IU)
2. Perturbed by white-noise at 80 dB delivered over headphones (HI)
3. Perturbed by a 22 mm bite-block between the lateral incisors (BB)
4. Perturbed by both white-noise and bite-block (WB)
5. Final unperturbed (FU)

(Abbreviations used in Table 1 in brackets)

The subject was asked to produce the vowels as accurately as possible and without delay following presentation of a card carrying the target vowel triad.

RESULTS

Vowel articulation was assessed by measuring the first and second formant frequencies for sentences produced in procedure. In contrast to earlier investigations the main results were obtained in a single approach to measurement since average values for the steady-state portions of the vowels were determined (an exception is the first vowel in the simple bite-block condition, see below). The results for each token were translated into /i/, /u/ and /a/ respectively, with the means for each condition then being given in Table 1. The range for the initial unperturbed condition is also indicated in figures. The results will first be presented and followed, by analysis of the results of the experiment as a whole.

White-noise condition

In this condition /i/ and especially /u/ show evidence of compensatory behaviour with a bite-block of this size close to the initial unperturbed condition with F1 for /i/ raised by 17 Hz and F2 lowered by 27 Hz while for /u/ F1 and F2 are raised by 27 and 72 Hz respectively, i.e. these formant values are all less perturbed than in the white-noise condition. However, if we adopt as criterion for success that both F1 and F2 reach within the normal range then in the case of /u/ this criterion is only reached in the last vowel of the sequence and only 5 of the 22 tokens for /u/ and /i/ are within the range of the initial unperturbed condition. In contrast to previous investigations the fact that the last four vowels show a progressive and conservative result in the complete absence of compensatory behaviour therefore occurs. For /u/ there is a fair amount of variability, but averaging the nine vowels for all four conditions under this condition the patient is, of course, effectively speaking without afferent information of any kind. The fact that /a/ is less perturbed than the rest of the data is better when the formant values are calculated as a measure of the percentage of the formant values remaining within the normal range. In this condition the vowel /u/ shows very similar problems while also apparently having substituted speech articulation at the same time as the patient was able to perform these experiments.

Steady-state F1 and F2 values in Hz averaged over each vowel in each condition

<table>
<thead>
<tr>
<th>Vowel</th>
<th>IU</th>
<th>HI</th>
<th>BB</th>
<th>WB</th>
<th>FU</th>
</tr>
</thead>
<tbody>
<tr>
<td>/i/</td>
<td>390</td>
<td>407</td>
<td>330</td>
<td>390</td>
<td>390</td>
</tr>
<tr>
<td>/u/</td>
<td>421</td>
<td>414</td>
<td>382</td>
<td>414</td>
<td>421</td>
</tr>
</tbody>
</table>

For /i/ F1 < 420 Hz, F2 < 2200 Hz
For /u/ F1 > 420 Hz, F2 > 2200 Hz

Looking at /i/ and /u/ in these terms the subject shows clear compensatory behaviour since in both cases average values are almost the same as the initial unperturbed condition. However, if we adopt as criterion for success that both F1 and F2 reach within the normal range then in the case of /u/ this criterion is only reached in the last vowel of the sequence and only 5 of the 22 tokens for /u/ and /i/ are within the range of the initial unperturbed condition. In contrast to previous investigations the fact that the last four vowels show a progressive and conservative result in the complete absence of compensatory behaviour; i.e., using the nine vowels classified by the last condition, the patient was, of course, effectively speaking without afferent information of any kind. The fact that /a/ is less perturbed than the rest of the data is better when the formant values are calculated as a measure of the percentage of the formant values remaining within the normal range. In this condition the vowel /u/ shows very similar problems while also apparently having substituted speech articulation at the same time as the patient was able to perform these experiments.

for specifically for speakers of Bavarian. There is no evidence of systematic changes in the articulatory configuration in the course of the sequences under this condition.

Simple bite-block condition

In the bite-block condition the main question is less whether compensation is achieved but rather how fast it occurs. In previous investigations compensation was virtually instantaneous, i.e., by the first glottal period. To put the following figures into perspective we cite the estimates given in /4/ for the bite-block condition in contrast to earlier investigations the main results were obtained in a single approach to measurement since average values for the steady-state portions of the vowels were determined (an exception is the first vowel in the simple bite-block condition, see below). The results for each token were translated into /i/, /u/ and /a/ respectively, with the means for each condition then being given in Table 1. The range for the initial unperturbed condition is also indicated in figures. The results will first be presented and followed, by analysis of the results of the experiment as a whole.

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This subject is thus capable of compensation, but it is certainly not instantaneous, requiring tenths of seconds, or even seconds for complete success. This suggests a reliance on auditory information. The results for /u/ are somewhat puzzling. We had expected that the bite-block would cause virtually no articulatory disturbance, however the disturbance is, in fact, greater than for /i/ and /u/. F1 and F2 deviate upwards by 61 Hz and 104 Hz respectively, with no sign of an approach to the normal range over the course of the sequence. Additionally, productions sounded considerably fronted. This may provide the clue as to why no compensation is apparent. Unlike /i/ and /u/ the distortion caused by the bite-block would not, in the German vowel system, push the vowel into a different phonological category. It is probably that normally this low, back vowel can be realized acceptably with very little jaw opening, hence the observed distortion with the bite-block in place.

**Fig. 1: Formant frequencies for all tokens of /i/ in each condition except initial unperturbed, Range for this condition indicated by horizontal lines.**

**Fig. 2: Formant frequencies for all tokens of /u/ in each condition except initial unperturbed, Range for this condition indicated by horizontal lines.**

**Fig. 3: Formant frequencies for all tokens of /a/ in each condition except initial unperturbed, Range for this condition indicated by horizontal lines.**

Combined white-noise/bite-block condition

Bearing in mind the interpretation offered above for the /i/ and /u/ results, it is to be expected in this combined condition that these vowels should be even more distorted. Figs. 1 and 2 show that this is indeed the case. The means in Table 1 show F1 for /i/ raised by 59 Hz and F2 lowered by 116 Hz, while F1 for /u/ is raised by 107 Hz and F2 by 140 Hz. Table 1 shows that this continues a tendency for /i/ to show greater disruption than /u/.

The distortion is substantial, and there is no evidence of compensation improving over the sequence. It is also interesting to note that these mean values for /i/ and /u/ are quite close to the values measured at the onset of the first bite-block vowel, thus reinforcing the interpretation that the subject's compensatory behaviour was guided by auditory feedback.

For /a/ the distortion is about the same as in the simple bite-block condition but with much increased variability.

**Final unperturbed condition**

Turning, finally, to this last, control condition it is again noticeable that /i/ and /u/ exhibit similar behaviour since the values tend to cluster around the extreme of the initial normal range opposite to the "perturbed" region. This suggests that the subject has indeed been trying to compensate, but that the necessary turning off the compensatory behaviour. The results for /a/ are again somewhat different, with a weaker tendency to depart from the perturbed region of the F1/F2 space. This again suggests that the case of /a/ is simpler and less effort was made to compensate, and that apparently the distorted productions were still considered phonologically acceptable. One could also suggest that the greater distortion for /i/ than for /u/ may be that the subject followed a strategy of tongue-fronting when trying to cope with the perturbation. This may, in addition to the greater jaw opening, have contributed to the unexpectedly large distortions for /a/.

**GENERAL CONCLUSIONS**

The results for /i/ and /u/ are clearly very different from those obtained by Kelso and Tuller /2/. Our results strongly suggest that success in this type of perturbation experiment crucially depends on intact oral sensibility. Different information seems, as suggested in /ji/, to be used to establish a frame of reference for motor commands. When sensory information is unavailable and when the natural geometry of the vocal tract is disturbed by a bite-block the necessary recalibration of the frame of reference fails to take place. It might have been expected that information from the temporomandibular joint would be more important for the establishment of this frame of reference than information from the oral mucosa. The results in /i/ and /a/ suggest that this is not the case. This fact may, however, provide a line of attack for explaining the major discrepancy between our results and those in /ji/ as well as the minor discrepancies between those of /i/ and /a/ regarding the amount of sensory deprivation necessary to cause vowel distortion.

The reduction in different information was clearly substantial in all reported experiments; it would thus be singularly unhelpful to simply put the different results down to surprisingly large effects of rather subtle differences in amount of sensory deprivation. We would like to conclude with a more concrete proposal: In the reported experiments it is generally unclear to what extent anesthesia included the pharyngeal region. In our patient substantial sensory losses extended as far down as the laryngeal level. Recalling the unexpected amount of disturbance for the back vowel /a/ we suggest that information from the pharyngeal region may have a prominent role to play in maintaining the integrity of the orosensory frame of reference as a whole.

**REFERENCES**


