Effect of Training and Level of External Auditory Feedback on the Singing Voice: Volume and Quality

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Summary: Background. Previous research suggests that classically trained professional singers rely not only on external auditory feedback but also on proprioceptive feedback associated with internal voice sensitivities.

Objectives. The Lombard effect and the relationship between sound pressure level (SPL) and external auditory feedback were evaluated for professional and nonprofessional singers. Additionally, the relationship between voice quality, evaluated in terms of singing power ratio (SPR), and external auditory feedback, level of accompaniment, voice register, and singer gender was analyzed.

Methods. The subjects were 10 amateur or beginner singers and 10 classically trained professional or semiprofessional singers (10 men and 10 women). Subjects sang an excerpt from the Star-Spangled Banner with three different levels of the accompaniment, 70, 80, and 90 dBA and with three different levels of external auditory feedback. SPL and SPR were analyzed.

Results. The Lombard effect was stronger for nonprofessional singers than professional singers. Higher levels of external auditory feedback were associated with a reduction in SPL. As predicted, the mean SPR was higher for professional singers than nonprofessional singers. Better voice quality was detected in the presence of higher levels of external auditory feedback.

Conclusions. With an increase in training, the singer's reliance on external auditory feedback decreases.

Key Words: Singing voice–Lombard effect–Auditory feedback–Voice training–Singing power ratio.

INTRODUCTION

It has been established that auditory feedback has a strong effect on the performance of singers and instrumentalists, and an integration of such feedback is important in the search for the ideal sound.[1] In the case of instrumentalists, the source of sound is external to their own body, whereas for vocal performers, the voice is generated internally. Therefore, vocal performers rely not only on external auditory feedback but also on proprioceptive feedback associated with internal voice sensitivities. These sensitivities, consisting primarily of pallesthetic (vibratory) and kinesthetic (muscular) sensitivities, provide performers with landmarks for controlling their emissions.[2] This means of control is more reliable than external auditory feedback, in which the perceived voice is substantially modified by the acoustics of the environment.[2]

Over the last few decades, several studies have been conducted to quantify external auditory feedback and to assess which acoustic parameters are relevant to performance quality.[3] Currently, the support (ST) parameters proposed by Gade[3] are part of the standard ISO 3382:2009.[4] A voice-specific support parameter, ST_V, was proposed by Brunskog et al[5] and revised by Pelegrín-García.[6] By analogy with Gade's ST parameters,[3] this parameter is termed voice support and is defined as the difference between the reflected sound and the direct sound of the impulse response (IR), measured using the mouth of a Head and Torso Simulator (HATS) as the source, with the ears as receivers.

During a performance, the singer moves around on the stage. In different positions, the acoustic conditions and the balance with the orchestra differ; however, the singer's voice emission should be internally consistent. Consequently, one of the goals of classical vocal training is to emit a consistent sound that is independent from the acoustics of the space. This goal is inconsistent with natural tendencies in the use of the voice, such as the Lombard effect. Lombard noted in 1911 that a speaker changes his or her voice level when the ambient noise level increases, on the one hand, and when the level at which he hears his own voice (his external auditory feedback) decreases, on the other hand.[7]

Few studies have examined the Lombard effect in singers. Coleman and Hicks[8] measured the sound pressure level (SPL) produced by singers (six professional singers, six choir singers) at 6 inches from the mouth during a performance of two songs with three different levels of accompaniment (80, 95, and 110 dB) presented by means of headphones. In most cases, professional singers were approximately 5–6 dB louder than choir singers. The only significant effect of the level of the accompaniment on that of the voice was found for choir and professional singers with a slope of 0.06 dB/dB and 0.12 dB/dB, respectively. In 1992, Tonkinson[9] found a similar effect in choir singers, but experience was not a significant factor.

The SPL of the voice is also influenced by the dynamics specified in the score. Boren et al[10] asked nine professional singers (six women and three men) to perform a piece (30–60 seconds long) from their repertoire at three levels: pianissimo, mezzo forte, and fortissimo. The range of the *L*eq for the mask singing voice was found to be 73.2–84.8 dBA, whereas the range of the peak SPL was 93.8–106.4 dBA.

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The Lombard effect involves not only an increase in SPL but also spectral changes.[11] Some voice acoustic measures take into account these spectral changes and their relationship with voice quality. Among them, the singing power ratio (SPR)[12] represents the ratio between the greatest spectral resonance peak between 2 and 4 kHz and the greatest spectral resonance peak between 0 and 2 kHz. This parameter, which typically relates to the number of years of voice training, is used for an objective evaluation of singing voice quality.[13]

In the present study, recordings of an excerpt of the Star-Spangled Banner (the American National Anthem) sung by 10 female and 10 male classical singers were analyzed. The singers comprised 10 professional and 10 nonprofessional singers. The Lombard effect in singers and the relationship between SPL and external auditory feedback were evaluated for both groups. Additionally, the relationship between voice quality (evaluated in terms of SPR) and external auditory feedback, level of accompaniment, voice register, and singer gender were analyzed.

METHODS

Subjects

The human subject research was approved by the institutional review board (IRB #13-1149). Ten female and ten male singers (mean age, 22.9 ± 4.5 years) participated in the experiment. The sample was divided into two groups: group 1 comprised amateur or beginner singers, whereas group 2 comprised professional and semiprofessional classical singers. In group 1, there were three sopranos, two mezzo-sopranos, three baritones, and two tenors. They were mainly choristers in *a cappella* choirs, with a primarily popular ("pop") repertoire, with years of singing experience ranging from 4 to 16 and an average number of years of private classical voice lessons equal to 4.7. In group 2, there were five sopranos, one mezzo-soprano, three basses, and one tenor. They were predominantly masters-level students in classical singing, with years of singing experience ranging from 4 to 14 and an average number of years of private voice lessons equal to 7.6.

Protocol

After an initial (guided) warm-up, subjects performed vocal tasks in three different external auditory feedback conditions. The tasks consisted of singing an excerpt from the Star-Spangled Banner with a musical accompaniment, without the use of falsetto. The keys used were B major for tenors and sopranos and Ab major for the other singers. These keys were chosen with the purpose of recording notes in the low, middle, and high registers according to the voice type. The scores of the excerpt for the different voice types are shown in Figure 1.

The experiment was conducted in a soundproof room (2.5 × 2.75 m and $h = 2$ m). This environment is referred to as set 1. In a second condition (set 2), two reflective panels were placed in this room at 0.5 m from the singers, 45° from the mouth axis. In this condition, external auditory feedback was increased. In the third condition (set 3), singers were asked to put on headphones, which cancelled external auditory feedback. Three different levels of the accompaniment were used: 70, 80, and 90 dBA measured at the singers' ears with a KEMAR 45BB-1 HATS (Denmark). In sets 1 and 2, the accompaniment was played by means of a loudspeaker, whereas in set 3, headphones were used.

A total of nine tasks were recorded for each subject by means of a boundary microphone (Behringer ECM8000, Germany) and a head-mounted microphone (HMM, Glottal Enterprises M-80, U.S.). Both microphones were connected to a PC via a Scarlett 2i4 Focusrite soundboard (U.K.). *Audacity 2.0.6* (U.S.) was used as the recording software. To avoid systematic effects introduced by the order of task presentation, task order was randomized.

Analysis

For each task performed by each subject, the time history of the SPL was calculated from the head-mounted microphone signal. The calibration of the signal was performed by means of a comparison with the signal of the boundary microphone, which was first calibrated with a Rion Sound Calibrator (NC-74, Japan). These analyses were conducted with *MATLAB R2014b (Mathworks, U.S.)*. The highest note in the excerpt from the Star-Spangled Banner (the vowel in the word "free") and a note in the low-middle voice register (the first portion of the vowel in the word "land") were selected in each task. The relevant notes are highlighted in Figure 1. SPR was calculated per vowel and task with *Praat 5.4.01 (Netherlands)*.

Linear mixed-effect models were fit by restricted maximum likelihood in *R 3.1.2*[14] using the *lme4* package[15] with *P* values

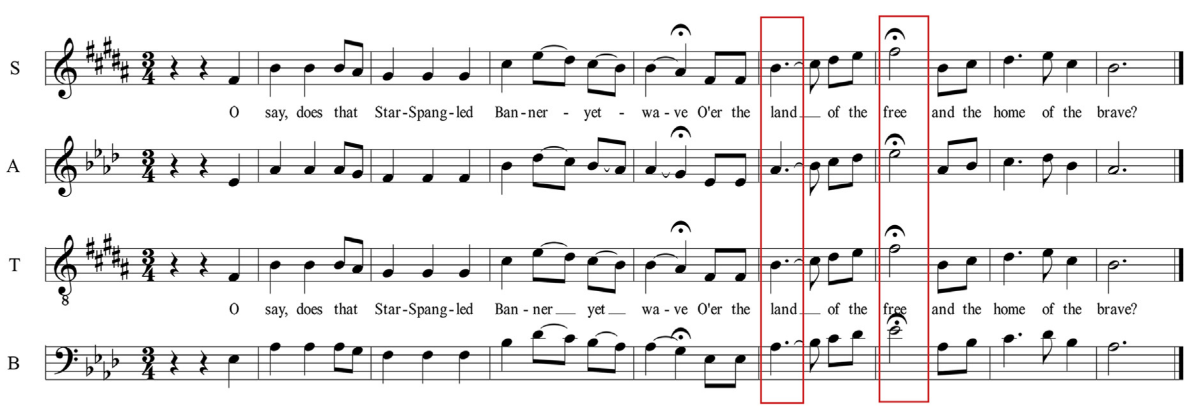

FIGURE 1. Scores of the excerpt from the Star-Spangled Banner used during the experiment. The keys used during the experiment were B major for tenors and sopranos and Ab major for the other singers.