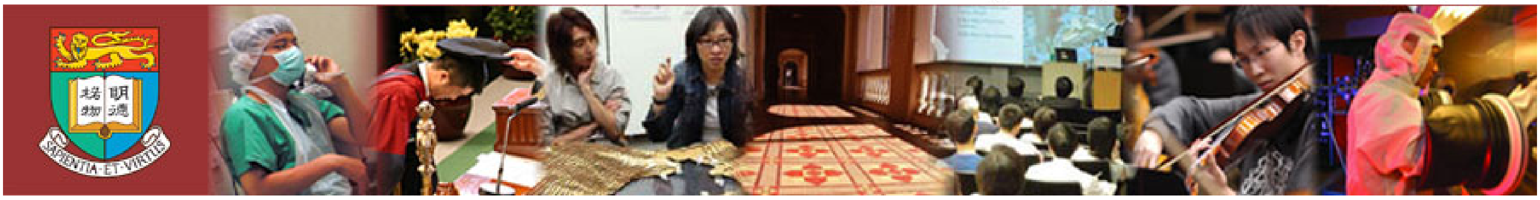

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Ambulatory Phonation Monitor study: vocal loudness and pitch in healthy young adults under environmental noise

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Abstract

This study investigated the effects of environmental noise on vocal intensity, fundamental frequency and perceived vocal effort among 24 vocally healthy young adults (12 males and 12 females, aged 19-22 years). All participants were asked to hold a monologue speech under three environments with different range of noise levels: a quiet clinic room (mean = 35.5 dBA), a clinic corridor (mean = 54.5 dBA) and a pantry room with an exhaust fan (mean = 67.5 dBA). The order of conditions was randomized in a predetermined order. Hydration and vocal rest were given to all participants prior to each recording condition. Both gender groups showed significant increase in mean vocal intensity, fundamental frequency and perceived vocal effort in the pantry room than other two conditions, and no significant difference between the quiet clinic room and the clinic corridor except in the fundamental frequency in female group. The results support the laboratory findings for Lombard effect in high background noise levels and also support the recommended noise levels of 50-55 dB where speech intelligibility maintained. In addition, the results warrant attention for individuals who often speak under environments with high background noise levels.

INTRODUCTION

Many public places, such as schools and restaurants, in Hong Kong are generally characterized by high background noise. Many people have to work under these conditions. Even if someone does not work in these places, chatting in noisy environments is not an uncommon daily activity for many people.

High background noise masks speech, which makes speakers difficult to be heard. To speak over high background noise, speakers often have to increase their vocal loudness, in order to maintain adequate intelligibility of their messages (Lane & Tranel, 1971) or to maintain a familiar level of internal auditory feedback (Siegel & Pick, 1974). This is commonly known as Lombard effect (Lane & Tranel, 1971). In addition to an increase in vocal intensity, fundamental frequency also increases under background noise (Gamming, Sunberg, Ternstrom, Leandersson & Perkins, 1988). Speakers often adopt a hyperfunctional vocal behavior as a strategy to raise vocal intensity and fundamental frequency (Vilkman, Lauri, Alku, Sala & Sihvo, 1998). Increase in vocal demand makes one vulnerable to vocal strain (Greene & Mathieson, 2001). Therefore, speaking under high background noise may exert an adverse effect on vocal health, and possibly pose a risk of developing voice disorders (Vilkman, 2000).

A number of laboratory studies have investigated the effects of background noise on voice by using different kinds of tasks (e.g. read aloud single words or passage, spontaneous speech). The findings consistently demonstrated an increase in vocal intensity, fundamental frequency and perceived vocal effort in speech under high background noise (e.g. Janqua, 1993; Pittman and Wiley, 2001; Tartter, Gomes and Litwin, 1993).

In an earlier study by Summers, Pisoni, Bernacki, Pedlow and Stokes (1988), two male subjects read aloud 15 vocabularies for approximately 40s in the presence of broadband white noise. The findings reported an increase in average vocal intensity of 3.5, 6.0, and 6.9 dB under 80dB, 90dB and 100dB SPL of white noise respectively. Tartter, Gomes and Litwin (1993) replicated the study of Summer et al (1988) by introducing lower white noise levels to two women. The findings also reported an average increase in vocal intensity of 1.0, 2.6, and 3.7 dB under 35, 60, and 80 dB SPL of white noise respectively. However, the sample size in their studies was too small (N = 2), which might not be representative of the general population.

Janqua (1993) further examined five men and five women who read aloud the single words in quiet and 85 dB SPL white noise. The findings revealed an average increase in 12.6 dB for female group and in 18.2 dB SPL for male group between quiet and 85 dB white noise. Consistent results were also found in the study by Pittman and Wiley (2001), which required five women to read single words under quiet and 80 dB SPL white noise and babble noise. An average increase in vocal intensity of 14.5 dB was found from quiet to 80 dB SPL white noise and babble noise.

Not only the effect of noise on vocal intensity has been investigated, its effect on fundamental frequency also has been examined. Letowski, Frank and Caravella (1993) examined five men and five women who read connected speech in quiet and in multi-talker babble noise, traffic noise, and wide band noise at 70 and 90 dB SPL. The findings reported a significant increase in vocal intensity of 3.4 dB and 7.4 dB under 70 and 90 dB SPL noise respectively, and also a significant increase in pitch of 2.5 and 18 Hz for female group, and 16 and 28.5 Hz for male group under 70 and 90 dB SPL noise, respectively. However, there was no significant difference across three types of noise. The findings were in line with the recent study by Sodersten, Ternstrom and Bohman (2005). In the study by Sodersten *et al.* (2005), a group of 23 healthy speakers (12 women and 11 men) were required to give an approximately two-minute oral presentation over four different types of background noises (Quiet room <30dBA, stationary white noise 70-78dBA, noise in day-care center 74dBA, loud pop music 87dBA). The findings reported a significant increase in the vocal intensity, fundamental frequency and perceived vocal effort when background noise levels increased. No significant difference was found between the types of noise at similar noise levels.

There are also some studies investigating the effect of noise on acoustic parameters in certain natural environments, such as schools, hospital, transportation (Pearson, Bennett & Fidell, 1977), and daycare centers (e.g. Sodersten, Granqvist, Hammarberg and Szabo, 2002).

Pearson *et al.* (1977), as cited by Olsen (1998), reported that vocal intensity levels are high in high natural environment background noise, such as schools and transportation. The vocal intensity of teachers in schools with high background noise ranged from 45 dB to 55 dB was reported to be producing speech at 67 dB to 78 dB at a conversation distance of 1m, whereas passengers in aircraft with noise level of 79 dB produced speech at 68dB. Similar findings were reported in the study by Sala, Aiko, Olkinuora, Simberg, Strom, Laine, Pentti and Suonpaa (2002) and Sodersten *et al.* (2002).

Sala *et al.* (2002) studied the vocal behaviors of day-care center teachers during working days. The findings revealed that those day-care center teachers produced speech at about 68 dB SPL under the background noise ranged from 64 dB to 70 dB. Sodersten *et al.* (2002) also reported that the preschool teachers exhibited significantly higher fundamental frequency and higher vocal intensity (about 9.1 dB louder) at day-care centers (mean = 76.1 dBA; range = 73.0-78.2 dBA) when compared with the baseline with relatively low background noise (range = 41.0-55.0 dBA).

Most of the studies are conducted in laboratory settings (e.g. Letowski *et a*l., 1993;; Sodersten *et al*., 2005; Summers *et al*., 1988; Tartter *et al*., 1993) while the field studies are only a few. This raises the question of generalizability of the laboratory results to real-life situations. In addition, some field studies did not control the variables other than noise, such as amount of phonation time and varied distance between the conversational partners (Sala *et al*, 2002; Sodersten *et al*., 2002). These extraneous variables might affect the vocal loudness and pitch of the participants. For example, prolonged speaking often leads to vocal fatigue, which in turn, requires more effort to continue speaking (Eustace, Stemple and Lee, 1996) and possibly changes in vocal intensity and pitch as a result (Gotaas and Starr, 1993). In addition, vocal intensity increases with the distance between conversation partners (Michael, Siegel & Pick, 1995). Therefore, in the present study, effect of natural environmental noise on voice was investigated with these two variables controlled: 1) a relatively short phonation time was required in each recording conditions and 2) the conversational distance was fixed to 1 m. These aimed to avoid other possible vocal loading factors which would affect the pitch and vocal loudness produced by the participants.

To allow recordings in natural environments, Amulatory Phonation Monitor (APM) was used as a recording instrument in this study. APM is a portable instrument that mainly consists of a microprocessor and a throat sensor (accelerometer). Throat sensor, which is attached to the user's neck in the area above the sternal notch, senses the skin vibration during phonation. The signals are then transmitted to the APM unit for analysis. The estimates of vocal parameters are stored and these data can be downloaded to Personal Computer for further statistical analysis. It can reliably and objectively record important vocal parameters, such as phonation duration, fundamental frequency and sound pressure level (Hillman and Cheyne, 2003).

Small size and unobtrusive location of APM allows portability to realistic environments. Moreover, the accelerometer of APM has advantages over microphone, which was usually used in previous studies (e.g. Pittman and Wiley, 2001;Tartter *et al.*, 1993). The accelerometer only records vibration from the skin surface of the user, and thereby, is immune to any environmental sounds and speech sounds from others (Hillman and Cheyne, 2003). This allows a more accurate measurement of acoustic parameters for the participants, with no interference by noise signals.

The purpose of the present study was to investigate the effects of natural environmental noise on vocal intensity, fundamental frequency and perceived vocal effort in 24 vocally healthy young adults and was to examine any gender differences among the parameters. This study also aimed to examine any correlation between self-perceived vocal effort and the acoustic parameters under natural environmental noise. It was hypothesized that increase in environmental noise levels would result in higher fundamental frequency, vocal intensity and perceived vocal effort, and the acoustic parameters would show positive relationship with the self-perceived vocal efforts.

METHODS

Participants

Twelve Hong Kong Cantonese-speaking males and 12 females participated in the study. Each male and female participant was matched by the age within four years (mean 21.2 years, standard deviation 1.17, ranged from 19 to 22 years). All the participants were university students and also satisfied the following criteria:

1. Reported to have no history of voice disorders.
2. Reported to have no medically diagnosed hearing loss.
3. Passed hearing screening at 25dB in 250, 500, 1000, 2000, 4000 and 8000 Hz.
4. Had no reported or observable upper respiratory infection on the day of the recording.
5. Had normal voice on the day of the recording as judged by the experimenter.

Procedures

Self-monologue task

All participants were briefly told that this study was to investigate normal voice use during speech. The main purpose and parameters studied were not mentioned. This aimed to reduce experimenter expectancy effect on voice use under different envirnomental noise levels.

The participants were required to hold a monologue under three recording conditions with different contents. The three recording conditions, which varied with the environmental noise levels, were a quiet clinic room, a clinic corridor and a pantry room with an exhaust fan.

The mean background noise levels for the quiet clinic room, the clinic corridor and the pantry room were 35.5 dBA, 54.5 dBA and 67.5dBA respectively (see Table 1). The order of conditions was randomized in a predetermined sequence for each gender group.

The monologue speech for each participant in each recording condition lasted about three- to five-minutes. The participants were asked to talk about their leisure activities with the experimenter. The conversation distance between the participant and the experiment was fixed to 1 m. During the monologue task, the experimenter did not give any feedbacks regarding how well the speech was heard. This aimed to avoid any effects on the vocal intensity levels and pitch levels adjusted by the participants, and also this allowed the study of their natural vocal behaviors under natural environmental noise. If the participants were not able to complete the monologue task for three minutes which was set as minimum task duration, prompting questions were given by the experimenter.

To ensure the noise levels of the same conditions were within the predetermined ranges for all participants, the background noise levels in each recording condition were measured by the sound level meter (TES instrument, 1350A). Every recording in each condition were within the corresponding noise level ranges, as shown in Table 1. Prior to each of the three recording conditions, the participants were given a three-minute vocal rest and 100ml of water, as vocal rest and hydration are useful ways to maintain vocal function and quality (Yiu & Chan, 2002).

The entire procedure was done on a single session. It took approximately 25 to 30 minutes for each participant.

Table 1. *Three recording conditions with different range of noise levels*

Conditions	Mean noise level (dBA)	Noise level ranges (dBA)
C-1: Quiet clinic room	35.5	34-37
C-2: School corridor	54.5	53-56
C-3: Pantry room	67.5	66-69

Voice recording for acoustic analysis

Each participant was asked to wear the Ambulatory Phonation Monitor (APM) (KayPENTAX, Model 3200) throughout the self-monologue tasks in all of the three recording conditions. The APM was calibrated for each participant before the start of the whole recording session. The throat sensor of the APM was attached to the participant's neck, which was in the area above sternal notch (see Figure 1). The skin vibrations during phonation were sensed and transmitted to the APM unit. The recordings C-1, C-2 and C-3 were carried out in three recording conditions, the quiet clinic room (34-37dBA), the clinic corridor (53-56dBA) and the pantry room (66-69dBA) respectively. Phonation time profile, including fundamental frequency and vocal intensity, of the whole monologue speech across three recording conditions for each participant were recorded and later transmitted to personal computer for analysis.

FIGURE 1. Ambulatory Phonation Monitor (APM) components: a APM unit (the white box) and a throat sensor (the small silver case glued at the neck)

Subjective vocal effort rating

After completing each of the monologue task, the subject was asked to rate the vocal effort used in the quiet room (C-1), the clinic corridor (C-2) and the pantry room (C-3). The participants were immediately asked to respond on a 11-point equal-appearing interval scale [0 – effortless; 10 – extremely effortful], regarding the question "What did you feel in your voice or throat during the monologue speech?".

Data analysis

Acoustic analysis

Mean fundamental frequency and vocal intensity were obtained from the monologue speech sample of each condition using APM analysis. The whole monologue speech sample in each condition was extracted and pooled for analysis. By using built-in APM analysis, the phonation time profiles were plotted for each participant, as shown in figure 2. Analysis results displaying mean fundamental frequency and mean vocal intensity were calculated from the corresponding phonation time profiles extracted, as shown in figure 3. The resting time between the conditions was excluded from the record.

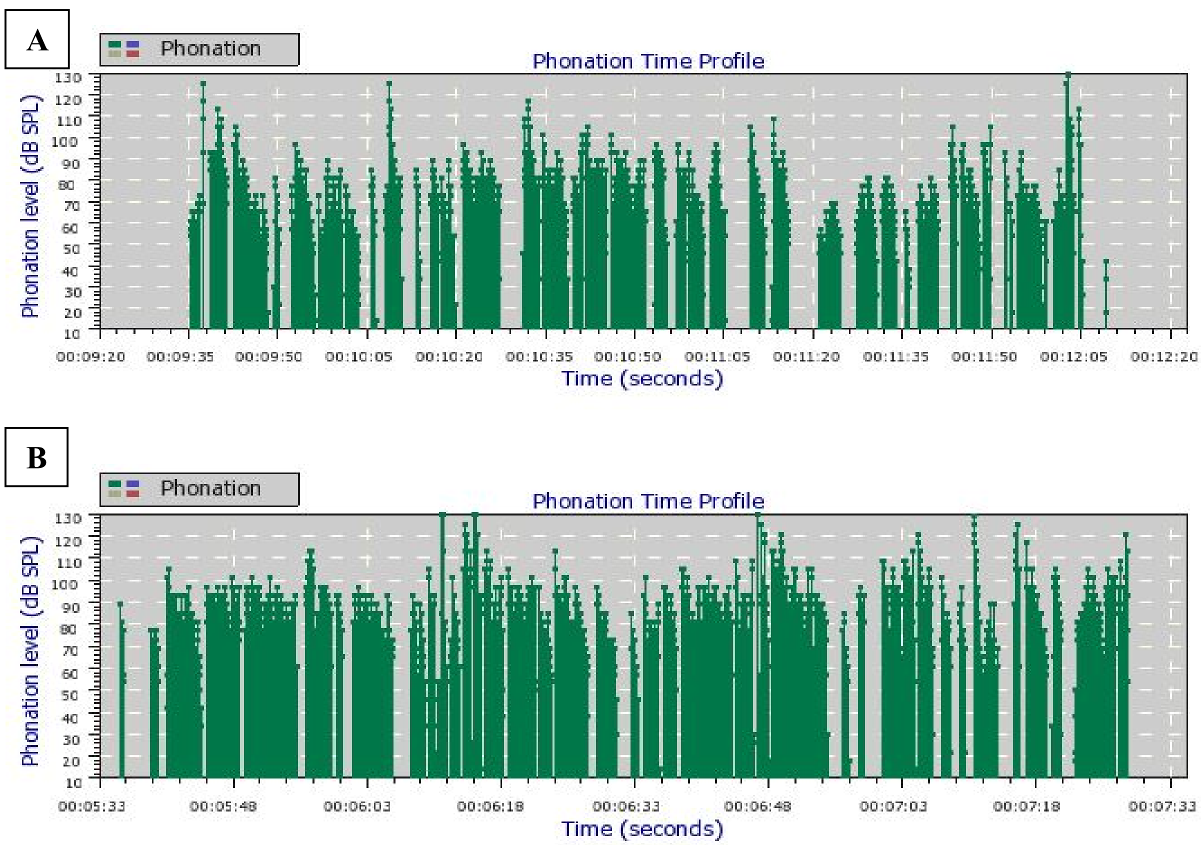

Figure 2. Two Phonation time profile from a female subject during **(A)** the quiet clinic room (34-37dBA) and **(B)** the pantry room (66-69dBA), with phonation time (s) on the horizontal axis, phonation level (dB SPL) on the vertical axis.

A

GENERAL	
Examination Date:	01/21/2009
Examination Started:	16:40:02
Total Exam Duration:	00:12:22
SPL Calibration:	SPL = (Acc - 34.04)/0.25 + 49.19
ANALYSIS RESULTS	
Note: results for displayed data only	
Phonation Time	
Displayed Duration:	00:03:02
Start Offset:	00:09:20
Phonation Time:	00:01:24 (46.22%)
Outside display settings:	00:00:01 (0.60%)
Fundamental Frequency	
F0 Mode:	164 Hz
F0 Average:	188.22 Hz
Sound Pressure Level	
Amplitude Average:	68.66 dB

B

GENERAL	
Examination Date:	01/21/2009
Examination Started:	16:40:02
Total Exam Duration:	00:12:22
SPL Calibration:	SPL = (Acc - 34.04)/0.25 + 49.19
ANALYSIS RESULTS	
Note: results for displayed data only	
Phonation Time	
Displayed Duration:	00:02:02
Start Offset:	00:05:33
Phonation Time:	00:01:17 (63.77%)
Outside display settings:	00:00:01 (1.31%)
Fundamental Frequency	
F0 Mode:	176 Hz
F0 Average:	204.20 Hz
Sound Pressure Level	
Amplitude Average:	81.51 dB

Figure 3. Analysis results from the same female subject in **(A)** the quiet clinic room and **(B)** the pantry room, corresponding to the plots in figure 2.

RESULTS

With small sample size (N = 24), nonparametric statistics were used for data analysis of acoustic and subjective rating parameters. In addition, Spearman correlation test was used to examine the correlation between the subjective vocal effort rating and the acoustic parameters.

Analysis of acoustic and subjective measures

Gender difference across conditions

Table 2 shows the mean acoustic and subjective parameters across three noise levels in each gender group. Mann-Whitney tests were carried out for each acoustic and subjective measure between gender groups in each of the three recording conditions. The average vocal intensity of male group was slightly higher than that of female group in all conditions. However, the difference was not statistically significant in the quiet clinic room (C-1) (Mann-Whitney, $U = 70$, $Z = -0.12$, $p = 0.908$), the clinic corridor (C-2) (Mann-Whitney, $U = 65$, $Z = -0.4$, $p = 0.686$) and the pantry room (C-3) (Mann-Whitney, $U = 54$, $Z = -1.04$, $p = 0.299$). As expected, the average fundamental frequency of female group was largely higher than that of male group in the quiet clinic room (C-1) (Mann-Whitney, $U = 0$, $Z = -4.16$, $p < 0.001$), the clinic corridor (C-2) (Mann-Whitney, $U = 1$, $Z = -4.1$, $p < 0.001$) and the pantry room (C-3) (Mann-Whitney, $U = 1$, $Z = -4.1$, $p < 0.001$). The average subjective vocal effort rating of male group was slightly higher than that of female group. However, same as the average vocal intensity, there was no significant difference between gender groups in the quiet clinic room (C-1) (Mann-Whitney, $U = 42.5$, $Z = -1.74$, $p = 0.081$), the clinic corridor (C-2) (Mann-Whitney, $U = 50.5$, $Z = -1.27$, $p = 0.205$) and the pantry room (C-3) (Mann-Whitney, $U = 43.5$, $Z = -1.68$, $p = 0.093$).

TABLE 2. *Mean acoustic measures of the monologue speech sample across the three conditions in each gender group.*

Gender	C1				C2				C3			
	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum
Fundamental frequency (Hz)												
Male	124.22	20.73	98.18	175.91	123.53	15.99	98.87	157.46	138.85	23.03	104.71	191.08
Female	204.79	18.42	175.08	248.13	198.69	19.26	168.06	245.69	215.30	19.29	190.16	266.43
Vocal Intensity (dB)												
Male	64.74	5.97	58.32	78.19	64.16	3.87	57.88	72.04	74.68	6.47	67.65	91.11
Female	63.64	4.93	57.04	71.32	63.02	4.81	54.32	69.12	72.00	4.30	65	81.51
Vocal Effort Rating												
Male	4.08	2.11	1	5	4.17	1.34	2	6	5.67	1.23	4	8
Female	2.58	1.44	0	5	3.33	1.61	2	6	4.58	1.51	2	7

C1 = recording in quiet clinic room (34-37dBA); C2=recording in clinic corridor (53-56dBA); C3 = recording in pantry room (66-69dBA)

Effects of noise levels on acoustic and subjective parameters

Friedman tests were carried for each acoustic and subjective measure across the three recoding conditions in each gender group. Significant changes in average fundamental frequency (chi-square = 15.5, $p < 0.001$), average vocal intensity (chi-square = 18, $p < 0.001$) and subjective vocal effort rating (chi-square = 17.42, $p < 0.001$) were found in the male group. It was the same in the female groups with significant changes in fundamental frequency (chi-square = 17.17, $p < 0.001$), vocal intensity (chi-square = 18.17, $p < 0.001$) and vocal effort rating (chi-square = 10.38, $p = 0.006$).

Further planned Wilcoxon signed ranked tests were then carried out, as shown in Table 3. Since three tests were carried out for each gender group, the adjusted level of significance was 0.0168 (i.e. 0.05/3). Results showed a significantly higher fundamental frequency, vocal intensity and vocal effort rating in the pantry room (C-3) when compared with those in the quiet clinic room (C-1) and the clinic corridor (C-2) in the male and the female group (See Table 3, all $p < 0.0168$). There was no significant difference on average vocal intensity, average fundamental frequency and subjective vocal effort rating between the quiet clinic room (C-1) and the clinic corridor (C-2) in the male group (See Table 3, all $p > 0.0168$). In the female group, no significant difference on vocal intensity and subjective rating in the quiet clinic room (C-1) and the clinic corridor (C-2) (See Table 3, all $p > 0.0168$), but exceptionally, a significantly higher fundamental frequency for the female group in the quiet clinic room (C-1) than that in the clinic corridor (C-2) (See Table 3, $p = 0.015$).

TABLE 3. *Further planned Wilcoxon signed ranked tests of mean acoustic measures across three conditions in each gender group.*

Gender		**Wilcoxon signed ranked test** Z	p
Fundamental frequency (Hz)			
Male	C1-C2	-0.24	0.814
	C2-C3	-2.98	**0.003**
	C1-C3	-3.06	**0.002**
Female	C1-C2	-2.43	**0.015**
	C2-C3	-3.06	**0.002**
	C1-C3	-2.59	**0.01**
Vocal intensity (dB)			
Male	C1-C2	-0.24	0.814
	C2-C3	-3.06	**0.002**
	C1-C3	-3.06	**0.002**
Female	C1-C2	-0.82	0.41
	C2-C3	-3.06	**0.002**
	C1-C3	-3.06	**0.002**
Vocal effort			
Male	C1-C2	-0.32	0.748
	C2-C3	-2.99	**0.003**
	C1-C3	-2.87	**0.004**
Female	C1-C2	-1.67	0.094
	C2-C3	-2.51	**0.012**
	C1-C3	-2.53	**0.012**

C1 = recording in quiet clinic room (34-37dBA); C2=recording in school corridor (53-56dBA); C3 = recording in pantry room (66-69dBA)

Correlation between subjective and acoustic measures

Mean Spearman's rank correlation coefficients for the correlation between mean vocal intensity and subjective vocal effort rating were 0.28 and 0.13 for male and female groups respectively. Mean Spearman's rank correlation coefficients for the correlation between mean fundamental frequency and subjective vocal effort rating were 0.49 and 0.41 for the male and the female groups respectively.

DISCUSSION

The main objective of this study was to examine the effects of natural environmental noise on the production of vocal intensity, fundamental frequency and perceived vocal effort ratings by individuals. Both female and male groups exhibited a significantly higher average vocal intensity, average fundamental frequency and perceived vocal effort in the pantry room (mean background noise = 67.5dBA) than those in the quiet clinic room (mean background noise = 35.5dBA) and the clinic corridor (mean background noise = 54.5dBA). These findings were consistent with the results of previous laboratory and field studies (e.g. Tartter, 1993; Sodersten *et al.,* 2002; Sodersten *et al.,* 2005) and supported that Lombard effects took place under high background noise levels. To overcome the masking effect of noise, the participants automatically increase vocal loudness. The fundamental frequency would increase as a passive consequence of increase in subglottal pressure (Gramming *et al*., 1988; Alku, Vintturi & Vilkman, 2002). The mechanical loading on the vocal fold tissues would correspondingly increase due to high fundamental frequency and vocal intensity during phonation (Jiang & Titze, 1994), which might result in an increase in perceived vocal effort.

Contrary to expectation, both groups exhibited no significant difference on average vocal intensity, average fundamental frequency and perceived vocal effort between the quiet clinic room (mean background noise = 35.5dBA) and the clinic corridor (mean background noise = 54.5dBA), except the average fundamental frequency in the female group.

Regarding the fact that no significant difference in acoustic and subjective parameters between these two conditions, it was postulated that background noise levels in these two conditions were not high enough to mask the speech production. International Organization for Standardization (1974), as cited by Sodersten *et al.* (2002), stated that "a noise level of 55 dBA gives 95% speech intelligibility for normal running speech at one meter." (p.358). It might have been not necessary for the participants to increase the vocal loudness, in order to maintain the speech intelligibility. The participants could still use their usual or comfortable speech levels as in the quiet clinic room. Therefore, both gender groups exhibited similar speech levels across these two recording conditions. Correspondingly, the fundamental frequency would not rise significantly and relatively little strain was exerted on vocal folds, comparing to that in the pantry room.

Regarding the fact of higher fundamental frequency in quiet clinic room (mean background noise = 35.5dBA) than that in clinic corridor (mean background noise = 54.5dBA) within female group, it might have been due to the type of speech samples used in this study.

Monologue speech task, which is a kind of spontaneous speech production, undoubtedly shows higher viability in intonation. As the contents of monologue speech in each recording conditions for every participants were different, this probably affected the fundamental frequency of their speech.

The second objective was to examine the gender differences on the acoustic and subjective parameters across different natural environmental noise levels. Female group exhibited significantly higher fundamental frequency than male group, which was not surprising. The average vocal intensity of male group was slightly higher than that of female group in all conditions, though the difference was not statistically significant. The findings were in line with the laboratory results from Pearson *et al.* (1977). The perceived vocal effort of both gender groups was similar and this suggested equal sensitivity to vocal effort in both groups. However, this result was inconsistent with the laboratory findings from Soderstern *et al.* (2005), which reported female experienced higher levels of effort than male. The differences are possibly due to higher noise levels (range = 70-80 dBA) introduced to the participants in the study by Soderstern *et al.* (2005). Untrained speakers, especially female, often adopted hyperfunctional vocal behavior as a strategy to raise vocal intensity (Vilkman *et al*., 1998). Higher noise levels, plus hyperfunctional vocal behavior with much higher fundamental frequency, might bring more vocal loading and strain to the female group. Another possible reason was related to the subjectivity of the rating scales. The susceptibility to vocal strain or effort varied from individuals to individuals. Therefore, the results differed from previous findings.

The third objective was to examine the correlation between acoustic parameters and perceived vocal effort ratings. Low to moderate positive but non-significant correlation was found between fundamental frequency and perceived vocal effort rating, whereas little or no correlation was found between vocal intensity and perceived vocal effort ratings. This is worth further investigation on what the vocal effort rating reflects by using a larger sample size.

In summary, this study showed that high natural background noise levels bought a significant increase in the production of fundamental frequency and average vocal intensity in monologue for both male and female. Lombard effect occurred when the natural environmental noise levels exceeded the values that masking noise made an adverse effect on speech intelligibility.

However, there were several limitations with the methodology. The first limitation related to subject recruitment. Only young adults ranged from age 19 to 22 year were recruited in this study. The sample recruited was not representative of the general population. In addition, the sample size was small as only twelve participants in each gender group. More powerful parametric test was not allowed to use and to conclude the difference and the correlation on the acoustic and subjective variables between gender groups. Therefore, future studies with a larger sample size and a wider age range will be recommended.

The second limitation related to the range of noise studied. Lombard effect was only found in the recording condition with the highest background noise level (i.e. the pantry room, mean background noise levels = 67.5 dBA), but not in the condition with a lower background noise level (i.e. the clinic corridor, mean background noise level = 54.5 dBA). As in many public places, such as Chinese restaurant and café, are prone to have higher background noise levels than the places in this study, further investigation on its effects on voice is recommended, in order to have thorough understanding on the extent of Lombard effect under very high natural environmental noise.

In spite of these limitations, the findings from this study are useful for theoretical and clinical purpose. It is shown that noise exerts adverse effects on voice parameters when the noise levels is at the range of 66-69 dBA while little or no effects below the range of 53-56 dBA. Specifically, both male and female groups produced speech at approximately 9-10dB SPL louder and 15-16 Hz higher in pitch when average background noise level rose from 54.5 dBA to 67.5 dBA. Results confirmed that noise is a vocal loading factor. As high fundamental frequency and vocal intensity will have detrimental effects on the vocal fold tissues, prolonged use of voice under noisy environments would increase the risk of having voice discomfort or problems. It warrants concern for the individuals who spend time working or speaking under high background noise environments, such as Chinese restaurant and transportation. It is recommended to avoid prolonged speaking under these noise environments or to introduce proper vocal hygiene for those individuals.

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