JSLHR

Research Note

Effects of Biofeedback on Control and Generalization of Nasalization in Typical Speakers

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Purpose: The purpose of this study was to determine the effects of biofeedback on control of nasalization in individuals with typical speech.
Method: Forty-eight individuals with typical speech attempted to increase and decrease vowel nasalization. During training, stimuli consisted of consonant-vowel-consonant (CVC) tokens with the center vowels /a/ or /i/ in either a nasal or nonnasal phonemic context (e.g., /mim/ vs. /bib/), depending on the participant's training group. Half of the participants had access to augmentative visual feedback during training, which was based on a less-invasive acoustic, accelerometric measure of vowel nasalization—the Horii oral–nasal coupling (HONC) score. During pre- and posttraining assessments, acoustically based nasalance was also measured from the center vowels /a/, /i/, /æ/, and /u/ of CVCs in both nasal and nonnasal contexts.
Results: Linear regressions indicated that both phonemic contexts (nasal or nonnasal) and the presence of augmentative visual feedback during training were significant predictors for changes in nasalance scores from pre- to posttraining.
Conclusions: Participants were able to change the nasalization of their speech following a training period with HONC biofeedback. Future work is necessary to examine the effect of such training in individuals with velopharyngeal dysfunction.

The ability to produce intelligible speech relies on both the accurate auditory perception of speech sounds and somatosensory (i.e., tactile and proprioceptive) information about the state of the vocal tract during their production (Guenther, 1994, 1995; Perkell, 1980; Tourville & Guenther, 2011). This feedback is important for control of the velopharyngeal (VP) port, the connection between the pharynx and the nasal cavity.

In spoken English there are three nasal phonemes, /m/, /n/, and /ŋ/, which require an open VP port. These phonemes are produced with a high degree of *nasalization:* the passage of acoustic energy through the open VP port and the nasal cavity. Due to coarticulation, vowels that are produced in a nasal context, either preceding or following a nasal phoneme, are also typically produced with an open VP port (Ali, Gallagher, Goldstein, & Daniloff, 1971; Kent, Carney, & Severeid, 1974). In obstruents, conversely, the VP port is closed to allow air pressure to build up in the oral cavity. *Nasality* is the percept of the nasalization of a voiced speech sound. When oral vowels are produced with an inappropriately open VP port, an excess of acoustic energy emanates from the nasal passages, which is perceived as hypernasality. In speech perceived as hyponasal, the VP port is closed to an inappropriate degree in sounds that are intended to be nasalized, resulting in reduction of the acoustic energy emitted through the nasal cavity.

Augmentative visual feedback may be employed to facilitate speech rehabilitation in VP mislearning, in which inappropriate articulation of the VP mechanism is not caused by a physical or anatomical problem with the VP mechanism (Loney & Bloem, 1987; Peterson-Falzone, Trost-Cardamone, Karnell, & Hardin-Jones, 2006; Trost-Cardamone, 1989) and potentially may be useful for individuals with VP incompetency with neurological origins. At the present time, augmentative visual feedback is often provided in clinical settings via two types of instrumentation: (a) a nasal endoscope, providing a direct visualization of the VP port opening, or (b) a nasometer, providing an indirect measure of VP port status. Although studies demonstrate that this biofeedback can be beneficial in assisting with

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Editor and Associate Editor: Amy Neel
Received August 18, 2015
Revision received December 17, 2015
Accepted January 20, 2016
DOI: 10.1044/2016_JSLHR-S-15-0286

Disclosure: The authors have declared that no competing interests existed at the time of publication.

VP port control in both children and adults (Brunner, Stellzig-Eisenhauer, Pröschel, Verres, & Komposch, 2005; Van Lierde, Claeys, De Bodt, & Van Cauwenberge, 2004; Witzel, Tobe, & Salyer, 1988, 1989; Yamaoka, Matsuya, Miyazaki, Nishio, & Ibuki, 1983; Ysunza, Pamplona, Femat, Mayer, & García-Velasco, 1997), both require invasive or bulky and uncomfortable hardware (Pratt & Hricisak, 1994), limiting their usability in clinical environments.

Although not typically used in clinical settings, vibration of the exterior surface of the nose, transduced by an accelerometer, has also been suggested as a correlate of perceived nasality (Horii, 1980, 1983; Laczi, Sussman, Stathopoulos, & Huber, 2005; Mra, Sussman, & Fenwick, 1998; Redenbaugh & Reich, 1985). The amplitude of this vibration can be either measured in isolation (Stevens, Kalikow, & Willemain, 1975) or compared to the combined oral and nasal acoustic output via a single microphone, referred to as the Horii oral–nasal coupling score, or HONC score (Horii, 1980, 1983). HONC instrumentation is lightweight, doesn't require bulky hardware, and has low power consumption (Stevens et al., 1975). Furthermore, HONC scores are correlated with experts' perception of nasality (Horii, 1983), and can effectively differentiate between nasalized and nonnasalized speech tokens (Mra et al., 1998; Thorp, Virnik, & Stepp, 2013; Varghese, Mendoza, Braden, & Stepp, 2014). In addition, previous work has shown that the use of HONC scores to differentiate between nasalized and nonnasalized speech tokens produces results comparable to the use of nasalance (Thorp et al., 2013).

The purpose of this study was to examine the nasalization of vowels in individuals with typical speech before and after a training period with biofeedback based on HONC scores. Although originally proposed as a training modality (Stevens et al., 1975), HONC instrumentation not been explicitly examined as a biofeedback modality to produce changes in nasalization. Adults with typical speech participated in a single training session in which they attempted to increase and decrease the nasalization of consonant-vowel-consonant (CVC) speech tokens. Augmentative visual feedback based on HONC scores was provided to half of the participants during training, whereas the other half of the participants only had access to their typical auditory feedback. During training, half of participants produced CVC speech tokens in a nasal phonemic context (/m/ and /n/), and the other half in a nonnasal phonemic context (/b/ and /d/). We hypothesized that individuals who received augmentative visual feedback during training would exhibit larger changes in their ability to modify their degree of nasalization as a result of training. We also hypothesized that participants would be more effective at changing the nasalization of tokens on which they were explicitly trained.

Method

Participants

Participants were 48 adults (30 women, 18 men) with an average age of 20.2 years (SD = 3.9 years) and no history of speech, language, or hearing disorders. All participants were fluent speakers of American English and were not fluent in any language with contrastive vowel nasalization (e.g., French). Testing occurred over 2 sequential days: Session 1 (approximately 90 min) and Session 2 (approximately 30 min). All participants provided written consent in compliance with the Boston University Institutional Review Board and were compensated for participation.

Experimental Design

Participants completed (a) a preassessment (*Pre*) of nasalance, (b) a training session with or without biofeedback based on the HONC scores, (c) a postassessment (*Post*) of nasalance, and (d) a follow-up assessment (*Follow-up*) of nasalance on the next day (see Figure 1). During all portions of the experiment, participants were instructed to either increase or decrease the nasalization of CVC speech tokens.

During the training portion, participants were assigned to one of four groups, with 12 people in each group (see Figure 1). Two groups were trained on stimuli with vowels in a nasal phonemic context (Nas) and two groups were trained on stimuli with vowels in a nonnasal phonemic context (Non). In addition, two groups (one Nas and one Non) only had access to their typical auditory feedback (*0vfb*), whereas the remaining two groups received augmentative visual feedback (*+vfb*) in addition to having access to their typical auditory feedback.

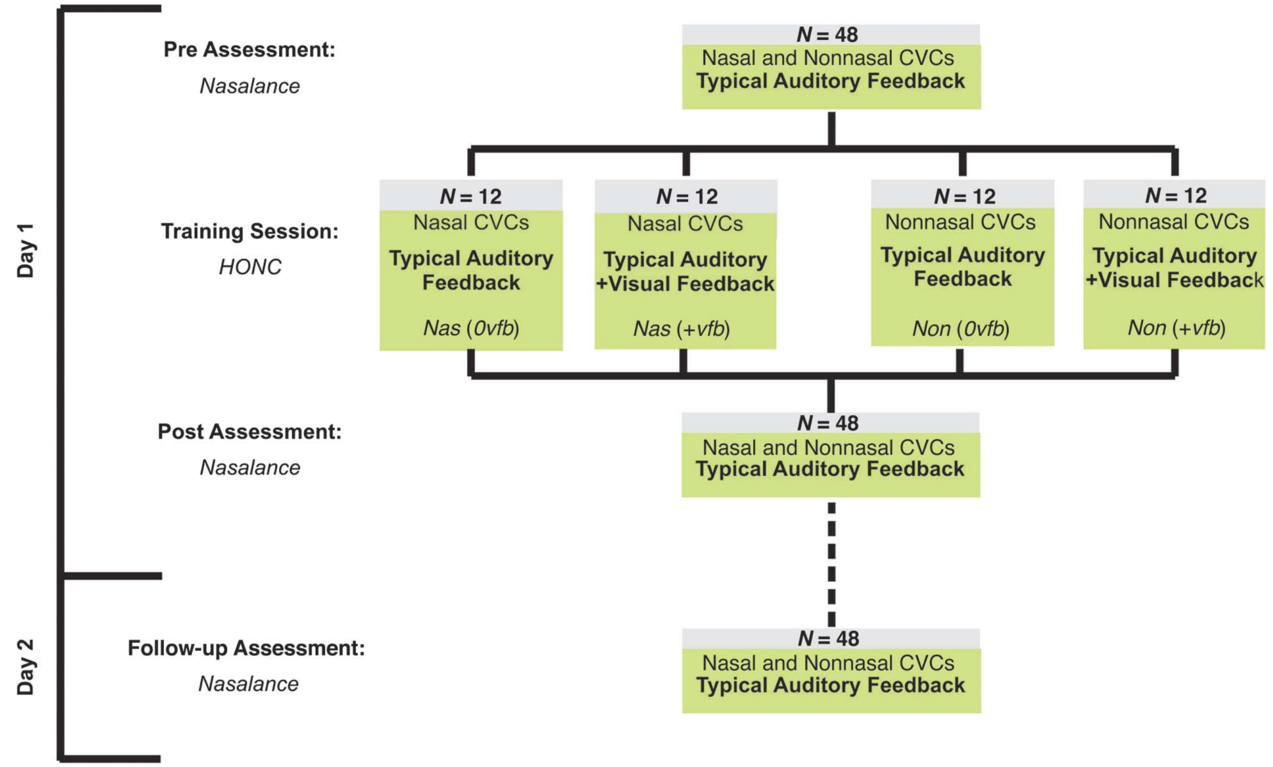
Signals Collected

All recordings were conducted in a sound-treated room. Nasalance was collected during assessments with the Nasometer II, model 6450 (Kay Elemetrics Corp, Lincoln Park, NJ) using standard Nasometer II software with a sampling frequency of 11025 Hz. HONC data were collected during training with a headset microphone (Shure model WH20; Shure, Inc., Niles, IL) and BU Series 21771 accelerometer (Knowles Electronic, Itasca, IL). The accelerometer signal was band-pass filtered from 400–1000 Hz and the microphone was filtered from 25–420 Hz, allowing for utilization of the low-frequency portion of the signals (Thorp et al., 2013; Varghese et al., 2014). The microphone was placed 7 cm from the mouth at a 45° angle. The accelerometer was placed on the lateral aspect of the nose, inferior to the nasal bone and superior to the ala (Lippmann, 1981). Both the microphone signal and nasal accelerometer signals were preamplified by a RME Quadmic II (RME, Haimhausen, Germany) and sampled at 44100 Hz using one of two sound cards: a MOTU ultralite mk3 hybrid (model UltraLite3Hy; MOTU, Cambridge, MA) or Komplete Audio 6 (Native Instruments, Los Angeles, CA).

Assessments

Nasalance was measured during the three assessment periods (*Pre, Post,* and *Follow-up*). Regardless of training group, during the assessments all participants produced

Figure 1. Experimental design with the number of subjects and training group designation indicated. Participants were presented visually with CVC speech tokens. During training half of the participants saw speech tokens in a nasal phonemic context (Nas) and half saw speech tokens in a nonnasal phonemic context (Non). Participants also either had access only to their typical auditory feedback (*0vfb*) or access to visual feedback in addition to their typical auditory feedback (*+vfb*).



eight CVC speech tokens in a nasal phonemic context and eight tokens in a nonnasal phonemic context. All tokens had a center vowel that was either /ɑ/, /i/, /æ/, or /u/ and were produced in both a congruent manner (e.g., say nonnasal "bob") and an incongruent manner (e.g., say nasal "bob"), resulting in 32 unique productions. These 32 unique tokens were presented randomly in each of the three blocks for the *Pre* assessment and the *Post* assessment. For the *Follow-up* assessment, the speech tokens were presented in five blocks, with only the last three repetitions of the 32 tokens analyzed.

Training Session

The training session was completed with the HONC instrumentation. Throughout the training session, participants were asked to produce four tokens, once in a congruent manner and once in an incongruent manner, for a total of eight unique speech tokens, which were then randomized and repeated in 28 training blocks. Half the participants were trained in a nonnasal phonemic context and the other half were trained in a nasal phonemic context. Participants in the Non (*0vfb*) and Nas (*0vfb*) groups were presented with directions regarding what to produce; no augmentative visual feedback was given. All speech tokens had the center vowels /ɑ/ and /i/. The training of only two of the vowels allowed for the evaluation of generalization (Maas et al., 2008) to the untrained vowels during the assessment periods.

For participants in the Nas (*+vfb*) and Non (*+vfb*) groups, augmentative visual feedback based on real-time HONC scores was provided during the training session via a custom MATLAB (2013) graphical user interface. A HONC score (see Equation 1; Horii, 1980) was calculated from the vowel of each speech token using MATLAB. HONC scores were calculated over the center 25% of the duration of each production, determined via a 5% threshold above the noise floor of the microphone signal. The root mean square (RMS) of the accelerometer signal, RMS_A, was divided by the RMS of the microphone signal, RMS_M. To reduce between-speaker variability, a normalization factor, defined as $RMS_{M\ of\ the\ sustained\ /m/}\ /RMS_{A\ of\ the\ sustained\ /m/}$, was calculated from the average of six productions of a sustained /m/ recorded prior to the training session (see Eq. 1; Horii, 1980).

$$HONC = \frac{RMS_{M\ of\ the\ sustained/m/}}{RMS_{A\ of\ the\ sustained\ /m/}} \times \frac{RMS_A}{RMS_M} \quad (1)$$

Prior to each training trial, participants were shown directions on a computer screen (e.g., say nasal "bob"), and an arrow pointing upward for attempts to increase nasalization, or downward for attempts to decrease nasalization. In addition, a threshold line was displayed on the screen. Prior to the start of the training, participants were asked to produce, in their typical speaking voice, eight CVC speech tokens, four in a nasal phonemic context and four in a nonnasal phonemic context, with the center vowels /ɑ/ and /i/, to establish the initial threshold. For intended increases in nasalization, participants were given positive visual feedback if they produced a HONC score above the threshold, whereas for intended decreases in nasalization, participants were given positive visual feedback if they produced a HONC score below the threshold. After each production, a vertical bar corresponding to the HONC score and the threshold were displayed. If the participant was successful, the vertical bar was green; otherwise, the vertical bar was red.

During the first 80 trials, thresholds were adjusted using an adaptive staircase procedure, separately for trials with attempted increases in nasalization and for trials with attempted decreases in nasalization. If the participant was successful for two successive trials with the same attempted changes in nasalization, the threshold was moved to make the next trial more challenging; that is, moved up for attempted increases in nasalization and moved down for attempted decreases in nasalization. If the participant continued to be successful, the threshold would continue moving after every subsequent trial until the participant was unable to reach the threshold. When the participant was unable to reach the threshold, the threshold was moved to make the next trial easier. The amount the threshold moved, the step size, when the participant was successful was initially set to 0.20 and systematically decreased throughout the initial part of training until it reached 0.02. The step size for unsuccessful trials was set to one-fifth of the successful step size. These step sizes were chosen empirically based on pilot studies and resulted in stabilization of participants' thresholds. After the first 80 trials, the thresholds were no longer modified adaptively. At that point, the average HONC score of the last five reversals (a change in the direction of the threshold) was calculated and the threshold was maintained at that level for the remainder of the trials. This threshold was chosen such that the participant was able to produce the correct nasalization the majority of the time, but not on every trial, in order to provide a constant challenge (Guadagnoli & Lee, 2004).

Thus, the augmentative visual feedback in this experiment utilized "knowledge of results" as well as "knowledge of performance" (Gentile, 1972; Salmoni, Schmidt, & Walter, 1984). Participants were provided with feedback in the form of the vertical bar color providing them knowledge of results; that is, whether they were successful or not. In addition, as the vertical bar height corresponded to the HONC score of their production, participants were aware of the how far their productions were from their target (the threshold line), providing them with the knowledge of performance. Further, this presentation of augmentative visual feedback was faded (reduced in frequency) throughout the training portion (Winstein & Schmidt, 1990; Wulf & Schmidt, 1989). The fading of feedback was intended to mitigate the possibility of individuals relying solely on the augmentative (visual) feedback, rather than their own intrinsic (auditory) feedback (Salmoni et al., 1984; Winstein & Schmidt, 1990). In the Nas (*+vfb*) and Non (*+vfb*) groups the first 80 trials had 100% augmented visual feedback, the feedback was faded to 50% for the next 48 trials, 25% of the following 48 trials, and 0% of the last 48 trials in the training. The presentations of the trials in which the visual feedback was not shown were identical to the trials seen by the Nas (*0vfb*) and Non (*0vfb*) groups throughout training.

Data Analyses

Analyses for this study focused on the clinically relevant tasks, the two incongruent conditions, and the congruent condition for nonnasal tokens. Therefore, nasalance scores were split into three different subsets for analyses, determined by the token type and the intended nasalization direction (see Table 1). Nasalance scores were calculated from the middle portion of the vowel in the CVC token with the Nasometer II software. The Nasometer calculates nasalance (%), which is the ratio of nasal acoustic energy to nasal-plus-oral acoustic energy, multiplied by 100 (Fletcher, 1972). Average changes in nasalance scores from *Pre* assessment to both the *Post* and *Follow-up* assessments were calculated to evaluate the magnitude of change in nasalance scores. On the basis of the larger nasalance changes noted in the incongruent (*I*) condition, additional analyses were conducted on the *I-nas* and *I-non* subsets. Statistical analyses were performed using Minitab Statistical Software (Minitab, 2012). Given the exploratory nature of the study, adjustments were not made for multiple testing. Two linear regressions, one for the *I-non* subset and one for the *I-nas* subset examined whether the dependent variables for change in nasalance scores from the *Pre* to the *Post* assessments were influenced by augmentative visual feedback (*+vfb* or *0vfb*), phonemic context (Nas or Non), or the interaction between augmentative visual feedback and phonemic context during training. Two additional linear regressions, one for *I-non* and one for *I-nas,* were similarly performed to examine whether the changes in nasalance scores from the *Pre* to *Follow-up* assessments were influenced by augmentative visual feedback, phonemic context, or the interaction between augmentative visual feedback and phonemic context during training.

To examine whether differences in the nasalance scores in the incongruent subsets of vowels were contingent on whether the vowel was trained (/ɑ/ or /i/) or untrained (/æ/ or /u/), four paired-samples *t* tests were performed. Two paired-samples *t* tests compared the differences in nasalance (trained vs. untrained vowels) at the *Pre* assessment

Table 1. Three subsets utilized for statistical analyses.

Manner of production	Subset	Speech token	Intended nasalization direction
Congruent	*C-non*	Nonnasal	Decrease
Incongruent	*I-non*	Nonnasal	Increase
	I-nas	Nasal	Decrease

compared to the differences in nasalance at the *Post* assessment. Two additional paired-samples *t* tests compared the differences in nasalance at the *Pre* assessment compared to the *Follow-up* assessment.

Results

Participants demonstrated the largest changes in nasalance scores in the incongruent productions when they received augmentative visual feedback during training and were trained in the specific phonemic context that was being assessed. These changes were maintained to the *Follow-up* assessment the next day. Although specificity of the phonemic context of trained stimuli was a significant predictor of training effects, there was no clear evidence for such specificity based on the vowels of stimuli used during training.

Descriptive Changes in Nasalance

During the congruent subset *C-non* there was minimal change in the nasalance values (see Figure 2). In contrast, participants were able to produce intended changes in nasalization in both incongruent subsets (*I-non* and *I-nas*) regardless of the phonemic context in which they were trained (see Figure 2). However, although participants were able to produce intended changes in nasalization in all subsets, participants who had training specificity and received augmentative visual feedback had the largest changes in nasalization. For the *I-non* productions, individuals who received augmentative visual feedback and were trained on nonnasal tokens (Non, +*vfb*) had the largest increases in nasalance from *Pre* assessment to *Post* assessment and from *Pre* assessment to *Follow-up* assessment. For the *I-nas* productions, individuals who received augmentative visual feedback and were trained on nasal tokens (Nas, +*vfb*) had the largest decreases in nasalance from the *Pre* assessment to the *Post* assessment, and from the *Pre* assessment to the *Follow-up* assessment.

Incongruent Manners of Production

Augmentative visual feedback, phonemic context, and the interaction of Augmentative Visual Feedback × Phonemic Context during training were examined as predictors for the change in nasalance scores from the *Pre* assessment to the *Post* assessment, and the *Pre* assessment to the *Follow-up* assessment within each subset.

Nonnasal Tokens Produced With Increased Nasalance (Subset *I-non*)

Neither augmentative visual feedback, nor phonemic context, nor the interaction of Augmentative Visual Feedback × Phonemic Context during training were significant predictors for the changes in nasalance scores from the *Pre* to the *Post* assessments in the *I-non* subset (*Post* − *Pre*; see Table 2). However, the interaction of Augmentative Visual Feedback × Phonemic Context significantly predicted the change in nasalance from the *Pre* to the *Follow-up* assessments (interaction effect; $\beta = 15.68$, $p = 0.04$; see Figure 3). Within the two groups that received augmentative visual feedback, individuals who were trained on nonnasal tokens (Non, +*vfb*), and therefore were trained in the phonemic context specific for this particular subset, had a larger increase in their nasalance between the *Pre* and the *Follow-up* assessments than individuals who were trained in a nasal phonemic context (Nas, +*vfb*). In the groups that did not receive augmentative visual feedback, individuals who were trained in a nasal phonemic context (Nas, *0vfb*) had a greater increase in their nasalance than individuals who were trained in a nonnasal phonemic context (Non, *0vfb*) from the *Pre* to the *Follow-up* assessments.

Nasal Tokens Produced With Decreased Nasalance (Subset *I-nas*)

A linear regression model for the change in nasalance scores from the *Pre* to the *Post* assessments (*Post* − *Pre*) revealed that augmentative visual feedback and phonemic context were not significant predictors for the changes in nasalance scores in the subset *I-nas*. However there was a trend towards significance in the interaction of Augmentative Visual Feedback × Phonemic Context (interaction effect; $\beta = -11.37$, $p = 0.07$; see Figure 4). Within the groups that received augmentative visual feedback, individuals who were trained on nasal tokens (Nas, +*vfb*), and therefore

Figure 2. Representation for the magnitude change in nasalance in the three subsets. Shaded squares indicate a change in the correct direction for that subset.

		C-non		I-non		I-nas	
Feedback Group	*Training Group*	Post	Follow-Up	Post	Follow-Up	Post	Follow-Up
Visual Feedback *(+vfb)*	Non	+	+	+++	+++	–	–
	Nas	–	–	++	++	– – –	– – –
No Visual Feedback *(0vfb)*	Non	–	–	++	++	– –	–
	Nas	+	+	++	+++	–	–

Change in Nasalance from Pre Assessment

–	0 to –5	+	0 to 5
– –	–5 to –10	++	5 to 10
– – –	<–10	+++	>10

Table 2. Results from linear regression examining the change in nasalance from the *Pre* to the *Post* assessments and from the *Pre* to the *Follow-up* assessments for subset *I-non*.

	Post–Pre			Follow-up–Pre		
Term	**β**	***SE* (β)**	***p***	**β**	***SE* (β)**	***p***
Constant	7.44	3.40	.03*	11.01	3.62	.01*
Visual feedback	−1.27	4.81	.79	−4.22	5.13	.42
Phonemic context	−1.51	4.81	.76	−5.40	5.13	.30
Visual feedback × phonemic context	9.47	6.81	.17	15.68	7.25	.04*

Note. β = coefficient; *SE* (β) = standard error of the coefficient.
significant p < 0.05.

were trained in the phonemic context specific for this particular subset, trended towards a larger decrease in their nasalance scores than individuals who were trained in a nonnasal phonemic context (Non, +*vfb*). In the group that did not receive visual feedback, individuals who were trained on nasal tokens (Nas, *0vfb*) had close to no change in nasalance scores at the *Post* assessment, whereas individuals who were trained on nonnasal tokens (Non, *0vfb*) had a small decrease in nasalance at the *Post* assessment. Similar results were seen for the changes in nasalance scores from the *Pre* assessments to the *Follow-up* assessment, which also showed a trend toward an interaction effect ($\beta = -13.88$, $p = .07$; see Figure 4). As independent factors, augmentative visual feedback and phonemic context were not significant predictors for the changes in nasalance scores from the *Pre* to the *Follow-up* assessments (see Table 3).

Effects of Vowel Training Specificity

Differences between nasalance scores for trained vowels (/i/ and /ɑ/) and nasalance scores for untrained vowels (/æ/ and /u/) were compared at each assessment period for each incongruent subset. For subset *I-non* the difference in nasalance between trained and untrained vowels during the *Pre* assessment was not significantly different than the difference in nasalance between trained and untrained vowels during either *Post* assessment or the *Follow-up* assessment (both $p > .05$). For the subset *I-nas,* the difference in nasalance between trained and untrained vowels during the *Pre* assessment was not significantly different than the difference in nasalance during the *Post* assessment, $t(48) = 0.87$, $p = .39$. However, trained vowels had a 9.9 point higher nasalance score than untrained vowels on the *Pre* assessment

Figure 3. Mean and 95% confidence intervals for the change in nasalance for nasal tokens produced with attempted decreases in nasalization (subset *I-nas*). Left, scores from the *Pre* to the *Post* assessments; *right*, scores from the *Pre* to the *Follow-up* assessments.

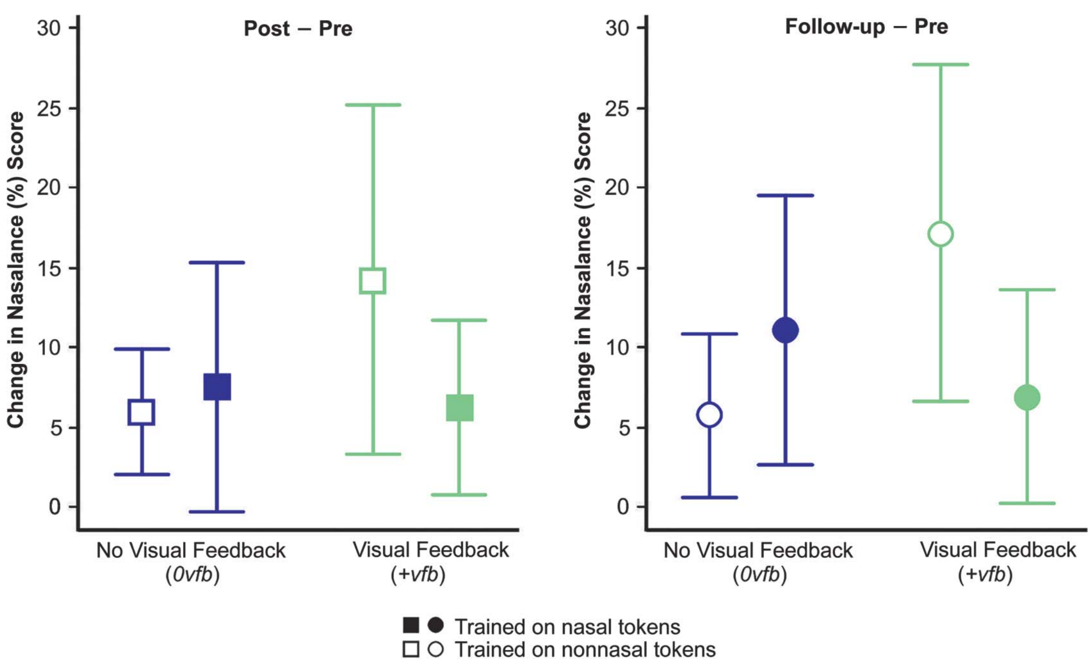
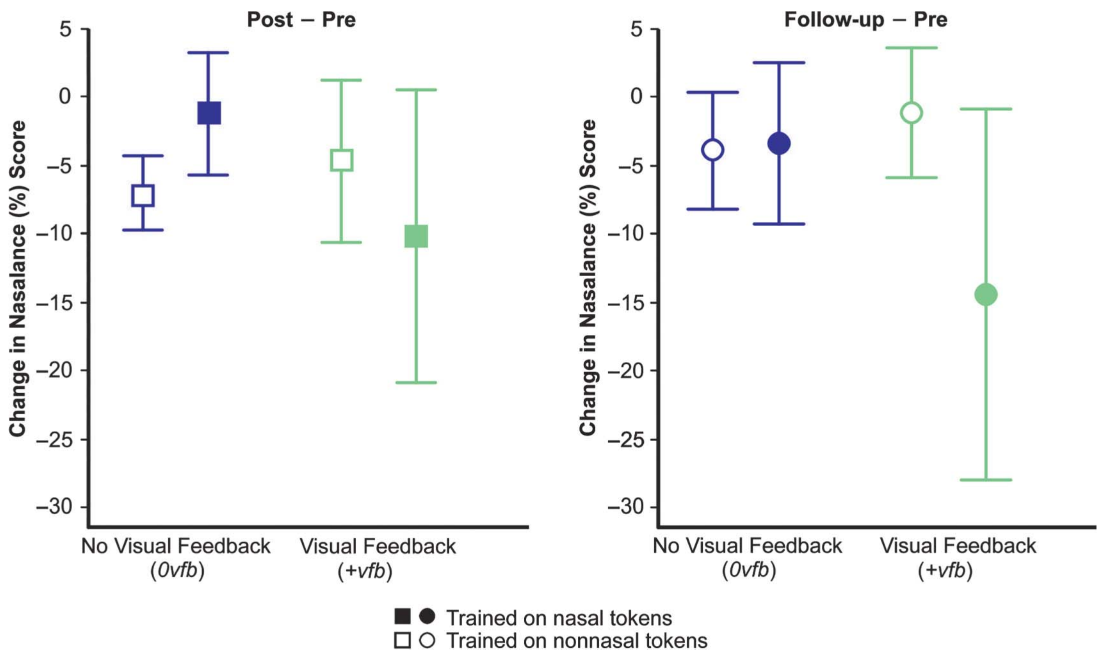


Figure 4. Mean and 95% confidence intervals for the change in nasalance for nasal tokens produced with attempted decreases in nasalization (subset *I-nas*). Left, scores from the *Pre* to the *Post* assessments; *right*, scores from the *Pre* to the *Follow-up* assessments.



compared to a 7.8 point higher score during the *Follow-up* assessment, $t(48) = 2.74$, $p = .01$.

Discussion

Overall, this study demonstrated the benefit of using the HONC instrumentation for training control of nasalization. Results from this study indicated that both specificity of phonemic context and presence of augmentative visual feedback during training were meaningful components of a training paradigm aimed at changing the level of nasalization (measured via nasalance).

Congruent Productions

Individuals with typical speech were not able to significantly change the nasalization of congruent productions. This is likely due to the anatomical constraints involved in speech production, making it difficult for individuals with typical speech to make large changes during these productions.

Incongruent Productions

Participants were more successful at changing nasalance scores of the incongruent productions. Many participants were able to change their nasalance scores to values that are considered clinically significant and would be cause for further evaluation in a clinical environment. In particular, for an oral passage (e.g., zoo passage; Fletcher, 1972), a nasalance score of 32 has been proposed as a critical threshold for diagnosing VP impairments (Dalston, Warren, & Dalston, 1991c). Participants in the Non (+*vfb*) group were able to produce nasalance scores above 32 during the *Post* and *Follow-up* assessments (range = 32.1–35.1) when they were asked to produce nonnasal words with increased nasalization (subset *I-nas*). Dalston et al. (1991a, 1991b) also

Table 3. Results from linear regression examining the change in nasalance from the *Pre* to the *Post* assessments and from the *Pre* the *Follow-up* assessments for subset *I-nas*.

	Post – Pre			Follow-up – Pre		
Term	**β**	***SE* (β)**	***p***	**β**	***SE* (β)**	***p***
Constant	−7.02	3.05	.03*	−3.98	3.68	.29
Visual feedback	2.37	4.32	.59	2.80	5.20	.59
Phonemic context	5.83	4.32	.18	0.54	5.20	.92
Visual Feedback × Phonemic Context	−11.37	6.10	.07	−13.88	7.36	.07

Note. β = coefficient; *SE* (β) = standard error of the coefficient.

*$p < .05$.

noted that when examining nasal-loaded sentences, production of nasalance scores that were under 50 resulted in a hyponasal quality. In subset *I-nas,* nasalance scores in the *Post* assessment for the Non (*0vfb*) and Nas (*+vfb*) groups, as well as nasalance scores from the *Follow-up* assessments in the Non (*0vfb*), Nas (*0vfb*), and the Nas (*+vfb*) groups were below a nasalance score of 50 (range = 34.3–49.0). The lowest nasalance scores were in the Nas (*+vfb*) group, with an average nasalance score of 38.6 at the *Post* assessment and 34.3 at the *Follow-up* assessment. Therefore, participants with typical speech in this study were able to produce speech with nasalance scores that approximated individuals with VP dysfunction. However, it should be noted that these cutoff values were developed for running speech, unlike the vowel stimuli in the current study.

Although previous research has indicated that knowledge of results feedback is initially beneficial (Guadagnoli & Lee, 2004), a continuation of feedback may have a detrimental impact on learning (Salmoni et al., 1984; Winstein & Schmidt, 1990). Individuals can begin to rely on the augmentative feedback instead of their own intrinsic feedback (Salmoni et al., 1984; Winstein & Schmidt, 1990). One study found a negative relationship between how frequently participants were presented with feedback and how successful they were at nasalizing a sustained /i/ during a 10-min training period (Steinhauer & Grayhack, 2000). However, it is possible that this negative relationship was either due to too short a training period, or too easy a task to allow for further improvements. The current study did not demonstrate a negative effect of feedback in the incongruent productions. One possible explanation for this observation is that the fading of augmentative visual feedback during training may have prevented the overreliance on external feedback as opposed to internal feedback.

The strongest predictor for changes in nasalance for the incongruent productions was the interaction between augmentative visual feedback and phonemic context. For subset *I-non,* within the groups that received augmentative visual feedback, participants who were trained in a nonnasal phonemic context were more effective at increasing their nasalization from the *Pre* to the *Follow-up* assessments relative to individuals who trained in a nasal phonemic context. The largest changes in nasalance scores for individuals who received augmentative visual feedback from the *Pre* to the *Post* assessment in subset *I-nas* were individuals who were trained in a nasal phonemic context relative to individuals who were trained in a nonnasal phonemic context. Participants in subset *I-nas* not only retained these changes in nasalance scores, but the scores further decreased when nasalance was evaluated during the *Follow-up* assessment. Although participants who were provided with augmentative visual feedback and phonemic context during training were effectively able to change their nasalizations, they displayed increased variability in the magnitude of these changes relative to individuals who did not receive both augmentative visual feedback and phonemic context during training. Overall, results from these incongruent productions indicated that it was not solely the presence of augmentative visual feedback or phonemic context during training that had an influence on changes in nasalization, but rather the interaction between these factors.

Although the results indicated the importance of the specificity of phonemic context (nasal or nonnasal) during training, there was less clear evidence of a vowel specificity effect during training in the incongruent productions. In all of the assessment periods, trained vowels (/ɑ/ and /i/) always had higher nasalance scores relative to the untrained vowels (/æ/ and /u/). This was likely due to the intrinsic nasalance values of the vowels (Awan, Omlor, & Watts, 2011; Gildersleeve-Neumann & Dalston, 2001); however, this did not affect how successful participants were at changing the degree of nasalization of stimuli.

Limitations and Future Directions

This study demonstrated the effectiveness of utilizing the less-invasive HONC instrumentation during a training paradigm to change nasalization in adults with typical speech, suggesting both research significance and clinical potential. This training paradigm was for a relatively short time period, and effects were seen immediately after the training period as well as the next day. Although this carryover is extremely important for clinical use and effectiveness of the training paradigm, future investigations of carryover should be performed.

This study presented a proof of concept for the use of the HONC instrumentation as a training tool, but it did not explore the potential effects of structural differences that may occur in individuals with VP dysfunction (Kummer, 2008). Future work will examine this paradigm in individuals with VP dysfunction to determine the effectiveness in changing nasalization in clinical populations. Furthermore, this biofeedback was only aimed at addressing differences in resonance in vowels. Other errors, such as weak production of pressure consonants, may not be as effectively changed with this paradigm. Last, although this study showed significant changes in nasalance, it was beyond the scope of the current project to assess the perception of nasality. The presence of hypernasality in speech has been shown to be received negatively by both children (Blood & Hyman, 1977) and adults (Lallh & Rochet, 2000; McKinnon, Hess, & Landry, 1986). Therefore, understanding the potential changes in the perception of nasality is an essential next step.

Conclusions

This study demonstrated the effectiveness of utilizing HONC instrumentation in a training paradigm to change the nasalization of speech production in adults with typical speech. Participants demonstrated the largest changes in nasalance in the incongruent productions when they received augmentative visual feedback during training and were trained in the phonemic context that was being assessed. These changes were maintained to the *Follow-up* assessment the next day. Although specificity of phonemic context during training was important, there was not a clear effect of specificity of the vowel used during training. Future work will examine the use of HONC scores in training nasalization changes in individuals with VP dysfunction.

Acknowledgments

This work was supported in part by the Deborah Munroe Noonan Memorial Research Fund (awarded to Cara Stepp), National Institute on Deafness and Other Communication Disorders Grant DC012651 (awarded to Cara Stepp), and a grant from the Dudley Allen Sargent Research Fund, Boston University, (awarded to Elizabeth Heller Murray). The authors would also like to acknowledge Kate Girouard and Ali Martinson for their help with data analysis.

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