Effect of Training and Level of External Auditory Feedback on the Singing Voice: Pitch Inaccuracy

Pasquale Bottalico, Simone Graetzer, and Eric J. Hunter, *East Lansing, Michigan*

Summary: Background. One of the most important aspects of singing is the control of fundamental frequency.
Objectives. The effects on pitch inaccuracy, defined as the distance in cents in equally tempered tuning between the reference note and the sung note, of the following conditions were evaluated: (1) level of external feedback, (2) tempo (slow or fast), (3) articulation (legato or staccato), (4) tessitura (low, medium, or high), and (5) semi-phrase direction (ascending or descending).
Methods. The subjects were 10 nonprofessional singers and 10 classically trained professional or semi-professional singers (10 men and 10 women). Subjects sang one octave and a fifth arpeggi with three different levels of external auditory feedback, two tempi, and two articulations (legato or staccato).
Results. It was observed that inaccuracy was greatest in the descending semi-phrase arpeggi produced at a fast tempo and with a staccato articulation, especially for nonprofessional singers. The magnitude of inaccuracy was also relatively large in the high tessitura relative to the low and the medium tessitura for such singers. Contrary to predictions, when external auditory feedback was strongly attenuated by the hearing protectors, nonprofessional singers showed greater pitch accuracy than in the other external feedback conditions. This finding indicates the importance of internal auditory feedback in pitch control.
Conclusions. With an increase in training, the singer's pitch inaccuracy decreases.
Key Words: singing voice–pitch accuracy–voice training–external auditory feedback–internal auditory feedback.

INTRODUCTION

Singers are typically required to sing with a high magnitude of precision in their fundamental frequency (f_o). This requires constant self-monitoring of vocal output and frequent small corrections in thyroarytenoid and cricothyroid muscle activity. In the context of singing, it is important that pitch accuracy be maintained even when singers cannot hear their own voices, so that their performance is not impaired by a loud orchestral accompaniment or by the choral sound of fellow singers.

During a performance, a singer will often perform in several different locations, in which the acoustic conditions and the balance with the orchestra will differ. Hence, with (classical) training, a singer will learn to rely not only on external auditory feedback, that is, the sound that the singer perceives of his or her own voice *via* air conduction, but also on proprioceptive feedback associated with internal (pallesthetic and kinesthetic) sensitivities. The main source of pallesthetic feedback is internal auditory feedback resulting from skull vibrations (bone conduction). Vibration of the vocal folds gives rise to a concomitant vibration in the bones of the skull, which stimulates the cochlea. There is also a perception of thoracic, facial, and other skeletal vibrations.[1–3] The most relevant receptors of kinesthetic feedback are the laryngeal sensory receptors.[4]

The significance of external and internal feedback to pitch control has been considered in a few previous studies. It has been found that, in the absence of auditory feedback, pitch accuracy typically decreases.[5–7] Hence, Ternström et al argued, "proprioceptive feedback plays a less important role than the auditory feedback in the [f_o] control by singers."[7(p191)] Elliot and Niemoeller[5] and Schultz-Coulton[8] found that external auditory feedback was vital to pitch accuracy, especially for adults without voice training (cf. Watts et al[9]).

There is some evidence of greater pitch accuracy for trained than untrained singers.[6,8,10] However, self-reported singing talent in untrained singers appears to compensate for a lack of training.[9–11]

In a partial replication of the Ward and Burns[6] study, Mürbe et al[12] found that the pitch accuracy of 28 singers who were at the beginning of their professional solo singing education decreased in the following conditions: (1) when auditory feedback was masked by noise at 105 dB(A) presented *via* headphones, (2) when a staccato *vs.* a legato articulation was used, and (3) when a fast *vs.* a slow tempo was used. In a second study, conducted immediately after the same subjects had completed 3 years of professional singing education, Mürbe et al[13] found the same trends with regard to masking noise, style, and tempo. They reported a smaller difference between masked and unmasked conditions in the slow (40 bpm) tasks in the second set of recordings, indicating a greater reliance on internal auditory feedback after the 3 years of education than before the education. There was no apparent effect of education on pitch accuracy in the fast tempo (160 bpm).

The effects of interval direction on pitch accuracy were reported by Edmonson.[14] He analyzed the pitch accuracy of five groups of music students (vocalists, string instrumentalists, pianists, brass instrumentalists, and woodwind instrumentalists) on four intervals (the perfect fourth, perfect fifth, major sixth, and minor third). It was demonstrated that vocal pitch acuity on ascending intervals is much better than acuity on the same descending intervals.

Accepted for publication January 27, 2016.
From the Voice Biomechanics and Acoustics Laboratory, Department of Communicative Sciences and Disorders, Michigan State University, East Lansing, Michigan.
Address correspondence and reprint requests to Pasquale Bottalico, Voice Biomechanics and Acoustics Laboratory, Department of Communicative Sciences and Disorders, Michigan State University, East Lansing, MI. E-mail: pb@msu.edu
Journal of Voice, Vol. 31, No. 1, pp. 122.e9–122.e16
0892-1997

http://dx.doi.org/10.1016/j.jvoice.2016.01.012

In the present study, the effects of the singers' level of training and the magnitude of external auditory feedback on pitch inaccuracy are investigated. In a previous study,[15] the magnitude of the Lombard effect[16] was investigated in the same 20 singers. It was found that trained singers were less responsive to changes in the level of the accompaniment than untrained singers, indicating less reliance on external auditory feedback. Therefore, the first prediction in the current study is that pitch accuracy is greater and less variable for trained than untrained singers across levels of external auditory feedback, tempo, articulation, and semi-phrase direction (ascending and descending) conditions. Second, it is predicted that pitch accuracy is better in an arpeggio produced at a slow tempo with a legato articulation and in the ascending semi-phrase than in an arpeggio produced at a fast tempo with a staccato articulation and in the descending semi-phrase. Finally, it is hypothesized that singers' pitch accuracy is reduced in the absence of external auditory feedback.

EXPERIMENTAL METHOD

Subjects

The use of human subjects for this research was approved by the Michigan State University's Human Research Protection Program (Institutional Review Board #13–1149). Ten female and 10 male singers (mean age 22.9 ± 4.5 years) volunteered to take part in the experiment. The sample was divided into two groups: the first comprised nonprofessional singers, and the second comprised professional classical singers. The age, gender, group, and voice type of the 20 subjects are reported in Table 1. The members of the nonprofessional group were mainly choristers in *a cappella* choirs, with a primarily popular repertoire. The professional singers were predominantly Master's students in classical singing, with a primarily operatic repertoire and a mean number of years of singing lessons equal to 7.6.

Protocol

The experiment was conducted in a sound-treated booth (2.5×2.75 m and $h = 2.0$ m). In the first condition, this environment was unchanged (set normal). In the second condition (set panels), 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 hearing protector), singers wore over-the-head, earmuff-style hearing protectors, which strongly attenuated external auditory feedback.

After an initial (guided) warm-up, consisting of five note scales covering the singer's range and a few repetitions of the arpeggio object of the study, singers performed arpeggi in three different external auditory feedback conditions. As a prompt, the first note was played on a keyboard before each arpeggio. The arpeggi were sung without musical accompaniment and without the use of falsetto. A metronome was displayed on a screen outside the sound booth and was visible but not audible.

A total of 12 tasks were recorded for each subject by means of a head-mounted microphone (Glottal Enterprises M-80 (Syracuse, NY, USA)), connected to a personal computer *via* a Focusrite (High Wycombe, UK) Scarlett 2i4 soundboard. The recording software used was *Audacity* 2.0.6 (U.S.). The order of set presentation was randomized, and the order of tempo and articulation conditions was randomized within each set. Tempo was varied between 40 and 160 bpm. Articulation varied between

TABLE 1.
Characteristics of the Sample, including Age, Gender, Group, Voice Type, Repertoire, Number of Years of Experience, and Number of Years of Classical Singing Lessons

Subject ID	Age	Gender	Group	Voice Type	Repertoire	Years of Experience	Years of Classical Singing Lessons
1	30	Female	Nonprofessional	Soprano	Choral classic	16	—
2	20	Female	Nonprofessional	Mezzo	Choral pop	10	—
3	21	Male	Nonprofessional	Baritone	Choral pop	10	—
4	19	Female	Nonprofessional	Soprano	Choral pop	12	—
5	20	Male	Nonprofessional	Tenor	Choral pop	4.5	—
6	29	Male	Nonprofessional	Tenor	Choral pop	12	—
7	19	Female	Nonprofessional	Mezzo	Choral pop	10	—
8	24	Male	Nonprofessional	Baritone	Choral classic	15	—
9	19	Male	Nonprofessional	Bass	Choral classic	10	—
10	19	Female	Nonprofessional	Soprano	Choral classic	10	—
11	19	Female	Professional	Soprano	Solo opera	4	3
12	25	Male	Professional	Tenor	Solo opera	12	10
13	19	Female	Professional	Soprano	Solo opera	7	2
14	32	Female	Professional	Soprano	Solo opera	14	12
15	21	Male	Professional	Baritone	Solo opera	12	12
16	22	Male	Professional	Baritone	Solo opera	12	6
17	24	Female	Professional	Soprano	Solo opera	7	7
18	26	Female	Professional	Mezzo	Solo opera	8	8
19	20	Female	Professional	Soprano	Solo opera	10	6
20	31	Male	Professional	Baritone	Solo opera	10	10