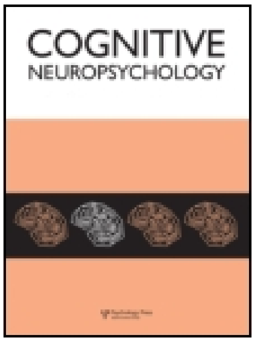

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Singing proficiency in congenital amusia: Imitation helps

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Singing out of tune characterizes congenital amusia. Here, we examine whether an aid to memory improves singing by studying vocal imitation in 11 amusic adults and 11 matched controls. Participants sang a highly familiar melody on the original lyrics and on the syllable /la/ in three conditions. First, they sang the melody from memory. Second, they sang it after hearing a model, and third, they sang in unison with the model. Results show that amusic individuals benefit from singing by imitation, whether singing after the model or in unison with the model. The amusics who were the most impaired in memory benefited most, particularly when singing on the syllable /la/. Nevertheless, singing remains poor on the pitch dimension; rhythm was intact and unaffected by imitation. These results point to memory as a source of impairment in poor singing, and to imitation as a possible aid for poor singers.

Keywords: Congenital amusia; Tone deafness; Singing; Memory; Imitation; Pitch; Rhythm.

When an aria floats from the lips of an opera singer or when a child is humming his favourite song, the action engages multiple systems located in several cerebral areas to integrate what is perceived with what should be produced (e.g., Zarate & Zatorre, 2008) beyond basic processing in motor and sensory systems (Berkowska & Dalla Bella, 2009a). Moreover, singing is a universal form of musical expression that is mastered by the general adult population (e.g., Dalla Bella, Giguère, & Peretz, 2007). Thus, the study of singing performance represents a unique opportunity to study music processing in its full complexity.

One of the best strategies to uncover the complexity of singing abilities is to study how singing breaks down. This characterizes most of the cases who suffer from congenital amusia. Most amusics sing out of tune as compared to controls, by both peers' judgements (Ayotte, Peretz, & Hyde, 2002) and acoustical analyses (Dalla Bella, Giguère, & Peretz, 2009). Their poor singing is typically associated with impoverished pitch perception.

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However, there is growing evidence that perception and production abilities can be dissociated in singing. For example, poor pitch perception does not necessarily lead to poor pitch singing. In a study conducted by Loui and collaborators (Loui, Guenther, Mathys, & Schlaug, 2008), amusic individuals (hereafter amusics) were able to reproduce pitch intervals in the correct direction while being unable to report whether the interval was going “up” or “down”. Furthermore, Dalla Bella et al. (2009) identified two amusics who were able to sing a well-known melody as proficiently as controls, despite severe pitch perception deficits. Such dissociations point to the existence of separate neural pathways for pitch perception and production. According to Loui and collaborators (Loui, Alsop, & Schlaug, 2009), the anomalous neural pathway concerns the right arcuate fasciculus, which is reduced in congenital amusia.

The reverse dissociation can also be observed. Poor pitch singing can occur in individuals with apparently intact pitch perception. Pfordresher and Brown (2007) found that 10 to 15% of the population was inaccurate in imitating unfamiliar pitch patterns despite having normal pitch perception. The same proportion of poor singers with normal pitch discrimination has been found in the production of familiar melodies from memory (Dalla Bella & Berkowska, 2009; Dalla Bella et al., 2007). Altogether, the data suggest that vocal pitch production ability does not necessarily match pitch discrimination abilities.

As many functional components are required to sing in tune, such as pitch perception, sensorimotor integration, motor control, and memory systems (see Berkowska & Dalla Bella, 2009a, and Pfordresher & Brown, 2007, for reviews), a deficiency in any one of these components may lead to poor pitch singing. One system that has received little attention is memory. Yet poor memory for pitch is likely to affect singing, as a deficit in short-term memory for pitch material has been recently reported in congenital amusia (e.g., Gosselin, Jolicoeur, & Peretz, 2009; Tillmann, Schulze, & Foxton, 2009; Williamson, McDonald, Deutsch, Griffiths, & Stewart, 2010). Similarly, Wise and Sloboda (2008) observed that self-reported “tone-deaf” individuals sang more poorly than self-reported “non-tone-deaf” individuals, and this effect was greater for long than for short pitch sequences. Moreover, amusics exhibit poor levels of melody recognition and memorization in the long term (Ayotte et al., 2002). Reliance on degraded memory representations may explain at least in part why singing a well-known melody on a new speech segment (such as on /la/) is impossible for many amusics (Dalla Bella et al., 2009). Indeed, Dalla Bella and colleagues observed that amusics who scored lower on the memory test of the Montreal Battery of Evaluation of Amusia (MBEA; Peretz, Champod, & Hyde, 2003) were those who failed to sing a well-known song on the syllable /la/. The authors argue that severe amusics may rely heavily on the memory associations between melody and text of this well-known song to support singing. The associative link created between text and melody memory representations may lead to deeper encoding, which may in turn facilitate retrieval in the long-term memory of both parts. If the melody part is not encoded in sufficient detail to support memory recognition, as is typically the case of amusics (e.g., Ayotte et al., 2002), the lyrics and the associative links may compensate for the lack of melodic precision. Without such an aid, humming or singing with a new speech segment (the syllable /la/) may break down. Note that the general population tends to sing more accurately on /la/ than with lyrics (Berkowska & Dalla Bella, 2009b). In sum, singing proficiency may depend on both short-term and long-term memory.

These observations are in line with recent neuroimaging evidence suggesting that long-term memory is tightly coupled with singing ability (Peretz et al., 2009). These authors found an activation of the right superior temporal sulcus when they compared cerebral responses to familiar versus unfamiliar music. The neuroimaging data further showed that familiar music was tightly coupled with action (singing), by involving the dorsal pathway (planum temporale, the supplementary motor area, and inferior frontal gyrus). Peretz and collaborators proposed a dual-stream process of familiar music processing whereby the ventral stream would serve for recognition and the dorsal stream for singing.

In principle, providing a model to imitate should reduce the demands on the ventral pathway (memory) and improve the use of the dorsal pathway, thereby improving singing. Current behavioural evidence is mixed in this regard. While Wise and Sloboda (2008) and Dalla Bella and Berkowska (2009) reported a positive effect of both accompaniment and imitation on singing accuracy in occasional singers, Pfordresher and Brown (2007) did not observe any influence on the performance of poor singers when they sang in unison with the correct melody. However, materials and tasks were different in the three studies. Moreover, the aid of an accompaniment may not be related to memory. Singing with an accompaniment may promote sensorimotor synchronization, but not necessarily memory. Indeed, in some cases of brain-damaged patients, it is the synchronization with a model that improves vocal production, not imitation (Racette, Bard, & Peretz, 2006).

The goal of the present study was to investigate the role of memory and synchronization on singing accuracy in both amusic and normal (matched) individuals. To this aim, we asked them to sing from memory a well-known song as well as to sing the same song after a model by imitation, and then again in unison with the same model. As memory load decreased across the three tasks, amusics' singing was expected to improve. In each condition, participants had to sing the song that is typically sung on birthdays in Quebec (i.e., the chorus of "*Gens du Pays*" by Gilles Vigneault; Vigneault & Rochon, 1978), both with the associated lyrics and on the syllable /la/. We expected to observe more pitch errors when amusics sang from (long-term) memory than when they imitated the melody. Predictions were less clear regarding singing in unison with the model, since synchronization has been observed to influence performance both positively (Racette et al., 2006; Wise & Sloboda, 2008) and negatively (Pfordresher & Brown, 2007). Music memory was evaluated with the memory recognition test of the MBEA (Peretz et al., 2003).

Method

Participants

Eleven congenital amusics aged between 58 and 71 years ($M = 64.8$ years) and 11 controls matched for age, education, and musical background participated in the study. Six of the amusics had participated in the study of Dalla Bella et al. (2009). The distinction between amusic and control participants was based on performance on the MBEA; amusics had a composite score ranging between 51.1% and 71.1% (see Table 1), which was below the cut-off score for amusia (i.e., 77.6%; Peretz et al., 2003). Results on the tests of the MBEA showed that all amusics were significantly impaired on the melodic dimension (i.e., in the scale, contour, and interval tests), while 8 of them performed on the rhythm or metric test as normals do.

An additional control group consisted of 10 university exchange students from France (hence referred to as the French group) without musical training who were unfamiliar with the song. All students did the online amusia test (Peretz et al., 2008), to ensure that they were not amusic. Group characteristics and scores on the online amusia test are presented in Table 1.

Material and procedures

All participants performed a warm-up in which they first imitated an exaggerated speech contour, to see whether they could vary the pitch of their speaking voice. Second, they were asked to vary their vocal pitch up and down their full range. Before starting the experimental phase, the French subjects, who had never heard the target song, participated in a learning phase of the chorus of *Gens du Pays*. This phase consisted of listening to and repeating the song until all the lyrics could be produced. Pitch accuracy was not required in an attempt to make them more comparable to amusics who typically exhibit poor vocal pitch accuracy. All French participants were

Table 1. *Characteristics of amusics and controls and percentages of correct responses on the MBEA and on the online test of amusia*

	B.L.	*J.L.*	*A.S.*[a]	*E.L.*[a]	*FA*[a]	*G.C.*[a]	*I.C.*[a]	*MB*[a]	*C.B.*	*J.G.*	*M.L.*	*Controls (SD)*	*French group (SD)*
Gender	M	M	F	F	F	F	M	F	M	M	F	7F 4M	6F 4M
Age (years)	63	71	67	58	68	62	65	66	67	60	68	64.8 (5)	22.8 (3.7)
Education (years)	14	15	14	19	15	20	19	21	19	19	15	17.1 (3)	19.8 (4.7)
Musical background	1	1	2	3	2	1	1	4	1	1	0	2.5(2)	0
MBEA													
Scale	63.3[b]	66.7[b]	63.3[b]	53.3[b]	66.7[b]	56.7[b]	50[b]	46.7[b]	58.1[b]	53.3[b]	56.7[b]	92(6)	n/a
Contour	60[b]	73.3[b]	63.3[b]	53.3[b]	70[b]	56.5[b]	50[b]	46.7[b]	67.6[b]	56.7[b]	63.3[b]	89(8)	n/a
Interval	53.3[b]	56.7[b]	60[b]	53.3[b]	70[b]	73.3	50[b]	73.3	41.9[b]	66.7[b]	50[b]	87 (8)	n/a
Rhythm	76.7	83.3	76.6	63.3[b]	66.7[b]	96.7	50[b]	93.3	76.7	80	53.3[b]	88(8)	n/a
Metric	50[b]	53.3[b]	60[b]	73.3	66.7[b]	70[b]	56.5[b]	70[b]	43.3[b]	56.7[b]	66.7[b]	87(8)	n/a
Memory	56.7[b]	70[b]	73.3[b]	66.7[b]	76.7[b]	73.3[b]	50[b]	76.6[b]	63.3[b]	66.7[b]	70[b]	92(6)	n/a
Composite score	60[b]	67.2[b]	66.1[b]	60.6[b]	69.4[b]	71.1[b]	51.1[b]	67.8[b]	58.5[b]	63.3[b]	60[b]	89(3)	n/a
Online test amusia	49	76	60	51	52	69	38	83	59	61	62	89.0 (4.9)	91.3 (4.4)

Note: n/a = not available. MBEA = Montreal Battery of Evaluation of Amusia. M = male. F = female.

[a] Indicates amusics who participated in Dalla Bella et al.'s (2009) study. [b] Below cut-off score as indicated in Peretz et al., 2003. Musical background is expressed in terms of years of private musical lessons and does not differ significantly between amusics and controls, *t*(29) = 1.27, *ns*.

able to repeat the correct lyrics within one to three repetitions of the song.

In the experimental phase, all participants were asked to sing the chorus of *Gens du Pays* (Vigneault & Rochon, 1978). As illustrated in Figure 1, this chorus includes 32 notes (16 measures), and each note is associated with a different syllable. The pitch range lies within an interval of a major sixth (nine semitones), and the chorus has a stable tonal centre in the key of F major. This song structure, in which the segment *a* is immediately repeated by the segment *a′*, allowed us to evaluate pitch stability. Participants had to sing the chorus in three conditions and two contexts. First, they sang the chorus from memory (referred to as the "spontaneous" condition). Next, they sang immediately after hearing a same-sex model ("after model" condition) and, finally, in unison with the model ("unison" condition). The instruction was to sing as accurately as possible. In each condition (spontaneous, after model, and unison), the participants sang with the original lyrics ("lyrics" context) first and then on the syllable /la/ ("la" context). Since all but the French participants were very familiar with the song, there was no practice trial.

There were two prerecorded models, one female and one male, who sang at 120 beats per minute (bpm). This tempo is associated with best

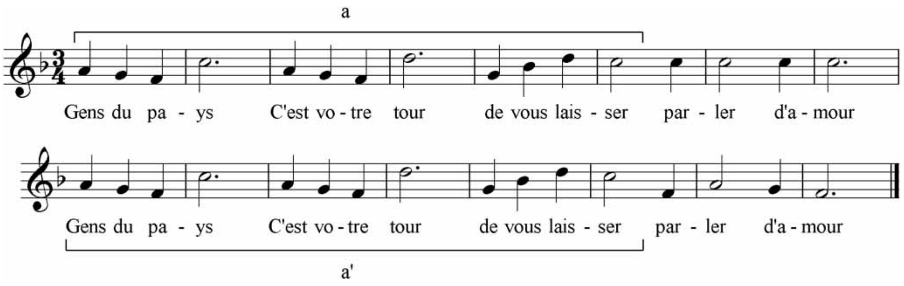

Figure 1. *Musical notation of the chorus "*Gens du Pays*" by Gilles Vigneault (Vigneault & Rochon, 1978).*

performance (Dalla Bella et al., 2007). The self-selected starting pitch of the female and male model was 223 and 196 Hz, respectively. As the same models were used in the "after model" and "unison" condition, the same key was used in both imitation tasks. Neither model was a professional singer to ensure a minimal amount of vibrato (as in Wise & Sloboda, 2008). Participants heard the model via Beyerdynamic DT770 Pro headphones in the "after model" and "unison" conditions. In the unison condition, participants heard the playback of their own voice in one ear and the model in the other ear in order to promote the use of self-monitoring. The participants' performance was recorded in a sound-attenuated booth with a Shure microphone, using Adobe Audition software.

Acoustical analyses of sung performance

When the sung performance included all 32 target tones, it was analysed with the acoustic-based method developed by Dalla Bella et al. (2007, 2009). This method allowed us to automatically compute various measures of pitch and time accuracy for each recording. Analyses were carried out on the vowels (i.e., /a/ in "ta"). As vowels carry the maximum voicing and stable pitch information, these are the best targets for acoustical analysis (e.g., Murayama, Kashiwagi, Kashiwagi, & Mimura, 2004). Vowel onsets were identified using a semiautomatic procedure with EasyAlign (Goldman, 2007) as implemented in Praat software (Boersma & Weenink, 2007).

Using Praat, the onset of the vowel was computed as the *note onset time*, and the median of the fundamental frequencies within vowels served to measure *pitch height.* To obtain the pitch and time variables of interest, note onset time and pitch height were analysed with Matlab 7.1. software (The Mathworks, 2005). The following measures of pitch and time accuracy were obtained. First, the *initial pitch*, which is the pitch of the first note of the song produced, was used to determine absolute pitch level. This measure was also used to assess the pitch distance from the model. The *pitch stability* was the difference between the pitches produced in the melody segment *a* and in the repetition *a′*. It was obtained by computing the average absolute difference (in semitones) between the 12 corresponding notes of the two song segments. The larger the mean difference, the more unstable was pitch in the performance. The number of *contour errors* was also calculated and represents the number of produced intervals that deviate in direction from their respective notated intervals. Pitch direction was counted as ascending or descending if the sung interval between two notes was higher or lower by more than one semitone. If pitch direction was different from the musical notation, it was counted as a contour error. Another measure, the *number of pitch interval errors*, indicated the number of produced intervals that deviated in magnitude from their respective notated intervals by more than one semitone. Pitch interval errors were coded irrespectively of pitch direction. That is, if a singer produced an ascending interval instead of a descending interval, this was not scored as a pitch interval error.

Finally, the *interval deviation* represented the size of the pitch deviations, by averaging the absolute difference in semitones between the produced and the notated intervals. Small deviations reflected high accuracy in relative pitch.

Variables on the time dimension were also computed. The *tempo* was the mean interonset interval (IOI) of the quarter note. The *number of time errors* indicated the number of duration deviations from the score. When a note was 25% longer or shorter than its predicted duration based on the preceding note, an error was scored. The first and last notes were not used to compute time errors. The *temporal variability* represented the coefficient of variation of the quarter note IOIs and was calculated by dividing the standard deviation of the IOI by the mean IOI.

Note that the acoustic-based analysis method could not be used to analyse an incomplete performance. As 6 amusics failed to produce all 32 notes of the chorus when asked to sing on the syllable /la/, we used the Melodyne 3.2 program (Neubäcker & Gehle, 2003) in order to segment each note automatically and obtain the exact pitch (to the nearest cent) of the selected note. From these values, the contour and pitch interval errors were computed.

Results and comments

Song renditions with and without the associated lyrics were analysed separately. In each context, we examined the mode of imitation first; we compared singing performance after hearing the model and in unison. Next, we assessed the role of memory by comparing singing accuracy in the two imitation conditions (after the model and in unison) to the singing from memory condition.

Singing with lyrics

Imitation and unison. Both amusics and controls were able to sing in time with the model. As an estimate of synchronization with the model, we measured the mean time lag between the model's onset and the produced note onset. Amusics started singing on average 320 ms (*SD*: 240 ms) after the model onset time, while controls started a little earlier, with 200 ms (*SD*: 108 ms). However, this group difference was not significant, $t(20) = 1.510$, *ns*.

An analysis of variance (ANOVA) was run with two groups (amusics and controls) and two conditions (after model and unison) as a between-subjects and within-subject factor, respectively, for each measure of accuracy.[1] As expected, amusics obtained lower scores than their matched controls for all pitch-related variables across conditions, with $F(1, 19) > 5.40$; $p < .05$. However, there was no significant effect of the imitation condition on any variable, including pitch interval errors, as illustrated in Figure 2 (all $F < 1$). The imitation condition did not improve performance significantly, despite the fact that singing in unison slowed down the tempo more than when singing after the model in both groups, $F(1, 19) = 24.59$, $p < .001$. Moreover, there was a strong correlation between the two imitation conditions on most variables in both amusics and controls (in amusics, $r = .90$, .81, and .70, $n = 11$, $p < .05$, for contour errors, pitch interval errors, and time errors, respectively).

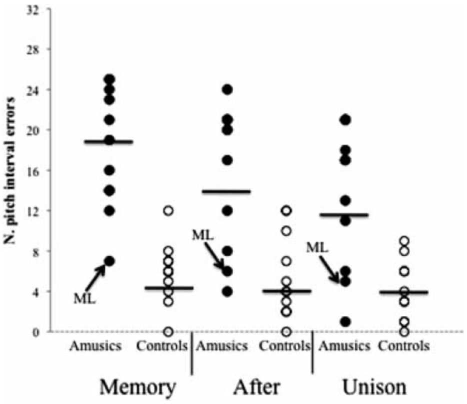

Figure 2. *Pitch interval errors produced by amusics and controls while singing with lyrics alone (from memory), after a model, or in unison with a model. Amusics are represented by black circles and controls by open circles. M.L., the amusic whose singing is spared, is indicated by an arrow. The bar represents the mean.*

In order to assess the effect of a potential discrepancy between the starting pitch of the model and that of the singer, we measured the distance between the first note produced by the model and that of the participant when singing after the model (because it was easier to isolate it in that condition than in the unison one). We then measured to what extent this distance in initial pitch predicted the number of errors produced in contour, pitch intervals, and time. We found a positive correlation between the distance in initial pitch and the number of contour and of pitch interval errors in both controls and amusics (see Figure 3). In amusics, the larger the pitch distance, the more contour errors, $r = .80$, $n = 11$, $p = .001$, and pitch interval errors, $r = .70$, $n = 11$, $p = .001$, they made. Similarly, in controls, the corresponding correlations were $r = .66$, $n = 11$, $p = .05$, and $r = .76$, $n = 11$, $p = .05$, respectively. These results suggest that nonmusicians in general are poor vocal pitch matchers. Only 2 amusics and 5 controls succeeded in matching vocally the initial pitch of the model by less than a semitone. Yet, the 2 amusics made pitch errors. Thus, difficulties in transposition cannot fully account for their poor imitation. This last idea is

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[1] Preliminary analyses showed that there was no effect of gender, nor any interaction with this factor.

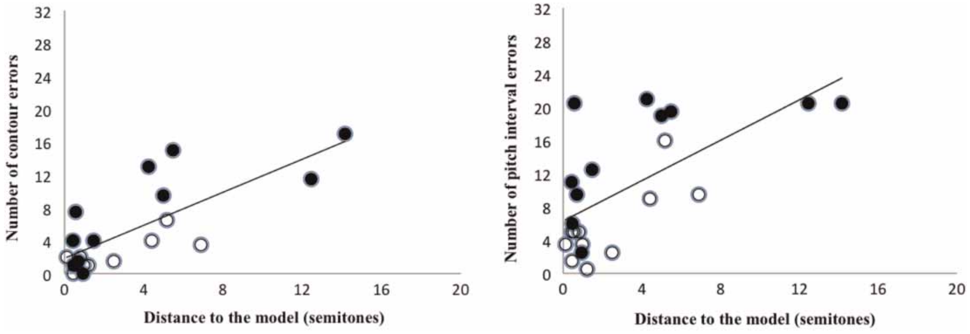

Figure 3. *Correlations between the distance in semitones from the first note produced by the participant to the one produced by the model, and the number of contour and pitch interval errors produced when singing by imitation. Amusics are represented by black circles and controls by open circles.*

further supported by the results obtained when the fourth note of the song (instead of the initial pitch) is considered.[2] Distance from the model only predicted pitch interval errors in controls, with $r = .63$, $n = 11$, $p = .05$. This weak distance effect is probably due to the fact that both controls' and amusics' pitch level was closer to the model on the fourth note than on the first one, with $t(10) = 2.61$ and 2.58, both $p < .05$, respectively.

Contribution of long-term memory. In order to assess the effect of long-term memory, we first assessed accuracy in singing without a model (from memory) and compared it to that in singing by imitation (by averaging performance across the after and unison conditions). When singing from memory, all amusics succeeded in producing the full set of 32 notes of the song with lyrics; the corresponding data are presented in Table 2. As previously observed (Dalla Bella et al., 2009), the production of amusics was characterized by poor pitch accuracy. Compared to controls, amusics' pitch production was less stable, $t(19) = 4.287$, $p < .001$, showed larger interval deviations, $t(19) = 5.773$, $p < .001$, and was characterized by more contour errors, $t(19) = 3.788$, $p < .005$, and pitch interval errors, $t(19) = 7.569$, $p < .001$. However, amusics' singing was comparable to that of normals on the temporal dimension in terms of tempo, $t(19) = -0.744$, *ns*, temporal variability, $t(19) = 0.816$, *ns*, and number of time errors, $t(19) = 1.041$, *ns*. Thus, in comparison to Dalla Bella et al. (2009), who found that a few amusic individuals had problems singing in time, the present results showed a performance level that is comparable to that of controls on the temporal dimension. These observations are probably due to the slightly different sample of amusics and suggest that in most of them, a dissociation between melodic and rhythmic processing is present.

All but one amusic (M.L.) was severely impaired on the pitch dimension. ML sang in tune and within the range of controls on all variables (see arrow in figures). This is a new case presenting a dissociation between (spared) pitch production and (impaired) pitch perception and is currently being studied in more detail.

In order to measure consistency in singing from memory over testing sessions, we compared the performance obtained by the 6 amusics who participated in both Dalla Bella et al.'s (2009) study and the present study. A sign test indicated that these amusics produced more pitch interval errors ($M = 17.2$) in the present than in the prior study ($M = 13.0$, $Z = -2.21$, $p = .03$). The errors did not occur on the same notes in the melody on the two occasions (only 42.6% affected the same notes), suggesting that the memory representation of the song is unstable or imprecise.

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[2] We wish to thank an anonymous reviewer for bringing this possibility to our attention.

Table 2. *Mean values for pitch and time variables obtained when singing from memory with lyrics*

Variables	*Amusics M (range)*	*Controls M (range)*	*French group M (range)*
Pitch dimension			
Initial pitch (Hz)			
Males	121.8 (86.8–175.0)	140.4 (131.7–162.0)	146.45 (95.4–187.9)
Females	224.1 (217.0–234.6)	249.2 (220.0–331.6)	207.27 (131.7–243.1)
Pitch stability (semitones)	2.0 (0.4–3.0)	0.6 (0.3–1.0)	0.83 (0.2–2.3)
No. of contour errors	9.6 (0.0–23.0)	1.6 (0.0–3.0)	6.0 (0.0–9.0)
No. of pitch interval errors	18.2 (2.0–25.0)	6.0 (0.0–8.0)	10.0 (1.0–17.0)
Interval deviation (semitones)	1.8 (0.7–3.9)	0.7 (0.3–0.8)	1.4 (0.3–2.0)
Time dimension			
Tempo (Mean IOI, ms)	300.8 (193.0–353.0)	313.4 (230.0–367.0)	420.0 (257.1–542.0)
No. of time errors	6.3 (2.0–12.0)	4.8(1.0–7.0)	4.0 (0.0–7.0)
Temporal variability	0.3 (0.2–0.4)	0.2 (0.1–0.5)	0.2 (0.1–0.2)

Note: The maximum value is 31 for contour and pitch intervals. IOI = interonset interval.

As singing in unison and after the model was similar, we examined the global influence of a model (imitation) on singing accuracy. That is, we compared the mean score of imitation to the score obtained in spontaneous singing (without a model) on each acoustical variable. An ANOVA was run with the two groups (amusics and controls) and two conditions (spontaneous and imitation) as a between- and within-subject factor, respectively, for each type of error. As can be observed in Figure 4, imitation tends to increase pitch stability, to decrease contour errors, and to reduce pitch interval deviations, but the improvement only reached significance for the number of pitch interval errors in amusics, $F(1, 9) = 13.5$, $p < .01$, but not in controls ($F < 1$); the interaction between group and condition was significant, with $F(1, 19) = 5.71$, $p < .05$. Imitation was so effective in improving pitch accuracy that 6 amusics (J.L., A.S., E.L., F.A., G.C., and M.B.) succeeded in reaching normal performance in terms of pitch stability (see Table 3). In contrast, imitation did not improve performance in controls on any pitch-related variable (all $F < 1$), probably due to a ceiling effect. Moreover, no interaction between group and condition (spontaneous, imitation) was observed for any of these variables.

In order to assess the effect of pitch interval size on vocal performance, we further examined pitch interval deviations for each of the 31 intervals from the chorus (ranging from zero = repeated note, to nine semitones) when singing both from memory and by imitation. The produced intervals were analysed in an ANOVA with two conditions (spontaneous and imitation), five levels of interval size (2, 3, 4, 7, and 9 semitones), and two levels of deviation type (compression and expansion) as within-subjects factors, and group as a between-subjects factor. The analysis revealed a significant interaction between group, interval size, and deviation type, $F(4, 80) = 3.56$, $p < .05$. Separate ANOVAs were then conducted in amusics and in controls. In amusics, there was no effect of interval size or of deviation type ($F < 1$) and no interaction between these two factors. In controls, a significant interaction between interval size and deviation type was found, $F(4, 40) = 6.36$, $p < .005$. When singing intervals of three semitones, controls exhibited a tendency to compress them.

On the time dimension, imitation slowed down the tempo in both amusics and controls, $F(1, 19) = 243.50$, $p < .001$, as compared to singing from memory. As singing at a slower tempo has been shown to reduce pitch and time errors (Dalla Bella et al., 2007), the reduction of pitch interval errors seen when singing by imitation could be due to this mediating speed factor. Whereas the model was useful in slowing down tempo, it

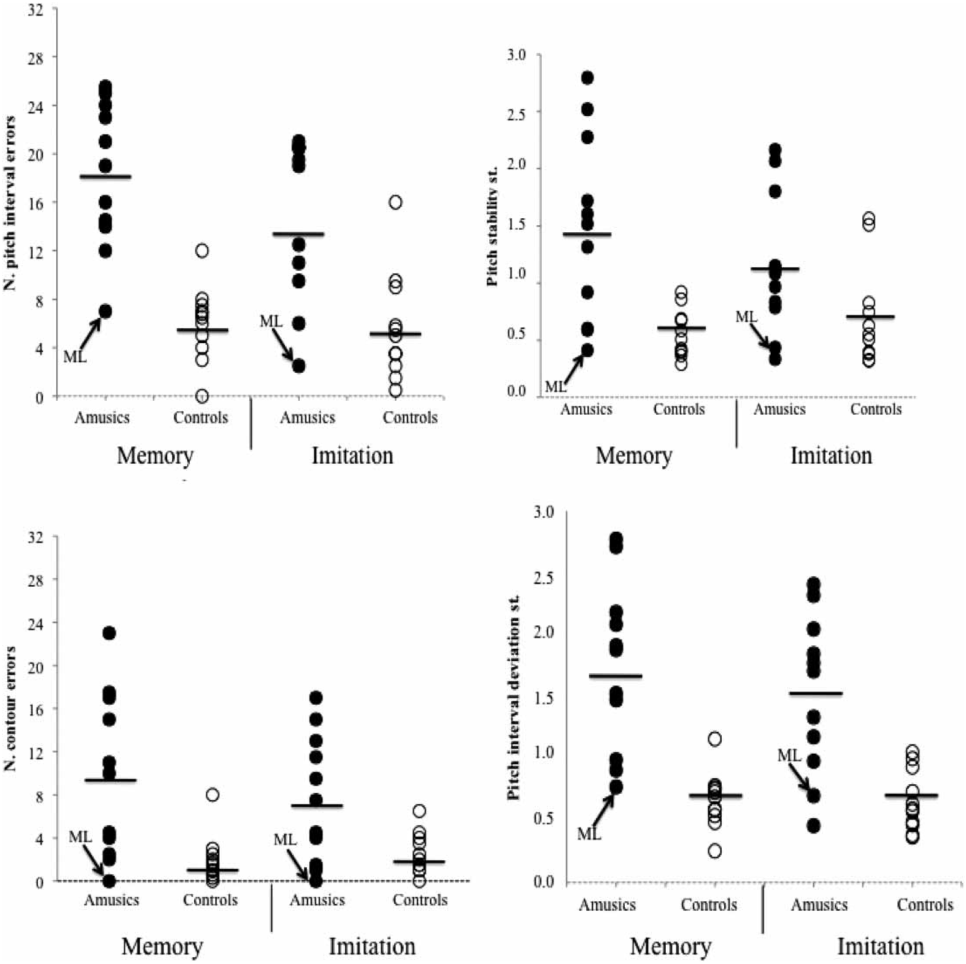

Figure 4. *Pitch stability, contour errors, pitch interval errors, and pitch interval deviations for singing with lyrics from memory and by imitation in amusics and controls. Amusics are represented by black circles and controls by open circles. M.L., the amusic whose singing is spared, is indicated by an arrow. The bar represents the mean.*

Table 3. *Mean values for pitch variables obtained by the 6 amusics who reached normal performance in pitch stability when singing by imitation*

Pitch dimension	*Amusics M (range)*		*Controls M (range)*	
	Memory	*Imitation*	*Memory*	*Imitation*
Pitch stability (semitones)	1.5 (0.6−2.3)	0.9 (0.2−1.6)	0.6 (0.3−0.9)	0.7 (0.3−1.9)
No. of contour errors	6.5 (2−17)	4.4 (0−9.5)	1.6(0−3)	2.4(0−6)
No. of pitch interval errors	17.3 (12−25)	12.5 (1−24)	6.0 (0−8)	5.0 (0−12)
Interval deviation (semitones)	1.6 (1.0−2.7)	1.2 (0.4−2.1)	0.7 (0.3−0.8)	0.7 (0.3−1.1)

Note: The 6 amusics were J.L., A.S., E.L., F.A., G.C., M.B.

did not reduce temporal variability, $F(1, 19) = 0.77$, *ns*, or time errors further, $F(1, 19) = 1.83$, *ns* (see Figure 5). This could be due to a floor effect.

Singing on the syllable /la/

Imitation and unison. Because amusics were highly variable in their ability to sing on /la/, they were separated into two groups based on their ability to complete the chorus of the song. Five amusics produced the full set of 32 notes when singing on /la/ from memory (A.S., F.A., G.C., M.B., and M.L.), and 6 (B.L., J.L., E.L., C.B., I.C., and J.G.) failed to do so (see Table 4). Several individuals produced just a few notes, and I.C. could not sing a single note. Therefore, I.C. will not be further considered in these analyses. Thus, about half of the amusics had a problem retrieving the melody from memory when requested to produce the song with the new speech segment /la/. A Pearson product–moment correlation coefficient was computed to assess the relationship between the memory test of the MBEA and the number of notes produced when singing from memory by amusics. There was a positive correlation between the two variables, with $r = .85$, $n = 11$, $p = .005$ (see Figure 6). This result supports the idea that music memory, as measured by the

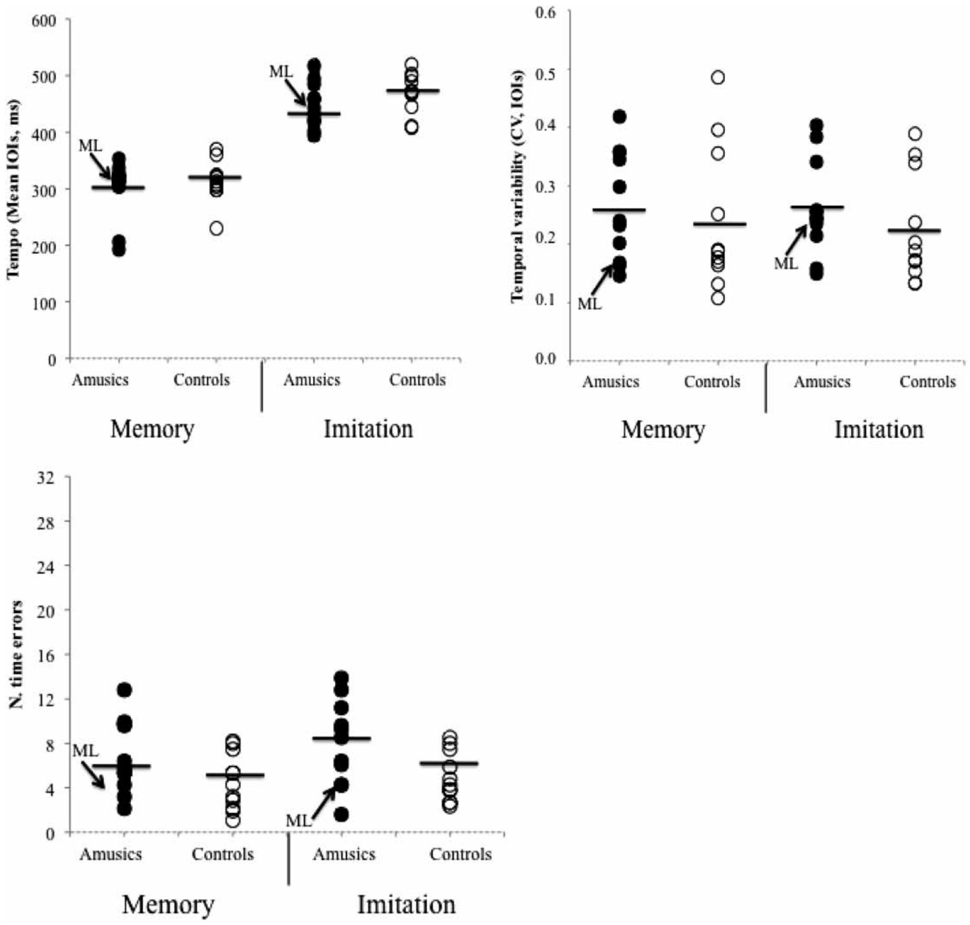

Figure 5. *Tempo, time errors, and temporal variability in amusics and controls. Amusics are represented by black circles and controls by open circles. M.L., the amusic whose singing is spared, is indicated by an arrow. The bar represents the mean.*

Table 4. *Number of notes produced by amusics when singing on /la/*

	B.L.	*J.L.*	*A.S.*	*E.L.*	*F.A.*	*G.C.*	*I.C.*	*M.B.*	*C.B.*	*J.G.*	*M.L.*	*Controls*
When singing from memory	11	12	32	18	32	32	0	32	26	17	32	32
When singing after a model	16	31	32	32	32	32	0	32	25	21	32	32
When singing in unison with a model	28	32	32	32	32	32	27	32	32	32	32	32

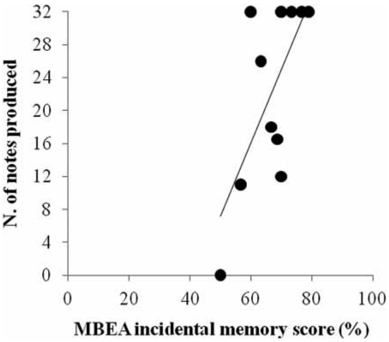

Figure 6. *Correlation between the incidental memory test of the Montreal Battery of Evaluation of Amusia (MBEA) and the number of notes produced when singing on /la/ by amusics.*

MBEA, predicts the ability to produce a well-known melody without the associated lyrics (Dalla Bella et al., 2009). We refer to the two groups of amusics who can and cannot sing on /la/ as mildly versus severely memory impaired, and these groups are examined separately in the following nonparametric analyses.

In singing on /la/, there was a difference between imitation conditions. The severely memory-impaired amusics sang more notes in unison ($M = 31.2$) than after the model ($M = 24.1$; $z = -2.02$, $p < .05$ by a Wilcoxon test) while the mildly memory-impaired produced the full set of 32 notes in both conditions. Thus, synchronization with the model facilitated note production in the most memory-impaired cases.

Despite the fact that more notes were produced in unison than after the model, there was little difference in proficiency. Severely memory-impaired amusics produced more contour errors (47.9%) and pitch interval errors (63.6%) than mildly memory-impaired ones (16.2% and 34.5%, respectively) and controls (4.8% and 12.3%, $p < .001$). The difference reached significance as assessed with Kruskal–Wallis tests in both singing after the model ($\chi^2 = 6.52$ and 6.34, $p = .05$, for contour and intervals, respectively) and singing in unison ($\chi^2 = 12.48$ and 13.53, $p = .005$, for contour and intervals, respectively).

Contribution of long-term memory. The influence of imitation on singing accuracy was analysed as previously by distinguishing the three groups (severely memory-impaired amusics, mildly memory-impaired amusics, and controls) and in comparing spontaneous singing from memory condition to singing by imitation. Singing by imitation tended to decrease the number of pitch interval errors in the severely memory-impaired amusics who produced fewer pitch interval errors when singing with a model (63.6%) than when singing from memory (without a model: 80.8%). However, this influence of the model did not reach significance ($z = -0.73$, *ns*). The number of contour errors did not differ between singing from memory and singing by imitation ($z = -0.94$, *ns*).

Effect of familiarity

The chorus of *Gens du Pays* is an overlearned song in Quebec. Thus, familiarity may have contributed to the limited effect of a model on singing proficiency in controls. In contrast, for the French students this was a novel song. To evaluate the effect of long-term exposure to the song on singing proficiency, performance of the French group was compared to that of the control group (see Table 2). When singing with lyrics, the French participants produced larger interval deviations, $t(18) = 1.985$, $p < .05$, and more contour errors than the Quebec controls matched to the amusics, $t(18) = 2.329$, $p < .05$. Pitch stability and number of pitch interval errors did not differ between the two groups, $t(18) = 1.097$ and 1.450, respectively. On the time dimension, the French group sang at a slower tempo than controls, $t(18) = 4.120$, $p < .005$, which might have contributed to the limited number of pitch interval errors that they produced (Dalla Bella et al., 2007). Finally, they did not differ from controls in terms of temporal variability, $t(18) = 1.375$, *ns*, or time errors, $t(18) = 0.752$, *ns*.

All French subjects succeeded in producing the complete rendition of the song on the syllable /la/ and were as accurate as controls in terms of contour and pitch interval errors, $t(18) = 0.600$ and 1.273, *ns*, respectively. Finally, there was no evidence that singing in unison was of any aid. All comparisons between the unison and after model conditions were not significant. Furthermore, there was no difference between singing from memory as compared to singing by imitation on the number of contour errors, $F(1, 19) = 2.86$, *ns*, and pitch interval errors ($F < 1$). Overall, these results suggest that imitation is of limited aid under normal conditions.

Conclusions

Singing by imitation decreased the number of pitch interval errors as compared to singing from memory in amusics. Moreover, the model helped half the amusics to sing the melody on /la/. In particular, we observed that singing on the syllable /la/ was very laborious for half of the amusics, who were also the most severely impaired in the recognition of novel melodies from memory. This result supports the idea that poor memory contributes to poor singing.

However, singing by imitation also slows down tempo. As shown previously, singing at a slower tempo reduces pitch and time errors in occasional singers (Dalla Bella et al., 2007). Thus, the observation of an improvement in pitch accuracy when singing by imitation as compared to singing from memory could be due to this mediating speed factor, not only memory. What is very likely is that a degraded memory representation of a song exacerbates poor singing. Providing an aid in the form of a model to imitate or to sing along is effective but insufficient, as all amusics remained poor singers in such conditions. This is consistent with the prior observation that vocal pitch-matching abilities are impaired in congenital amusia across different pitch heights and feedback conditions (Hutchins, Zarate, Zatorre, & Peretz, 2010).

In contrast, the aid of a singing model could not be demonstrated in normal controls. We found little influence of the model on the performance of French subjects who learned the song just before testing. Although the learning episode reduced the singing tempo of the French group as compared to the Quebec singers, imitation did not further reduce the size of pitch deviations or the number of contour errors. These results suggest that singing by imitation is of limited aid in general, but effective in poor singers with poor memory. However, the role of imitation in singing is confounded here with the learning method. The French participants learned the song by imitation just before testing. A different pattern might emerge if the same group were tested in a separate session. Indeed, the Quebec singers did show some slight benefit from listening to someone else as compared to singing alone from memory.

It should be noted that all participants were tested here in the same fixed order, with singing from memory followed by singing after a model and then in unison with the same model. Although singing alone (from memory) had to be performed first in order to isolate the effect of memory from the potential influence of a model, singing after or in unison with the model can be counterbalanced within and across subjects. With repeated practice in the two conditions with a model, amusics, particularly the most memory-impaired ones, might have improved their singing proficiency in chorus singing. Testing this possibility should be the goal of future testing, preferably in using an unfamiliar song to avoid ceiling effects in control participants. An adaptive procedure would be a well-suited design, as shown previously in normal students and aphasic patients (Racette & Peretz, 2007; Racette et al., 2006).

In sum, imitation can support singing in severe cases of poor singing. It is worth mentioning that the present situation is advantageous by being more ecological than prior studies in several aspects. For example, Pfordresher and Brown (2007) used a synthesized voice as a model, and participants listened to their own singing at a reduced volume as compared to the synthesized voice. This setting may explain why singing with a model in this prior study was not effective, at least for the poor singers. In the present study, the model was a prerecorded natural voice, leaving the possibility for the singers to monitor their own voice as distinctly as the model. Thus, new rehabilitation strategies may exploit similar settings and target both speed and memory in poor singers in order to moderate the severity of their singing disorder. However, in future studies, the long-term benefits of imitation should be assessed, especially in amusics who suffer from severe memory problems. By testing amusics after a delay, it could be possible to evaluate whether singing by imitation can be a long-term rehabilitation strategy, not only an immediate one.

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