Vibrational Therapies for Vocal Fatigue

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Summary: Background. Vibration is commonly used to relax tension in the limb and truck muscle. Vibration used directly on the muscle concerned and vertical vibration used on the whole-body through a foot platform have been reported in the literature to be useful to release muscle tension.

Aim. The present study investigated the effect of indirect whole-body vibration (WBV) and direct localized perilaryngeal vibration (LPV) on the phonatory functions of nondysphonic individuals with vocal fatigue.

Methods. Forty-four subjects (mean age = 21.67 years) with normal voice, were randomly assigned to either the WBV group, the LPV group, or the Control (sham hand-held vibratory device) group. They performed karaoke singing for at least 95 minutes. They then received either WBV through a Turbosonic vibratory machine, LPV with a Novofan vibrator, or a sham vibrator for 10 minutes. The highest pitch produced, and self-reported vocal fatigue score were taken before singing, after singing, and after the intervention. Data were analyzed separately for the gender subgroups.

Results. All subject groups showed significant reduction of vocal function (highest pitch production, and vocal fatigue score) after singing. Following the vibrational interventions, both the WBV and LPV groups showed significantly recovery in the highest pitch production and the perception of vocal fatigue ($P < 0.002$) than the Control groups.

Conclusion. Vibrational therapy, whether it is localized vibration on the peri-laryngeal muscles, or whole-body vibration, is more effective than voice rest *per se* in relieving vocal fatigue. Vibrational methods are recommended for treating vocal fatigue.

Key Words: Whole-body vibration−Localized vibration−Voice therapy−Dysphonia.

IMPACT OF VOCAL FATIGUE

Vocal fatigue is frequently experienced by professional voice users, like teachers,[1,2] performing artists,[3,4] and telemarketers.[5] It is a reduction in the vocal function that occurs following prolonged voice use.[6] People with vocal fatigue often report an “increased sense of vocal effort with prolonged voice use.”[7] Commonly reported vocal fatigue symptoms include sense of discomfort (soreness, pain, and tightness) in the laryngeal area,[7] increased voicing effort,[8] difficulty in voice projection,[6] reduced pitch range, and deterioration in voice quality or hoarseness.[7,9,10] Furthermore, it is common that such changes are not easily noticed or detected by other listeners or instrumental measures[7,10] since vocal fatigue is a subjective percept and is not easily identified or quantifiable. However, such fatigue can be severe enough to result in reduced work attendance,[11] job dissatisfaction[12] and stress or anxiety.[13]

PHYSIOLOGY OF VOCAL FATIGUE

Physiological changes associated with vocal fatigue has been postulated to be related to excessive thyrohyoid muscle tension,[14] and extra-/perilaryngeal muscle tension during prolonged phonation.[7,13] Mechanical stress on the mucosal membrane of the vocal folds during phonation is also postulated to be another cause of vocal fatigue.[13] Prolonged exposure to such mechanical stress could lead to deformation and structural damage in the laryngeal mucosa and contributes to the development of vocal fatigue.[13,15] Change in the tissue viscosity following prolonged phonation reduces the lubricating and shock-absorbing functions of the vocal folds, which has been contended as another contributing factor to vocal fatigue.[7,16−19] It has also been shown that increased muscular activities causes blood vessel constriction that leads to a reduction in blood circulation.[20] Whether this applies to the intrinsic muscles of the larynx or not is still unclear, but it has been hypothesized that blood vessel constriction would reduce the efficiency of oxygen supply to the muscles and lactic acid waste removal from the muscles.[6]

VIBRATIONAL EXERCISES AS A TREATMENT FOR VOCAL FATIGUE

Localized vibration on the throat area is one form of vocal fatigue relief technique used by some singers and performers (eg, the Vibrant Voice Program promoted by Ley[21]). Ley[21] contended that the use of a hand-held vibrator on the neck reduces muscle tension that causes vocal fatigue. Kosztyła-Hojna et al[22] reported the use of a CyberBioMed LLC vibration massager (Palm Beach, FL), together with pharmacotherapy, benefited more postradiotherapy (laryngeal cancer) participants with hyperfunctional dysphonia. The reported data, however, lack details and prevent in-depth interpretation.

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In a more recent study, the immediate effect of localized vibration (SIRI; Lelo) (50-Hz setting) on five groups of head and neck muscle (masseter, suboccipital, sternocleidomastoid, submental/submandibular, and paralaryngeal areas) was found to significantly reduced phonatory effort in a group of trained singers (N = 14), compared to a control group (N = 12) who received a sham intervention.[23] In another study (N = 11) by Barsties v. Latoszek,[24] the effect of a 5-week behavioral voice therapy with localized vibration using a Novafon vibrator at 100 Hz (Novafon GmbH, Weinstadt, Germany) was reported[24] to be effective in improving Acoustic Voice Quality Index,[25] Dysphonic Severity Index,[26] and Voice Handicap Index[27] in dysphonic subjects. Barsties v. Latoszek[28] also reported another study which compared the effect of voice therapy with or without localized vibration (N = 11) on voice production with two groups of dysphonic individuals. Large treatment effects were also demonstrated in narrowband spectrogram measures and Dysphonic Severity Index. Therefore, these studies point to the potential benefit of combination of localized vibration and voicing exercise in improving phonation.

Vibration, defined as mechanical oscillatory action,[29] can either facilitate or inhibit muscle activity when applied externally to a muscle or its tendon.[30,31] High-frequency vibration (100−300 Hz) is known to evoke tonic response like muscle contraction[30−32]; while lower frequency vibration (20−50 Hz) inhibits muscle activity and facilitates release of muscle tension.[30,31,33,34] Hence, release of vocal fatigue associated extralaryngeal muscle tension, particularly that of the thyrohyoid, is possible with the use of external vibration on the muscles. Current knowledge on the inhibitory or facilitatory effect of localized vibration is based on studies on limb muscles.[30,31,35] Studies based on laryngeal and perilaryngeal musculature are still scarce.

Another form of facilitatory exercise for voice production commonly employed by performing artists is the enhancement of whole-body relaxation or elasticity to release their muscle tension. The concept of maximizing body elasticity has indeed been used in voice therapy to improve voice production.[36,37] Our research team hypothesizes that the use of an external vibratory device could enhance whole-body elasticity to relieve symptoms of vocal fatigue and promote better voice production. Whole-body vibration (WBV), which involves a mechanical vertical oscillation delivered by a vibrating platform to the body, has been used widely in physiotherapy and sports training.[29] WBV has been found to strengthen muscles,[38−40] reduce muscle tightness and fatigue,[41] and reduce pain in muscles.[42] However, there is little information on what the relationship between the vibrating frequency, intensity and the body type, like height, weight or body mass index (BMI), of the individual undergoing whole-body vibration.

METHODOLOGICAL ISSUES IN STUDYING VOCAL FATIGUE

Measurement of vocal fatigue

The threshold (identification) and quantification of fatigue level are two of the challenges that researchers have to deal with in studying vocal fatigue. As the definition of vocal fatigue relies on the self-perception of the speaker,[7] self-perception rating has been used as a means in identifying and tracking vocal fatigue. The Vocal Fatigue Index (VFI)[10] is the only validated self-report questionnaire on vocal fatigue to date. The VFI consisted of 19 statements covering three areas of key symptoms of vocal fatigue: (1) tiredness of voice and avoiding voice use (2) physical discomfort, and (3) improvement of symptoms with rest. Users rate each statement according to their perception. The index reliably identifies vocal fatigue and estimate its severity.[10] The VFI, does not, however, assess instantaneous vocal fatigue perceived at a particular time. It takes into consideration about individuals' report whether there is relief of symptoms following rest.

Strobo-laryngoscopic image appearance is another subjective measurement of vocal fatigue that has also been used to study vocal fatigue. However, this method has failed to provide a reliable indicator of vocal fatigue. Presence of atypical glottal configurations, like anterior glottal chink or a spindle-shaped glotti[17,43] have been reported in individuals with vocal fatigue, but others did not find any changes in laryngeal appearance[44,45] following vocal fatigue.

Identification of objective measures in identifying or quantifying vocal fatigue has also been controversial. Attempts to find the acoustic correlates (eg, jitter and shimmer) of vocal fatigue have been unsuccessful.[45−47] Contradictory findings with regard to the use of phonatory range, especially in the frequency domain, in detecting vocal fatigue have been reported.[43] Stemple et al[43] found the pitches (comfortable, highest, and lowest) in sustained vowels produced by nondysphonic speakers were not different before and after vocal fatigue while another study by Yiu and Chan[8] found a significant reduction in the highest pitch after vocal fatigue in their nondysphonic speakers. The discrepancy in the findings between these two studies could have been attributed to the different tasks and methodology used. Yiu and Chan[8] employed a full voice range profile assessment whereas Stemple et al[43] simply asked the participants to glide from a midrange pitch to their highest or lowest pitches in a continuous breath. A recent study reported that repeated trial practices and coaching as critical factors in producing maximum frequency range.[48]

In summary, while self-perceptual rating stands as a valid tool in quantifying vocal fatigue, production of pitch range may be a useful measure for quantifying vocal function as long as the assessment ensures that the participants are coached to produce their maximum capability.

Induction of vocal fatigue

Another challenge in studying vocal fatigue is how to induce the condition. Research studies have utilized different types of vocal-loading tasks to induce vocal fatigue for their investigation. Prolonged and loud phonation are the main factors leading to vocal fatigue,[49] hence, prolonged reading task has been commonly used in a number of studies.[49−52] This task usually involves continuous oral reading for up to 2 hours and often required individuals to read at a designated high intensity, ranging from 70 to 85 dB.[49,51] Another vocal-fatigue inducing method involves using vocally-demanding tasks that are part of daily activities, such as class-room teaching by teachers.[53,54] A third vocal-fatigue inducing method is continuous singing task.[8,55] Yiu et al[55] asked their participants to perform Karaoke singing continuously for at least 95 minutes without vocal rest or hydration. Karaoke singing is a popular leisure activity among the young population, which they sing through an amplifier with background music.[8] This method was adopted in the present study since Karaoke is a popular activity among the people in many places and vocal fatigue is a common phenomenon experienced by Karaoke singers. Karaoke singing task satisfies the prolonged duration and loud phonation principle in inducing vocal fatigue. Furthermore, using a singing task for studying fatiguing voice is clinically important as the task simulates a common leisure activity in young people. Hence, this is ecologically more valid when compared to extended reading aloud task, which is not a common activity. This could reflect the fatigue situation in a more functional way compared to oral reading task.

The objective of this study was to determine if vibrational therapy can effectively improve vocal fatigue in nondysphonic young adults immediately. Both the whole-body vibration and localized perilaryngeal vibration were included in the present study.

METHODS

Research Ethics Approvals were granted by Ethics Committee, Faculty of Education, The University of Hong Kong (U3035058812-16-12-2016 and U3505546-09-01-2017). All participants were given the objectives and procedures of the study and were given opportunities to ask question prior to the start of the study. Informed consent was signed by all participants.

Participants

A total of 44 young adults (24 males, 20 females) aged between 19 and 25 years (mean age = 21.9 years SD = 1.68 years) participated in this study. The participants: (1) had normal voice quality on the day of assessment and also for the previous 3 months as reported; (2) had no prior experience with vocal training; (3) had no medical conditions or taking medication that might affect voice production, such as respiratory or psychiatric conditions; (4) were nonsmokers and (5) nondrinkers. Adults over the age of 40 years were excluded to prevent possible inclusion of individuals with presbylarynges.

Procedures

Vocal fatigue induction

Karaoke singing was employed to induce vocal fatigue. The Karaoke took place in a quiet sound booth with a karaoke microphone system (Tuxun K068, Guangzhou, China) connected to an Apple iPad mini 2 using Bluetooth. "*Tianlai K Songs*" (Tianlai 4.5.0, Beijing, China) App was used to provide background karaoke music for the singing. In two previous studies, it has been found that a mean of 85.48[8] to 103.8 minutes[55] of continuous karaoke singing would induce vocal fatigue in vocally healthy individuals. Two participants were asked to sing together continuously at the same time. They were instructed to sing at least for 95 minutes until they reported they could not sing anymore. After that, they were further asked to sing one more song, which was at least 3 minutes long. This ensured they had reached the threshold of vocal fatigue. Throughout the singing, no water was allowed. All but one participant were capable to sing beyond 95 minutes. The mean singing time was 107.6 minutes (SD = 8.49 minutes; range = 95−128 minutes).

Interventions

Following the karaoke singing, participants were randomly assigned to one of the three groups: (1) 10-minute whole-body vibration (WBV group, N = 15, seven females, eight males), (2) 10-minute localized perilaryngeal vibration (LPV group, N = 14; eight females, six males), and (3) 10-minute control group (Control group, N = 15, nine females, six males) using a placebo hand-held device. All the participants were told that the intervention they received might reduce their vocal fatigue.

WBV. Each participant received 10 minutes of WBV by standing on the platform of the machine (TurboSonic Ovation, OR; Figure 1A). The vibrational frequency for each participant was determined before the start of the study by noting the frequency which produced the largest vibrational sensation on the individual's neck using frequencies from 8 to 15 Hz in a 0.5-Hz step. The mean vibrational frequency which produced the largest neck vibrational sensation was 10.8 Hz (SD = 0.62 Hz, range 10−11.5 Hz). A vibration amplitude of 25%, which was equivalent to a 1 mm of vertical displacement of the vibrational platform, was used. The dosage of 10-minute vibration was determined by reviewing the literature on WBV usage. Ten minutes has been reported to bring about positive effects to muscles[29]; while prolonged vibration (over 30 minutes) caused more fatigue.[56] The participants were asked not to talk throughout the 10-minute intervention. The height and weight of this group of participants were recorded to determine if the vibrational frequency causing greatest sensation at the neck region was correlated with them or not.

FIGURE 1. Devices used in the study A. Turbosonic whole body vibration machine, B. Novafon vibrator, C. Sham vibration device.

LPV. The Novafon Pro electric vibrational massager (Novafon GmbH, Weinstadt, Germany; Figure 1B) was used to provide vibration at 50 Hz for 10 minutes. The manual pressure applied to the neck, which was between 0.8 and 1.5 newton as measured by a digital force gauge (San Liang Digital Force Gauge, Model SL50, Shanghai, China), was first demonstrated by the examiner before the study. The participant was then asked to use similar amount of force as the examiner's demonstration for the subsequent 10 minutes of vibration on the following neck areas: (1) slowly gliding the vibrator from the lower rim of the mandible along the perilaryngeal muscles to the tip of the left and right clavicle respectively on either side of the larynx for 10 times in total, (2) hold the vibrator at one side of the thyroid lamina for one minute; repeat on the other side, (3) repeat the exercises for 10 minutes. The movement patterns were designed to apply external vibration to the perilaryngeal muscles susceptible to the building up of excessive muscle tension during vocal fatigue. The participants were asked not to talk throughout the 10-minute therapy.

Voice rest using a sham hand-held device (Control). The control group was given a hand-held vibrational device (Panasonic electric toothbrush, model EW DM81 with a tailor-made flat-shape head (Figure 1C) placed on the laryngeal area for 10 minutes. The participants were instructed to alternate the placement of the device head between the left and right side of the thyroid lamina every other minute. The participants were told that the device would emit ultrasonic pulses and relax the laryngeal muscles while in reality the device was never powered on. Therefore, this procedure was merely a vocal rest condition. The participants were asked not to talk throughout the 10-minute period.

Outcome measures

Two primary outcome measures were used: (1) vocal function test, measured as the highest pitch (Hi-F0) produced; and (2) self-rating of vocal fatigue at the time of study using a Vocal Fatigue Score (VFS) with selected items from the VFI.[10] In the vocal function test, the participants undertook a glissando task[57] by gliding an /a/ from C4 (261.6 Hz) to the highest pitch three time. The productions were captured by the Swell real-time DSP Phonetograph Version 2.0 (Phog 2.0, AB Nyvalla DSP, Stockholm, Sweden) with a head-mounted microphone (AKG Acoustics C420, Vienna, Austria) calibrated with a microphone-to-mouth distance of 5 cm. The Phog 2.0 registered a phonation with a minimum duration of 25 ms. In each trial, verbal encouragement and upward hand-sweeping gesture was used (by examiners CL and CC) to encourage the participant to produce the highest possible pitch.[48] To ensure the highest pitch was reached, after the participant produced the highest pitch, each participant was asked to imitate a note (presented with a keyboard) which was two semitones above his/her highest pitch just produced. If a higher pitch was produced, it would be recorded as the highest pitch for that trial. The highest pitch among the three trials was noted for the final analysis. The self-rating of vocal fatigue was based on a four-item questionnaire (Appendix) adopted from the Vocal Fatigue Index[10] using a 10-point rating scale (1- no feeling of the symptom; 10-very strong feeling of the symptom). These four items pertained to the participants' perception of their fatigue level at the time of the study. A 10-point scale was used as the investigators would like to determine their perception with a finer scale. These two outcome measures were collected first before (pre-singing), and after karaoke singing (post-singing), and then after the vibrational or control intervention (post-intervention). Each round of measurement took approximately 15 minutes and the vocal function test was always taken before the self-rating of vocal fatigue.

Data analysis

Analyses were carried out separately for the male and female gender subgroups in each experimental group. Since the sample size for each gender subgroup was small, normal distribution of the data could not be assumed, nonparametric statistics was used in the analyses. The changes between pre-singing baseline measurements and post-singing measurement (i.e., changes due to fatigue) were used in the analyses to determine how the singing task reduced vocal function (Hi-F0) and increased perception of vocal fatigue (VFS). The changes between post-singing measurement and post-intervention measurement (i.e., Intervention Change) signified the effect of the intervention in restoring vocal function (Hi-F0) and vocal fatigue perception (VFS). Bonferroni adjustment for each gender subgroup (0.05/3 = 0.0166) was used for repeated pairwise comparison.

RESULTS

The mean ages of the males and female subgroups in each of the experimental group were between 20.42 and 22.84 years (Table 1). The three subgroups of males across the three experimental groups were not significant different in their age (Kruskal Wallis chi square = 2.21, df = 2, $P = 0.35$). Neither were the female subgroups (Kruskal Wallis chi square = 6.12, df = 2, $P = 0.05$).

Table 1 shows the mean Hi-F0 and VFS in each subject group and Table 2 shows the changes after the singing and intervention conditions. Figures 2 and 3 show the distribution and outliers of the changes in Hi-F0 and VFS in each subject group. The details will be described in the following sections.

In order to determine whether the participants all had similar phonatory abilities in producing Hi-F0 and similar degree

TABLE 1.
Mean (SD) Age, Highest Fundamental Frequency (Hi-F0) Produced and Vocal Fatigue Score (VFS)

		Whole-body vibration		Control		Localized perilaryngeal vibration	
		Female (N = 7)	Male (N = 8)	Female (N = 9)	Male (N = 6)	Female (N = 8)	Male (N = 6)
Age (SD) (years)		20.42 (1.39)	21.63 (1.99)	21.89 (1.45)	22.84 (0.75)	22.50 (1.69)	22.33 (1.86)
Mean (SD) Hi-F0 (Hz)	Presinging	1461.03 (254.42)	898.79 (186.59)	1373.07 (195.32)	893.85 (211.09)	1541.15 (390.72)	951.87 (57.55)
	Postsinging	1278.39 (266.28)	801.49 (202.09)	1137.46 (196.02)	745.57 (206.29)	1334.24 (352.17)	841.27 (75.33)
	Z (1-tailed p)	−2.38 (0.008)*	−2.52 (0.004)*	−2.53 (0.004)*	−2.20 (0.016)*	−2.37 (0.008)*	−2.21 (0.016)*
	Postintervention	1418.97 (280.87)	848.84 (207.97)	1183.93 (212.51)	762.5 (205.84)	1497.32 (431.32)	943.15 (64.63)
	Z (1-tailed p)	−2.37 (0.008)†	−1.57 (0.008)†	−1.35 (0.1)	−1.07 (0.25)	−2.37 (0.008)†	−2.2 (0.016)†
Mean (SD) VFS	Presinging	10.43 (5.29)	12.87 (5.36)	10.56 (7.13)	12.33 (5.75)	13 (6.55)	12.83 (5.67)
	Postsinging	25.71 (5.34)	30.75 (6.27)	24.44 (7.78)	27.17 (7.71)	26.0 (5.26)	24.5 (3.51)
	Z (1-tailed p)	−2.39 (0.008)*	−2.53 (0.004)*	−2.67 (0.002)*	−2.02 (0.03)	−2.52 (0.004)*	−2.20 (0.016)*
	Postintervention	17.71 (6.07)	21.13 (6.03)	22.0 (8.59)	26.33 (7.92)	16.75 (5.31)	17.17 (4.26)
	Z (1-tailed p)	−2.37 (0.008)†	−2.53 (0.004)†	−2.55 (0.004)†	−1.89 (0.06)	−2.52 (0.004)†	−2.2 (0.016)†

* Wilcoxon Signed Ranks Test: significant difference between pre- and post-singing
† Wilcoxon Signed Ranks Test: significant difference between post-singing and post-intervention
SD- standard deviation

TABLE 2.
Mean Change in Highest Fundamental Frequency (Hi-F0) and Vocal Fatigue Score (VFS)

		Whole-body vibration group		Control group		Localized perilaryngeal vibration Group	
		Female (N = 7)	Male (N = 8)	Female (N = 9)	Male (N = 6)	Female (N = 8)	Male (N = 6)
Mean (SD) Hi-F0 (Hz)	Postsinging changes	−182.64 (67.72)	−97.31 (44.13)	−235.61 (116.09)	−148.28 (100.84)	−206.91 (153.27)	−110.6 (57.8)
	Postintervention changes	140.58 (62.82)	47.35 (68.55)	46.48 (118.41)	16.93 (44.41)	163.09 (116.14)	101.88 (44.434)
Mean (SD) VFS	Postsinging changes	15.28 (3.68)	17.87 (6.33)	13.78 (6.44)	14.83 (8.59)	13.0 (6.52)	11.67 (6.98)
	Postintervention changes	−8.0 (2.52)	−9.63 (4.37)	−2.44 (1.42)	−0.83 (0.75)	−9.25 (4.95)	−7.33(4.03)

SD- standard deviation.

of self-perceived vocal fatigue at the start of the study, Kruskal Wallis analyses were carried out on the pre-singing baseline measures. Neither the male (893.85−951.87 Hz, chi square = 0.31, df = 2, $P = 0.87$) nor the female subgroups (1373.07−1541.15 Hz, chi square = 1.42, df = 2, $P = 0.51$) were significantly different in their baseline Hi-F0 measure. The male and female subgroups also showed similar baseline VFS (mean VFS for males: between 12.33 and 12.87, chi square = 0.11, df = 2, $P = 0.95$; mean VFS for females: between 10.43 and 13, chi square = 1.07, df = 2, $P = 0.6$; Table 1).

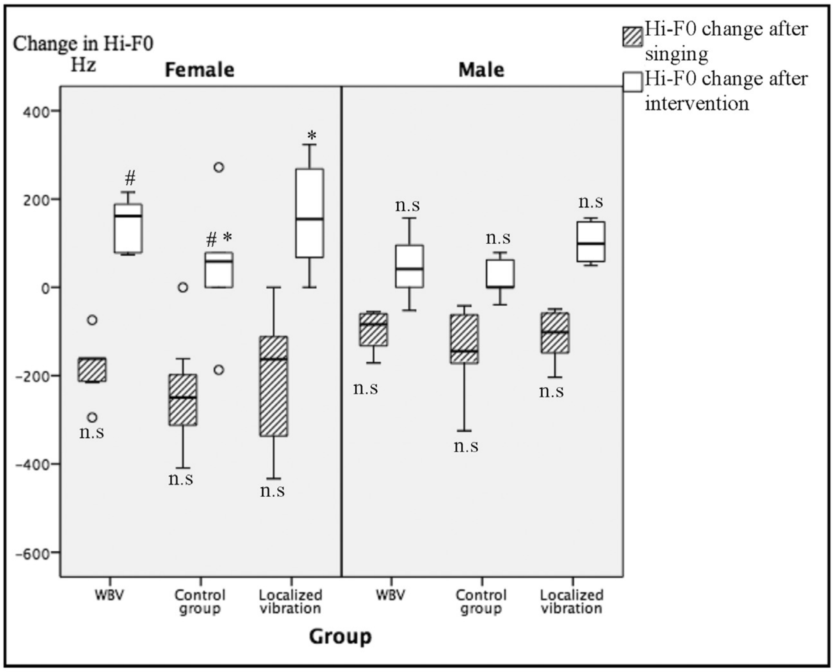
Vibration frequency of WBV group The mean, standard deviation, minimum and maximum value of the participants' height, weight, BMI and vibrational frequency on the WBV machine that induced the maximum self-perceived vibration in the neck region are listed in Table 3. Pearson's r was used to examine the correlation between height, weight or BMI against vibration frequency. There was a significant positive correlation between height of participants and the vibration frequency ($r(15) = 0.7$, $P < 0.01$, $r^2 = 0.49$); and no significant correlation between the vibration frequency against weight ($r(15) = 0.31$, $P = 0.27$, $r^2 = 0.09$) or the BMI ($r(15) = 0.01$, $P = 0.97$, $r^2 = 0.01$).

Changes in vocal function (Hi-F0) following singing

Following singing, all subject groups showed significant reduction in Hi-F0 (1-tailed $P \leq 0.016$, Table 1). The male subgroups demonstrated a reduction in Hi-F0 that varied between −97.31 Hz to −148.28 Hz (Table 3). These degrees of fatigue were not significantly different (Kruskal Wallis test: chi square = 1.04, df = 2, $P = 0.61$; Figure 2). Neither was there significant difference among the three female subgroups (mean Hi-F0 reduction between −182.64 Hz and −235.61 Hz; Kruskal Wallis chi square = 1.38, df = 2, P=0.52; Figure 2).

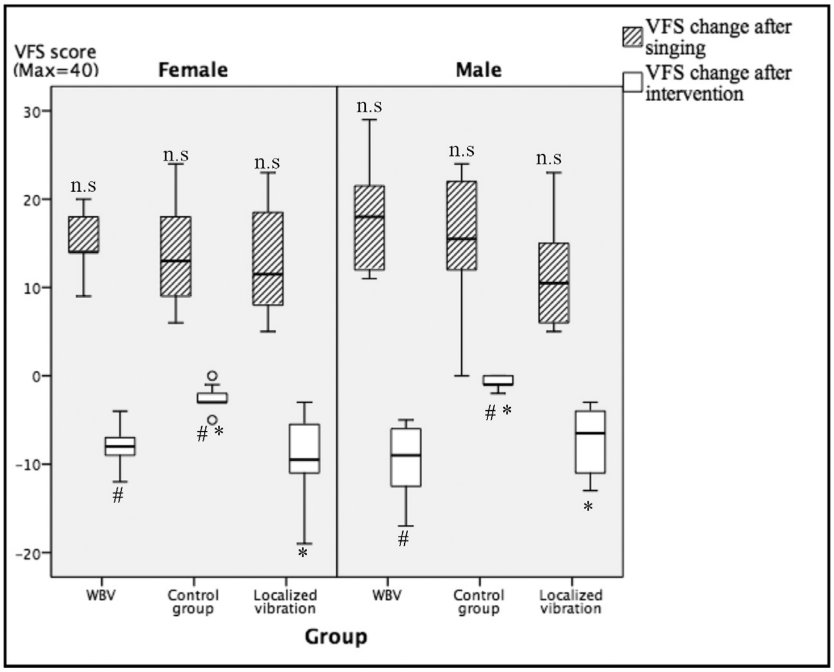
Changes in vocal function (Hi-F0) after intervention

Following intervention, all subject groups, except the male and female Control groups, showed significant increase in Hi-F0 when compared to the postsinging condition ($P \leq 0.016$, Table 1). The male LPV group showed a mean of 101.88 Hz increase in the Hi-F0, followed by the WBV group (mean 47.35 Hz increase) and the Control group (mean 16.93 Hz increase; Table 2). However, there was no significant difference among these three groups in the Hi-F0 increases (Kruskal Wallis: chi square = 5.48, df = 2, $P = 0.06$; Figure 2). For the female subgroups, the WBV and LPV groups showed a mean increase of 140.58 Hz and 163.09 Hz, respectively in the Hi-F0, while the ControlL group showed a mean increase of 46.48 Hz. Kruskal Wallis test confirmed a significant difference among these three groups Hi-F0 increases (chi square = 5.87, df = 2, $P = 0.048$). Planned post-hoc tests showed significantly more Hi-F0 increases in the WBV (Mann Whitney $U = 11$, Z = −2.19, one-tail $P = 0.01$) and LPV (Mann Whitney $U = 16$, Z = −1.93, one-tail $P = 0.02$) groups when compared to the CONTROL groups. There



n.s - No significant difference among the three experiemtnal groups with each gender
* - Signifcant difference between these 2 female subgroups
# - Signifcant difference between these 2 female subgroups
○- outlier

FIGURE 2. Changes in highest frequency (Hi-F0) within each gender subgroup after singing and after intervention.



n.s - No significant difference among the three experiemtnal groups in this gender
* - Signifcant difference between these 2 subgroups in this gender
# - Signifcant difference between these 2 subgroups in this gender
○- outlier

FIGURE 3. Changes in Vocal Fatigue Score (VFS) within each gender subgroup after singing and after intervention.

TABLE 3.
Mean Height, Weight, Body Mass Index (BMI) and Vibration Frequency, and Their Standard Deviations (SD), and Range of the Whole-Body Vibration Group

	Mean	SD	Minimum	Maximum
Height (cm)	167.73	10.59	154	182
Weight (kg)	60.80	17.00	42.00	101.00
BMI	21.38	4.63	17.04	34.95
Vibration frequency* (Hertz)	10.80	0.62	10.00	11.50

* Vibration frequency was determined when the participant reported the maximum effect on their neck region.

was, however, no significant difference in the Hi-F0 changes between the WBV and LPV groups (Mann Whitney $U = 27$, $Z = -0.12$, $P = 0.93$). It should also be noted there were two outliers in the female Control subgroup, one showing a nearly 300 Hz increase in Hi-F0, while the other demonstrated a reduction of 200 Hz (Figure 2).

Changes in self-perceived vocal fatigue (VFS) following singing

Following singing, the VFS changed from a mean around 10−13 to more than 24−30 (Table 1). The changes were all significant ($P \leq 0.016$, except in the male Control group ($P = 0.03$).

Three male subgroups demonstrated an increase of VFS between +11.67 to +17.87, while the female subgroups showed an increase between +13 to +15.28 (Table 2). Figure 3 shows the box plots with similar distributions among the male subgroups (Kruskal Wallis: chi square = 1.91, df = 2, $P = 0.4$) and female subgroups (Kruskal Wallis: chi square = 0.85, df = 2, $P = 0.67$).

Changes in self-perceived vocal fatigue (VFS) after intervention

Following the intervention, the VFS reduced from around 24−30 to 16−26. The male Control group did not show a significant reduction in VFS ($P = 0.06$, Table 1) while all other subgroups showed a significant reduction in VFS ($P \leq 0.016$, Table 1). Figure 3 shows clearly that the male and female Control subgroups demonstrated very little change in the VFS when compared to the other two experimental groups. Significant difference was found among the three male subgroups (Kruskal Wallis: chi square = 12.61, df = 2, $P < 0.0001$), with post-hoc Mann-Whitney U tests showed significant difference between the WBV and the Control groups ($Z = -3.12$ $P < 0.0001$), and the LPV and the Control groups ($Z = -2.9$, P=0.002), but not between WBV and LPV groups ($Z = -1.03$, $P = 0.33$). Similar significant finding was found with the female subgroups (Kruskal Wallis: chi square = 14.32, df = 2, $P < 0.0001$). Post-hoc planned contrast using Mann-Whitney showed significant difference between the WBV and Control groups ($Z = -3.26$, $P < 0.0001$), as well as the LPV and Control groups ($Z = -3.2$, $P = 0.00$). No significant difference was found between the WBV and LPV groups ($Z = -0.41$, $P = 0.72$)

DISCUSSION

This study investigated the effect of vibrational therapy on young adults (age: 19−25 years) that showed similar baseline in phonatory function (Hi-F0) and perception of vocal fatigue (VFS). Vocal fatigue was induced using karaoke singing for more than 95 minutes. The karaoke singing was successful in inducing vocal fatigue with the phonatory ability in producing Hi-F0 and perception of vocal fatigue (VFS) being reduced significantly.

Following intervention, both the WBV and LPV groups (female and male) all showed significantly increased ability in producing Hi-F0 and reduced perception of vocal fatigue (VFS) than the Control female and male groups respectively. It should be noted that while the female Control group did not show a significant increased Hi-F0 production following voice rest, they did, however, perceived significantly less vocal fatigue after the rest (Table 1). Voice rest has often been recommended for dealing with vocal fatigue.[17,51] In the present study, it has been shown the recovery in the Control group, which was merely voice rest without vibrational intervention, but was made to believe the hand-held vibratory device had some effect on the neck muscles, was not as efficient as those who were given vibrational therapy. Therefore, it is reasonable to conclude that both whole-body and localized perilaryngeal vibration therapies resulted in significant better recovery from vocal fatigue when compared to voice rest *per se*.

It should be noted that although the WBV and LPV groups showed better recovery of phonatory functions than the Control group, only the female subgroups showed significant differences in these changes while the three male subgroups showed no such significant differences (Figure 2). There are two possible explanations: either that the females responded better to the vibrational therapies or the sample size in the present study was too small that did not allow the male subgroups to show statistical significance.

Furthermore, the usefulness of whole body vibration and localized vibration appears to be of similar effect as there was no significant difference among the groups that used whole body vibration or localized vibration. If one were to consider clinical applicability, the localized vibration is obviously a preferable choice for it is a more mobile and cheaper option, which users can use anytime and anywhere at their own convenience. However, the exact location and the amount of pressure to be applied to the perilaryngeal surface would not be easy to control. On the other hand, the whole-body vibration would have a more definitive setting (frequency and intensity) to be manipulated and there is no concern of whether the site of vibration is appropriate or not.

There are at least three other reports todate that suggested that localized vibration has the potential of improving vocal conditions in human.[23,24,28] The present study adds further evidence to that. Furthermore, the present study also found whole-body vibration demonstrated similar effect as the localized vibration. The potential of vibrational therapy in voice should not be under estimated and more studies should be needed in this.

Hypothesis why vibration helps to relieve vocal fatigue

It has been suggested[7] that excessive perilaryngeal muscle tension develops following vocal fatigue. This increased muscle tension is likely to impact on the laryngeal adjustments required in producing high pitch. In addition, in vocal fatigue, vocal folds tissue viscosity would have increased, the velocity of the mucosal wave would be affected which makes soft and high phonation difficult.[58] We postulate that vibration, whether through a whole-body platform or localized on the perilaryngeal muscles, relieved this excessive muscle tension, and permitted the production of relatively higher pitches. We also hypothesize that external vibration also causes increased blood flow and metabolism in the fatigued muscles. Based on the literature, whole-body vibration facilitates improvement in gross motor functions by increasing blood flow and metabolism to the muscles.[59] It has been argued that a reduction in blood circulation to the laryngeal area as one of the possible underlying physiological mechanisms causing vocal fatigue.[6] Increase of blood flow to the muscles helps to remove lactic acid[60] and to enhance recovery of muscle fatigue. Obviously, more studies, especially those which involved muscle physiology, will be needed in order to test these hypotheses.

Limitations

There are a few methodological issues which need to be pointed out here so that caution can be used to generalize these results. First, one might argue that the experimenters were not blinded to the eliciting procedure of Hi-F0. We admit that possible bias could not be completely ruled out. However, such procedure had been validated in a separate study by Barrett et al[57] (in press) and the elicitation procedure reduces possible examiner's bias. Second, the present study included only participants with induced vocal fatigue using karaoke singing and not those with chronic vocal fatigue. It is unclear if the effect on induced vocal fatigue would be different from that on the vocal fatigue experienced chronically by many professional voice users in real life. Thus, this usefulness of vibrational therapy in individuals with chronic vocal fatigue should be tested clinically. Third, this study was only preliminary in nature and did not explore other intervention variables, such as vibrational intensity, frequency or duration of each vibrational intervention. Further studies will be needed to determine how the different treatment variables might affect the effectiveness. Fourth, given the small sample size, only nonparametric statistics were used and this admittedly had lower power. Larger sample size would have allowed the use of more powerful parametric statistics. However, since significant results were found with the nonparametric statistics, it is believed that similar significant results will be obtained with a design that allows parametric statistics. Fifth, the VFS is not a validate test and it was only four-item long. This may not be adequately reflecting the vocal fatigue. Finally, a word of caution about the long-term use of vibrational devices. There is also limited information on the long-term effect of the vibrational mechanism on human in general. The trade-off between risk and benefits can only be considered with more available information.

CONCLUSION

The present study is an initial attempt to evaluate the effects of WBV and localized perilaryngeal vibration on vocal fatigue. Results demonstrate that the localized vibration treatment used in this study can relieve sense of phonatory effort and vocal fatigue symptoms as well as facilitate recovery of maximum pitch level. Further research with a larger sample size could be carried out to investigate the effects of WBV on other phonatory measurements such as maximum phonation time or vocal intensity. In addition, in order to maximize effects of WBV on laryngeal area, vibrational frequency could be individualized for different gender.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.jvoice.2019.07.009.

APPENDIX. SELF-RATING VOCAL FATIGUE QUESTIONNAIRE

	Original item number in Vocal Fatigue Index (Nanjundeswaran et al., 2015)
1. My voice feels tired when I talk.	(2)
2. My voice gets hoarse with voice use.	(4)
3. I find it difficult to project my voice with voice use.	(10)
4. I experience discomfort in my neck with voice use.	(16)

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