The use of sensory feedback in the adaptation of perturbed /s/

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Abstract

The study investigates the contribution of tactile and auditory feedback in the adaptation of /s/ towards a palatal prosthesis. Five speakers were recorded via electromagnetic articulography, at first without the prosthesis, then with the prosthesis and auditory feedback masked, and finally with the prosthesis and auditory feedback available. Tongue position, jaw position and acoustic centre of gravity of productions of the sound were measured. The results show that the initial adaptation attempts without auditory feedback are dependent on the prosthesis type and directed towards reaching the original tongue palate contact pattern. Speakers with a prosthesis which retracted the alveolar ridge retracted the tongue. Speakers with a prosthesis which did not change the place of the alveolar ridge did not retract the tongue. All speakers lowered the jaw. In a second adaptation step with auditory feedback available speakers reorganised tongue and jaw movements in order to produce more subtle acoustic characteristics of the sound such as the high amplitude noise which is typical for sibilants.

1 Introduction

Previous work on perturbation has shown that sensory (auditory and tactile) feedback is essential in order to adapt for a perturbation of the articulation. Jones & Munhall [2], for example, show that speakers need auditory feedback in order to adapt the acoustic characteristics in /s/ produced with extended upper incisors. Honda & Murano [1] tested the influence of both auditory and tactile feedback during adaptation to an inflatable palate. They report the best results in adaptation when both kinds of feedback were available, less good results when auditory feedback was masked, even worse results when tactile feedback was masked and the worst results when both kinds of feedback were unavailable.

The present study investigates the influence of auditory feedback on adaptation when speech is perturbed with different palatal prostheses. Our expectation was that when the auditory feedback is masked and speakers have only tactile feedback available adaptation will depend on the prosthesis type since speakers will try to achieve the tongue palate contact pattern they used to have in the unperturbed condition. When both kinds of feedback are available speakers will change the adaptive strategy and try to produce the acoustic output (the same centre of gravity) they used to have even if this involves a change of the tongue palate contact pattern.

2 Methods

A perturbation experiment was carried out where speakers' palate shape was modified with a palatal prosthesis. Two types of palatal prostheses were used, one which lowered the palate and moved the alveolar ridge posteriorily ("alveolar prosthesis") and one which lowered the palatal surface by filling out the palatal vault ("central prosthesis"). Five German subjects took part in the study. Three of them, TP, AP and DS had an alveolar prosthesis, the other two, BP and SK had a central prosthesis. The articulatory movements of the speakers were recorded via electromagnetic articulography (three speakers with the AG 100 and two with the AG 500). Sensors were placed midsagittally on the tongue tip, tongue dorsum and tongue back, jaw and both lips. For the present purpose the data of the tongue tip and the jaw sensor were analysed.

In a first session speakers were recorded without the perturbation (to be called *unperturbed condition*). Then the artificial palate was inserted and speakers' auditory feedback was masked with white noise (to be called *white noise condition*). Afterwards, the masking noise was removed and speakers were recorded while adapting with auditory feedback available (to be called *auditory feedback condition*). /s/ was recorded in the nonsense word /'zasa/ which was spoken in a carrier phrase: *Ich sah sassa an* ("I looked at zassa."). There were 20 repetitions (randomised with other material) in each session. Acoustic recordings were carried out as well.

The fricative was acoustically segmented (friction onset to friction offset) in each utterance. The acoustic centre of gravity (COG) for a band pass filtered signal (700 Hz to 12 kHz) was measured. Furthermore, the horizontal position of the tongue tip sensor and the vertical position of the jaw sensor in the middle of the acoustically measured interval were estimated. Repeated measures ANOVAs were calculated for data split by speaker in order to judge whether the measured parameters differed significantly in different sessions.

3 Expectations

Speakers with an *alveolar* prosthesis were expected to retract the tongue in the white noise condition in order to keep the alveolar place of articulation, which would result in lower COG values. In the session thereafter when auditory feedback was available these speakers would adapt the tongue position so that the original COG is reached.

In contrast to that, speakers with a *central* prosthesis were expected not to retract the tongue since their alveolar ridge was not moved posteriorily by the prosthesis. The centre of gravity would therefore stay the same in all sessions for these speakers.

Both groups of speakers were expected to lower the jaw when speaking with the prosthesis in order to avoid a closure.

4 Results

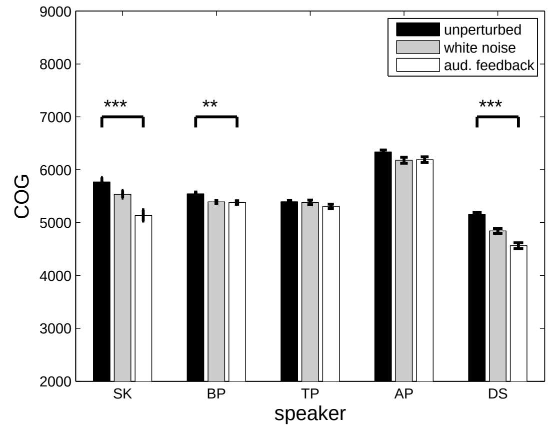

Figure 1: *Mean COG values in the different sessions. Error bars show standard error. When the difference between the unperturbed and the auditory feedback session is significant this is signalled by a bracket above the bars. Significance levels:* *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Acoustic centre of gravity. The results for the measurements of the centre of gravity are shown in figure 1. Each bar shows the mean over one session. Bars belonging to the same triple refer to one speaker and they are in the order of the recordings: The first bar corresponds to the unperturbed session, the second to the white noise condition and the third to the auditory feedback condition. The two leftmost speakers (SK and BP) had central prostheses, the other three had alveolar prostheses.

For four speakers (SK and BP with a central prosthesis and AP and DS with an alveolar prosthesis) the COG is lower in the white noise condition than in the unperturbed condition. For three speakers (SK with a central prosthesis and TP and DS with an alveolar prosthesis) the COG is lower when auditory feedback is available than when it is not.

The results thus do not match our expectations: The COG does not generally become lower in the white noise condition for speakers with an alveolar prosthesis, and it does not stay the same for speakers with a central prosthesis. Furthermore, speakers do not seem to use auditory feedback in order to correct the acoustical change induced by the prosthesis: The values measured in the auditory feedback condition (third bar) are not generally more similar to the ones from the unperturbed condition than the values measured in the white noise condition (second bar).

Horizontal tongue position. Figure 2 shows the results for the horizontal tongue position. Again the abscissa gives the speaker, the first bar of a triple refers to the unperturbed session, the second to the white noise condition and the third to the auditory feedback condition. The ordinate gives the horizontal position of the tongue tip sensor. Higher values represent a more retracted position.

The two speakers with a central prosthesis (SK and BP) protrude the tongue in the white noise condition but correct for this change afterwards. For the three speakers with an alveolar prosthesis (TP, AP, DS) a consistent retraction of the tongue tip over the three sessions was found (but only one of those speakers, DS, also has a decrease in COG).

Thus, in line with our expectations there is a dependence of the tongue position on the prosthesis type. Speakers with an alveolar prosthesis (where the alveolar ridge was moved posteriorily) retracted the tongue when no auditory feedback was available. Speakers with a central prosthesis did not.

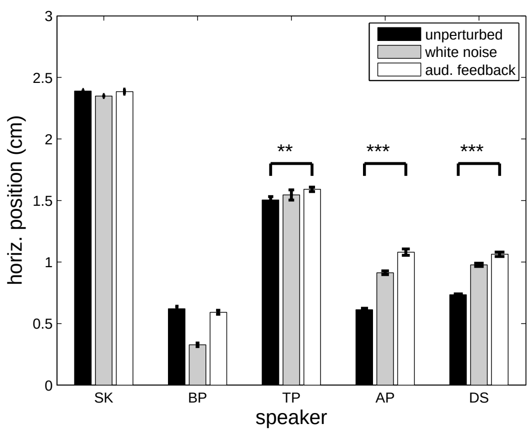

Figure 2: *Mean horizontal position of the tongue tip. Higher values denote more retracted positions. Error bars show standard error. When the difference between the unperturbed and the auditory feedback condition is significant this is signalled by a bracket above the bars. Significance levels:* *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Vertical jaw position. Figure 3 shows the results for the vertical jaw position. Higher values signify a higher jaw position, lower values a lower one. For all speakers the jaw position is lowered when the prosthesis is inserted, but raised again when auditory feedback becomes available.

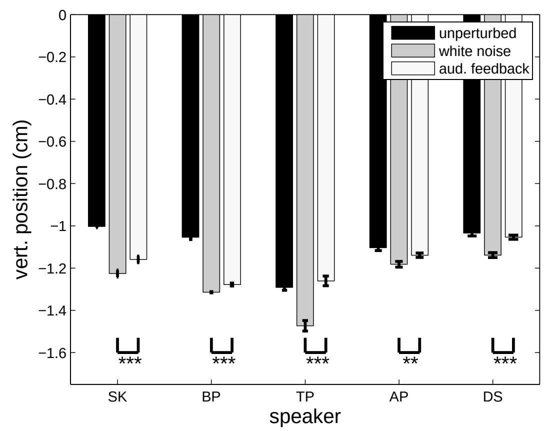

Figure 3: *Mean vertical position of the jaw sensor at the consonantal target position in /s/. Higher values denote higher positions. Error bars show standard error. When the difference between the white noise condition and the auditory feedback condition is significant this is signaled by a bracket above the bars. Significance levels:* *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Thus, in line with our expectations speakers with both kinds of prosthesis lower the jaw in order to produce a constriction and not a closure when the prosthesis is inserted. Contrary to our expectations, however, the lower jaw position is not kept in the session with auditory feedback available.

5 Summary of the results

The results do not match our initial expectations completely. As indicated above we expected speakers with an alveolar prosthesis to retract the tongue in the white noise condition and correct for this change in the auditory feedback condition. This was expected to result in lower COG values in the white noise condition. Speakers with a central prosthesis where expected not to show any changes neither in horizontal tongue position nor in the COG. All speakers were expected to lower the jaw in the white noise condition and to keep this lower jaw position in the auditory feedback condition.

As expected, we found a difference in the adaptive behaviour of speakers with different prosthesis types: Speakers with an alveolar prosthesis retracted the tongue in the white noise condition whereas speakers with a central prosthesis protruded it. However, a correction of this positional change in the auditory feedback condition could only be found for speakers with a central prosthesis.

Furthermore, the expected relation between COG and horizontal position of the tongue could not be found. For a retracted tongue the centre of gravity did not always decrease, nor did it increase consistently for a protruded tongue. This suggests that the COG is affected by a further mechanism apart from the constriction position.

As expected, independent of the prosthesis type the jaw was lowered for all speakers when the prosthesis was inserted. Contrary to our expectations, however, it was raised again when auditory feedback became available.

6 Discussion

Even if the results thus match our expectations only partly, they can be interpreted in the following way. When speakers insert the prosthesis (white noise condition) they might try to keep the same global articulatory position in reference to the palate: For the speakers with an alveolar prosthesis the tongue is retracted because the alveolar ridge is retracted; for the other speakers the tongue is protruded probably as a mechanical effect of the prosthesis.

When auditory feedback becomes available speakers' first aim should be to check the acoustic output they produce and to correct it. However, no adaptation of the COG can be found. Hence COG could be an inappropriate parameter to characterize the perception of the fricatives, which was already suggested by Jones & Munhall [2].

However, the adaptation efforts could be directed towards another, more prominent acoustic characteristic of the sound. /s/ is a sibilant, and an important acoustic characteristic of sibilants is the high amplitude noise produced by directing the air jet against an obstacle (the incisors) in front of the constriction (Shadle [4], Shadle [5]). This, however, necessitates a high jaw position, otherwise the distance between the incisors is too large and no turbulences are created (Mooshammer et al. [3]). This higher jaw position can in fact be found in the auditory feedback condition. When auditory feedback becomes available speakers can thus be assumed to notice that they are lacking the high amplitude noise typical for /s/, and this might lead them to raise the jaw. The retraction of the tongue which can be found in the auditory feedback condition could be seen as a consequence of the higher jaw position: When the jaw is high the space available for the tongue in the alveolar region can be assumed to be no longer sufficient so that the tongue is moved to a more retracted position where there is more space.

To conclude, our results show that certain properties of the sound, such as the constriction size, can be adapted by using tactile feedback only. More subtle acoustic characteristics of /s/, however, require a reorganisation of the articulatory strategy, i.e. the positional relation of tongue and jaw has to be changed. For these articulatory changes auditory feedback becomes essential.

References

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