Quantifying vibration in resonant voice

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Abstract

Resonant voice therapy emphasizes on proprioceptive vibratory sensation of maxillary bones. However, no quantitative measurement on the extent of vibration is available in the literature. The present study compared the bone vibration in resonant phonation of nasal and non-nasal stimuli, and investigated the correlation of objective vibration measurement and perceptual rating of phonatory resonance. Thirty-six adults aged 20 to 33 with normal voice received a session of resonant voice training. Three judges rated the resonance of the phonatory samples independently with an 11-point equal-appearing interval (EAI) scale. The results demonstrated no significant difference in the increase of vibration after resonant voice training between nasal and non-nasal stimuli. The correlation of vibration measurement and perceptual rating was significant but low (r = .389, p < .0001). The findings suggest the usefulness of vibro-detector as noninvasive quantitative measurement of vibration. Future studies in using vibro-detector for providing visual feedback in resonant voice training are recommended.

Resonant voice therapy is a widely used therapeutic approach in the field of voice intervention (Boone, McFarlane, & Von Berg, 2005; Colton, Casper, & Leonard, 2006; Verdolini, 1998; Verdolini, 2000). The therapy involves training of resonant voice, which is defined as a voicing pattern with forward tone focus in the context of easy phonation (Boone et al., 2005; Verdolini-Marston, Burker, Lessac, Glaze, & Caldwell, 1995). In resonant voice training, speakers are asked to produce the natural “um-hum” or the sound /m/ with their lips closed in a relaxed manner as opposed to the habitual effortful and inefficient voice production. The use of nasal stimuli has been regarded as facilitative in the acquisition of resonant voice (Boone et al., 2005). Justification in the choice of nasal stimuli in resonant voice training has been argued on the basis of acoustic properties. Titze (2001) explained that as the acoustic pressure near occlusions of the vocal tract is maximal, vibratory sensation could be detected in sites where the vocal tract area is small. The area of nasal cavity was comparatively smaller than the vocal tract area, accounting for greater vibration sensed in phonation of nasal stimuli than non-nasal stimuli.

Two features of resonant voice have been emphasized in the therapy. Firstly, the phonation with vocal folds in a barely adducted configuration. Many have advocated that such laryngeal posture is favourable in treating patients with a range of vocal pathologies associated with vocal hyperfunction, misuses or abuses with or without organic lesions such as vocal nodules and vocal polyps (Verdolini, 1998; Verdolini & Titze, 1995). It is believed that the impact force on the vocal folds would be reduced with easy phonation, and resulted in an improvement in voice quality (Verdolini-Marston et al., 1995). The second feature is the proprioceptive sensation of resonance, which is the perception of oral vibratory sensations on the anterior alveolar ridge and adjacent maxillary bones. During voice production, the vibrations from the acoustic waves in the oral cavity were picked up by facial bone structures. If the conversion of aerodynamic energy to acoustic energy is effective, vibratory sensation in the facial bone structures would be resulted (Titze, 2001).

In evaluating the efficacy of resonant voice therapy, researchers have used instrumental measurements and performed perceptual judgment. Instrumental measurements of resonant voice reported in the literature include videostroboscopic evaluation of the larynx (Chen, Hsiao, Hsiao, Chung, & Chiang, 2006; Smith, Finnegan, & Karnell, 2005; Verdolini, Druker, & Samawi, 1998; Verdolini-Marston et al., 1995); acoustic measurements of fundamental frequency, jitter, shimmer, and noise to harmonic ratio (Chen et al., 2006; Smith et al., 2005; Titze, 2001; Verdolin-Marston et al., 1995; Yiu & Ho, 2002); aerodynamic measurements which includes maximum phonation time, airflow rate, and phonation threshold pressure (Chen et al., 2006); and electroglottographic measurement of laryngeal muscle activities (Verdolini et al., 1998). Perceptual judgments include perceptual rating of phonatory effort (Verdolini-Marston et al., 1995), auditory perceptual voice quality evaluation (Barrichelo & Behlau, 2007; Chen et al., 2006; Verdolini-Marston et al., 1995; Yiu & Ho, 2002), and self-reported functional voice assessment (Chen et al., 2006). These studies showed generally slightly adducted vocal folds during resonant voice phonation. However, there is a lack of study in the literature on another feature of resonant voice phonation, namely sensation of facial bone vibration.

Currently, individuals receiving resonant voice training rely on feedback provided by clinicians on the extent of resonance they produced, or on the individual's tactile sensation over the skull. Although perceptual judgment of resonant voice is an essential component in resonant voice training, there are few studies that investigated the perceptual rating of resonance in resonant voice. Studies usually involve perceptual rating of the roughness and breathiness of the dysphonic voice, while the resonance parameter was generally not investigated (e.g. Verdolini-Marston. 1995; Yiu & Ho, 2002). There are two studies that involved perceptual evaluation of resonance. In the study by Barrichelo and Behlau (2007), the ability of listeners in identifying resonant voice was investigated. Nine actors participated in the study as speakers with the habitual voice samples before resonant voice training and the post-training resonant voice samples collected. Fiver listeners were asked to differentiate between habitual voice and resonant voice. The results indicated that the judges achieved 74% accuracy in identifying resonant voice. Since the study did not require judgment on the degree of resonance, the listener's reliability in rating resonance could not be determined. In the study reported by Chen et al. (2006), twenty-four teachers with voice disorders were recruited and received resonant voice therapy over eight weeks. Three speech pathologists each with at least five years of experience in voice treatment were recruited as raters. They were asked to perceptually rate the severity of different voice qualities, including resonance, of the participants' voice using a six-point scale, with 0 representing normal and 5 as extremely severe. The results indicated significant reduction in perceptual severity of resonance after therapy. The definition of resonance was not clearly described in the study but it appears to be referring to abnormal resonance severity. The lack of clear definition of the "severity of resonance" makes it difficult to interpret the results. Furthermore, the inter- and intra-judge reliabilities on resonance rating were not reported in this study, making it difficult to determine the reliability of perceptual resonance evaluation *per se*.

As Kreiman and her associates proposed, perceptual voice evaluation requires listeners to compare external stimuli with individual internal standards of vocal qualities (Kreiman, Gerratt, Kempster, Erman, & Berke, 1993). The internal representations among listeners differ from one listener to another related to their prior experience with voices (Kreiman, Gerratt, Precoda, & Berke, 1992). The process of mapping incoming voice signal with internal standards is affected by the memory of the listeners and the acoustic context in which qualitative voice evaluations are made (Kreiman et al., 1993; Kreiman et al., 1992), leading to inter-rater variability in perceptual voice judgment. The provision of anchors as fixed external standards with constant set of perceptual referents was suggested to reduce variability in voice quality rating (Chan & Yiu, 2002; Gerratt, Kreiman, Antonanzas-Barroso, & Berke, 1993; Kreiman et al., 1993). On the other hand, the establishment of quantitative measurement of resonant voice would help to improve the reliability of feedback provision in resonant voice training.

While there is a lack of quantitative measurement of the extent of resonance available in the field of speech language pathology, the purpose of the present project is thus to identify a noninvasive instrumental tool to measure the degree of resonance quantitatively. Piezoelectric accelerometers (see Appendix A for the diagram of the accelerometer) are the vibration sensors that have been used in a variety of industrial application. The miniature DeltaTron® accelerometers are specifically designed for measuring small amount of vibration in small structures. With the high output sensitivity, low mass, and small physical dimensions of the miniature DeltaTron® accelerometer, this industrial technique is applied in this project to detect the vibration in the facial bones caused by resonant voice production.

To investigate the feasibility of the piezoelectric DeltaTron® accelerometer as a noninvasive quantitative measurement studying the degree of resonance, two research questions were asked: i) Whether the increase in bone vibration after resonant voice training is significantly difference between production of nasal and non-nasal stimuli. ii) Whether the extent of facial bone vibration during production of nasal and non-nasal stimuli correlates with the degree of perceptual rating of resonant voice.

Pilot Experiment

Prior to the implementation of the main study, a pilot experiment was designed to determine suitable vibro-detector placement that could yield significantly different vibration detected in resonant voice when compared to at rest.

Method

Participants

Seven females and four males (mean age = 21.9 years, *SD* = 0.94, range = 21-24) with at least one year of tertiary education were recruited. All participants had Cantonese as their first language. They claimed to be medically healthy, have normal hearing, no history of speech or voice disorders, and no prior experience with the use of vibro-detector.

Instrumentations

Vibration detection and recording. Brüel & Kjær's piezoelectric DeltaTron® accelerometer (Type 4507-B-002, Denmark) was applied to measure the vibration in the facial bones detected during resonant voice phonation. Three 1 cm x 1 cm x 1cm vibration detectors were placed stably on the participant's middle forehead, nose bridge, and cheek (see Figure 1). For the forehead site, the vibro-detector was placed 1 cm above the midline of eyebrow. For the nose bridge site, the vibro-detector was placed at the right nasal bone just above the septal cartilage. For the cheek site, the vibro-detector was placed at the maxillary bone, 1 cm next to the left septal cartilage. Vibration detected using piezoelectric accelerometer was amplified with Nexus™ conditioning amplifier (Type 2693, Brüel & Kjær, Denmark). The vibration detected at each site was displayed and recorded for statistical analysis in the computer software Chart (v 5.4.2, Power Lab AD Instruments, Australia).

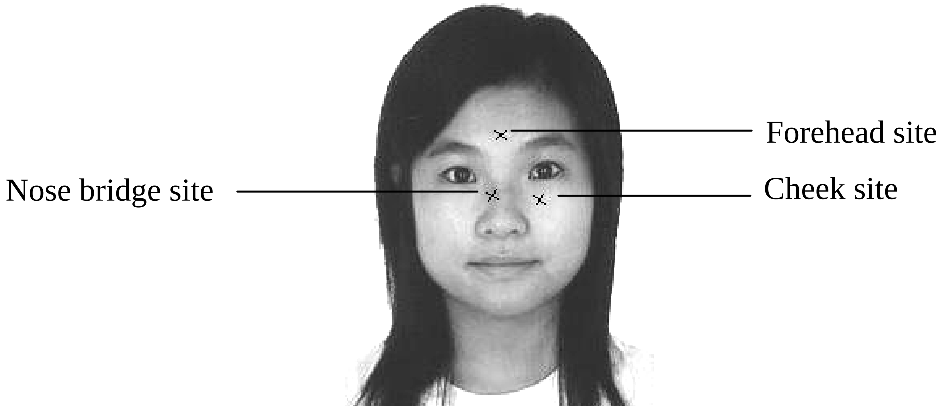

Figure 1. Placement of vibro-detectors at the forehead, nose bridge, and the cheek in pilot experiment

Procedures

Each participant participated in one session that consisted of baseline measurement, resonant voice training, and post-training resonant and strained voice measurement.

Resonant voice training. All participants were trained to use resonant voice after baseline taking. The training involved instruction and demonstration of resonant voice phonation. The training instructions used in this project were based on the resonant voice therapy program developed by Verdolini (2000) and Yiu and Ho (2002). The instructions are indicated in Appendix B. Participants were asked to monitor the feeling of sensory information and concentrate on the auditory feedback. Participants were also taught to have strained phonation. Strained phonation was used as an anchor for participants to compare with the easy phonation of resonant voice. The issue of whether the participants would be able to produce perfect resonance was not important as long as they managed to produce some form of resonant voice in contrast to strained phonation.

Vibration measurement. All data were collected in a sound-treated room with background noise kept below 35 dBA. Participants were seated comfortably at an upright position throughout the experiment. The participants were asked to sustain, at their most comfortable daily conversational pitch and loudness, the humming sound /m/ for 5 seconds. Three sets of voice recording of /m/ were carried out. The first set of recording was carried out before resonant voice training, and was used as a baseline measurement. The second and third sets of recording were carried out after resonant voice training. Participants were required to have resonant phonation for the second set of stimuli, and have strained phonation for the third set of stimuli. Four trials were taken for each set of recording.

Data analysis

Three seconds of vibration measurement without phonation, and the first three seconds of vibration from each of two sets of /m/ (pre-training habitual voice and post-training resonant voice) were extracted manually using a pair of cursors in the Chart program. Root mean square voltage (V_{RMS}) of the vibration (in microvolts) was obtained with Chart for comparison of vibration at rest, in habitual voice and in resonant voice.

Wilcoxon signed ranks test was used to compare the vibration measurement at rest with habitual voice phonation, and with resonant voice phonation at three vibro-detector sites.

Result

Table 1 displays the means and standard deviations of vibration (in microvolts) over the three targeted sites on the sustained /m/ phonation task. The bone vibration in habitual voice phonation was significantly greater than at rest (Z = -2.93, p = .003), and the vibration in resonant voice phonation was significantly greater than at rest (Z = -2.93, p = .003). However, no significant difference in vibration between habitual voice and resonant voice phonation was demonstrated (Z = -.62, p = .53). Further analysis was carried out to compare the vibration at rest and in resonant voice at three sites. When comparing the difference of vibration at rest and in resonant voice at the targeted sites, significant differences between the two conditions were demonstrated at all three sites (Forehead: Z = -2.85, p = .004; Nose bridge: Z = -2.85, p = .004; Cheek: Z = -2.76, p = .006). The mean vibration difference at rest and in resonant voice was greatest at nose bridge, followed by forehead site. The vibration difference at rest and in resonant voice was significant but comparable at cheek site.

Recommendation for the main study

This pilot experiment compared the mean vibration difference at rest and in resonant voice over three targeted sites. The results suggested that the mean differences were significant across the three sites; however, the mean difference at check site was not as great during phonation when compared to that at forehead and nose bridge site.

The cheek site would be replaced by thyroid site in the main study to investigate any changes in vibration at the laryngeal bone in resonant voice and strained voice phonation.

Table 1. Means (and standard deviations) of vibration in microvolts for the sustained phonation of /m/ over three phonatory conditions at three targeted sites

	Forehead		Nose bridge		Cheek	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
At rest	2.36	0.07	2.37	0.21	2.45	0.10
Habitual voice of /m/	4.67	3.68	5.91	4.00	2.86	0.34
Resonant voice of /m/	4.61	3.83	7.52	4.38	3.00	0.54

SD = standard deviation

Main Experiment

Method

Participants

Eighteen females and eighteen males (mean age = 22.67 years, *SD* = 2.78, range = 20-33) were recruited to participate in this study. Equal numbers of male and female participants were recruited to minimize the possible confounding factor of gender. All participants had Cantonese as their first language. They reported to be medically healthy, have normal hearing, no history of speech or voice disorders and no prior experience with the use of vibro-detector. The participants were all selected from the social circle of the author and were recruited based on their willingness to participate.

Instrumentations

Vibration detection. The apparatus used in the main experiment was the same as described in the pilot experiment. The placements of vibro-detectors at forehead and nose bridge were maintained, while the cheek site was replaced by thyroid site. The vibro-detector was placed at the laryngeal prominence of the thyroid cartilage at thyroid site (see Figure 2).

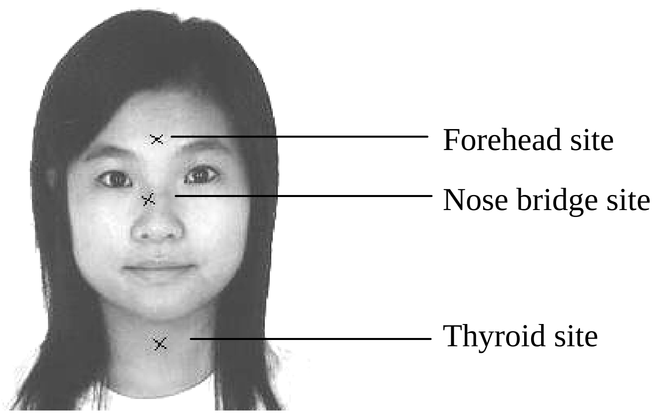

Figure 2. Placement of vibro-detectors at the forehead, nose bridge, and the thyroid in main experiment

Procedures

Vibration measurement and resonant voice training. Each participant participated in one session that covered baseline measurement, resonant voice training, and post-training resonant and strained voice measurement. All measurements were collected in a sound-treated room with background noise kept below 35 dBA. Participants were seated comfortably at an upright position throughout the experiment. The participants were asked to sustain, at their most comfortable daily conversational pitch and loudness, two nasal sounds (/ma/ and /mi/), two non-nasal sounds (/pa/ and /pi/) and a hum /m/ for 4 seconds. Participants were also asked to read one sentence loaded with nasal consonants (nasalized sentence) /ma ma mɔ mao/ (meaning mother touches the cat) and one non-nasalized sentence /pa pa ta pɔ/ (meaning father hits the ball).

Three sets of voice recording of nasal and non-nasal stimuli and sentences were carried out. The first set of recording was carried out before resonant voice training. It was used as a baseline measurement and was named as habitual voice in this study. The second and third set of recordings were carried out after the training session (same training as in the pilot experiment was provided, see Appendix B for instructions of training). Participants were required to phonate with resonant voice for the second set of stimuli, and phonated with strained voice for the third set of stimuli. For each set of recording, four trials were taken for each sound and sentence. Hence a total of 28 voice samples were obtained for each set of recording, and a total of 84 voice samples were obtained from each participant. Among each set of stimuli, the order of stimuli to be produced was counterbalanced among each participant to minimize any potential order effects in the data collection procedure.

Voice recording for perceptual analysis. All the voice samples were recorded for perceptual analysis using Dr Speech version 4 (Tiger DRS Inc.) with a microphone at a

10-cm mouth-to-microphone distance. The Dr Speech Program was also used to monitor the intensity and pitch level of participant's productions during the task, as the waveform of vibration displayed in Chart would be changed with these parameters being altered. Figure 3 and 4 display the vibration of sustained /mi/ in habitual and resonant voice shown in Chart.

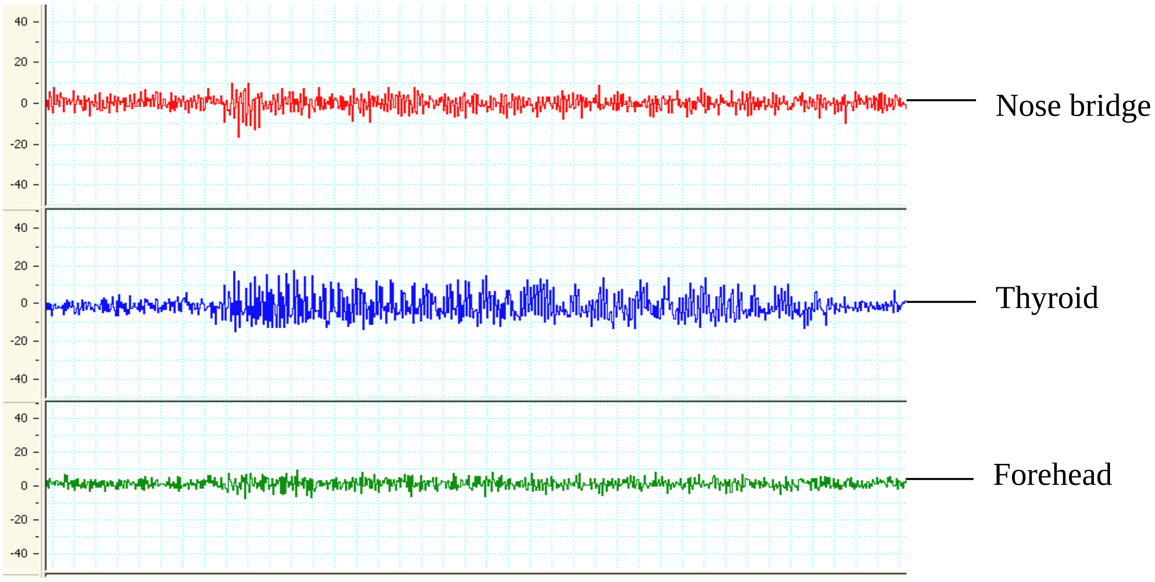

Figure 3. Vibration displayed in Chart in sustained phonation of /mi/ with habitual voice

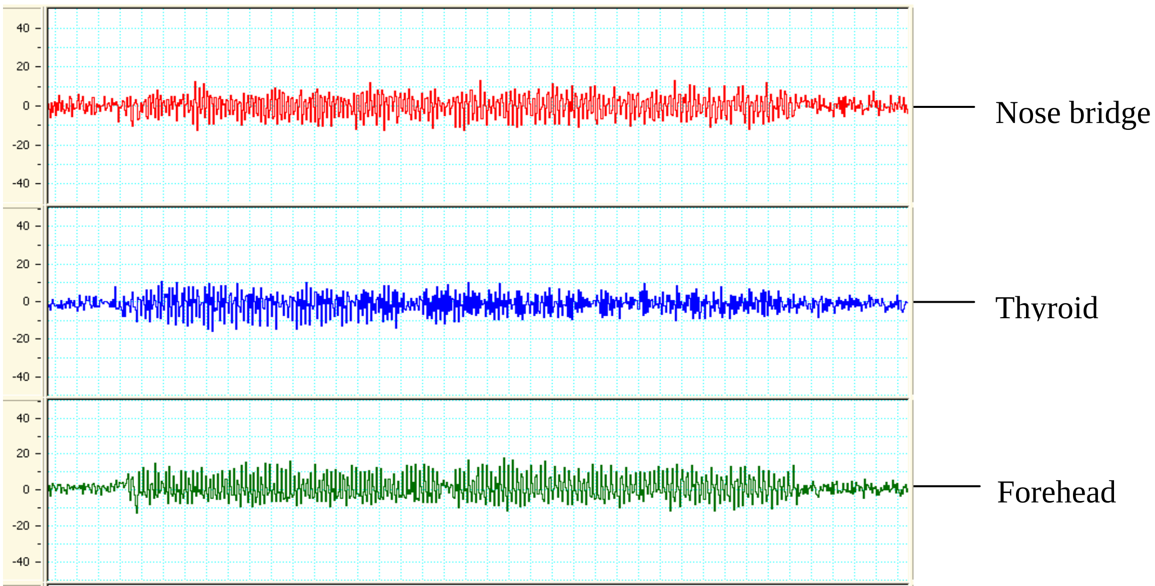

Figure 4. Vibration displayed in Chart in sustained phonation of /mi/ with resonant voice

Perceptual rating of voice samples. Three final-year speech pathology students aged 23 served as listeners for perceptual rating of voice samples. A training program consisted of listening to a set of 36 training stimuli with a range of resonance was presented to the listeners prior to the actual evaluation of experimental stimuli. The training stimuli was obtained from five males and six females speakers selected from the pilot study and the main study group. Only one out of four trials of nasal and non-nasal stimuli was obtained from speakers in the main study group, and these stimuli were excluded in the set of experimental stimuli. The training stimuli were selected to represent three degrees of resonance including minimal (corresponds to the rating of 0-3), moderate (corresponds to the rating of 4-7), and prominent (corresponds to the rating of 8-10) resonance. These stimuli acted as anchors for the listeners in perceptual rating.

Three out of four trials of each habitual and resonant voice of sustained /ma/ and /pa/ were selected randomly for perceptual rating. With a total of 36 participants and four stimuli with three trials each, the experimental stimuli set therefore contained a total of 432 voice recordings. All the stimuli were presented in a random order to the three listeners. The listeners were required to rate the degree of resonance of the voice samples on an 11-point equal-appearing interval (EAI) scale with “0” represented no resonance and “10” represented prominent resonance. The use of EAI scale over visual analogue (VA) scale in this project was supported by the findings from Yiu and Ng (2004), which showed that inexperienced listeners had significantly higher intra-rater agreement in using an 11-point EAI scale than in using a 10 cm-long VA scale, and the inter-rater agreement in using EAI scale and VA scale was similar. Further, an 11-point EAI scale was used as it was more sensitive than the 7-point EAI scale (Yiu & Ng, 2004). The ratings were carried out individually in a sound-treated booth. The raters were allowed to listen to each recording as many times as they required.

To evaluate intra-rater agreement of perceptual rating, 43 voice samples (10% of the 432 experimental voice samples) were randomly selected and presented to the listeners for re-rating after rating the set of experimental stimuli.

Data Analysis

Vibration measurement. Three seconds of vibration from sustained phonation of /ma/, /mi/, /pa/, /pi/, and /m/, and the whole portion of nasal and non-nasal sentence in the three sets of recording were extracted manually using a pair of cursors with the Chart program. Root mean square voltage (V_{RMS}) of the vibration (in microvolts) was obtained using Chart. Repeated ANOVA was used for data analysis, as more than one independent factor was varied for comparison. The independent variables were the phonatory condition (habitual voice, resonant voice, and strained voice), the site of vibro-detectors (forehead, nose bridge, and thyroid), and the nasality of the stimuli (nasal and non-nasal stimuli). The dependent variable was the V_{RMS} of vibration. To investigate the main phonatory condition and nasality effect of stimuli on the extent of resonance, the vibration in phonation of nasal and non-nasal stimuli over three conditions at the forehead and nose bridge site was computed. Vibration at thyroid site was not included because it was not reported in the literature as a site for vibratory sensation of resonance.

Perceptual rating. The mean perceptual rating among three raters was calculated. The type and strength of correlation between mean perceptual rating and V_{RMS} of vibration during production of nasal and non-nasal sounds with habitual and resonant voices was evaluated using Pearson's Correlation Coefficient r. Inter-rater agreement of 432 experimental voice samples, and intra-rater agreement of 43 voice samples (10% of the 432 experimental voice samples), were also determined. Two ratings that were within one point of one another on the EAI scale were considered as agreeing with each other.

Results

Vibration measurement

Main nasality, phonatory condition, and site effects. Table 2 presents the means and standard deviations of vibration (in microvolts) during habitual voice, resonant voice, and strained voice phonation with nasal stimuli (/m/, /ma/, /mi/ and nasal sentence) and non-nasal stimuli (/pa/, /pi/, and oral sentence) at forehead, nose bridge, and thyroid sites. The results demonstrated significant main nasality effect with greater vibration with the nasal stimuli than with the non-nasal stimuli (F = 28.56, df = 1, p < .0001) .The main effects of phonatory condition and site of vibro-detectors were all significant. (Main Phonatory Condition effect:

$F = 15.27$, $df = 2.00$, $p < .001$; Main Site effect: $F = 6.57$, $df = 1.79$, $p = .004$).

Table 2. Means (and standard deviations) of vibration in microvolts during phonation of nasal and non-nasal stimuli over three phonatory conditions at three targeted sites

	Nasal stimuli			Non-nasal stimuli		
	Forehead	Nose bridge	Thyroid	Forehead	Nose bridge	Thyroid
Habitual voice	3.36 (2.70)	4.13 (1.58)	4.74 (1.65)	2.87 (0.70)	2.80 (0.47)	4.25 (1.19)
Resonant voice	3.55 (2.34)	5.72 (2.92)	4.88 (1.71)	3.25 (1.92)	3.88 (1.50)	4.46 (1.22)
Strained voice	3.70 (3.36)	4.89 (2.48)	4.63 (1.64)	3.28 (1.96)	3.51 (1.08)	4.38 (1.50)

Interaction effects of nasality, phonatory condition, and site. Significant interaction effect of site and nasality ($F = 15.68$, $df = 2.00$, $p < .0001$), and significant interaction effect of site and phonatory condition ($F = 5.78$, $df = 2.00$, $p = .001$) were demonstrated. However, no significance interaction effect in the phonatory condition and nasality ($F = .437$, $df = 1$, $p = .609$) (see Figure 5) was found nor in the interaction effect of condition, site, and nasality ($F = 1.78$, $df = 3.60$, $p = .181$).

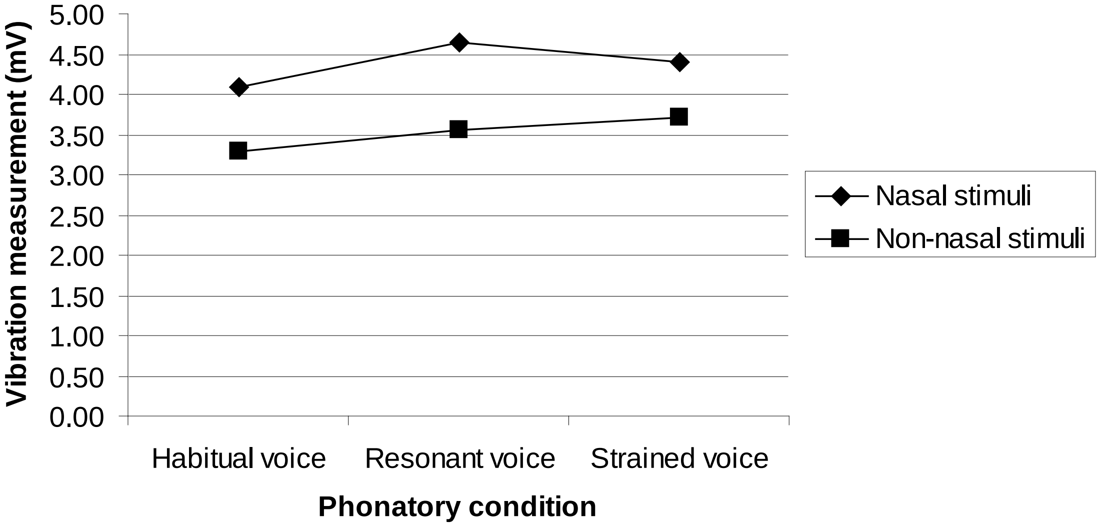

Figure 5. Vibration measurement in production of nasal and non-nasal stimuli across three phonatory conditions

Post-hoc analysis. Post-hoc analysis was carried out to further investigate the significant main phonatory condition and site effect. Analysis showed significant greater vibration in resonant voice than in habitual voice (F = 20.11, df = 1, p < .0001), and significant greater vibration in strained voice than in habitual voice (F = 7.85, df = 1, p = .008). The difference in vibration between resonant voice and strained voice was not significant (F = 2.82, df = 1, p = .102). Further, analysis indicated significant greater vibration in nose bridge than in forehead site (F = 6.49, df = 1, p = .015), and significant greater vibration in thyroid than in forehead site (F = 9.02, df = 1, p = .005). The difference in vibration between nose bridge and thyroid site was not significant. (F = 1.91, df = 1, p = .177).

Perceptual rating

The inter- and intra-rater agreement measures are listed in Table 3 and Table 4. The inter-rater agreement was moderate, and the intra-rater agreement was moderate to high.

Table 3. Percentage of inter-rater agreement within 1 point on the equal-appearing interval (EAI) scale

Raters	Inter-rater agreement (%)
1 and 2	46.3%
2 and 3	41.7%
1 and 3	40.3%

Table 4. Percentage of intra-rater agreement within 1 point on the equal-appearing interval (EAI) scale

Rater	Intra-rater agreement (%)
1	95.4%
2	83.7%
3	76.7%

The correlations between perceptual rating and vibration measurement during production of nasal and non-nasal stimuli with habitual and resonant voices are shown in Table 5. The mean perceptual ratings of the three raters showed a significant but low correlation with vibration values, as measured by piezoelectric DeltaTron® accelerometer. The individual correlation of perceptual rating of three raters with the vibration measurement ranged from .092 (p = .056) to .359 (p < .0001) (see Table 5). Further evaluation was implemented to compare the strength of correlation between vibration and perceptual rating of habitual voice and resonant voice separately. Significant and similar strength of correlation was obtained in habitual voice (N = 216, r = .372, p < .0001) and resonant voice (N = 216, r = .336, p < .0001).

Table 5. Correlation of mean perceptual rating and individual ratings from three raters with vibration measurement in habitual and resonant voice

	N	*r*	*p*
Mean rating	432	.389	< .0001*
Rater 1	432	.092	.056
Rater 2	432	.359	< .0001*
Rater 3	432	.300	< .0001*

N = number of habitual and resonant voice samples for perceptual rating
r = Pearson's Correlation Coefficient *r*
*significant at 0.01 level (2-tailed)

Discussion

Bone vibration during phonation was quantified and measured with piezoelectric accelerometer in the present study. Participants demonstrated acquisition of resonant voice with significantly greater vibration measured at the forehead and nose bridge using resonant voice than habitual voice. The results of the present study showed the following findings:

(1) no significant difference in the increase in bone vibration after resonant voice training between production of nasal and non-nasal stimuli

(2) vibration in resonant voice was not significantly different from that in strained voice

(3) the perceptual rating had low correlation with vibration values

Effect of nasality of treatment stimuli on acquisition of resonant voice

In resonant voice training, individuals are asked to produce the natural “um-hum” or the nasal sound /m/ with their lips closed in a relaxed manner, as these sounds are generally assumed to facilitate the acquisition of resonant voice (Boone et al., 2005). Greater vibratory sensation in phonation of nasal stimuli than non-nasal stimuli was accounted by greater acoustic pressure in nasal cavity than the vocal tract during phonation (Titze, 2001). The present study indicated greater vibration measured across three phonatory conditions with nasal stimuli than non-nasal stimuli. However, it was shown in the current study that the bone vibration increased in similar extent after resonant voice training with the production of nasal and non-nasal stimuli. The notion of nasal stimuli being facilitative in resonant voice acquisition was thus not supported in this study.

Proprioceptive sensation of resonance on acquisition of resonant voice

Resonant voice training emphasizes the importance of proprioceptive sensation of resonance (Verdolini, 1998). Individuals are encouraged to feel the vibration with their fingers at the nose bridge in the initial phase of training. This study demonstrated that the vibration measured during resonant voice and strained voice phonations was not significantly different. Hence, the extent of vibration an individual can feel in the skull may not be a good indicator of resonant voice. It can be interpreted that with resonant voice training emphasizes only on proprioceptive sensation of resonance, individuals might acquire the mislearnt behavior of effortful phonation in contrast with the easy phonation in resonant voice. It is therefore suggested that the vibratory sensation of the maxillary bone and the slightly adducted vocal folds in easy phonation should both be emphasized in resonant voice training.

Provision of visual feedback in resonant training

Current training of resonant voice relies on clinician's perceptual judgment and feedback on individual's voice. Individuals are required to listen to the auditory feedbacks and have self-monitoring of their voice use. The present study demonstrated a significant but low correlation between perceptual rating and vibration measurement, showing that the perceptual voice evaluation would not be a good indicator of whether an individual has acquired resonant voice. Provision of visual feedback in resonant voice training is therefore warranted. Individuals could be asked to follow a model and practice on the use of resonant voice, then look at the computer screen showing the extent of vibration as visual feedback to monitor their voice use. Nevertheless, the effect of visual feedback provision was not studied in the present study. Participants were asked to monitor their voice use with auditory feedback and proprioceptive feedback only, while no visual feedback was provided during resonant voice training. Further study on comparing the effects of provision of the two types of feedback, namely auditory feedback and visual feedback, in individual's voice quality, bone vibration, and vocal folds adduction during resonant voice training is necessary.

Reliability of perceptual rating

Even significant correlation between perceptual rating and vibration measurement was demonstrated, the strength of correlation was however small. This could be related to rater's experience in perceptual evaluation. It has been suggested that individuals develop internal standards for different vocal qualities through their previous exposure to voices (Kreiman et al., 1993; Kreiman et al., 1992). Nevertheless, these internal standards differ from one individual to another in terms of how specific the vocal qualities exist in their mental representation (Kreiman et al., 1993). This accounts for a low inter-rater agreement in the perceptual rating of inexperienced individuals, as individuals has to compare the voice stimuli to own internal standard when rating voice samples.

The use of external anchors in perceptual voice evaluation has been suggested to improve inter-rater reliability (Chan & Yiu, 2002; Gerratt et al., 1993; Kreiman et al., 1993). The present study provided external anchors for raters in perceptual rating of degree of resonance, which should yield higher inter-rater agreement in perceptual rating when compared to an unanchored paradigm which raters have to make judgment based on own criteria. However, the inter-rater agreement of this study was only moderate. It might be possible that there were only three anchor points (minimal, moderate and prominent resonance) provided on the 11-point rating scale, extrapolation from anchors was needed in ratings that were not covered by anchors (Yiu, Chan, & Mok, 2007). To improve inter-rater reliability, future studies on perceptual rating of resonance could adopt paired comparison paradigm which anchors are provided to match with each point on the rating scale (Yiu et al., 2007).

Limitations of the present study

Some cautions are warranted in interpreting the results of the current study.

Firstly, the resonant voice training provided in this study was only a brief one that took around 30 minutes. The participants were trained to produce monosyllabic sounds and sentences within the same session, which was different from what suggested in other resonant voice trainings that training at another level should be proceeded after the individual can successfully phonate with resonant voice at the previous level (Boone et al, 2003, Verdolini, 1998; Verdolini, 2000). Further studies could involve more than one session of resonant voice training, and the participants' vibro-measurements across sessions could be compared to demonstrate the effectiveness of resonant voice training.

Secondly, in order to reduce the fatigue effect of strained phonation, all participants were asked to have a block of resonant voice phonation before strained voice phonation in this study. The practice effect of resonant voice training was therefore not counterbalanced among participants. It would be possible that the increase in bone vibration in strained voice reflected practice effect of resonant voice training, rather than the hypothesized result of effortful phonation. It has been suggested that easy phonation facilitates tension reduction in the supralaryngeal areas and in the extrinsic laryngeal muscles (Harris, Harris, Rubin, & Howard, 1998), while strained phonation results in increase tension in laryngeal muscles. Further studies on comparing vibration in resonant voice and strained voice, with the use of surface electromyography in monitoring laryngeal muscle tension, are needed.

Thirdly, the study was a preliminary one that did not include a dysphonic group. Further studies on the use of vibration measurement in dysphonic group are necessary to conclude if vibro-measurement is applicable in this population.

Conclusion

The present study supported the use of noninvasive quantitative measurement of vibration in resonant voice in speakers with normal voice. It was however not demonstrated that acquisition of resonant voice would be facilitated with nasal stimuli. Further studies would be needed to determine whether the vibration measurement is applicable in dysphonic population, and the effectiveness of visual feedback provision in resonant voice training.

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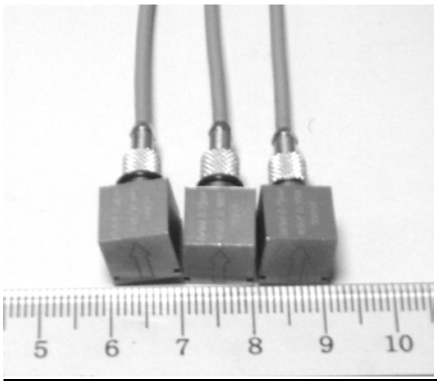
Appendix A

Diagram showing the piezoelectric accelerometer (1 cm x 1 cm x 1 cm in size)



Appendix B

Instructions of resonant voice training (Yiu & Ho, 2002)

1) The participant is reminded to sit at a relaxed manner throughout the training.
2) Say "uh-um" or a hum /m/ softly as in acknowledgement of someone asking a question. The hum has to be produced in a relaxed manner. Demonstration will be provided by the trainer.
3) Glide /m/ up and down a musical scale to find a pitch that resulted in maximum resonance/vibration without straining of laryngeal muscles. The located pitch will then be used as the note for further humming. Demonstration will be provided by the trainer.
4) Put a finger on the nose bridge to feel the vibration. The kinesthetic feedback of tingling sensation around the lip area is also explained.
5) Listen to the voice quality of hum with comments on the performance given by the trainer.

Feedback related to the participant's gentle onset, resonance, and comfortable amplitude and pitch level is provided.

6) Hum at a comfortable pitch in a relaxed manner and add a sustained vowel to the end of the /m/. Smooth transition from the sound /m/ to /a/ is emphasized. Demonstration will be provided by the trainer.
7) Listen to the voice quality of /ma/ with comments on the performance given by the trainer.
8) Hum at a comfortable pitch in a relaxed manner and produce the disyllabic word /ma ma/ (meaning mother), and gradually increased word length to produce the sentence /ma ma mɔ mao/ (meaning mother touches the cat).
9) Listen to the voice quality of disyllabic word /ma ma/ and nasal sentence /ma ma mɔ mao/ with comments on the performance given by the trainer.
10) Procedure 2 to 9 is repeated for the production of non-nasal stimuli /p/.