The Effect of Altered Auditory Feedback of Voice Focus on Nasalance Scores

L'effet d'une rétroaction auditive dans laquelle la résonance vocale est altérée sur les scores de nasalance

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Abstract

Voice focus is a term that describes the perceived brightness or throatiness of the voice. In previous research, forward voice focus resulted in higher and backward focus in lower nasalance scores. This study explored whether electronically altered auditory voice focus feedback prompts speakers to adjust their voice focus and whether this affects nasalance scores. Twenty females with normal speech wore a Nasometer headset and headphones. They repeated a single sentence with oral and nasal sounds. Their auditory feedback was gradually changed with a voice transformer, so the speakers heard themselves with a more forward or backward voice focus, respectively. Oral-nasal balance was quantified as a nasalance score. Analysis of variance results of the averaged first and second vowel formants of three repetitions of the stimulus at the different baselines and maximum forward and maximum backward voice focus feedback conditions demonstrated significant effects of the voice shift condition. Analysis of variance for the nasalance scores demonstrated a significant effect of feedback condition. From the initial mean nasalance scores of 29.5%, the mean nasalance dropped to 27.5% in the backward and to 25.7% in the forward focus feedback condition. The altered auditory feedback induced voice focus adjustments that resulted in lower nasalance scores. The use of altered auditory feedback in speech therapy of hypernasality needs to be investigated in future research.

Abrégé

La résonance vocale (*voice focus*) est un terme qui décrit la brillance (*brightness*) ou la sombreur (*throatiness*) perçues de la voix. Les résultats d'études précédemment publiées ont montré qu'une résonance vocale antérieure générait des scores de nasalance plus élevés, tandis qu'une résonance vocale postérieure générait des scores de nasalance plus bas. La présente étude avait pour objectif d'explorer si une rétroaction auditive dans laquelle la résonance vocale est altérée de façon électronique incitait des locutrices à modifier leur résonance vocale et si cet ajustement avait pour effet de modifier leurs scores de nasalance. Vingt femmes ayant une parole normale ont été équipées d'un casque d'un nasomètre et d'écouteurs. Elles ont répété une même phrase contenant des sons oraux et nasaux. La rétroaction auditive a été graduellement altérée à l'aide d'un appareil de transformation de la voix, de sorte que les locutrices s'entendaient avec une résonance vocale antérieure ou postérieure. Le ratio de l'énergie acoustique nasale et de la somme de l'énergie acoustique orale et nasale a été quantifié grâce aux scores de nasalance. Des analyses de variance de la moyenne des premiers et deuxièmes formants des voyelles et des scores de nasalance ont été réalisées avec trois répétitions de stimuli recueillis dans différentes conditions expérimentales : conditions de référence, condition où la résonance vocale a une mise au point maximale vers l'avant et condition où la résonance vocale a une mise au point maximale vers l'arrière. Les résultats montrent un effet significatif du changement de la mise au point de la résonance vocale sur les formants et sur les scores de nasalance. Lorsque comparées à la moyenne initiale des scores de nasalance (c.-à-d. 29,5 %), les moyennes des scores de nasalance ont diminué à 27,5 % et 25,7 % dans les conditions où la rétroaction auditive altérait la résonance vocale vers l'arrière et l'avant respectivement. L'altération de la rétroaction auditive a ainsi entraîné des mises au point de la résonance vocale qui se sont traduites par une diminution des scores de nasalance. Le recours à l'altération de la rétroaction auditive dans le cadre de traitements orthophoniques de l'hypernasalité doit être davantage étudié dans de futures recherches.

Voice focus is a term used in vocal pedagogy and voice therapy to describe the relative brightness or throatiness of the voice (Boone et al., 2010), which is determined by vocal tract length (Sundberg & Nordström, 1976) and tongue movement (Bressmann et al., 2017). The bright and juvenile quality associated with forward focus is achieved by shortening the vocal tract, raising the larynx, positioning the tongue more anteriorly, and narrowing the pharynx. Acoustically, this results in an upward frequency shift of spectral energy and formant frequencies (de Boer & Bressmann, 2016; Sundberg & Nordström, 1976). The dark and throaty quality associated with backward focus is achieved by lengthening the vocal tract, lowering the larynx, positioning the tongue more posteriorly, and widening the pharynx, which in turn results in a downward frequency shift of spectral energy and formant frequencies (de Boer & Bressmann, 2016; Sundberg & Nordström, 1976). Singing teachers have argued that an ideal voice in Western classical music will be balanced between these two qualities, a state which is termed "chiaroscuro" (light and dark; Stark, 1999).

Oral-nasal balance in speech is regulated by the opening and closing of the velopharyngeal sphincter, which is formed by the velum and the pharyngeal walls (Kummer, 2008). A measure that is commonly used to assess oral-nasal balance in speech is a nasalance score, which is calculated as the proportion of the sound pressure level of nasal signal to the combined oral and nasal sound pressure level. Nasalance scores are obtained using instruments such as the Nasometer 6450 (KayPentax). This instrument has a face plate with separate microphones for the oral and nasal signal (Fletcher, 1976). Pathological hypernasality can arise from structural insufficiency and/or functional incompetence of the velopharyngeal sphincter, resulting in excess transmission of air and sound through the nose (Kummer, 2008). Watterson et al. (2013) noted that even mild forms of hypernasality may result in negative social judgements.

Studies have demonstrated the importance of auditory feedback for the control of different aspects of speech production. Speakers compensate for differences in intended and perceived loudness. In studies using altered auditory feedback, participants usually compensate in a direction that is opposite to the auditory manipulation. For example, louder auditory feedback of the speaker's own voice may cause the person to lower their speaking volume, and vice versa (Bauer et al., 2006; Lane & Tranel, 1971; Siegel & Pick, 1974). Similar effects can be shown for the speaking fundamental frequency, where electronically lowered or raised pitch feedback will prompt compensation (Elman, 1981; Larson et al., 2000), and for vowel formants, where altered feedback from a vocoder-style voice effect will prompt the participant to alter their tongue movement (Houde & Jordan, 1998; Mitsuya et al., 2015; Purcell & Munhall, 2006). In two studies investigating the effect of altered auditory feedback on the control of oral-nasal balance in speech, de Boer and Bressmann (2017) and de Boer et al. (2019) showed that higher nasal signal level auditory feedback (i.e., the speaker heard more of the nasal component of their speech) led to lower nasalance scores in normal speakers. Lower nasal signal (i.e., the speaker heard less of the nasal component of their speech) did not result in a compensatory reaction of the same magnitude. A similar effect was demonstrated by Santoni, de Boer, et al. (2020a) using a singing task. Srinivas and Bressmann (2021) demonstrated that speakers showed an automatic compensation reaction for nasal signal level changes even when instructed not to compensate.

Treating hypernasal oral-nasal balance disorders with speech therapy is exceedingly difficult because speakers have no conscious proprioceptive awareness of the velopharyngeal mechanism and are therefore not able to change the movement of the velopharyngeal sphincter at will (Hixon et al., 2008). Non-speech exercises, such as blowing or sucking, do not improve velopharyngeal closure in speech (Ruscello & Vallino, 2020). Speech therapy exercises for hypernasality usually only yield positive outcomes in patients who already demonstrate sufficient velopharyngeal closure for other speech sounds (Kummer, 2008). However, if there is structural velopharyngeal insufficiency, patients are treated with surgical procedures (e.g., pharyngeal flaps) or, less frequently, prosthodontic devices such as speech bulbs or palatal lifts (Ferreira et al., 2020; Kummer, 2018).

In previous research, it has been speculated that voice focus adjustments could be a useful adjunct in the therapy of hypernasal disorders of oral-nasal balance in speech. Based on a computer model, Rong and Kuehn (2012) predicted that a more posterior tongue position should help reduce hypernasality by lowering the larynx, carrying the tongue more posteriorly, and widening the pharynx. Kummer (2008) proposed a yawning maneuver to redirect more sound orally as a therapy technique for nasally substituted /l/ sounds. On the other hand, Bressmann et al. (2012) described the case of a speaker with hypernasality who could use an extreme forward focus to reduce her nasalance scores. In two studies with typical speakers, de Boer and Bressmann (2016) and de Boer et al. (2016) demonstrated that a forward voice focus resulted in higher nasalance scores while a backward focus resulted in lower nasalance scores. Santoni, de Boer, et al. (2020b) replicated this finding but also described a single participant who demonstrated lower nasalance scores with a forward voice focus. Santoni, Thaut, and Bressmann (2020) tested the approach clinically with five children with hypernasal speech and found lower nasalance scores with backward focus, except for one individual who had lower nasalance scores with a forward focus.

Oral-nasal balance and the corresponding nasalance score are mostly controlled by the degree of closure of the velopharyngeal sphincter. However, the shape of the pharyngeal and oral aspects of the vocal tract may also affect the nasalance score. Sentences with many high front vowels have been shown to be produced with higher velar elevation (Bzoch, 1968; Moll, 1962), tighter closure (Kuehn & Moon, 1998; Moon et al., 1994), higher nasal sound pressure levels (Clarke & Mackiewicz-Krassowska, 1977), and higher nasalance scores (Awan et al., 2011; Lewis et al., 2000). It has been argued that high front vowels increase the impedance of the oral cavity (Mayo et al., 1998; Warren et al., 1969), so that more sound is transmitted through the elevated but partially acoustically transparent velum (Blanton et al., 2015; Gildersleeve-Neumann & Dalston, 2001).

The present study combined the approaches of the previous research about voice focus (i.e., de Boer & Bressmann 2016; de Boer et al., 2016; Santoni, de Boer et al., 2020b; Santoni, Thaut, & Bressmann, 2020) and altered auditory feedback (i.e., de Boer & Bressmann, 2017, de Boer et al., 2019; Santoni, de Boer, et al., 2020a; Srinivas & Bressmann, 2021). It explored whether electronically altered auditory feedback (speakers heard their own speech with a more forward or backward focus) would prompt speakers to involuntarily adjust their voice focus and whether this would change their nasalance scores in turn. Based on previous findings by de Boer and Bressmann (2016), de Boer et al. (2019), Santoni, de Boer, et al. (2020b), and Santoni, Thaut, and Bressmann (2020), the hypotheses of the research were (a) auditory feedback with a more forward focus would lead speakers to speak with a more backward voice focus, which in turn would result in lower nasalance scores and (b) auditory feedback with a more backward focus would lead speakers to speak with a more forward voice focus, which in turn would result in higher nasalance scores.

Method

Participants

Twenty female participants (mean age 22.6 years, range 19–28) were recruited using flyers posted around the campus of the University of Toronto. The participants were all fluent speakers of Canadian English with the accent common to Southern Ontario. They had normal hearing according to their self-report. The study protocol was reviewed and approved by the University of Toronto's Office of Research Ethics (protocol number 00034643). All participants gave written informed consent to participate.

Procedure

During the experiment, the participants were seated in a sound booth and wore a Nasometer 6450 headset that was connected to the custom Nasometer signal processor box. An Asus Model X53U laptop was used to run the Nasometer software and measure nasalance. The signals from two additional Sony ECM-CS3 microphones attached to the Nasometer plate were amplified by a Tiger DRS Model T-02 NasalView stereo pre-amplifier. One of these microphones was placed on the nasal side of the Nasometer baffle plate and the other one on the oral side. The two signals were fed into separate channels of a Tascam DP-008 digital multitrack recorder, which recorded continuously during the experiment. Both channels were centred in the stereo-panorama, and the headphone output from the multitrack recorder was sent to a Roland AIRA VT-3 voice transformer, which had a vocoder function that adjusted overall formant values with a slider. The output from the voice transformer was played back to the participants through Philips SHL3000RD headphones.

The vocoder slider on the voice transformer was labelled with notches from -10 to +10. The instruction manual for the device did not provide information on the scaling of the effect. Based on experimentation with the device, it was decided that the effect became too obvious at the extreme settings. The maximum settings used in the experiment were -8 for the backward focus feedback and +8 for the forward focus feedback. To estimate the effect of the vocoder effect on vowel formants, a sustained vowel approximating /ɛ/ was synthesized in the Praat software for speech analysis (Boersma, 2001). The /ɛ/ had a fundamental frequency of 200 Hz, an F1 of 720 Hz, and an F2 of 2000 Hz. When the vocoder slider on the voice transformer was set to +8, the F1 changed to 920 Hz (+28%) and the F2 to 2480 Hz (+24%). When the vocoder slider on the voice transformer was set to -8, the F1 changed to 600 Hz (-17%) and the F2 to 1600 Hz (-20%). It was also confirmed that the vocoder effect did not change the fundamental frequency, which remained constant at 200 Hz.

With this setup in place, the participants continuously repeated a single sentence containing both oral and nasal sounds as well as a range of Canadian English vowels: "*Molly has two spa coupons she plans to use with Eva*." While repeating the sentence, the participants received auditory feedback through the headphones. Over the course of the experiment, the voice transformer was used to gradually increase or decrease formant values so speakers heard themselves with a more forward or backward voice focus, respectively. Half of the group experienced an upward and then a downward shift of their vowel formants while the other half experienced the reverse order of presentation.

After a baseline of five repetitions of the sentence, the transformer setting was changed during the sixth repetition to the +2 or -2 setting, depending on the initial direction of change. A next set of five repetitions was recorded, and the next adjustment to +4 or -4 was made on the following twelfth repetition. The procedure was repeated until the maximum setting was reached at +8 or -8. After the participants repeated the sentence five times at this setting, they were returned to baseline, and a second baseline of five repetitions was recorded, resulting in 35 repetitions. After a short break, the procedure was repeated with the voice transformer changing the participants' vowel space into the other direction. Of the 70 repetitions, the 10 items that were produced while the slider was adjusted were not included in the analysis. From the five repetitions that were produced in each of the stable phases of the experiment, only the final three were included in the analysis. Recording 35 repetitions took around 3 minutes for the participants.

Measurements and Statistical Analyses

To analyze the effect of the voice transformer on the participants' vowel formants, the oral and nasal signal multitrack recordings from the supplementary microphones were combined into mono sound files using a Sony Soundforge 10. The second author then used the Praat signal analysis software (Boersma, 2001) to segment and annotate the underlined vowels from the stimulus sentence "M<u>o</u>ll<u>y</u> has tw<u>o</u> sp<u>a</u> c<u>ou</u>p<u>o</u>ns sh<u>e</u> pl<u>a</u>ns to <u>u</u>se with <u>E</u>va." This resulted in a mix of different vowels in various phonetic contexts. The formant values in the centres of these vowels were measured in Praat using the software's standard settings of five formants with a maximum frequency of 5,500 Hz, a window length of 0.025 s, and a dynamic range of 30 dB. Data for the first formant F1 and the second formant F2 were included in the analysis. Since the goal of the research was to induce a global voice focus change in the speakers, and since oral-nasal balance was the focus of the manipulation, the formant data for the vowels were combined for F1 and F2 for the statistical analysis. Oral-nasal balance was quantified as a mean nasalance score for each sentence repetition, using the Nasometer 6450 computer software. The Nasometer bandpass filters the signal so that mainly low frequency energy of voiced speech segments is measured. The nasalance score expresses the contribution of the nasal sound pressure level (SPL) to the overall speech signal as a percentage according to the formula nasalance = [nasal SPL / (nasal SPL + oral SPL)] * 100.

For the statistical analysis, formant and nasalance data from the initial baseline, the maximum increased and decreased formant shift conditions, and the final baseline were used. Since the two groups experienced the maximum increased and decreased formant shifts in different orders, the second and third baselines were excluded from the statistical analysis. Mixed-factorial analyses of variance (ANOVAs) with post-hoc Tukey-Kramer tests were run in the Number Cruncher Statistical Software version 8.0.

Results

Descriptive statistics of the results for F1, F2, and the nasalance scores are reported in **Table 1**. A mixed-factorial ANOVA was run with the mean F1 scores as the dependent variable, the formant shift condition (Baseline 1, maximum forward focus feedback, maximum backward focus feedback, and Baseline 4) as the within-subject variable, and the direction of change (forward focus first vs. backward focus first) as the between-subjects variable. The results showed a significant effect of shift condition, $F(3, 54) = 3.45$, $p < .05$, $\eta^2 = .0015$. There was also a significant interaction between shift and the initial direction of the focus change, $F(3, 54) = 2.96$, $p < .05$, $\eta^2 = .0013$. The interaction was explained by the pattern of numerical differences in Baselines 1 and 4 based on the initial direction of focus change. The group that experienced the forward voice focus first had numerically lower scores at Baseline 1 and numerically higher scores at Baseline 4 (see **Figure 1**). However, there was no significant main effect for the initial direction of the focus change. Therefore, both groups were combined for the post-hoc Tukey-Kramer multiple comparison tests, which showed a significantly higher mean F1 for the maximum backward focus feedback compared to the maximum forward focus feedback condition ($p < .05$).

A second mixed-factorial ANOVA was run with the mean F2 scores as the dependent variable, the formant shift condition (Baseline 1, maximum forward focus, maximum backward focus, and Baseline 4) as the within-subject variable, and the direction of change (forward focus first vs. backward focus first) as the between-subjects variable. The results showed a significant effect of shift condition, $F(3, 54) = 12.69$, $p < .05$, $\eta^2 = .0025$. For both directions of change combined, post-hoc Tukey-Kramer multiple comparison tests showed a significantly higher mean F2 in the maximum backward focus compared to maximum forward focus condition and Baselines 1 and 4 (all differences $p < .05$). **Figure 2** shows the results.

A final mixed-factorial ANOVA was run with the mean nasalance scores as the dependent variable, the formant shift condition (Baseline 1, maximum forward focus, maximum backward focus, and Baseline 4) as the within-subject variable, and the direction of change (forward focus first vs. backward focus first) as the between-subjects variable. Results showed a significant effect of

Table 1

Average Values and Standard Deviations for First and Second Vowel Formants and Nasalance Scores

	F1		F2		Nasalance	
Condition	*M*	*SD*	*M*	*SD*	Score	*SD*
Backward focus feedback first						
Baseline 1	531	225	1863	623	30.0	8.9
Backward focus feedback	542	222	1915	609	30.6	7.2
Baseline 2	520	218	1874	614	29.9	7.3
Baseline 3	525	232	1858	606	28.7	7.8
Forward focus feedback	515	206	1837	588	27.6	8.4
Baseline 4	514	218	1839	592	29.1	8.1
Forward focus feedback first						
Baseline 1	505	199	1806	637	29.1	9.4
Forward focus feedback	516	199	1773	590	23.7	8.3
Baseline 2	524	203	1794	588	25.5	9.7
Baseline 3	528	210	1777	609	26.0	10.0
Backward focus feedback	532	213	1864	618	24.4	10.8
Baseline 4	529	211	1840	605	23.6	9.2

shift condition, $F(3, 54) = 4.94$, $p < .05$, $\eta^2 = .0248$. For both directions of change combined, post-hoc Tukey-Kramer multiple comparison tests showed significantly lower mean nasalance scores in the maximum forward focus feedback and Baseline 4 compared to Baseline 1 (both $p < .05$). **Figure 3** shows the results.

Discussion

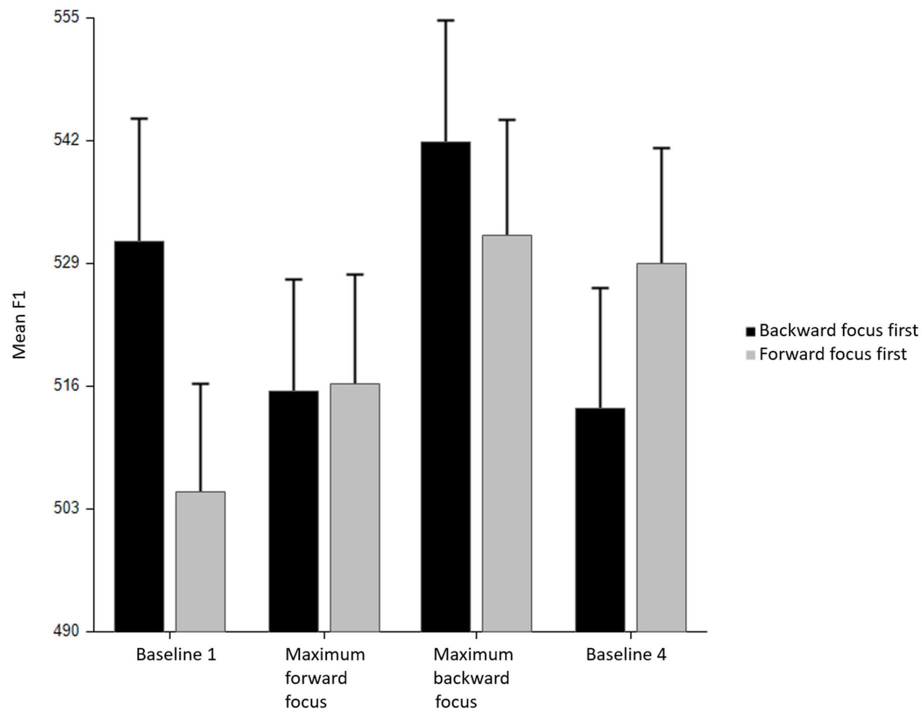
The research hypotheses motivating the present study were that auditory feedback with a more forward focus would lead participants to speak with a more backward voice focus, which in turn would lower their nasalance scores, and that, conversely, auditory feedback with a more backward focus would lead participants to speak with a more forward voice focus, which in turn would increase their nasalance scores. Both hypotheses were only partially supported.

The analysis of the averaged first formants demonstrated significantly higher F1 measurements for the backward than the forward focus condition. Neither condition was significantly different from any of the baselines so the results did not support the hypothesis that the participants compensated against the perturbation. The first formant is often attributed to the jaw height of the vowel (Hixon et al., 2008), while voice focus adjustments are thought to be the result of more forward or backward tongue placement in the horizontal plane (Boone et al., 2010). Therefore, voice focus adjustments may not have a strong effect on F1. It should also be noted that the participants' F1 values in the forward focus first group were numerically lower than in the backward focus first group, although this difference was not statistically significant.

The analysis of the averaged second formants demonstrated significantly higher F2 measurements for the backward than for the focus condition and Baselines 1 and 4. This could be taken to indicate that the participants compensated against the feedback by focusing their voice more anteriorly in the backward focus feedback condition. For the forward focus feedback, participants' averaged second formants were numerically lower but this difference was not statistically significant.

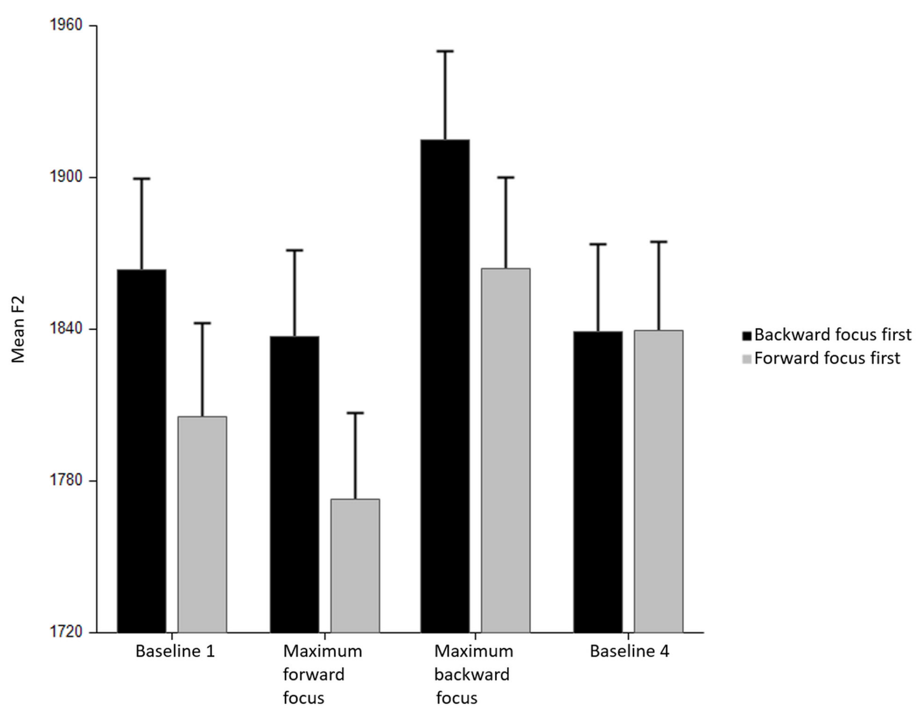
The analysis of the nasalance scores demonstrated significantly lower scores in the forward focus feedback and the Baseline 4 conditions, compared to Baseline 1, which could be interpreted as compensation against the direction of the altered auditory feedback. The nasalance scores for the backward focus feedback condition were numerically

Figure 1



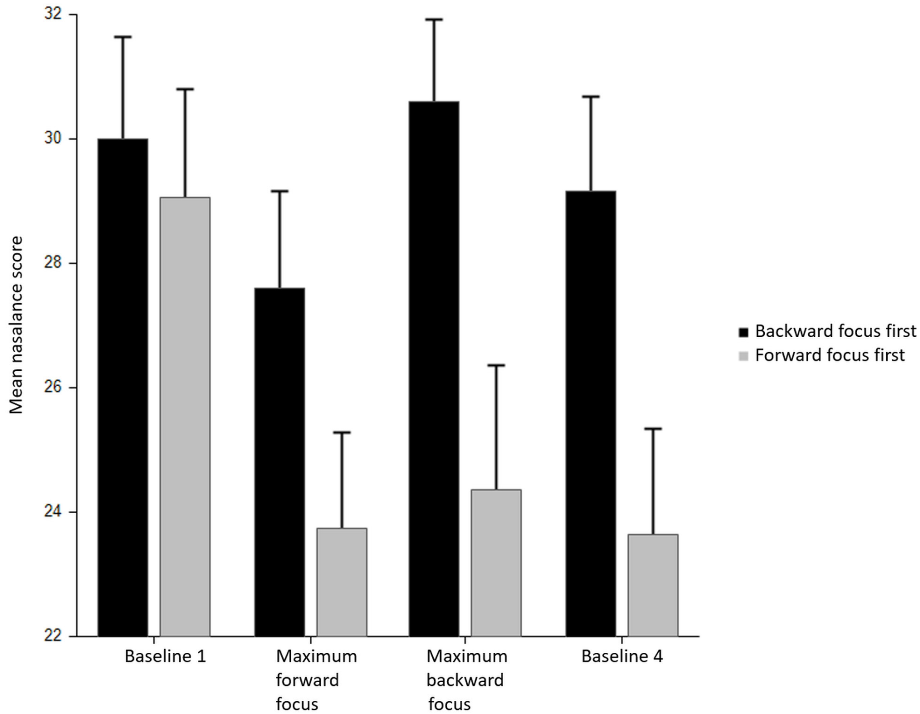
Effect of the altered auditory feedback on the mean first formant.

Figure 2



Effect of the altered auditory feedback on the mean second formant.

Figure 3



Effect of the altered auditory feedback on the mean nasalance scores.

higher but this difference was not significant. These results posed an interesting contrast to the results of the second formant, where the backward focus feedback resulted in significantly higher F2 values but no significant differences were observed for the forward focus feedback condition.

While there were no statistically significant differences between the two groups, **Figure 3** shows that the group that experienced the forward focus auditory feedback first had a numerical decrease in nasalance scores that appeared to carry over to the subsequent feedback conditions. Santoni, de Boer, et al. (2020a) made similar qualitative observations in a study using altered auditory feedback in a singing task where the group that experienced increased nasal signal level feedback first showed numerically lower nasalance scores across all ensuing conditions. The changes in nasalance scores that were induced with the altered auditory feedback of the voice focus were small and would not have resulted in notable auditory-perceptual differences. If a stronger compensation effect could be achieved in future research, possible effects of the order of presentation may emerge more clearly.

Santoni, de Boer, et al. (2020b) and Santoni, Thaut, and Bressmann (2020) demonstrated how extreme voice focus adjustments changed nasalance scores in typical speakers and in individuals with cleft palate. This could be a promising new therapy approach for hypernasal speech, which is a perennial challenge in speech therapy (Kummer, 2018; Ruscello & Vallino, 2020). For most patients, such an approach would probably be based around direct instruction how to achieve the changed voice focus and how to carry over and retain the reduced nasality in everyday speech production. However, some patients may find the physical maneuvers and the auditory-perceptual results of voice focus adjustments unusual and uncomfortable, at least during the initial stages. Other patients may not have the cognitive abilities or the motivation necessary to attain the new vocal tract configurations. Altered auditory voice focus feedback with the method used in the present study could possibly be used to help ease these patients into the task.

In previous research using altered nasal signal level feedback (de Boer & Bressmann, 2017; de Boer et al., 2019; Santoni, de Boer, et al. 2020a; Srinivas & Bressmann, 2021), it was found that speakers showed a stronger compensatory response to increased than to decreased nasal signal levels. This could be taken to indicate that listeners are less sensitive to hyponasality than to hypernasality, which carries a strong social stigma (Watterson et al., 2013). In future research, it would be of interest to combine altered nasal signal level feedback with altered voice focus feedback to investigate whether this combination would further increase the observed effects and whether it would lead to a more symmetrical response to increased and lowered feedback. It would also be of interest to investigate whether changed auditory feedback of voice focus could be used to improve oral-nasal balance in hypernasal speakers with cleft palate.

The present study had several limitations. Only acoustic measures were used so it is not possible to explain conclusively why and how changes in the voice focus may have changed the nasalance scores. In previous research, ultrasound imaging demonstrated that speakers who consciously changed their voice focus did so by positioning their tongue more anteriorly to produce a forward focus and more posteriorly to produce a backward focus (Bressmann et al., 2017). Such changes in tongue position and movement would likely affect the relative impedance of the oral and nasal cavities (Mayo et al., 1998; Warren et al., 1969). To assess possible effects of changes in voice focus on the height or quality of the velopharyngeal closure, it would be necessary to use imaging procedures such as transnasal endoscopy in future research.

The feedback manipulation with a vocoder effect was unspecific (i.e., it affected all voiced sounds). The stimulus sentence contained a range of different vowels in varied phonetic contexts. This was deemed appropriate because it was the goal to achieve a global change in the participants' voice focus in somewhat natural sentence level speech. As a result, the vowel formant results were only separated into first and second formants but otherwise analyzed together. To assess specific effects of the altered auditory feedback on individual vowel sounds, it would have been necessary to create better controlled linguistic stimuli loaded with a specific vowel. However, this would then have had the downside that the effects on the formants and the nasalance could only have been demonstrated for this vowel.

Conclusion

The study demonstrated that altered auditory feedback can induce voice focus adjustments that result in lower nasalance scores. The possible use of altered auditory feedback of voice focus as an adjunct in the behavioural therapy of hypernasality needs to be investigated in future research.

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