Singing proficiency in the general population

Simone Dalla Bella[a)]
Department of Cognitive Psychology, University of Finance and Management in Warsaw, Ul. Pawia 55, 01-030 Warsaw, Poland

Jean-François Giguère and Isabelle Peretz
Department of Psychology, University of Montreal, Montreal, Canada

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Most believe that the ability to carry a tune is unevenly distributed in the general population. To test this claim, we asked occasional singers ($n=62$) to sing a well-known song in both the laboratory and in a natural setting (experiment 1). Sung performances were judged by peers for proficiency, analyzed for pitch and time accuracy with an acoustic-based method, and compared to professional singing. The peer ratings for the proficiency of occasional singers were normally distributed. Only a minority of the occasional singers made numerous pitch errors. The variance in singing proficiency was largely due to tempo differences. Occasional singers tended to sing at a faster tempo and with more pitch and time errors relative to professional singers. In experiment 2 15 nonmusicians from experiment 1 sang the same song at a slow tempo. In this condition, most of the occasional singers sang as accurately as the professional singers. Thus, singing appears to be a universal human trait. However, two of the occasional singers maintained a high rate of pitch errors at the slower tempo. This poor performance was not due to impaired pitch perception, thus suggesting the existence of a purely vocal form of tone deafness. © *2007 Acoustical Society of America.*
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I. INTRODUCTION

Singing is generally regarded as the privilege of a select few who are widely prized for their skill. Accordingly, most believe that the majority of individuals with vocal training or formal musical education are unable to carry a tune. However, singing is quite natural for humans. Singing is a universal form of vocal expression that transcends places and cultures. Moreover, singing is a group activity that is typically associated with a highly pleasurable experience and thought to promote group cohesion (Mithen, 2006; Wallin *et al.*, 2000).

Singing abilities emerge spontaneously and precociously during development. The first songs are produced at around 1 year of age and, at 18 months, children start to generate recognizable songs (e.g., Ostwald, 1973; see Dowling, 1999, for a review). This precocious emergence of basic singing abilities is reflected in the characteristics of adult singing, which is remarkably consistent both within (Bergeson and Trehub, 2002; Halpern, 1989) and across subjects (Levitin, 1994; Levitin and Cook, 1996) when considering both starting pitch and tempo. Therefore, it is expected that the general population can sing proficiently.

Singing represents one of the richest sources of information regarding the nature and origins of musical behavior because it is a universal and socially relevant activity and it emerges precociously. Yet, surprisingly, sung performance has received relatively little empirical attention (Gabrielsson, 1999; Parncutt and McPherson, 2002). The few studies on sung performance have mostly targeted professional singing. Differences have been found between professional singers and nonsingers in terms of voice quality (e.g., Sundberg, 1987, 1999). More specifically, partials falling in the frequency range of 2.5–3.0 KHz (the so-called *singer's formant*; see Sundberg, 1987) are much stronger in sung vowels than in spoken vowels; the intensity of the *singer's formant*, the presence of vibrato, and the maximum phonational frequency range increase with musical experience (e.g. Brown *et al.*, 2000; Mendes *et al.*, 2003). Occasional singers have accurate memory for initial pitch and tempo of popular songs but poor vocal pitch matching abilities (Amir *et al.*, 2003; Murbe *et al.*, 2002; Ternstrom *et al.*, 1988). When asked to reproduce single pitches in pitch matching tasks, nonmusicians deviate by 1.3 semitones on average as compared to 0.5 semitones for musicians (Amir *et al.*, 2003; Murry, 1990; Murry and Zwiner, 1991; Ternstrom *et al.*, 1988). These findings may not apply to singing notes in the context of songs. In songs, the melody is highly structured on both pitch and time dimensions, thereby providing multiple musical cues aiding to plan and monitor sung performance. Furthermore, prior studies have focused on pitch accuracy. Yet, time accuracy is also an important characteristic of proficient singing. In sum, there is insufficient information regarding the distribution of singing abilities in occasional singers.

The paucity of research on singing in the general population might be related to the difficulties that are inherent in the analysis of sung performance. The analysis of sung performance is arguably more challenging as compared to the analysis of piano performance, for example, where key strokes can be accurately recorded (in MIDI format) by way of a computer-monitored electronic keyboard. In previous

[a)]Electronic mail: sdallabella@vizja.pl

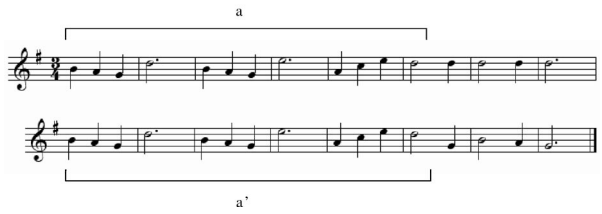

FIG. 1. Refrain of *Gens du Pays*.

studies of sung performance, objective methods based on pitch extraction algorithms have been successfully applied in the analysis of single pitch performance (e.g., Alcock *et al.*, 2000a, b; Amir *et al.*, 2003). However, there is currently no consensus on how to obtain similar objective measures of singing proficiency in sung melodies. In the past, singing accuracy was assessed by expert musicians (e.g., Alcock, 2000a, b; Hebert *et al.*, 2003; but see Murayama *et al.*, 2004). For example, Alcock and collaborators (2000a, b) asked experts to rate singing accuracy separately for pitch and rhythm in healthy and brain-damaged subjects. However, when making judgments, experts are subject to the constraints of both music notation and their perceptual system. Musicians often categorize pitch and duration information with respect to the closest musical value. Moreover, they tend to integrate pitch and time information when embedded in a musical context (Jones and Pfordresher, 1997; Peretz and Kolinsky, 1993). These difficulties might explain the reported discrepancies between raters in their evaluations of singing proficiency (e.g., see Kinsella *et al.*, 1988; Prior *et al.*, 1990). Thus, acoustic-based analyses of sung performance are more likely to yield a reliable measure of singing proficiency than expert judgments.

Such an objective approach was adopted in the present study to examine pitch and time accuracy of sung performance in the general population. To this aim, 62 individuals were asked to sing a well-known Quebec folk tune, "*Gens du pays*" (Gilles Vigneault; see Fig. 1), including 20 nonmusicians who were tested in the laboratory, and 42 individuals who were tested in a public park. A customized computer-guided analysis of sung performance was devised to objectively measure pitch and time accuracy. This technique is based on acoustical segmentation of sung recordings and pitch extraction, and was inspired by recent "query-by-humming" methods that serve to access large electronic musical databases through singing (e.g., Pardo *et al.*, 2004). The analyses yield several measures of pitch and temporal accuracy such as pitch interval deviation and temporal variability (i.e., the coefficient of variation of inter-onset-intervals between sung notes) that are known to be indicative of expert performance (e.g., Repp, 1998; Vurma and Ross, 2006). If indeed singing abilities are poorly developed in the general population, we expect that the vast majority of individuals will sing out-of-tune and have problems keeping time. Alternatively, if singing proficiency is widespread, we expect that singing abilities will be normally distributed, and that the majority of individuals will sing in-tune and in-time.

II. EXPERIMENT 1

A. Method

1. Participants

Twenty individuals (hereafter referred to as *group 1*), ten males and ten females, were recruited from the University of Montreal community. Their age ranged from 19 to 29 (M = 23.9 years). Forty-two individuals (*group 2*), 19 males and 23 females, were recruited randomly in a public park. Their age ranged from 18 to 75 (M = 41.4 years). Participants from group 1 were nonmusicians and participants from group 2 were not selected for musical training. For the sake of simplicity, participants from groups 1 and 2 are hereafter referred to as *occasional singers*. For comparison, four professional singers (M = 11 years of vocal training; range = 8–17 years) and Gilles Vigneault (G.V.), the composer and singer of the target song, participated in the experiment. Participants had no neurological history. Group 1 and the four anonymous singers were compensated for their participation.

2. Material and procedure

Participants were asked to sing the well-known refrain of the song *Gens du pays* (Vigneault and Rochon, 1976), which is typically sung in Quebec to celebrate birthdays. As can be seen in Fig. 1, the refrain is composed of 32 notes with a vocal range of less than one octave and a stable tonal center. Each note is associated with one syllable. The segment a' is an exact repetition of a and can be used to evaluate pitch stability. The experimenter (Michel) pretended that it was his birthday and that he had made a bet with friends that he could get 100 individuals each to sing the refrain of *Gens du pays* for him on this special occasion. This strategy was effective for the purposes of recruiting the participants that formed group 2. The performances of group 1 subjects and the professional singers were recorded in the laboratory, while G.V.'s performance was recorded in a studio. Group 1 was asked to sing the refrain three times: at the beginning of the experiment (test 1), immediately afterwards (test 2), and one week later (test 3). Only tests 1 and 2 were completed by the four professional singers (eight performances overall). G.V. sang the song twice. Sung performance was recorded at a sampling frequency of 44.1 KHz using a Shure 565SD microphone directly onto a IBM-compatible computer using Cooledit software in the laboratory and using a portable Sony TCD-D10 Pro DAT for group 2, professional singers, and G.V.

Sung renditions of group 1 (test 1) and group 2 were presented in random order to ten nonmusicians who had not participated in the singing session. The peers had to rate each performance on a 10-point scale with 1 indicating "very inaccurate" and 10 "very accurate."

3. Acoustical analysis of sung performance

In order to compute various measures of pitch and time accuracy, an acoustic-based method was used to analyze the recordings of the sung performances. Acoustical analyses of each sung performance were carried out on the vowel groups (e.g., "i" in "Mi"). Vowel-groups are the best targets for

acoustical analysis because vowels carry the maximum of voicing and stable pitch information (see Murayama *et al.*, 2004). These groups were determined by visual inspection of the waveform and of the spectrogram. The onsets of vowel groups were used to compute *note onset time* and were measured in ms. The median of the fundamental frequencies of the vowel-group was computed with Praat software (Boersma, 2001) using an accurate autocorrelation method (Boersma, 1993) (sampling rate= 100 Hz; Gaussian window= 80 ms) and served to measure *pitch height* (F0 in Hertz). It is noteworthy that pitch extraction based on autocorrelation methods when applied to pitch detection in normal speech is prone to false detections (e.g., octave jumps), for instance in presence of weak fundamental frequencies or strong high harmonics. In the present study, when false pitch detections occurred they were manually corrected.

Note onset time and pitch height were used to obtain various pitch and time variables as described below. These analyses were implemented with Matlab 7.1 software.

3.1. Pitch dimension variables.

Pitch stability is the difference between the produced pitch in the melody segment a and in the repetition a' (as in Flowers and Dunne-Sousa, 1990). The absolute difference in semitones between the 12 corresponding notes (e.g., note 1 in segment a and a', note 2 in segment a and a', and so forth) was computed. Pitch stability is the mean of these absolute differences. The larger this mean difference, the less stable is the pitch.[1]

Number of pitch interval errors (see Fig. 2) indicates the number of errors in the performance of musical intervals compared to the musical notation. An error was scored when the sung interval was larger or smaller by 1 semitone than the interval prescribed by the notation. This measure was not influenced by absolute pitch level, nor by the size of the deviation.

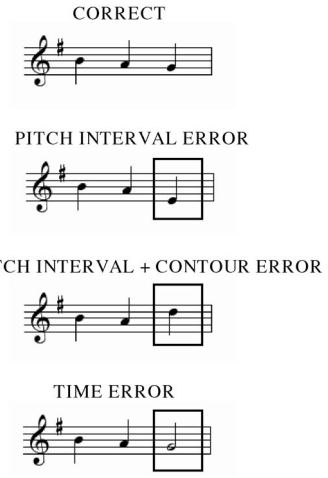

FIG. 2. Examples of pitch interval error, contour error, and time error.

Number of contour errors (see Fig. 2) refers to the number of changes in pitch directions relative to musical notation. Pitch direction was considered as ascending or descending if the sung interval between two notes was higher or lower by more than 1 semitone. A contour error was counted when the pitch direction deviated from the musical score.

Interval deviation is a measure of the size of the pitch deviation from the score and is calculated by averaging the absolute difference in semitones between the produced intervals and the intervals prescribed by the score. A small deviation reflects high accuracy in terms of relative pitch.

3.2. Time dimension variables.

Tempo was obtained by computing the mean inter-onset-interval (IOI) of the quarter-note.

Number of time errors (see Fig. 2) represents duration deviations from the score. When the duration of the sung note was 25% longer or shorter than its predicted duration based on the preceding note, as prescribed by the musical

TABLE I. Mean values for pitch and time variables for group 1 (n=60) at test 1, test 2, and test 3, group 2 (n=42), professional singers (n=8), and G.V. (n=4). *N*s indicate the number of performances.

	GROUP 1			GROUP 2	SINGERS	G.V.
	Test 1	Test 2	Test 3			
Variable	*M* (SE)	*M* (SE)	*M* (SE)	*M* (SE)	*M* (Range)	*M*
Pitch dimension						
Pitch first note (Hz)						
Males	134.0 (6.6)	135.1 (6.8)	129.3 (4.9)	143.0 (6.5)	165.8 (134.5–199.0)	221.1
Females	252.1 (9.7)	259.7 (8.1)	257.7 (8.8)	234.6[a] (6.1)	308.9 (276.8–338.3)	…
Pitch stability (semitone)	0.5[a] (0.1)	0.6[a] (0.1)	0.6[a] (0.0)	0.7[b] (0.3)	0.3 (0.1–0.4)	0.4
No. of coutour errors	0.7[b] (0.3)	1.2[b] (0.4)	1.2[b] (0.3)	2.5[b] (0.4)	0.0 (0.0)	0.3
No. of pitch interval errors	5.5[b] (1.2)	4.8[b] (1.2)	4.4[b] (1.0)	9.8[b] (0.8)	0.5 (0.0–2.0)	1.8
Interval deviation (semitone)	0.6[b] (0.1)	0.6[b] (0.1)	0.6[b] (0.1)	0.9[b] (0.1)	0.3 (0.2–0.4)	0.3
Time dimension						
Tempo (Mean IOI, ms)	275.0[b] (10.0)	281.0[b] (12.2)	289.7[b] (10.4)	239.7[b] (8.6)	398.8 (366.9–427.6)	338.7
No. of time errors	2.2 (0.5)	1.5 (0.3)	2.2 (0.4)	4.7[a] (0.5)	0.9 (0–4.0)	2.5
Temporal variability (CV IOIs)	0.12 (0.01)	0.10 (0.01)	0.10 (0.01)	0.17 (0.01)	0.10 (0.06–0.16)	0.16
Rubato	0.6 (0.06)	0.7 (0.05)	0.6 (0.06)	0.6 (0.04)	0.6 (−0.3–1.0)	0.6

[a]± 2 SD from the mean of professional singers
[b]± 3 SD from the mean of professional singers

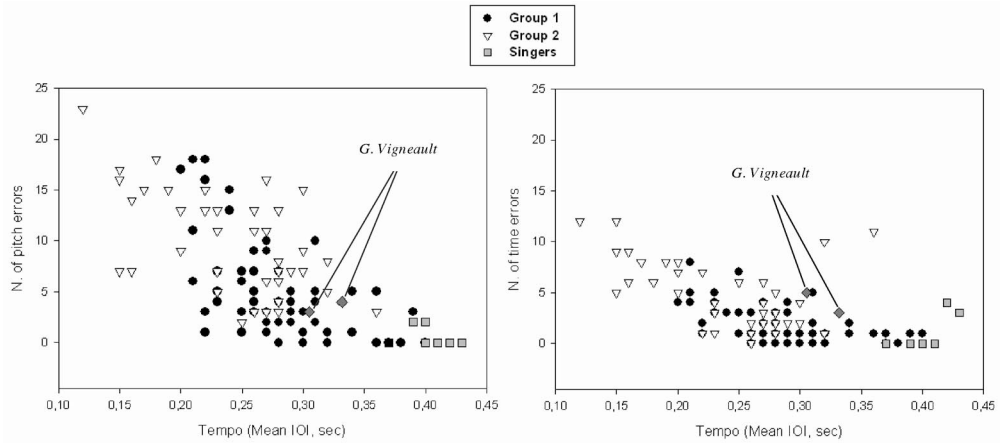

FIG. 3. Number of pitch interval errors and time errors plotted against tempo (i.e., mean quarter-note IOI) for group 1, group 2, professional singers, and G.V.

notation, this was considered as a time error (using a stricter criterion than in piano performance studies; e.g., Drake and Palmer, 2000). The first and last notes were not used to compute time errors.

Temporal variability is the coefficient of variation of the quarter-note IOIs, calculated by dividing the standard deviation of the IOIs by the mean IOI (as in Repp, 1998). This measure of time accuracy is less dependent on tempo than the simple strandard deviation of the IOIs.

Rubato is an additional measure of timing consistency. This can be observed, for instance, when a musician increases the tempo at the beginning of a musical phrase and slows down at the end (Todd, 1985). To obtain a measure of Rubato, the quarter-note IOIs for the segment a were correlated with the IOIs for segment a' (for a similar measure in piano performance, see Timmers *et al.*, 2000). High correlation corresponds to high consistency in the rubato pattern.

B. Results

Means and standard error of pitch and time variables for groups 1 and 2 are reported in Table I. Corresponding measures of singing proficiency of professional singers and for G.V. are also reported for comparison purposes. As shown in Table I, the occasional singers seemed to have less control over pitch relative to time as compared to expert singers. They differed from professionals on all pitch dimension variables, with the exception of the pitch of the first note. In addition, occasional singers tended to produce more pitch intervals that were out-of-key (group 1: 2.72 errors, SE =0.28; group 2: 4.93 errors, SE=0.76) than in-key (group 1: 2.18 errors, SE=0.28; group 2: 4.88 errors, SE=0.75). This trend reached significance in group 1 [one-tailed $t(59)=-1.70$, $p<0.05$]. Nevertheless, occasional singers rarely produced pitch intervals that deviated by more than one semitone (see Table II) and made few time errors (Table I). However, they sang, on average, almost twice as fast as professional singers.

TABLE II. Number and percentage of pitch intervals that deviated from the score by a quarter of tone, 1, 2, and 3 semitones in the laboratory setting (group 1) and outdoors (group 2).

Interval deviation from the score	Group 1 n (%)	Group 2 n (%)
>1 quarter of tone	29 (48)	3 (7)
>1 semitone	53 (88)	30 (71)
>2 semitones	60 (100)	41 (97)
>3 semitones	···	42 (100)

This difference in tempo between occasional and professional singers may account for the higher error rates observed in the nonexperts. Fast tempos typically lead to reduced accuracy in piano performance (e.g., see Repp, 1998). To examine this possibility, pitch and time errors were plotted against tempo for all participants. As can be seen in Fig. 3, faster tempi were associated with reduced accuracy, especially on the pitch dimension. Interestingly, the occasional singers who sang at a slow tempo exhibited accuracy comparable to that of professionals. Regression analyses confirmed that tempo accounted for pitch accuracy [pitch stability, $R^2=0.36$, $F(1,112)=63.94$, $p<0.001$; contour errors, $R^2=0.30$, $F(1,112)=47.13$, $p<0.01$; pitch interval errors, $R^2=0.47$, $F(1,112)=100.07$, $p<0.001$; interval deviation, $R^2=0.46$, $F(1,112)=96.84$, $p<0.001$] and time accuracy [time errors, $R^2=0.32$, $F(1,112)=53.17$, $p<0.001$]. Fast singing is also judged to be less accurate than slow singing by the peers [$R^2=0.39$, $F(1,100)=64.43$, $p<0.001$]. Hence, a significant portion of the variability in sung performance may be accounted for by tempo differences. Sung performance was optimal at slow speeds.

The peer ratings did not differ significantly from normality (Kolmogorov-Smirnov test, p=ns), as shown in Figs. 4(a) and 4(b), respectively. The peer ratings for the performance of the subjects who were tested in the laboratory (group 1) were higher than those who were tested in a natural setting [group 2; $t(100)=2.87$, $p<0.01$]. However, the objective measures of accuracy derived from the acoustical analysis revealed that the general population is not as homogenous as may be inferred from perceptual judgments. A closer look at the distribution of pitch interval errors and time errors [see Figs. 4(a) and 4(b)] reveals that the majority of individuals were fairly in-tune and in-time, while a minority were poor singers. In group 1, 70% committed less than 6 pitch errors and less than 4 time errors, whereas 3% sang clearly out-of-tune, making more than 17.6 pitch errors, which corresponds to 2 standard deviations above the average of both groups. In group 2, accuracy was lower but simi-

larly distributed with 70% making less than 14 pitch errors and less than 7 time errors (i.e., threshold of 2 standard deviations above the average). It is worth noting that poor singers were the fastest singers and were inaccurate in both the pitch and time dimensions. In general, proficiency in pitch and time were correlated; the occasional singers who made more pitch errors were also those making more time errors ($r=0.36$ and 0.37, $p<0.01$, for groups 1 and 2, respectively). However, only 15% of pitch and time errors jointly occurred on the same notes.

The data from group 1 were further analyzed so as to assess the consistency across performances, and possible practice effects. No significant effect of time of testing (test 1, 2, and 3) was found for any of the variables. To estimate which parameters were the most stable across repetitions, the mean values for each variable at test 1 were correlated with the corresponding values at test 2 and at test 3. All the variables with the exception of rubato were highly correlated, even when performances were recorded 1 week apart (with r values between 0.56 and 0.97, $p<0.01$), showing remarkable consistency in untrained singing. Finally, between-subjects consistency was assessed for absolute pitch and tempo with reference to the most frequently heard version of "Gens du pays," sung in G Major and with a tempo (mean quarter-note IOI) of 347 ms. This "frequent" version was obtained from six commercial recordings by G.V.[2] The results reported in Table III show that the untrained population has a good memory for absolute pitch. In the majority of performances (72%), the first note laid within 2 semitones of the original note. In comparison, the tempo was more variable, with only 11% of the performances where the tempo was within 8% of the original tempo.

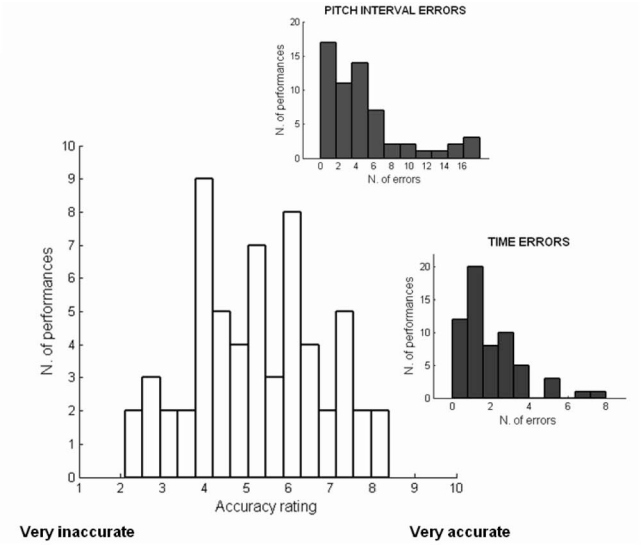

FIG. 4. Peer judgments, objective pitch interval errors and time errors for group 1 (a) and group 2 (b).

C. Discussion

Singing proficiency appears to be normally distributed in the general population with a majority of occasional singers being able to sing on time, with few pitch deviations. The pitch deviations were also fairly subtle, typically smaller than a semitone. Thus occasional singers are more accurate when they sing well-known melodies than isolated pitches (Amir *et al.*, 2003; Ternstrom *et al.*, 1988). It is remarkable that the occasional singers were extremely proficient along the time dimension. Although they tended to sing more quickly than professional singers, occasional singers performed as accurately as professionals in terms of regularity, rubato, and time deviations. Finally, the present study showed that occasional singers' performance is particularly consistent, both between-subjects (mostly for the pitch dimension, as in Levitin, 1994, and Levitin and Cook, 1996) and across repetitions (as in Bergeson and Trehub, 2002).

Given that the occasional singers sang at a faster tempo than professional singers, a speed-accuracy trade-off may be responsible for the observed differences in pitch accuracy between the two groups. If this hypothesis holds true, occasional singers should be able to make minimal to no errors in singing at a slower tempo. We tested this hypothesis in experiment 2.

III. EXPERIMENT 2

A. Method

This follow-up session with 15 participants from group 1 was carried out 3 years following experiment 1. Experi-

TABLE III. Comparison between the pitch of the first note and tempo of performances in groups 1 and 2 and pitch and tempo of the original version of "Gens du Pays".

Dimension	Group 1 n(%)	Group 2 n(%)
Pitch of the first note		
Same as the original	9 (15)	5 (12)
Within 1 semitone	30 (50)	13 (31)
Within 2 semitones	43 (72)	30 (71)
Tempo		
Within 4% of the actual tempo	5 (8)	0 (0)
Within 8% of the actual tempo	10 (17)	2 (5)

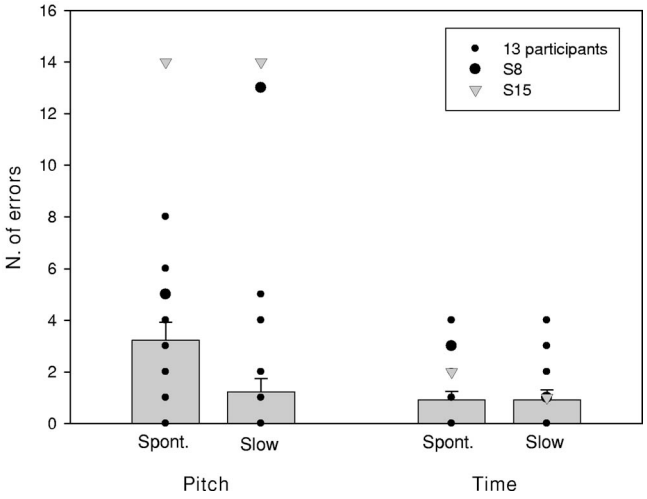

FIG. 5. Number of pitch interval errors and time errors in experiment 2 when singing at spontaneous tempo and slow tempo.

ment 2 involved the same material and procedure as those used in experiment 1. The only difference was that participants were asked to sing *Gens du pays* in two conditions: (1) at a spontaneous tempo as in experiment 1 and (2) at a tempo of 120 beats per min (corresponding to a mean IOI of 500 ms) as marked by a metronome. As soon as the participants felt they could synchronize their performance with the metronome, the latter was turned off and the sung production was recorded.

Eleven participants were further tested for music perception. They were presented with 60 unfamiliar tonal melodies of which half contained a pitch or time error. The task was to press one button when an error was detected and another button when there was no error.

B. Results and discussion

As shown in Fig. 5, all participants succeeded in singing at the imposed tempo (mean IOI=499 ms, SE=7 ms) and making less errors while doing so. There were two notable exceptions. Two participants (S8 and S15) exhibited a large number of pitch interval errors in both the spontaneous and slow tempo conditions and were qualified as poor singers. Their performance will be described in more detail below.

Performance in the spontaneous condition did not differ from that obtained in experiment 1, on all pitch and time variables previously examined [all $t(12)$ tests being n.s.]. As shown in Fig. 5 and Table IV, pitch accuracy markedly improved with slower tempos [pitch interval errors, $t(12)=4.28$, $p<0.01$; pitch stability, $t(12)=2.12$, $p<0.05$; contour errors, $t(12)=2.31$, $p<0.05$; and interval deviation, $t(12)=6.63$, $p<0.01$]. As a result of slowing down, proficiency measures for occasional singers fell within the range exhibited by professional singers. For instance, when singing at slow tempo occasional singers exhibited small pitch interval deviation (i.e., 0.3 semitones), as observed in professional singers. Such interval deviation is acceptable in singing as estimated by expert listeners (Vurma and Ross, 2006). These findings confirm that a speed-accuracy trade-off was mostly responsible for the observed differences between occasional singers and professionals in experiment 1.

TABLE IV. Mean values for pitch and time variables at the slow tempo for 15 occasional singers re-tested in experiment 2.

Variable	13 singers *M* (SE)	S8 *M*	S15 *M*
Pitch dimension			
Pitch stability (semit.)	0.3 (0.0)	0.4	0.4
No. of contour errors	0.2 (0.2)	6.0	6.0
No. of pitch interval errors	1.2 (0.5)	13.0	14.0
Interval deviation (semit.)	0.3 (0.0)	1.0	1.1
Time dimension			
Tempo (Mean IOI, ms)	497.0 (8.7)	494.2	535.1
No. of time errors	0.9 (0.4)	1.0	1.0
Temporal variability (CV IOIs)	0.07 (0.01)	0.07	0.08
Rubato	0.4 (0.01)	0.1	0.9

In contrast, the two poor singers (S8 and S15) maintained a high rate of pitch interval errors when requested to slow down (Fig. 5). Their sung performance was clearly out-of-tune, by producing many intervals that deviated from the score by more than 1 full semitone, while this type of deviation never occurred in the other 13 participants (Table IV). As a result, the poor singers sang mostly out-of-key notes (9 out of 13 errors for S8; 8 out of 14 errors for S15) that often fell on strong beats (51% of the cases). While their singing was out-of-tune, it was in-time. The poor singers did not make more time errors than the other participants (their sung performance can be heard along with representative renditions of the other occasional singers at www.umontreal.brams/peretz). Moreover, their poor vocal control of pitch was not due to a perceptual deficiency. S8 and S15 correctly detected 90% and 96% of pitch deviations in a melodic context. Their performance falls within 2 SD of the mean (88%, SE=1.1) scores obtained by 71 university students (mean age= 26.5 years). That S8 and S15 exhibited a normal perception is consistent with the observation that these subjects were aware that they sang out-of-tune.

IV. GENERAL DISCUSSION

In the present study, we found that the majority of individuals can carry a tune with remarkable proficiency. Occasional singers typically sing in-time but are less accurate in pitch as compared to professional singers. When asked to slow down, occasional singers greatly improve in performance, making as few pitch errors as professional singers. Thus, singing appears to be a widespread skill.

It is noteworthy that time precision in sung performance is well suited for group synchronization. Indeed, choral singing requires time accuracy, precise alignment of note onsets, and rapid adaptation to changes in tempo, as in the case of rubato (e.g., Aschersleben *et al.*, 2002). *Gens du pays* (the Quebec version of *Happy Birthday*) is typically sung in choir. Occasional singers' spontaneous control of time factors in vocal performance is optimal for singing in a group context. If, in addition, singing along imposes a slower

tempo, then the group should sing perfectly in tune. These are the necessary and sufficient conditions for producing a harmonious choral performance, thus making singing a pleasurable experience for everyone.

There were two notable exceptions. Two participants were unable to correct the numerous pitch errors that they made, although they sang in-time and were normal at detecting pitch errors in musical contexts. The inability to sing accurately despite efforts to do so characterizes self-declared tone deaf individuals (Sloboda *et al.*, 2005). Tone deafness is rare, affecting about 4% of the general population (Kalmus and Fry, 1980). To date, tone deafness has been studied and defined in terms of poor perceptual abilities (congenital amusia; see Ayotte *et al.*, 2002; Foxton *et al.*, 2004; Peretz, 2006; Peretz *et al.*, 2002; Peretz and Hyde, 2003). Poor singing, a landmark of this perceptual disorder as well as a selection criterion, is interpreted as a consequence of an impoverished perceptual system. Nonetheless, the present results suggest that poor singing may occur in the presence of normal perception. This possibility finds support in a recent study conducted with poor singers who exhibited pitch production deficits but normal pitch discrimination (Bradshaw and McHenry, 2005). Similarly, brain damage can selectively impair sung performance without affecting perception (Schon *et al.*, 2003). Thus, the present findings suggest that tone-deafness may emerge as a pure output disorder, indicating that there may exist a variety of lifelong musical disorders, just as there are a variety of acquired musical disorders consequent to brain damage (see Stewart *et al.*, 2006, for a recent review).

An acoustically based analysis of sung performance proved to be useful to characterize singing proficiency in the general population. Furthermore, in order to obtain an optimal estimate of singing proficiency, one must control for tempo. As observed here, occasional singers performing at a fast tempo tend to make more errors than professional vocalists. This may lead to erroneously qualifying many occasional singers as poor singers. Hence, acoustically based analyses and tempo control should be adopted by researchers who are interested in the acoustical correlates of accurate singing to ensure a true measure of singing proficiency.

In summary, the present study indicates that singing in the general population is more accurate and widespread than is currently believed. The average person is able to carry a tune almost as proficiently as professional singers. This result is consistent with the idea that singing is a basic skill that develops in the majority of individuals, enabling them to engage in musical activities. In short, singing appears to be as natural as speaking with the added value of promoting social cohesion and activity coordination at a group level (Brown *et al.*, 2004; Peretz, 2006; Wallin *et al.*, 2000).

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[1]An additional measure of *intranote pitch stability* was obtained from the SD of the extracted fundamental frequency within a vowel group. Average intranote pitch stability for occasional singers (group 1=4.6 Hz, *SE* =0.2 Hz; group 2=5.9 Hz, *SE*=0.3) was within two standard deviations from the mean of professional singers (average intranote pitch stability= 5.9 Hz, range= 2.4–9.2 Hz). Nonetheless, this measure is difficult to interpret since intranote pitch stability does not distinguish between abnormal pitch fluctuations (e.g., random changes) and deliberate pitch variations for expressive purposes (e.g., vibrato).

[2]G.V.'s performance recorded for the purposes of our study (see Table I) is very representative of his recordings. Nevertheless, G.V. sang "Gens du pays" in F Major instead of G Major. Since listeners are more likely to be exposed to recordings, we used the frequent version for comparison.

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