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An Experimental Study of Comfortable Pitch and Loudness with Target Matching: Effects on Electroglottographic and Acoustic Measures

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ABSTRACT

This study was designed to examine comfort levels of pitch and loudness with target matching and their effects on electroglottographic (EGG) and acoustic measures. Twelve speakers, six males and six females, were instructed to produce /a/ sustained vowel for three seconds at a comfortable pitch and loudness level without any instruction and with a target matching procedure of either a certain f0 or SPL separately with visual and auditory feedback. The range of pitch for females and males were presented by progressing up and down randomly at intervals of 5Hz from 150 Hz to 310 Hz (total 33 frequency targets) and from 85 Hz to 190 Hz (total 22 frequency targets), respectively. The loudness levels were 65, 75, 85, 95 dB (total of four intensity targets) for both males and females. Subjective estimations of comfortable levels were obtained using a 10-point equal-appearing interval rating scale following each phonation. The results showed that males and females demonstrated similar trends in loudness levels with greatest comfort at 75 dB, whereas pitch comfort ratings showed a greater variability with females having a wider range with target matching. In the comfort levels of individuals, most male and female speakers rated higher comfort at soft, rather than loud phonations. On the other hand, most male speakers perceived highest comfort levels below the comfort pitch levels they phonated under natural conditions. Higher frequency ranges, however, were perceived to be more comfortable than those of natural condition in most female speakers, although the comfortable pitch levels in spontaneous phonations were within the comfort level ranges determined by targeted phonations. When comparing acoustic (%jitter, %shimmer, SNR) and EGG measures (CQ%) between spontaneous comfortable phonations and targeted phonations produced by the same subject at similar f0 and intensity, no significant differences were observed (p>0.05). Thus, target matching procedures may be considered a compatible and alternative method to reduce the variability of comfortable pitch and loudness levels by eliciting consistent comfortable phonations.

Keywords: comfortable pitch and loudness, target matching, acoustic, EGG, comfortable effort rating, normal speakers

1. Introduction

Pitch and loudness are important elements in the evaluation of the human voice [1]. Voice disorders involve the problems of abnormality of vocal pitch, loudness (e.g., too high or too low, too soft or too loud) for the individual's age and/or gender or voice quality. Typically, fundamental frequency is associated with physical aging, vocal fold thickness, and stiffness/or tension [2]. A number of studies have been explored to measure the comfortable effort level [3-5] or habitual or optimal pitch and loudness [6-8]. "Comfortable effort level" is analogous term such as "habitual" and "natural", implying there is a level of vocal output, or "effort", which for a speaker is typical when repeating an utterance or phonation used by an individual on a daily bases with minimal effort [4]. In another studies, 25% method which takes the frequency 25% of the way from the bottom of the f_0 range including falsetto was used to determine

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derived optimum fundamental frequency for normal individuals [9]. While many researchers used a speaker defined comfortable pitch and loudness to elicit phonation that reflects the speaker's typical phonation patterns, studies have shown that speakers tended to vary their pitch and loudness significantly between recording sessions and different speech tasks [6-8, 10]. Sustained vowel yielded significantly higher F_0 values than the reading or spontaneous speech samples [8, 10] and intra-subject variations in F_0 over time was observed [11].

Additionally, Zraick et al. (2004) pointed out that the definition of "comfortable" loudness was subject to question. Although the instructions for speaking at "their most comfortable pitch and loudness", they were not speaking at a truly habitual loudness level due to some variables such as ambient noise and different performance during recording [6]. Moreover, these variations in pitch and loudness could impact the outcome of acoustic analysis. A high fundamental frequency, for example, leaded to a decrease in perturbation parameters [12]. With decreasing vocal loudness, especially below 75 dB, an increase in jitter and shimmer has been observed [13]. In general, the highest jitter and shimmer values were associated with low frequency and low intensity phonation [14-16]. As a result of the variability introduced by changes in pitch and loudness, many studies endeavored to control these features and speakers were provided with a target pitch and/or loudness at which to phonate during the study. Pitch levels ranged between 70Hz and 250Hz for males and 100Hz and 300Hz for females [17]. Generally, percent jitter and percent shimmer have been employed as basic acoustic measures, and computed on a sustained /a/ at a comfortable pitch and loudness. Most studies asked participants to phonate near the average pitch for their gender; 125Hz for males and 200Hz for females [18]. Many pathologies resulted in a decrease fundamental frequency range and could shift fundamental frequency up or down from its baseline value [19-20]. A reduction in habitual loudness has been identified as a salient feature of many speech and voice disorders [21-22].

Electroglottography (EGG) is a non-invasive measurement for assessing the degree of contact between the vibrating vocal folds during voice production over time [23]. Closed quotient (CQ) derived from EGG waveform is defined as the percentage of each cycle for which the folds are in contact and has been considered a good indicator of voice quality [24]. Moreover, CQ strongly related to vocal fold impact stress [25], frequency, intensity, and vocal effort [26]. Accordingly, CQ can be used for indirectly measuring easy phonation or vocal effort regarding comfortable level of pitch and loudness.

Although the effect of comfortable pitch and loudness levels may have potential importance in clinical practice and research, no standardized protocol on determination of appropriate comfortable pitch and loudness levels or for eliciting the consistent comfortable phonation was established yet. Thus, target matching procedure can give the benefit in reducing variations of pitch and loudness levels during the recordings even though this protocol may come with a number of limitations, being a further divergence from natural speech as patients are asked to modify their speech. The purpose of this study was to determine the comfortable pitch and loudness levels with target matching from normal speakers. For target matching, normal speakers were instructed to phonate at each target pitch and loudness as the frequency or intensity changes and rated their comfortable levels subjectively at each targeted phonation (targeted frequency or intensity). Using these findings we can define achievable comfortable pitch and loudness ranges for normal speakers and predict more accurate comfortable levels. Moreover, since there are very few data on acoustic and EGG derived measures for normal speakers with target matching procedure, acoustic and EGG measures in spontaneous phonation at comfortable F_0 and intensity were compared to target matching phonation at similar frequency/intensity produced by the same subject.

2. Methods

2.1 Subjects

The normal voice samples were obtained from 12 normal speakers; 6 healthy males ranged in age from 21 to 23 years (mean of 21.8, SD = 1.34) and 6 healthy females ranged in age 20 to 22 years (mean age of 20.8, SD = 1.85) in the study. Participation was approved by the IRB of the University of Wisconsin, Madison. All participants were nonsmoking native speakers of American English. They reported normal hearing ability, no laryngeal and airway infection, good health condition, no formal vocal training, and normal stroboscopy findings, and also were judged to present normal language skills as determined by a certified speech-language pathologist.

2.2 Recording

Participants were asked to produce a sustained /a/ for three seconds at a comfortable pitch and loudness levels without any instruction. Voice samples were recorded using a unidirectional cardioids microphone (SM58; Shure, Niles, IL) placed 10 cm from the lips at a 45 angle, connected to a preamplifier (Bluetube DP; PreSonus, Baton Rouge, LA) and digital audio tape (DAT) recorder (Fostex D-5; Foster Electric, Schaumburg, IL). Digitization was performed using a 44.1 kHz sampling rate and 16-bit quantization.

For target pitch and loudness matching experiment, a target matching program was developed to allow the speakers to easily adjust the target pitch, loudness, and tolerance levels for each trial as shown in <Figure 1>. Also, the speakers were instructed to produce /a/ sustained vowel with target matching procedure either a certain f_0 or SPL separately with visual and auditory feedback as shown in <Figure 2>. The program emitted a tone at the target pitch that presented to the speaker via headphones for auditory feedback. As a speaker phonated, the program provided a visual indication of their current levels relative to the target. Once the speaker sustained phonation within the tolerance ranges for both pitch and loudness for the predetermined trial length, a sample was saved and the speaker was notified of the trial's completion.

Participants were supplied with a reference tone and visual feedback in reference to their pitch and loudness. Once they were comfortable with the feedback, participants progressed up and down through major notes to the highest and lowest note they achieved. Each note was sustained for 1 second within a predefined tolerance range to constitute a successful recording.

Vocal fry was excluded during the recording process and participants were allowed to use falsetto in obtaining their highest pitch. However, the upper limit of their modal register was noted. Auditory and visual feedback provided to the speakers to assist each target pitch in achieving an ideal level. For target loudness matching, phonation was monitored by a digital sound pressure level meter (332055, Radioshack, Fort Worth, TX). Visual feedback provided only to the speakers to help them in producing the target loudness. The subjects were able to hold the specified target frequency within a range of ± 5Hz and intensity targets were held within a range of ±3dB. The range of pitch for females and males were presented by progressing up and down randomly at intervals of 5Hz from 150 Hz to 310 Hz (total 33 frequency targets) and from 85 Hz to 190 Hz (total 22 frequency targets), respectively. The loudness levels were 65, 75, 85, 95 dB (total 4 intensity targets) for both males and females. When a speaker moved up and down in frequency and loudness, the pitch and loudness tasks presented randomized trial order to avoid the learning or training effects to match a target.

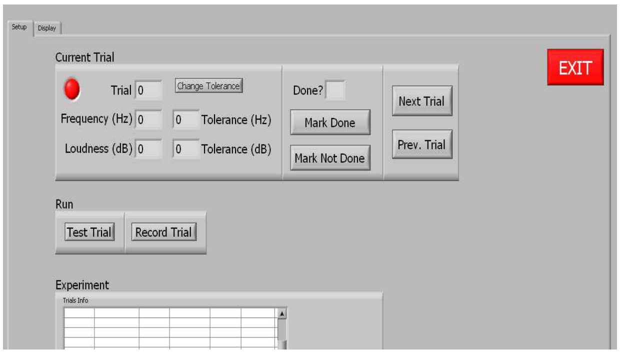

Figure 1. Recordings for each phonation with target matching procedure.

2.3 Comfortable effort ratings

Participants rated their comfort level at each pitch and loudness. Comfortable effort levels of self-report were obtained using a 10-point equal-appearing interval rating scale ; 1 – most comfortable, 10 – most uncomfortable at 10Hz tolerance level of pitch and 6 dB tolerance level of loudness.

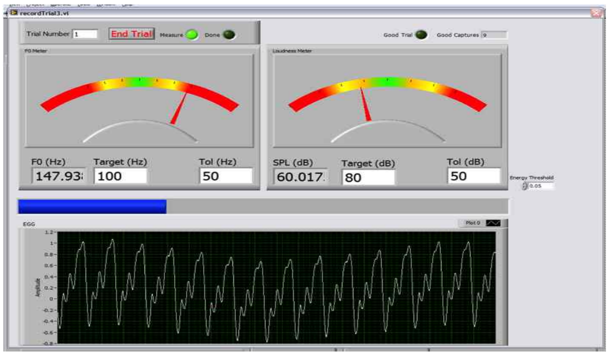

Figure 2. Shown is a screen shot of the pitch matching interface. At the bottom is an EGG trace that can be displayed to confirm proper electrode placement. The right and left boxes show loudness and frequency respectively. The target pitch and tolerance is shown a long with the subject's current pitch and loudness. The blue bar fills as the subject phonates within the tolerance ranges, giving them an indication of their progress on the trial.

2.4 Electroglottographic analysis

Electroglottograph (EGG, Glottal enterprises, Syracuse, New York) attached to the subject's neck by a Velcro strap. Closed quotients (CQ%) were calculated by dividing the duration of each marked closed period by the duration of the corresponding entire glottal period.

2.5 Perturbation analysis

Percent jitter, percent shimmer, and SNR were measured with TF 32 software (Milenkovic, 2001, Madison, WI) [27].

2.6 Statistical analysis

Statistical analysis was conducted using Sigma Stat 3.0 (Jandel Scientific, SanRafael, CA). Wilcoxon Signed Rank Test was performed to determine the differences of frequency, intensity, %jitter, %shimmer, SNR, and closed quotients (CQ%) between spontaneous and targeted phonation produced by the same subject with no distinction between male and female speakers. A level of significance was 95% for all measures.

3. Results

3.1 Self-reports of comfortable level ratings in target matching procedure

Self-reports of comfortable level ratings across the pitch range in normal female speakers demonstrated high difficulty with pitches below approximately 175Hz with a relatively stable comfort level at all achievable pitches above this. Normal male speakers had a more contracted pitch range with less variability in comfort level with most comfortable in 95 ~ 115 Hz. Males were most challenged by phonation at the upper end of their phonation spectrum as shown in <Figure 3>.

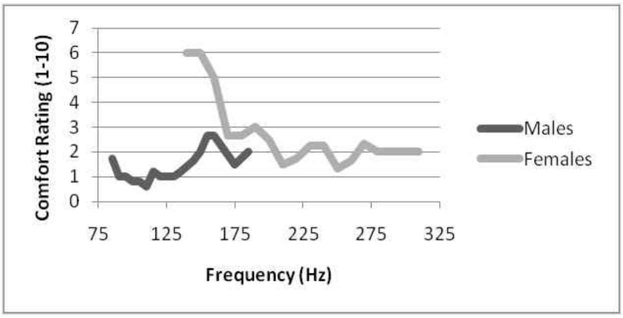

Figure 3. Comfort levels across pitch range for 6 males and 6 females normal speakers. 1 = Comfortable, 10 = Uncomfortable/Extremely challenging

For each individual regarding comfortable pitch levels, most male speakers perceived the most comfortable at the range of 90 ~ 120 Hz. <Figure 4> exhibited comfort levels across loudness. Both males and female found the 75dB phonation easiest with phonation at lower and higher loudness levels being consistently rated as more challenging.

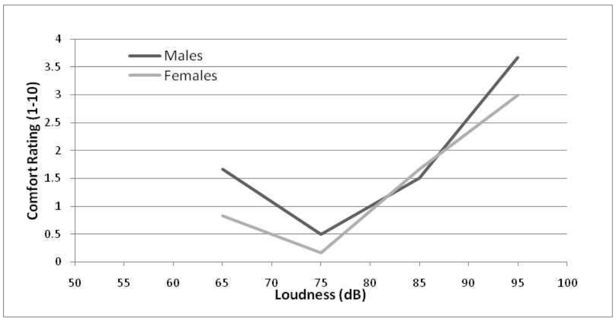

Figure 4. Comfort levels across loudness range for 6 males and 6 females normal speakers. 1 = Comfortable, 10 = Uncomfortable/Extremely challenging

3.2 Comfortable levels between at natural condition vs. target matching for individuals

3.2.1. Comfortable loudness levels

<Figure 5> and <Figure 6> demonstrated the mean comfortable loudness values at natural condition, as well as most perceived comfortable loudness levels at target matching for each of the 6 normal males and 6 normal females, respectively. As can be seen, although several most comfortable loudness levels existed in target matching in several individuals, most comfortable loudness levels were perceived at around 75dB and most speakers rated relatively more comfortable at soft phonation than loud phonation in target matching.

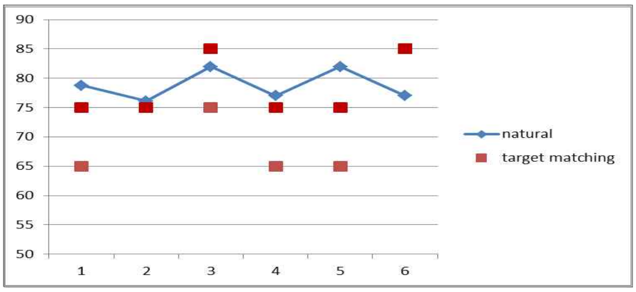

Figure 6. Most perceived comfortable loudness levels in natural vs. target matching procedure in each female speaker (N=6)

3.2.2. Comfortable pitch levels

The mean comfortable pitch values under natural condition, as well as the most comfortable pitch levels at target matching for each male and female normal speakers were shown in <Figure 7> and <Figure 8>.

For target matching, most male speakers perceived the most comfortable at the range of 90 ~ 120 Hz. When compared to those at natural condition, 4 of 6 male speakers perceived most comfortable below the comfortable pitch levels they phonated under natural condition including at the same f_0 in their spontaneous phonation.

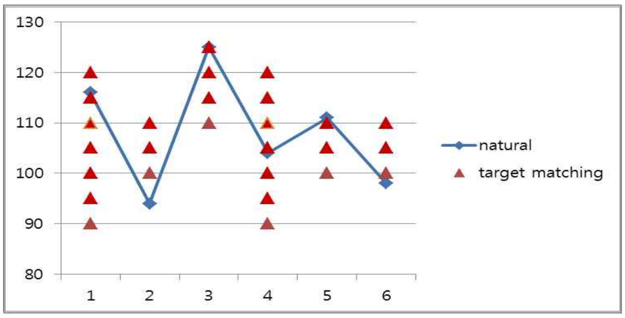

Figure 7. Most perceived comfortable pitch levels in natural vs. target matching procedure in each male speaker (N=6)

On the other hand, most female speakers perceived the most comfortable at the range of 200 ~ 260Hz. Higher frequency ranges were perceived to be most comfortable than those of natural condition in 5 of 6 female speakers in targeted phonation.

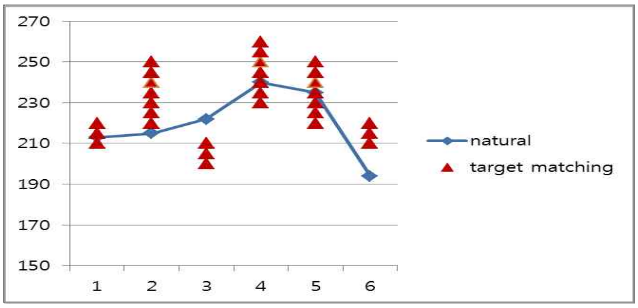

Figure 8. Most perceived comfortable pitch levels in natural vs. target matching procedure in each female speaker (N=6)

3.4 Perturbation and electroglottographic measures with spontaneous vs. targeted phonation samples

The comfortable pitch, loudness, and CQ values from spontaneous phonation were compared with those of similar F_0 and intensity that were produced during the target matching. Summary of means and standard deviations of comfortable pitch, loudness, and CQ values for spontaneous phonation and target matching phonation at similar frequency/intensity produced by the same subject were shown in <Table 1>. Wilcoxon Signed Rank Test revealed no significant differences in f_0, intensity, and CQ data between spontaneous vs. targeted phonation ($p>0.05$).

For perturbation measures, %jitter, %shimmer, and SNR values from spontaneous phonation were compared with those of similar F_0 and intensity that were produced during the target matching also shown in <Table 2>. Wilcoxon Signed Rank Test yielded there were no significant differences in all parameters between spontaneous vs. targeted phonation ; %jitter (p = 0.519), %shimmer (p = 0.740), SNR (p = 0.635).

Table 1. Means and Standard deviations of frequency, intensity, and Closed Quotient measures of spontaneous and targeted phonation matched with each comfortable spontaneous phonation

	Spontaneous phonation			Targeted phonation		
Subject	F_0(Hz)	Intensity (dB SPL)	CQ (%)	F_0(Hz)	Intensity (dB SPL)	CQ (%)
1	116	78.9	0.57	117	80.3	0.59
2	94	76.1	0.55	92	83.1	0.63
3	128	83.1	0.51	122	92.7	0.58
4	96	82.2	0.5	95	81.5	0.42
5	111	79.5	0.49	110	83.6	0.46
6	98	79.5	0.53	98	77.3	0.47
Mean	107	79.9	0.53	106	83.1	0.53
SD	13.5	2.50	0.03	12.4	5.22	0.09
7	216	75.9	0.81	215	71.9	0.89
8	215	78.7	0.53	215	73.7	0.45
9	221	76.9	0.63	222	82.3	0.67
10	240	83.3	0.64	240	90.9	0.67
11	220	80.6	0.66	220	88.6	0.63
12	194	81.2	0.61	193	76.7	0.60
Mean	218	79.4	0.65	218	80.7	0.65
SD	12.4	5.22	0.09	2.50	0.26	0.14

Table 2. Means and Standard deviations of perturbation measures of spontaneous and targeted phonation matched with each comfortable spontaneous phonation

	Spontaneous phonation			Targeted phonation		
Subject	%jitter (%)	%shimmer (%)	SNR (dB)	%jitter (%)	%shimmer (%)	SNR (dB)
1	0.91	2.87	17.1	0.37	1.96	24.5
2	0.22	2.56	19.0	0.21	3.47	16.6
3	0.19	1.33	24.7	0.26	2.13	18.8
4	0.42	2.41	23.5	0.53	2.52	21.2
5	0.31	1.83	20.9	0.39	1.77	24.5
6	0.44	1.88	19.1	0.32	1.92	20.7
7	0.74	4.75	16.1	0.47	6.14	15.2
8	0.29	3.00	17.6	0.36	4.31	15.8
9	0.35	4.85	16.0	0.34	2.95	19.1
10	0.25	1.42	21.5	0.27	1.51	21.5
11	0.19	1.65	19.9	0.14	0.88	27.9
12	0.31	2.54	21.0	0.2	2.66	17.8
Mean	0.39	2.59	19.7	0.32	2.69	20.3
SD	0.22	1.17	2.77	0.11	1.42	3.88

4. Discussion and conclusion

In current study, comfortable effort levels were identified using a target matching method and no instruction in normal speakers. Due to the potential impact of variable pitch and loudness on acoustic measures, a number of researchers have used target matching procedure to control these features during phonation.

In terms of speech tasks to elicit the habitual pitch from phonation range, spontaneous monologue or reading tasks appear to provide more valid measures than those obtained during sustained phonation [8]. Meanwhile, no special phonatory instructions with more natural has been used to elicit the comfortable pitch and loudness with the sustained vowel [3], [4], [10] or some special instruction such as sustained phonation following a monotone starter of "one, two, three" [8] and modeling by the examiner [7] or visual and/or auditory feedback to match the target frequency of an auditory or visual stimulus corresponding to the musical scale have been used [26], [28]. Therefore, clinical and research protocols may need to use external feedback or alternative method to elicit a comfortable pitch and loudness. This variability can be reduced with external devices to control the effort level or by instructing speakers with auditory or visual feedback to produce the voice/speech samples in a "comfortable" manner. However, currently the procedures to elicit the comfortable pitch and loudness have been inconsistent across the literatures. Target matching effect was investigated in terms of frequency and intensity with visual and auditory feedback [26] and they found that both CQ (closed quotient) and SQ (speed quotient) were significantly increased when targeted phonation samples were compared to spontaneous samples, suggesting that targeted phonation which required much greater effort was different from that for spontaneous phonation. Nevertheless, in current study, we need to explore the comfortable effort range across a wider range of pitch and loudness in normal speakers by controlling each pitch and loudness level. Self-reports of comfortable effort level were obtained by going through randomized different pitch or loudness levels with target matching to determine the comfort level, showing that males and females demonstrated similar trends in loudness levels with greatest comfort at 75dB; however, stability measures indicated improvement at with louder phonation. Pitch comfort ratings showed a greater variability with female having a wider range. Interestingly, there were a variety of the comfortable pitch and loudness levels with target matching in each individual.

Self-reports of comfortable level ratings across the pitch range in normal female speakers demonstrated high difficulty with pitches below approximately 175Hz with a relatively stable comfort level at all achievable pitches above this whereas most uncomfortable around 175Hz in male speakers. This may give a clinical implication for transgender voice intervention. Prior studies demonstrated that the mean Speaking Fundamental Frequencies (SFFs) of female-perceived transsexuals were 172 Hz or 187Hz [29], [30] and lower SFFs were consistently identified as male voices. Therefore, it might be important to select a target pitch for voice treatment of transgender clients and this pitch borderline should be considered for successful therapeutic intervention.

Brockmann*et al.* (2008) demonstrated that %jitter and %shimmer significantly increased with decreasing voice loudness, especially in phonation below 75 dB and 80 dB. Furthermore, they found gender differences in jitter and shimmer at medium loudness, which may be mainly linked to different habitual voice loudness levels [31]. Although male loudness (80dB) was slightly higher than that of female (79dB) under natural condition, we did not found gender difference of habitual loudness in our study. Furthermore, recently, Aithal *et al.* (2012) compared acoustic parameters of voice between normal and high pitch phonation in normal adults and concluded females showed a significant difference in the frequency perturbation measures – percent jitter and relative average perturbation, while males demonstrated a significant difference in the noise-to-harmonic ratio [32]. In current study, the acoustic measures at different pitch levels were not compared statistically due to broad pitch range from 150 Hz to 310 Hz investigated but perturbation measures (%jitter and %shimmer) decreased and SNR increased gradually with higher pitch in both male and female speakers.

In comfortable levels of individuals, most of male and female speakers rated more comfortable at soft phonation than louder phonation. On the other hand, most of male speakers perceived most comfortable below the comfortable pitch levels they phonated under natural condition whereas higher frequency ranges were perceived to be most comfortable than those of natural condition in most female speakers. Thus, the most comfortable levels perceived subjectively were likely to have more than one single point when investigating the most comfort levels with target matching.

To the best understanding of target matching effect, when we compared acoustic (%jitter, %shimmer, SNR) and EGG measures (CQ%) between spontaneous comfortable phonation and targeted phonation produced by the same subject at similar F_0 and intensity while matching a particular frequency/intensity target, no significant differences were yielded. Although CQ% was used as an objective parameter to measure easy phonation/ or effort level in this study, it was not significantly increased when targeted phonation samples were compared to spontaneous samples in this study. Thus, target matching procedure may consider a compatible and alternative method to reduce the variability of comfortable pitch and loudness levels by eliciting consistent comfortable phonation.

Despite the potential benefits of a target matching procedure, this protocol can be a challenge for some subjects. While providing a reference tone assists speakers to achieve a target pitch, some speakers are unable to correctly identify a pitch because all participants had no vocal training before. Clinician modeling also may have some impact on the phonation produced by the speaker, but would not provide as good control of pitch and loudness as the target matching procedure.

The additional challenge of target matching procedure in this study may induce fatigue due to 30~40 repetitions across different pitch and loudness ranges for each speaker and/or vocal effort to arrive a certain target pitch and loudness level which may present the impact on their vocal quality as a result of greater vocal strain. Nevertheless, in current study, no significant differences in CQ% values were observed between spontaneous phonation and targeted phonation at similar f_0 and intensity level. Since relatively small numbers of young female and male speakers were investigated in the current study to determine the comfortable pitch and loudness levels, there is some limitation of the generalization of these findings to all normal populations. Future research was needed, therefore, to investigate with more normal speakers to precisely define the comfort levels and to establish standardized methods for clinical evaluation and research of voice.

In conclusion, a target matching procedure provided easy modification of pitch and loudness of interest to determine the comfortable pitch and loudness levels. In the future study, appropriate reference standards for comfortable pitch and loudness ranges in subjects of different age, gender, and vocal pathology also can be explored.

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