Influence of Altered Auditory Feedback on Oral-Nasal Balance in Song

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Summary: Objectives. This study explored the role of auditory feedback in the regulation of oral-nasal balance in singing in trained singers and non-singers.

Study design. Experimental repeated measures study.

Methods. Twenty non-singers (10M/10F) and 10 female professional singers sang a musical stimulus repeatedly while hearing themselves over headphones. Over the course of the experiment, the nasal level signal in the headphones was increased or decreased so that the participants heard themselves as more or less nasal. Nasalance scores in the different phases of the experiment were quantified using a Nasometer 6450.

Results. A repeated measures analysis of variance demonstrated a significant main effect for singing condition $F(5, 135) = 3.70$, $P < 0.05$, and multiple comparison tests demonstrated that the nasalance scores for final baseline and the maximum and minimum nasal feedback conditions were all significantly lower than the first baseline (all comparisons $P < 0.05$).

Conclusion. There were no differences between the singers and non-singers. All participants had lower nasalance scores in response to both increased and decreased nasal signal level feedback.

Key Words: Nasality−Auditory feedback−Singing−Nasalance−Compensation.

INTRODUCTION

The vocal mechanism consists of a source of power (the lungs), an oscillator sound source (the vocal folds), and a filter (the pharynx, oral and nasal cavities).[1] As sound travels through the epilarynx and reaches the pharynx, the velopharyngeal sphincter acts as a valve that enables the speaker to differentiate between oral and nasal sounds. In speech and singing, oral consonants and oral vowels are projected from the oral cavity, nasal sounds (for example /m/, /n/, /ŋ/) are projected from the nasal cavity, and nasalized vowels (for example /ɑ̃/, /ɛ̃/, /õ/, /ʉ̃/) are projected from the oral and nasal cavities. The balance of oral and nasal sound is determined by the degree of opening and closing of the velopharyngeal sphincter.[2] The velopharyngeal sphincter consists of a group of muscles attached to the velum and the pharynx. This sphincter is situated between the oral and nasal cavities. A competent velopharyngeal sphincter is fundamental for normal speech, normal singing, and normal swallowing. In order to produce nasal sounds, the velum is lowered, opening the velopharyngeal sphincter. To produce oral sounds, the velum is lifted, closing the port.[3] For velopharyngeal closure, the superior constrictor, the palatopharyngeus, the levator veli palatini, and the uvular muscle are considered important.[4] The mechanisms guiding the control of oral-nasal balance in speech and song are incompletely understood, as proprioception in the velopharyngeal sphincter is not accessible to conscious introspection.[3] Through conscious introspection and specific training following instruction methods such as Resonant Voice Therapy,[5] speakers, and singers can learn to localize and focus on vibrotactile sensations associated with oral-nasal balance. However, absent such specific training, it is likely that most typical speakers and singers rely in large part on auditory feedback to control oral-nasal balance.

The importance of auditory feedback for different aspects of speech motor control has been demonstrated in previous research. Relative to amplitude, Lombard[6] described how speakers compensated for ambient noise level increases by unconsciously increasing their own speaking loudness. Lane and Tranel[7] later termed this the "external" or "public" loop, wherein a speaker is focused on conveying a message to an interlocutor. They contrasted this external loop with a "private" loop that is created when a speaker's regular voice-to-ear auditory feedback is substituted with headphone feedback. By altering headphone loudness, Lane and Tranel found that listeners compensate for a volume reduction in feedback intensity of their own voice by increasing their speaking volume, and vice versa. Subsequent research by Siegel and Pick[8] demonstrated how a change of auditory feedback could lead to adaptive changes in the speakers' feedforward motor planning. A recent speech production model guiding adaptation studies is the segmental theory of speech motor control called the Directions Into Velocities of Articulators (DIVA) model.[9−13] Within this model, speech segments are thought to be coded by the central nervous system as auditory-temporal and somatosensory-temporal goal regions, driven by both feedforward (predictive) and feedback (reactive) mechanisms.

Similar effects of compensation (immediate response to a change in auditory feedback) and adaptation (prospective change of feedforward motor plans based on the altered

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auditory feedback) have been demonstrated for other aspects of speech motor control. Elman,[14] along with Larson et al.[15] demonstrated that when the speaking pitch of a speaker's voice was manipulated up or down, speakers produced a compensatory adjustment in the opposing direction. Altered auditory feedback of vowel formants has also been shown to result in compensatory articulatory adjustments to partially offset the effects of the manipulation.[16,17] These compensation and adaptation reactions are described as unconscious and automatic; even when speakers were informed about the nature of the manipulation, the knowledge did not alter their compensatory reactions.[18]

While the control of the singing voice should arguably show commonalities with speech production, there has been very little research about compensation or adaptation in singing. Hanrahan[19] investigated the effects of frequency-altered feedback on trained singers' pitch control, vowel formants, vocal fold contact quotient, and intensity in song. His findings indicated that all aspects of voice production studies were affected to some degree by the feedback procedures; compensation being most prevalent during a protocol that intensified the Singers Formant (2,500−4,000 Hz). However, no statistical analysis of the results was provided. Using more rigorous methodology, Jones and Keough[20] explored the effects of frequency-altered feedback on trained singers and non-singer's pitch control, and found that trained singers compensated less for frequency-altered auditory feedback, but showed larger after effects when their feedback was returned to normal. These results suggested that trained singers rely more strongly on internal models to update feedforward control than untrained singers do. Moreover, the authors speculated that internal representations of pitch may be more ingrained in singers as a result of their training. In a subsequent study by Scheerer & Jones,[21] a positive correlation was found between baseline variability of an untrained signer's pitch and their degree of compensation to the altered auditory feedback of pitch, further demonstrating that a more stable internal motor model of fundamental frequency results in a heavier reliance on feedforward control over feedback-driven control. Finally, Bottalico et al.[22] studied the effects of intensity-manipulated auditory feedback on a singing task also using professional and non-professional singers. While both groups increased the intensity of their voices when they heard an increase in accompaniment volume, the professional singers did so to a lesser degree, indicating again a heavier reliance on other internal representations of the motor targets.

An area of speech (and singing) motor control that has not been investigated in much detail to date is the control of oral-nasal balance. Acoustically, nasality adds a low frequency nasal murmur to the spectrum.[3,23] Since spectrographic quantification of nasality can be challenging, a convenient, and clinically popular method of quantifying the relative contribution of the nasal signal to speech is the calculation of an average nasalance score for a speech sample, using a Nasometer (KayPentax, New Jersey). The nasalance score is calculated using the formula: nasalance % = nasal/(nasal + oral) x 100[24]. Higher nasalance scores indicate more nasality, while lower nasalance scores indicate less nasality.[2] A first study by de Boer and Bressmann[25] using altered auditory feedback during the production of sentence-level speech demonstrated that increased nasal signal levels led to a compensatory effect on nasalance scores in the opposite direction in speakers of Canadian English. Decreased nasal signal levels however, did not elicit a compensatory reaction of the same magnitude. A second study confirmed the same effects in speakers of Brazilian Portuguese[26].

It would be of interest to better understand the control of oral-nasal balance in singing because it is an important concept in singing instruction. Alderson[27] (page number 25) states that "...by training the student's ears to detect changes in vowel colour, one trains the student to make changes in velar position". It should be noted that in singing pedagogy, *vowel colour* references refer to vowel perception based on formant frequency analyses.[28] Scotto di Carlo and Autessere[29] argue that singers rely on acquired internal motor targets to control the height of their velum elevation in singing. Sundberg et al.[30] state that professionally trained classical singers carefully shape their velopharyngeal port to fine-tune their vocal-timbre. However, there is little experimental research to underpin these beliefs, which are nevertheless quite widely held in singing instruction.[31−33] Correspondingly, Miller[34] (page number 27) argues that "there is probably more confusion concerning the role of velopharyngeal closure in singing than about any other acoustic consideration". Physiologically, it has been observed in numerous studies that velopharyngeal closure is more pronounced in singing compared to speech tasks, especially in the higher range.[35−39] In the only study available on the quantitative acoustic assessment of oral-nasal balance in song, Jennings and Kuehn[40] described lower nasalance scores in trained classical singers compared to amateur singers. These differences were found in singing tasks in all pitch ranges and on all vowels, with the exception of vowel /o/. Based on their results, the authors speculated that classical singing training may implicitly teach students to reduce nasality in their singing.

The goal of the present study was to assess to what degree altered auditory feedback with increased or reduced nasality in a singing task would lead to changes in nasalance scores. Based on de Boer and Bressmann[25], and de Boer et al.[26], it was expected that increased nasal feedback would lead to a compensatory decrease in nasal signal sound level, while decreased nasal feedback would lead to a smaller compensatory increase in nasal signal sound level. Since professionally trained classical singers are said to carefully control their velopharyngeal movement[30], a comparison of trained singers and non-singers was included in the research design. Based on Jones and Keough[20], it was expected that professional singers would show a smaller change in nasalance scores in response to the altered auditory feedback. Our hypotheses were the following:

H1: When the participants heard their nasal feedback increase, they would show a compensatory reaction, indicated by a decrease in nasalance scores
H2: When the participants heard their nasal feedback decrease, they would produce a compensatory reaction, indicated by an increase in nasalance scores
H3: Professional singers would show a smaller compensatory reaction to the altered auditory feedback than non-singers

MATERIAL AND METHODS

Participants

Thirty participants (10 female singers, 10 female non-singers, 10 male non-singers) between the ages of 18−35 years, with a mean age of 24.7 (standard deviation 3.23 years) were recruited for this study. All were native speakers of Canadian English with the accent common to Southern Ontario. The female singers were either students majoring in voice, enrolled in a postsecondary music program or graduates of such a program, currently earning a living as a professional musician. The non-singers had no formal musical training or performance experience. All participants had normal hearing, normal speech, and no history of previous speech therapy, based on self-report.

Stimulus

A short song was composed by the last author (Figure 1). The words to the song contained both oral and nasal sounds and were taken from the stimulus sentence used in de Boer and Bressmann[25]: "My hamper was damp so the towels are smelly". The rhythmic structure was waltz-like in a 3/4 time signature at an *allegro moderato* tempo of 120 beats per minute. The song was composed in the key of B^b major and the pitch range spanned F3 (174.6 Hz) to D4 (293.7 Hz) so that the song could be sung comfortably by both male and female participants. To cue participants, an introduction consisting of two broken triads in B^b Major and F Major (the dominant fifth) were played before the melody as a prompt. The duration of the song was 25 seconds.

Participant training

The first author sang the stimulus to the participants once before the experiment to orient them to the tune. Participants could also listen to the midi file of the song several times before beginning to sing, and they had the sheet music and lyrics in front of them to follow along. Participants were instructed to sing at a *mezzo forte* dynamic (medium loud).

Recording procedures

Participants wore the Nasometer 6450 headset (Kay Pentax, Montvale, New Jersey). They sang the melody along to a midi file with a flute sound patch, played back from a computer (Compaq Mini, Hewlett-Packard Enterprise Canada, Mississauga, Ontario). The continuously looped melody was fed into a mixing console (Xenyx 8, Behringer USA, Bothell, Washington) connected to the participants' headphones (SHL3000RD, Philips Canada, Mississauga, Ontorio). While singing 38 repetitions of the melody, participants received auditory feedback of their voice through headphones. The signals from two additional oral and nasal tie-clip style microphones (ECM-CS3, Sony Canada, Toronto, Ontorio) mounted on the Nasometer's baffle plate were fed into a multi-track recorder (Tascam DP-008, TEAC America, Montebello, Califronia). The oral and nasal sound channels were centered in the stereo panorama. Gradual changes to the nasal channel of the Tascam DP-008 multitrack recorder provided more or less nasal sounding feedback. A schematic diagram of the experimental setup is included below (Figure 2).

The experiment proceeded in the following order: in the first set of 15 recordings of the stimulus, three recordings were made at the 50% baseline 1 setting. Using the sound mixer, feedback from the nasal channel was then increased in 5% increments and six more repetitions of the song were

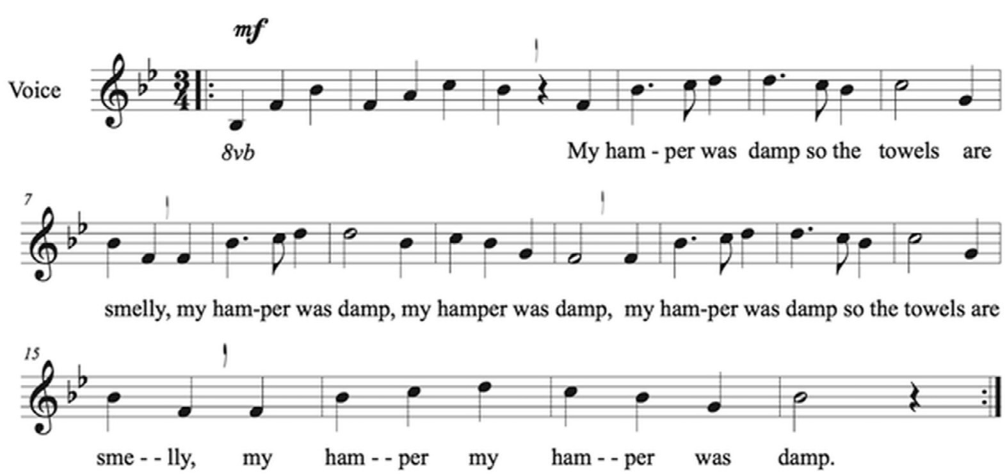

FIGURE 1. Singing task.

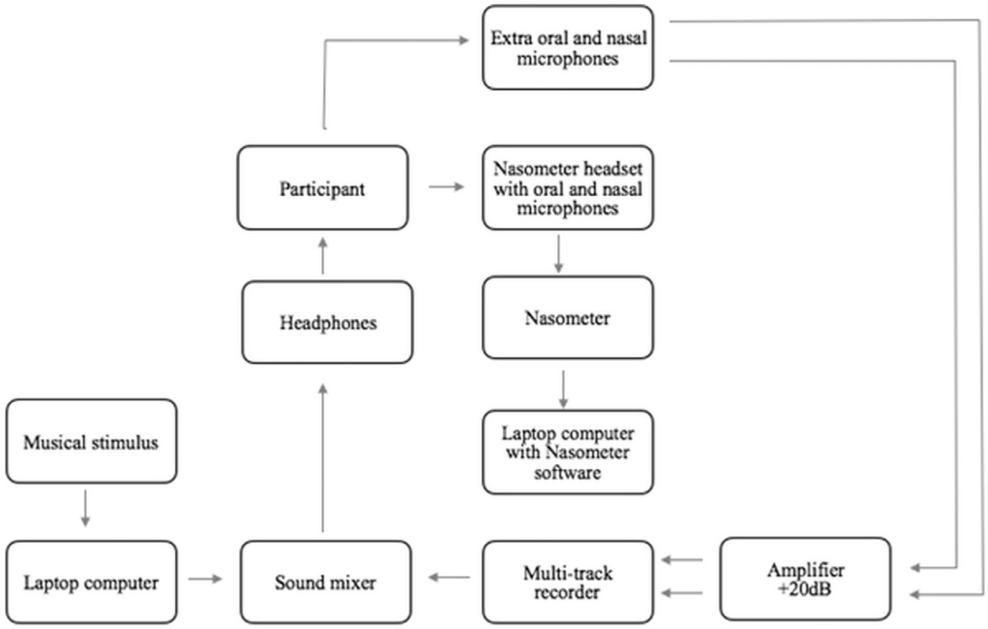

FIGURE 2. Schematic diagram of equipment for influence of altered auditory feedback on oral-nasal balance in song.

recorded during the ramp-up from 50% to 85%. De Boer & Bressmann[25] demonstrated that the potentiometers of the particular multitrack recorder used in the experiment reached their maximum at 85% and their minimum at 15%. Turning the potentiometer knob to 100% or 0% had no further effect on the signal volume. Three recordings of the participants were then made at the maximum setting. Then, three final recordings were acquired at the baseline 2 level, with the nasal signal level abruptly turned back to 50% before the first of the three final recordings. At this point, a short rest period was allowed and participants were offered water. After the break, a second set of 15 repetitions of the song were recorded. Three recordings were made for a third baseline at the 50% setting. Using the sound mixer, feedback from the nasal channel was then decreased in 5% decrements and six more repetitions of the song were recorded during a ramp-down from 50% to 15%. Three recordings of participants at the minimum setting were then taken, after which three final recordings were acquired during a fourth baseline. The nasal signal level was abruptly turned back to 50% before the first of the three final recordings.

It was necessary to carry out the recordings in blocks of three repetitions of the song in order to work with the Nasometer software's recording time limitations (100 seconds). To avoid interruption of the experiment, the participants were instructed to keep singing during a fourth repetition, which was not recorded, while data were saved and the Nasometer recording window was cleared and restarted.

Data analysis

Statistical analyses were conducted with Number Cruncher Statistical Software version 8.0 (NCSS, Kaysville, Utah). The effect of the nasal feedback levels was analysed with a repeated-measures analysis of variance of the mean nasalance scores of averages of three repetitions of the stimulus in six feedback conditions: baseline 1, maximum nasal feedback, baseline 2, baseline 3, minimum nasal feedback, baseline 4. Bonferroni tests were used for further *post hoc* testing.

RESULTS

The mean nasalance scores and standard deviations for the groups of speakers in the different feedback conditions can be found in Table 1. The overall distribution of the data is shown in the error bar chart below (Figure 3). The figure shows that nasalance was highest in the first baseline. The maximum and minimum feedback conditions resulted in lower mean nasalance scores, and the second and fourth baselines directly following the maximum and minimum feedback conditions, respectively, had numerically lower nasalance scores than both the first and third baselines.

A repeated measures analysis of variance of the nasalance scores was run with group (male non-singers, female

TABLE 1.
Mean Nasalance Scores and Standard Deviations (SD) for the Groups of Speakers in the Different Feedback Conditions (n = 30)

	Male Nonsingers		Female Nonsingers		Female Singers	
Condition	Mean	SD	Mean	SD	Mean	SD
Baseline 1	33.37	5.41	37	6.23	35.13	6.84
Maximum	30.87	5.59	34.6	6.68	33.47	6.15
Baseline 2	31.07	6.11	35.33	6.97	34.17	6.34
Baseline 3	32.27	6.33	35.83	6.91	34.27	6.75
Minimum	30.65	7.8	34.23	7.72	34	6.72
Baseline 4	30.43	7.67	34.77	6.81	34.57	6.55

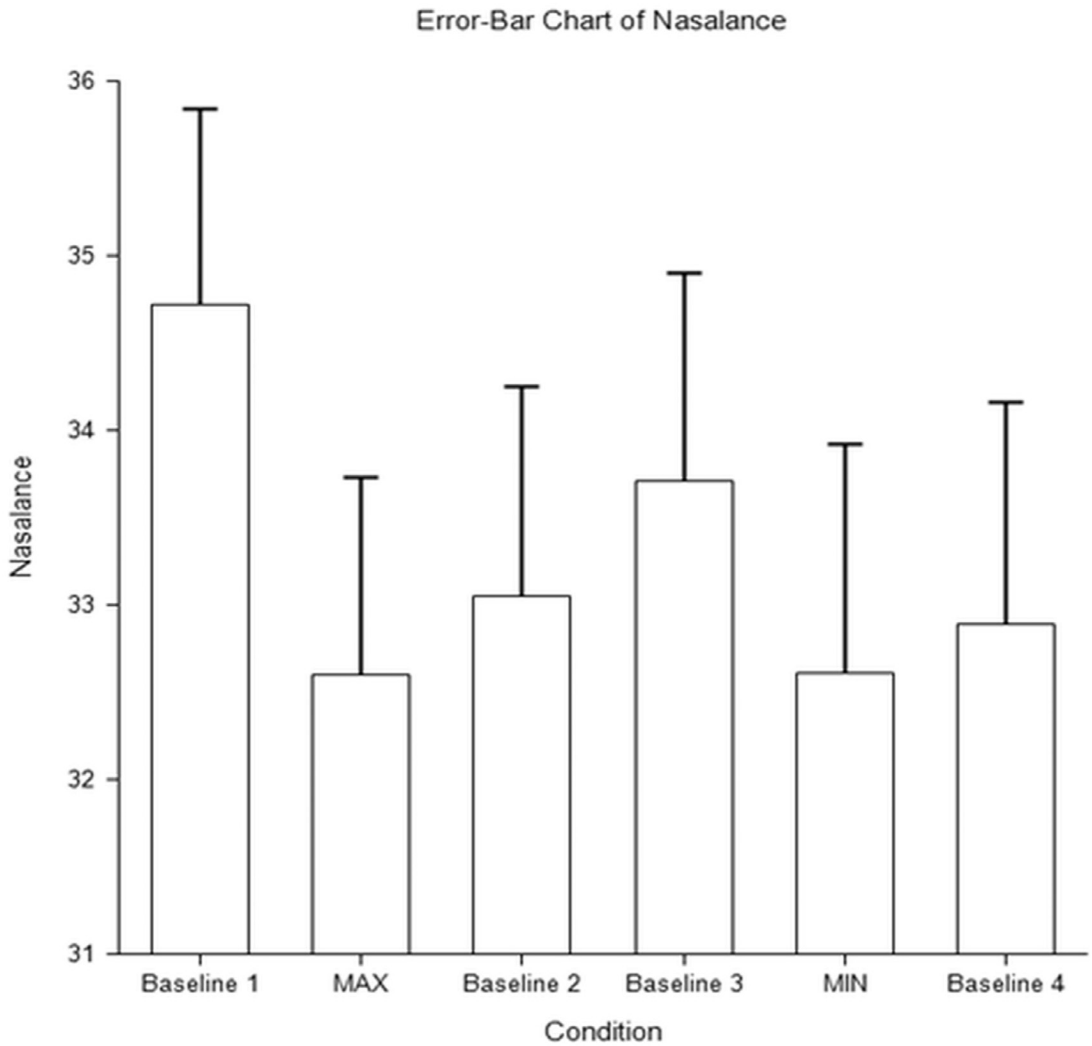

FIGURE 3. Error-bar chart of the average nasalance scores in the different nasal signal level feedback conditions.

non-singers, female singers) as the between subjects variable and feedback condition (baselines 1–4, maximum and minimum nasal feedback) as the within subjects variable. The Geisser-Greenhouse adjusted results showed no significant difference in the mean variance between groups, but a significant main effect for condition $F(5, 135) = 3.70$, $P < 0.05$. *Post hoc* Bonferroni multiple comparison tests demonstrated that the nasalance scores for baseline 4 [33.26 (standard deviation 7.08)] and the maximum and minimum nasal feedback conditions [32.98 (standard deviation 6.15), 32.96 (standard deviation 7.36)] were all significantly lower than the first baseline [35.17 (standard deviation 6.16)] (all $P < 0.05$).

DISCUSSION

This study investigated how singers and non-singers respond to altered auditory feedback of their oral-nasal balance when singing. Nasalance scores were the outcome measure. The first hypothesis stated that when the participants heard their nasal feedback increase, they would show a compensatory reaction, indicated by a decrease in nasalance scores. The results of our statistical analysis revealed that when study participants (singers and non-singers) heard the nasality of their singing increase, they demonstrated lower nasalance scores. This could be taken as evidence to support the first hypothesis and was commensurate with the findings of de Boer and Bressmann.[25]

The second hypothesis stated that when the participants heard their nasal feedback decrease, they would produce a compensatory reaction, indicated by an increase in nasalance scores. Contrary to these expectations, when the participants heard the nasality of their singing decrease, they demonstrated lower nasalance scores. More specifically, nasalance scores were significantly lower than the first baseline, and numerically lower than the third baseline. This finding was different from the observations of de Boer & Bressmann[25], whose participants showed an inconsistent increase in nasalance scores in response to decreased nasal signal level feedback. It is possible that singers (like speakers) do not perceive decreased nasality (hyponasality) as critically as increased nasality (hypernasality). Based on clinical observations, Shprintzen, Lewin and Croft (page number 54)[41] argued: “while hyponasal speech is not normal, it is far more desirable than hypernasal speech since the majority of consonant phonemes in the English language have no nasal resonance.” It is possible that this observation applies equally to song.

The third hypothesis was that professional singers would show a smaller compensatory reaction to the altered auditory feedback than non-singers. The results indicated that there were no significant differences in nasalance scores between the singers and the non-singers in their responses to the altered auditory feedback. These results differ from those by Jones and Keough[20], Scheerer and Jones,[21] and Bottalico, Graetzer and Hunter,[22] all of whom found that singers showed more feed-forward control of their vocal production than non-singers in response to fundamental frequency and amplitude perturbations, demonstrating that the internal models guiding a singer’s control of amplitude and pitch production were more refined than those of untrained singers. However, based on the present study results, the control of oral-nasal balance does not show similar differences related to the level of participants’ singing training in response to altered feedback. It could be argued that oral-nasal balance is an area of mostly non-explicit instruction for singing students, so there may be less opportunity to refine internal models of oral-nasal balance in song. As a result, the trained and untrained singers appeared to have reacted to the altered auditory feedback in comparable patterns.

In the only previous study investigating nasalance scores in singing, Jennings and Kuehn[40] found lower nasalance scores in classically trained singers compared to amateur singers. However, the singing tasks in their study focused on sustained vowels while the present study involved a complete song with more varied phonetic content. There were also no perturbation conditions in their study design, so the results of the two studies may not be directly comparable.

The observed decrease in nasalance scores in response to decreased nasal feedback was unexpected and intriguing. The altered auditory feedback conditions were always presented in the same order (first increased and then decreased nasal feedback). This was based on an observation in de Boer & Bressmann’s[25] speech study that the order of presentation had no statistically significant effect on the speakers’ compensatory reactions. However, the auditory manipulations in de Boer & Bressmann[25] were gradually ramped up and down while the present study abruptly changed the nasal signal levels feedback from the maximum and minimum levels back to baseline. In Figure 3, the numerical differences between the four baseline conditions show that baseline 2 and baseline 3 scores were lower than for the first baseline. This could indicate that participants had not fully recovered from the increased nasal feedback and were showing after-effects. Baseline 4 also showed significantly lower nasalance scores than the first baseline. Altered auditory feedback can cause speakers to temporarily update their internal motor model for speech production, leading to adaptive changes in feed-forward motor planning.[42,43] Therefore, a possible interpretation for the results was that the participants’ feed-forward motor planning had undergone an update during the maximum nasal signal level feedback condition, and that this update was maintained through the remainder of the experiment. In future research, the experiment should be replicated with a reverse order of the feedback conditions, as well as with gradual ramp-downs, as used by de Boer and Bressmann.[25]

CONCLUSION

The present study investigated the effect of altered auditory feedback on the control of oral-nasal balance in song and found that all participants showed lower nasalance scores in response to both increased and decreased nasal signal level feedback. There were no differences between trained singers and untrained non-singers. Future research should investigate the order of the feedback conditions and the transitions of the auditory feedback back to the baseline in more detail.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found, online at doi:10.1016/j.jvoice.2018.06.014.

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