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ABSTRACT

The ability of a patient suffering from loss of oral sensibility to produce acoustically accurate vowels in the presence of a bite-block, both with and without additional auditory masking, was examined. The results indicated that in the absence of oral afferent information articulatory compensation was forced to rely on auditory feedback.

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, Lubker & Gay (1979) 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 sensory information from the oral region is suppressed was addressed by Lindblom, Lubker & McAllister (1977) and Gay & Turvey (1979). The former reported distorted formant values when the bite-block condition was combined with anesthesia of the oral mucosa; the latter also reported distortion, but only when sensory deprivation also included temporo-mandibular nerve-block. The results of these two experiments were interpreted by Perkell (1979) as demonstrating the motor system's dependence on afferent information to mark out an orosensory frame of reference.

In Gay & Turvey (1979) one subject was able to approach normal formant values over the course of several syllables, presumably by using auditory information. This led to Kelso & Tuller's (1983) logical extension of the paradigm, with auditory information now being eliminated as well through masking with white noise. For their 5 subjects, including, remarkably, Gay & Turvey's subject just mentioned *no* significant vowel distortion was found, even under these more difficult conditions.

These results thus cast doubt on Perkell's concept of an orosensory frame of reference underlying compensatory behaviour.

Using a different paradigm (unexpected electrical stimulation of orbicularis oris) Linke (1980) has reported undisturbed spontaneous speech but reduced compensatory abilities in a patient suffering from absence of trigeminal afferent information bilaterally following surgical treatment for trigeminal neuralgia.

These conflicting results impelled us to perform a bite-block experiment with a patient from our clinic who showed substantial deficits in oral sensibility.

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 utterances, 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 so 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 stereognosis. Less formal testing techniques also revealed substantial deficits in the pharyngeal region. As far as the speech system is concerned, the sensory deficits of our patient were thus probably more severe than those of Linke's patient and possibly also than those of the subjects in Gay & Turvey (1979), Kelso & Tuller (1983), and Lindblom et al. (1977). It is perhaps also relevant to point out that in contrast to these subjects the sensory deprivation no longer constituted a novel experience for our patient.

Regarding the patient's articulatory abilities we have mentioned above that they recovered quickly, and at the time of the experiment he had for a considerable period no longer been considered dysarthric. Intentional mobility of the tongue for non-speech tasks had remained impaired, however (e.g. moving the tongue along the outer surface of the upper lip on command); yet it is important to note that the patient described by Linke showed very similar problems while also apparently having undisturbed speech articulation.

PROCEDURE

We endeavoured to replicate the procedure followed in Lindblom et al. (1979) as closely as possible, regarding vowels produced, mode of elicitation and size of bite-block (although we restricted our investigation to the larger-size bite-block, i.e. 22 mm). The patient was asked to produce nine repetitions (in three sequences of three) of the German vowels **/ i /**, **/ u /** and **/ ɑ /** under the following conditions and in the following order (abbreviations used in Table 1 in brackets):

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

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

The order of the triads in conditions 1 and 5 was randomized, while in the perturbed conditions all 9 tokens of a particular vowel were spoken as one sequence with the headphones or bite-block being removed briefly between each sequence. The order of the vowels was arbitrarily chosen as **/ ɑ u i /** in condition 2, **/ i ɑ u /** in condition 3 and **/ u ɑ i /** in condition 4.

The order of the perturbed conditions was so chosen that any learning effects would lead to a conservative result in the combined perturbation condition, i.e. would tend to *under*estimate the actual degree of disturbance (if any)

RESULTS

Vowel articulation was assessed by measuring the first two formants using an LPC-based procedure. In contrast to earlier investigations the main results again adopt a conservative 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 are displayed in Figs. 1 - 3 for **/ i /**, **/ u /** and **/ ɑ /** respectively, with the means for each condition being given in Table 1. The range for the initial unperturbed condition is also indicated in the Figures. The results will first be presented and discussed for each condition individually, followed by assessment of the results of the experiment as a whole.

White-noise condition

In this condition **/ i /** and especially **/ u /** show evidence of centralisation: for **/ i /** mean F1 is raised by 19 Hz and F2 lowered by 97 Hz; for **/ u /** F1 and F2 are raised by 89 and 119 Hz respectively. On the other hand **/ ɑ /** is relatively unperturbed. Under this condition the patient is, of course, effectively speaking without afferent information of any kind. The fact that **/ ɑ /** is less perturbed may reflect the fact that it is nearer than **/ i /** or **/ u /** to a neutral “setting”, particularly for speakers of Bavarian. There is no evidence of systematic changes in the articulatory configuration in the course of the sequences under this condition.

Table 1
Steady-state F1 and F2 values in Hz averaged over each vowel in each condition

	/ i /		**/ u /**		**/ ɑ /**	
	F1	**F2**	**F1**	**F2**	**F1**	**F2**
IU	273	2137	311	793	626	1083
WN	292	2040	400	912	628	1119
BB	291	2099	338	865	687	1187
BB/WN	332	2021	418	1176	717	1219
FU	266	2175	298	799	672	1068

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 Lindblom et al. (1979) for the formant shifts to be expected for **/ i /** and **/ u /** in the complete absence of compensatory behaviour with a bite-block of this size:

/ i /: F1 +250 Hz, F2 −300 Hz
/ u /: F1 +300 Hz, F2 +500 Hz.

Looking at **/ i /** and **/ u /** in these terms the subject shows clear compensatory behaviour since means over all vowels in the sequences are quite 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 should be 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 a total of 18 F1 and F2 values are within the range of the initial unperturbed condition. Particularly striking is the fact that the last four vowels show a progressive and in- creasingly successful approach to the normal region.

For **/ i /** there is a fair amount of variability, but three of the nine vowels fulfil the criterion, with 10 of 18 F-values within the normal range. Note, however, that all these remarks apply to the measurements made in the steady- state portion of the vowel. For **/ i /** and **/ u /** we also measured a frame of 25 ms at the onset of the first vowel in each sequence. These values are indicated by squares in Figs. 1 and 2. The onset of the first **/ i /**, in particular, was rather hesitant, 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

Clearly these are a long way off target.

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 / **ɑ** / 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. Auditorily the / **ɑ** / 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 probable 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.

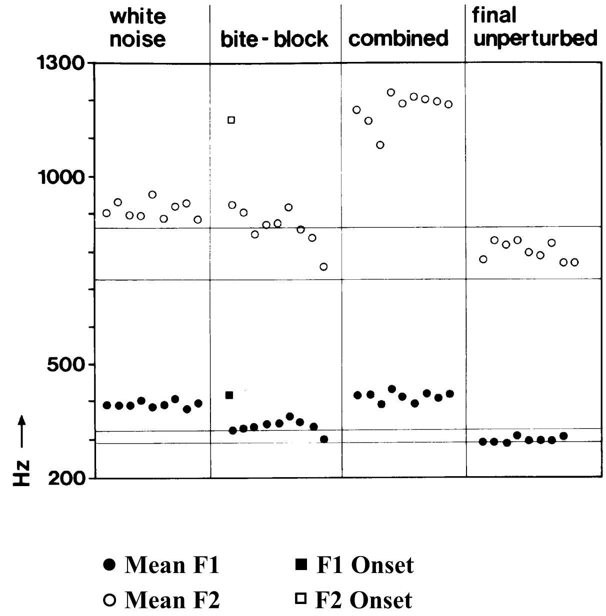

Fig. 2: Formant frequencies for all tokens of / **u** / in each condition except initial unperturbed. Range for this condition indicated by horizontal lines.

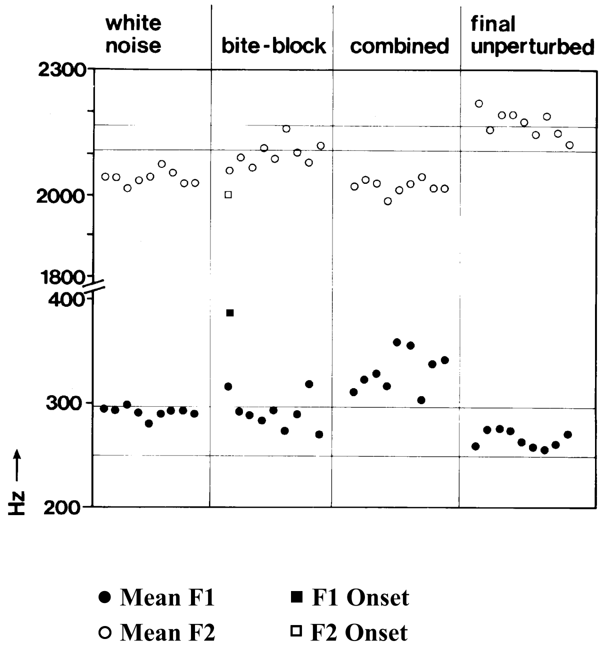

Fig. 1: Formant frequencies for all tokens of / **i** / in each condition except initial unperturbed. Range for this condition indicated by horizontal lines.

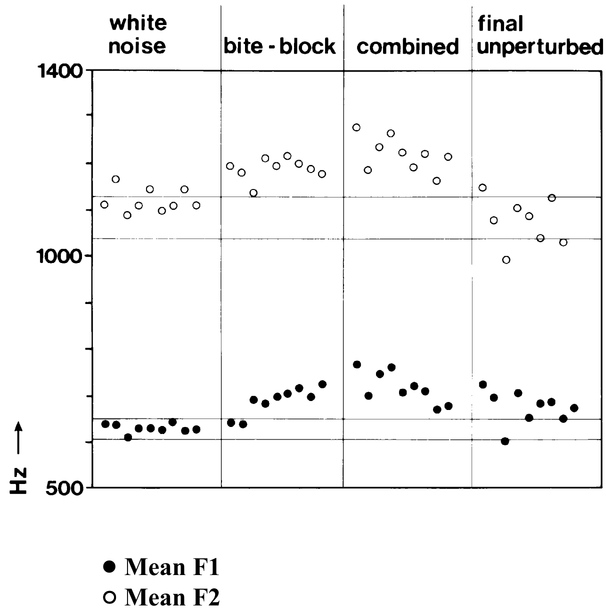

Fig. 3: Formant frequencies for all tokens of / **ɑ** / in each condition except initial unperturbed. Range for this condition indicated by horizontal lines.

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 as much as 383 Hz. This continues a tendency for / **u** / to show greater disruption than / **i** /.

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 / **ɑ** / 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, and may even be rather slow in turning off the compensatory behaviour. The results for / **ɑ** / are again somewhat different, with a weaker tendency to depart from the perturbed region of the F1/F2 space. This again suggests that in the case of / **ɑ** / simply less effort was made to compensate, and that apparently the distorted productions were still considered phonologically acceptable. One could also note that the greater distortion for / **u** / than / **i** / suggests that the subject followed a strategy of tongue-fronting when trying to cope with the perturbed conditions. This may, in addition to the greater jaw opening, have contributed to the unexpectedly large distortions for / **ɑ** /.

GENERAL CONCLUSIONS

The results for / **i** / and / **u** / are clearly very different from those obtained by Kelso & Tuller (1983). Our results strongly suggest that success in this type of perturbation experiment crucially depends on intact oral sensibility. Afferent information seems, as suggested by Perkell (1979), 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 temporo-mandibular joint would be more important for the establishment of this frame of reference than information from the oral mucosa. The results in Gay & Turvey (1979) and Lindblom et al. (1977) 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 Kelso & Tuller (1983), as well as the minor discrepancy between those of Gay & Turvey (1979) and Lindblom et al. (1977) regarding the amount of sensory deprivation necessary to cause vowel distortion.

The reduction in afferent 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 / **ɑ** / we suggest that information from the pharyngeal region may have a prominent rôle to play in maintaining the integrity of the orosensory frame of reference as a whole.

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