Effect of Noise on Vocal Loudness and Pitch in Natural Environments: An Accelerometer (Ambulatory Phonation Monitor) Study

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Summary: Purpose. This study investigated the effects of environmental noise on the production of vocal intensity and fundamental frequency using an accelerometer.

Methods. Twenty-four vocally healthy young adults (12 men and 12 women, aged 19–22 years) recorded a monologue passage using KayPENTAX (Montvale, NJ, USA) Ambulatory Phonation Monitor (model 3200) under three natural environmental conditions in a randomized order: a quiet room (mean noise, 35.5 dBA), room with moderate level of noise (mean noise, 54.5 dBA), and a room with high noise (mean noise, 67.5 dBA).

Results. Both gender groups showed significant increases in the mean vocal intensity, fundamental frequency, and perceived vocal effort in the high-noise environment than in the other two conditions. No significant difference was found in the vocal intensity between the quiet and moderately noisy environment except in the fundamental frequency in the female group.

Conclusions. This study showed that the use of accelerometer for laryngeal signal recordings could be a useful tool for measuring phonation without being affected by the background noise. The findings also support the recommendation that noise levels for conversation should be kept <50–55 dB to maintain speech intelligibility.

Key Words: Lombard effect–Accelerometer–Background noise.

INTRODUCTION

Human communications can be prone to breakdown if the living environment is filled with background noises. To speak over the background noise, speakers often have to increase their vocal loudness so as to maintain an adequate loudness level for self-auditory monitoring[1] and for the listeners' comprehension.[2] This automatic increase in vocal loudness is known as Lombard effect.[2] In addition to an increase in vocal intensity, fundamental frequency is also found to increase with the background noise.[3] The increase in these two dimensions may have a negative impact on the speakers as they may adopt a habitual hyperfunctional vocal behavior as a strategy to raise vocal intensity and fundamental frequency.[4] The increase in vocal demand makes one vulnerable to vocal strain and poses a possible risk of developing vocal damages.[5]

One of the challenges in studying Lombard effect involves the measurement of the vocal intensity and frequency of the speakers separated from the background noises. Hence, many of these studies reported in the literature were carried out in well-controlled laboratory situations involving tasks that varied from reading aloud single words to passage reading and spontaneous speech.[6–8]

A study by Van Summers et al[9] found the speakers' vocal intensity increased from 3.5 to 6.9 dB when the noise level increased from 80 to 100 dB SPL. The sample size in this study was, however, small (n = 2), and the noise used was an artificial broadband white noise. Tartter et al[8] replicated the study with two female subjects and lower noise level (35 dB SPL). The vocal intensity increased from 1.0 to 3.7 dB when the white noise was increased to 80 dB SPL. Similar increase in vocal intensity was found in a study by Junqua.[6] In that study, five male and five female subjects demonstrated an increase of 12.6 dB (male) and 18.2 dB (female), respectively, in vocal intensity when a white noise of 80 dB SPL was introduced. Similar increase in vocal intensity (14.5 dB) was also demonstrated in five female subjects in another study by Pittman and Wiley,[7] who used 80 dB SPL of white noise and babble noise in their study. In summary, vocal intensity has found to increase by 3.7 to 18.2 dB when the background noise level is increased from 35 to 80 dB SPL.

The effect of noise on vocal fundamental frequency has also been examined rather extensively in controlled situations. Letowski et al[10] examined five men and five women who were asked to read aloud connected speech under different situations that included quiet, multitalker babble noise, traffic noise, and wideband noise at 70 dB SPL and 90 dB SPL. They found not only a significant increase in vocal intensity of 3.4 dB and 7.4 dB when 70 dB SPL and 90 dB SPL noises were applied, respectively, but also a significant increase in fundamental frequency of 2.5 Hz and 18 Hz in the female group, and 16 Hz and 28.5 Hz in the male group with the 70 dB SPL and 90 dB SPL noise, respectively. There was, however, no significant difference across three types of noise, suggesting that the type of noise did not have specific effect on the vocal output. These findings were later replicated in a study by Södersten et al.[11] In that study, a group of 23 healthy speakers (12 women and 11 men) were required to give oral presentations under four different contexts each with a different type of background noise (quiet room <30 dBA, stationary white noise 70–78 dBA, noise in a day care center 74 dBA, loud pop music 87 dBA). The investigators found a significant increase in the vocal intensity, fundamental frequency, and

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perceived vocal effort when the background noise was increased. No significant difference was found between the types of noise at similar noise levels though.

The studies reviewed previously were all carried out under simulated situations. There are also studies which used more naturalistic situations that have demonstrated Lombard effect. Pearsons et al[12] reported that the vocal intensity of school teachers increased from 45 to 55 dB (measured at 1 m distance) when the noise in the classroom increased from 67 to 78 dB SPL. Sala et al[13] also found the vocal intensity of day care center teachers to be as high as 68 dB SPL during work days with a background noise between 64 and 70 dB. Södersten et al[14] found similar increase in fundamental frequency and vocal intensity in preschool teachers when the noise level was increased from 48 to 78 dBA.

Not all of these studies, whether laboratory based[8–11] or naturalistic based,[12–14] documented or controlled the amount of speaking in their subjects before the recording. Prolonged speaking often leads to vocal fatigue, which in turn, requires more effort to continue speaking.[15] This may subsequently affect the vocal loudness and pitch.[16] Therefore, there is a need to document or control for the amount of talking (phonation) when one investigates the Lombard effect. One of the challenges in measuring vocal pitch and loudness under natural background noise situation is how to measure the source of phonation without being affected by the background noise.

One of the recent developments is the application of accelerometer in measuring voice activities.[17,18] This instrument is marketed as Ambulatory Phonation Analyzer and has been used rather extensively to study the voice use in student singers[19]; monitoring and logging voice use in call center operators,[20] teachers,[21] after surgery[22]; and for clinical use with patients with voice disorders.[18] With the attachment of the accelerometer to the neck above the sternal notch, the accelerometer detects the skin vibration during phonation. Voice accumulator recordings can be made through a portable microprocessor. Voice accumulator measures that have been developed include phonation duration, fundamental frequency, and sound pressure.[17]

Voice accumulator recording has a number of advantages over microphone recording. Voice accumulator only records vibration from the skin surface of the speaker and therefore is immune to any environmental noise other than the vocal source.[17] This allows the analyses of the data without interference from the background noise. In summary, the small size of the accelerometer allows an unobtrusive use of the voice accumulator in naturalistic settings.

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. The amount of talking before and during recording was controlled for in the study. Gender differences were also examined. This study also aimed to examine the correlation between self-perceived vocal effort and the vocal performance in terms of intensity and fundamental frequency under natural environmental noise. It was hypothesized that an increase in the 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 Cantonese-speaking men and 12 women from The University of Hong Kong participated in this study. The two gender groups were matched in age (±4 years; mean age, 21.2 years; standard deviation, 1.17 years; range, 19–22 years). All the participants satisfied the following criteria:

1. No reported history of voice disorders.
2. Passed a hearing screening of 25 dB at 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz.
3. No reported or observable upper respiratory infection on the day of the recording.
4. Normal voice on the day of the recording as judged by the examiner.

Procedures

All the participants were informed of the objective of this study was to investigate normal voice use pattern in daily life. The exact measures to be collected were not mentioned to the participants so as to minimize the expectancy effect. All the participants were reminded not to talk in the morning before they came to have their voice recording done. Recordings were done as early as possible in the morning so that all participants were expected to have a full night of voice rest.

KayPENTAX Ambulatory Phonation Monitor (APM; model 3200, Montvale, NJ, USA) was used as the recording instrument in the study. The recording provided a phonation time profile which displayed the vocal intensity across time (Figure 1). Summary statistics included total duration of recording, time of phonation, mean fundamental frequency, and sound pressure level. Calibration of the APM was undertaken according to the manual before the beginning of the recording session for each participant. The throat sensor (accelerometer) of the APM was attached to the participant's neck just above sternal notch (Figure 2). Skin vibrations during phonation were detected and transmitted to the APM unit.

Initial tasks required the participants to carry out three monologues, each under a different recording condition. The three recording conditions varied in the level of background noises. These include (1) quiet (clinic room, mean 35.5 dBA, ranged from 34 to 37 dBA), (2) medium noise (clinic corridor, mean 54.5 dBA, ranged from 53 to 56 dBA), and (3) high-noise (a pantry room with a noisy exhaust fan, mean 67.5 dBA, ranged from 66 to 69 dBA) situations. The order of recordings under these three conditions was randomized for each participant.

Each monologue lasted between 3 and 5 minutes according to the speech rate of the each participant. Each participant was asked to talk about their leisure activities facing the experimenter at a 1-m distance. No verbal feedback was provided to the participants during the recording regarding how well the