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Memory disorders and vocal performance

Simone Dalla Bella,[1,2,3] Alexandra Tremblay-Champoux,[3] Magdalena Berkowska,[2] and Isabelle Peretz[3]

[1]EuroMov, Movement to Health Laboratory, University of Montpellier-1, Montpellier, France. [2]Department of Cognitive Psychology, University of Finance and Management, Warsaw, Poland. [3]International Laboratory for Brain, Music, and Sound Research (BRAMS), Montreal, Canada

Address for correspondence: Simone Dalla Bella, EuroMov, Movement to Health Laboratory (M2H), University of Montpellier-1, 700 Avenue du Pic Saint Loup, 34090 Montpellier, France. simone.dalla-bella@univ-montp1.fr

The ability to carry a tune, natural for the majority, is underpinned by a complex functional system (i.e., the vocal sensorimotor loop, VSL). The VSL involves various components, including perceptual mechanisms, auditory-motor mapping, motor control, and memory. The malfunction of one of these components can bring about poor-pitch singing. So far, disturbed perception and deficient sensorimotor mapping have been treated as important causes of poor singing. Yet, memory has been paid relatively little attention. Here, we review results obtained from both occasional singers and individuals suffering from congenital amusia, who were asked to produce from memory or imitate a well-known melody under conditions with different memory loads. The findings point to memory as a relevant source of impairment in poor-pitch singing and to imitation as a useful aid for poor singers.

Keywords: amusia; vocal performance; memory disorders; music performance

Introduction

The majority of people can carry a tune. Most of us can sing from memory well-known songs (e.g., "Happy Birthday") and imitate short novel melodies quite accurately,[1–3] although not always precisely.[4] This observation is not totally surprising. Singing is as natural as speaking for humans. This ability emerges early during development without needing vocal training or musical tutoring.[5–7] Moreover, singing, due to its participatory character, is thought to foster group bonding, an advantage that may have had some adaptive value in the course of evolution.[8–10] In sum, singing is a fundamental function that is likely to be deeply rooted in human biology.

Some individuals (i.e., tone deaf), representing approximately 10–15% of the general population, are particularly inaccurate in producing pitch. When asked to produce familiar melodies or imitate single pitches, intervals, or short melodies, they typically sing quite far from the target.[1–3] This estimate rises to about 55% of the population when the consistency of repeated attempts to produce pitches (i.e., precision) is taken into account.[4] A few recent studies have aimed to characterize poor-pitch singing and elucidate its causes.[2,11,12] Different sources of impairments may underline inaccurate singing including motor control, perceptual processes, auditory-motor mapping, and memory. In this paper, we will particularly focus on the latter by providing evidence in favor of the idea that memory deficits often accompany poor-pitch singing. To this aim, the mechanisms underlying normal singing will be presented first, and the different explanations of poor-pitch singing briefly addressed.

The vocal sensorimotor loop

People generally tend to underestimate their ability to carry a tune. Almost 60% of 1,000 university students report that they cannot accurately imitate melodies.[2] Moreover, self-declared tone-deaf individuals (around 17% of the student population) believe that they cannot sing proficiently.[13] This picture is clearly too defeatist though. When singing is assessed systematically, we find that about 85–90% of the general population can sing accurately.[1–3,11]

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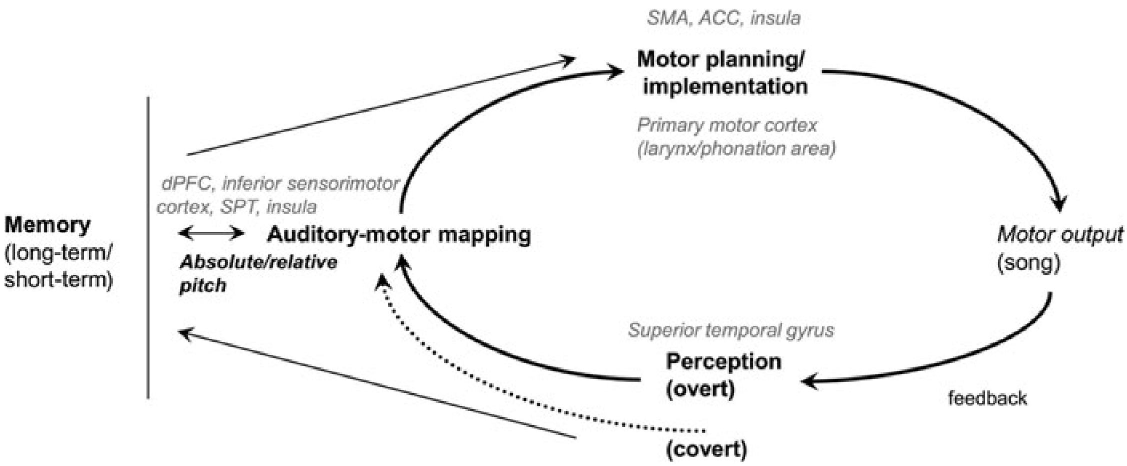

Figure 1. The vocal sensorimotor loop (VSL).[11,14] SMA, supplementary motor area; ACC, anterior cingulate cortex; dPFC, dorsal prefrontal cortex; SPT, cortex of the dorsal Sylvian fissure at the parietal–temporal junction.

Proficient singing in the general population has been shown across a variety of tasks focusing on vocal performance, spanning from singing from memory of a familiar melody, imitation (e.g., single-pitch matching or melody matching), and imitation with reduced or augmented feedback.

Which functional mechanisms and brain circuitry support the widespread ability to sing in tune? The functional components of the song system underlying accurate pitch production have been summarized using the VSL,[13–15] as illustrated in Figure 1. The VSL comprises four main components: perceptual mechanisms, motor planning/implementation, auditory-motor mapping, and memory (short term and long term). Pitch production in the aforementioned tasks can be accounted for by the VSL. Singing of familiar melodies requires the retrieval from long-term memory of pitch and temporal information, directed to fine motor planning/implementation mechanisms (e.g., articulation and eventually phonation). The output of the system (i.e., vocal production) is then fed back to perception. Matching the percept of the produced melody with the memory representation of the intended melody (auditory-motor mapping) warrants error correction if there are discrepancies, thus ultimately affecting planning of upcoming events. Imitation of novel pitch sequences engages similar mechanisms; however, it relies more on short-term memory, without tapping retrieval from long-term memory. The target pitches to be imitated are perceptually analyzed, stored in short-term memory, and eventually mapped into motor gestures. Accurate imitation is made possible by self-monitoring of vocal performance through feedback analysis, and, in some cases, error correction. Note that overt and covert pathways for pitch perception are included in the VSL. The overt pathway is engaged when performing explicit judgments of pitch differences (e.g., pitch discrimination). The covert pathway is supposed to account for cases in which participants are very inaccurate in judging pitch differences, but still exhibit proficient singing (i.e., revealing an implicit ability to make the difference between pitches).[16–18]

The components forming the VSL are underpinned by a complex neuronal network, as revealed by neuroimaging studies (Fig. 1).[11] Singing recruits motor areas (e.g., primary motor cortex), in particular, the mouth region and the larynx/phonation area,[19,20] the anterior cingulate cortex (ACC), the insula, and the supplementary motor area (SMA). The ACC and the insula are linked with initiation of vocalization and articulatory processes, respectively.[19,21–23] The SMA, rather, is involved in high-level motor control, which guarantees efficient motor planning.[24] Sensory areas (e.g., the superior temporal gyrus) are also engaged by vocal performance.[19,22,25] Finally, auditory-motor mapping involves various areas such as the dorsal prefrontal cortex, inferior sensorimotor cortex, the superior temporal gyrus and sulcus,[23,26,27] and area SPT (i.e., cortex of the dorsal Sylvian fissure at the parietal–temporal junction).[28,29] To sum up, brain imaging contributes to uncovering the major components of the song system by providing the neural substrates of the mechanisms identified at a functional level in the VSL.

Our understanding of the song system paves the way for explaining poor-pitch singing. Indeed, poor-pitch singing is not a monolithic deficit and can be brought about by the malfunctioning of any of the components in the VSL. Here, the most relevant accounts will be summarized.[2,11,12,14] Poor-pitch singing is often treated as the outcome of perceptual deficits (e.g., in congenital amusics), resulting from the impaired extraction of pitch information from the auditory input (herein, the "perceptual account"). Impaired perception makes monitoring of the ongoing performance more difficult, thus hindering error correction and leading to reduced accuracy. However, perceptual deficits are not a *sine qua non* for poor-pitch singing. The fact that inaccurate singing can occur despite spared perception points to postperceptual mechanisms as a cause of poor-pitch singing.[1,2] An alternative explanation is that auditory-motor mapping is not carried out properly (the "sensorimotor account").[2,30] A correct auditory representation of the vocal performance can be inaccurately mapped to motor representations for phonation. This mismap concerns local musical features (absolute pitch and secondary pitch intervals) without affecting global features (e.g., melodic contour).[2] Note that mapping relative and absolute musical features (i.e., absolute pitches and intervals) to phonation may engage at least partly independent mechanisms. This possibility is supported by the observation that imitation of absolute and relative pitch can be selectively disrupted in poor-pitch singers,[3] and by differential effects of feedback on pitch accuracy (i.e., choral singing enhances pitch accuracy in producing intervals and contour, but is detrimental for producing absolute pitch).[2] Finally, the sensorimotor account gained some neurobiological plausibility after the discovery of abnormally reduced connectivity through the fasciculus arcuatus (i.e., a pathway connecting temporal and frontal brain regions) in tone deafness.[31]

Another possibility, although little examined in the literature, is that poor-pitch singing results from (or is linked to) a faulty memory system. Despite spared perception and normal motor control, difficulties with encoding, storage, or retrieval of pitch information during reproduction (e.g., in imitation tasks) may bring about inaccurate singing. The possibility that memory disorders are associated with poor-pitch singing is plausible. Congenital amusics, who are typically poor-pitch singers,[16,32] also exhibit impaired memory.[32–35] Pitch representations in amusic individuals are typically less stable and decay more rapidly. It is worth noting that amusics do not suffer from general memory difficulties, as observed, for example, in amnesic patients or in patients with dementia. Amusics' memory disorder is highly selective and is likely to be confined to music.

One way to examine the role of memory in poor-pitch singing is to observe the effect of manipulating memory demands. If poor-pitch singing stems from weak memory traces, reducing memory demands (e.g., via additional feedback or by reducing stimulus length) should alleviate deficits in imitating and producing pitch. For example, Wise and Sloboda[36] asked self-reporting tone-deaf individuals to imitate short-pitch sequences (i.e., formed by one up to five notes). In one condition, the target was presented before participants' imitation; in another condition, the participants were asked to sing along (i.e., synchronized condition), a situation that reduces the memory load. All participants were less accurate with longer sequences. However, increasing the length of the sequence had a more disruptive effect on the performance of tone-deaf individuals as compared with non-tone-deaf participants. Moreover, tone-deaf individuals were aided more than controls by singing along. These findings suggest that tone-deaf individuals cannot maintain short-term memory traces of the presented sequences as compared with non-tone-deaf individuals. Similar stimulus manipulations were adopted by Pfordresher and Brown[2] to test a group of occasional singers. In addition, normal feedback, augmented feedback (i.e., singing along), and masked feedback (i.e., pink noise presented during sung performance) were provided. However, neither an effect of stimulus length nor an advantage due to augmented feedback was observed for poor-pitch singers. In sum, previous studies manipulating memory demands yield a conflicting picture.

In this paper, we briefly review recent studies in which pitch accuracy was examined when the memory load was manipulated, by asking congenital amusics and occasional singers to sing a familiar song from memory either with lyrics or on a syllable, and by presenting a model to be imitated.

In the first case, it is assumed that recalling a familiar melody without lyrics (i.e., when singing on a syllable) will put less demand on long-term memory, thereby allowing the singers to focus on retrieval of the correct melodic information and enhancing auditory-motor mapping. In the second, it is expected that presenting a model to be imitated will enrich the memory trace of the melody to be reproduced (i.e., facilitating its retrieval from memory), thus eventually leading to improved singing accuracy (via auditory-motor mapping).

Study 1: Singing with lyrics versus on a syllable

In a previous experiment we asked 11 congenital amusics (as assessed with the Montreal Battery of Evaluation of Amusia, MBEA[37]) and 11 matched controls to sing the chorus of a familiar melody from memory (i.e., "Gens du Pays") with lyrics, and on a syllable (i.e., /la/ or /ta/).[16] In another experiment, 50 occasional singers (35 females and 15 males, mean age = 25.1 years), mostly university students without musical training, were asked to perform a similar task with three familiar melodies ("Brother John," "Jingle Bells," and "Sto lat"; see also[3,38] for preliminary results). Accuracy in pitch production was computed using acoustical analyses.[1,3] This method, based on acoustical segmentation of sung recordings, provides reliable estimates of pitch heights and note onset times; this data is used to compute various measures of singing accuracy. For the sake of simplicity, we report here only two measures of singing accuracy in terms of relative pitch, which have proven to be very sensitive to individual differences in the general population.[1,3] The first measure is the *number of pitch interval errors*, namely the number of produced intervals that depart from the intended intervals (i.e., based on the musical notation) by at least one semitone. The second measure is *pitch interval deviation*, a continuous measure of pitch deviation obtained by averaging the absolute difference in semitones between the produced intervals and the intervals prescribed by musical notation. Small deviation indicates high accuracy in relative pitch.

All participants in the two experiments were able to produce complete performances with lyrics (i.e., including the full set of notes). Amusics were typically more impaired than controls, though, exhibiting on average 13 pitch-interval errors (vs. 3.6 errors for controls), and pitch interval deviation of 1.3 semitones (vs. 0.5 semitones). The difference between amusics and controls was even more striking, however, when amusics sang on a syllable. Six out of 11 amusics could not produce complete renditions of the melody; their performance was limited to just a few pitches. Note that they were the most impaired amusics, and that they had impaired incidental memory, as revealed by the MBEA. Pitch accuracy for the remaining five amusics, as compared to controls and to 50 occasional singers is reported in Figure 2. As can be seen, these five amusics were still on average less accurate than controls ($P_s < 0.05$, by the Mann–Whitney test) and occasional singers ($P_s < 0.01$). It is worth noting that the opposite dissociation (i.e., higher accuracy when singing on

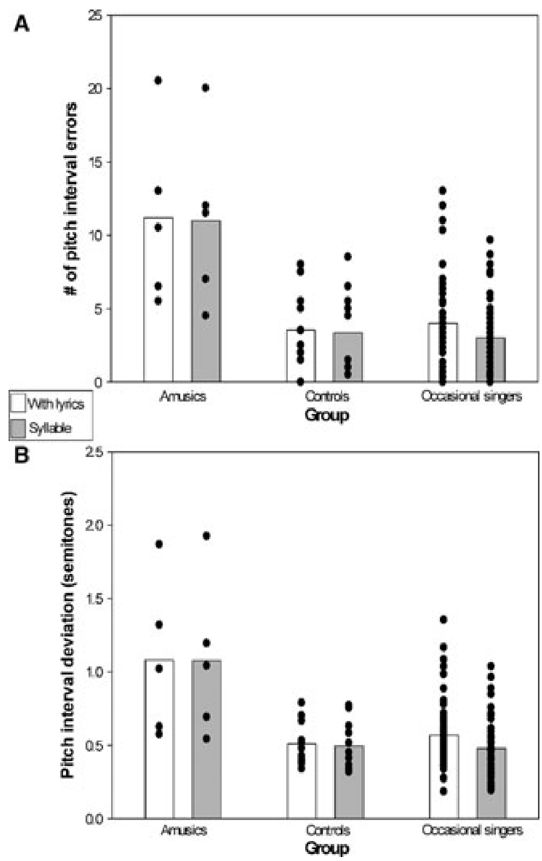

Figure 2. Mean (A) number of pitch interval errors and (B) pitch interval deviations for congenital amusics ($n = 5$), controls ($n = 11$), and occasional singers ($n = 50$) when singing familiar songs from memory with lyrics and on a syllable. For amusics and controls, the maximum possible number of errors was 31; for occasional singers, 25.

a syllable than when singing with lyrics) was observed in the group of 50 occasional singers (for the number of pitch interval errors, $t(49) = 5.0$, $P < 0.001$; for pitch interval deviation, $t(49) = 5.1$, $P < 0.001$).

In sum, these findings indicate that memory disorders and impoverished perception coexist in congenital amusia. The fact that congenital amusics have major difficulties when asked to sing on a syllable can result from weak memory traces of the musical component of songs. Severe amusics can still produce complete performances with lyrics, although inaccurately, probably owing to the strong association between melody and text. However, when an association of a well-known melody to a new speech segment is required (like when singing on a syllable), the melody information may become more difficult to retrieve.

Study 2: Effects of imitation on singing proficiency in congenital amusia

In another study we tested congenital amusics with the goal of examining whether providing an aid to memory (i.e., asking amusics to imitate a model) enhances singing accuracy.[39] Eleven congenital amusics and 11 matched controls were asked to sing a well-known melody from memory ("Gens du pays") with lyrics and on the syllable /la/. In one condition ("memory"), the melody was sung from memory without any model. In two other conditions, a model to be imitated was presented (i.e., an accurate performance of the melody by a nonprofessional singer). The melody was sung after the model was presented ("after model") and, in another condition, along with it (i.e., "in unison").

As before, the number of pitch interval errors and pitch interval deviation were computed based on acoustical analyses of the sung renditions. The results showed that pitch accuracy when singing with lyrics was not affected by the fact that imitation occurred after the model or in unison. Nevertheless, the amusic individuals benefited from the imitation of a model as compared to singing from memory. This effect is visible in particular when considering the number of pitch interval errors ($F(1,9) = 13.5$, $P < 0.01$); a tendency is found with pitch interval deviation (see Fig. 3). Remarkably, for 6 of 11 amusics, imitation led to pitch productions as stable as those observed in controls.[39] When singing on a syllable, only five amusics were able to produce complete performances (i.e., the full set of 32 notes), confirming what we observed in the previous study.[16] The six amusics who could not sing complete performances were the most impaired in terms of incidental memory, as indicated by the MBEA. Interestingly, these individuals sang more notes when they imitated a model, in particular when singing in unison. In sum, these findings confirm that poor-pitch singing is often associated with impaired memory. Providing a memory support (i.e., a model to be imitated) aids congenital amusics to sing more accurately, in particular for individuals exhibiting a faulty memory system.

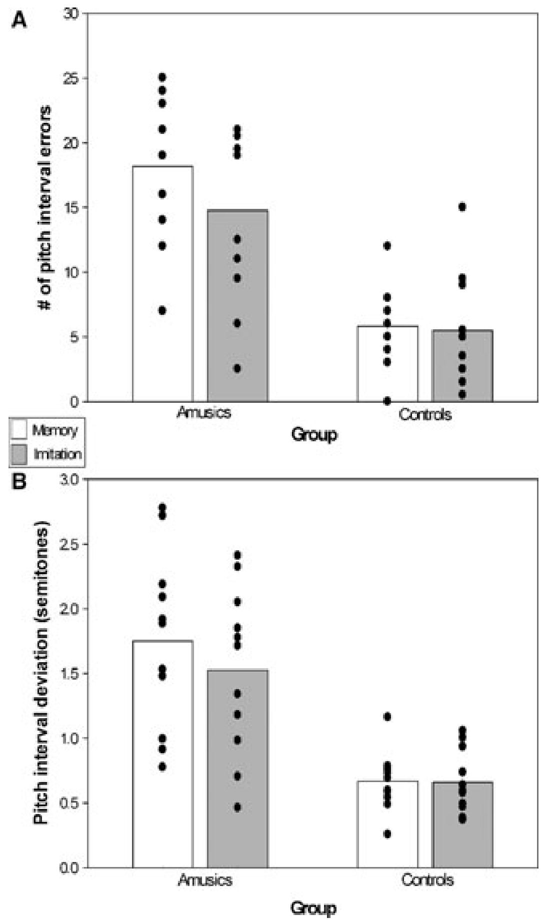

Figure 3. Mean (A) number of pitch interval errors and (B) pitch interval deviations for congenital amusics ($n = 11$) and controls ($n = 11$) when singing from memory (*Memory* condition) and when imitating a model (*imitation*, average of the *After Model* and *in Unison* conditions). The maximum possible number of errors was 31.

Conclusions

In this article, we sought to briefly illustrate the mechanisms underlying accurate singing using the VSL, and to review the existing explanations of poor-pitch singing. The most popular causes of poor-pitch singing rely on impoverished perception (the perceptual account) or disrupted auditory-motor mapping (the sensorimotor account). Less attention has been paid to memory disorders. Here, we reviewed recent findings showing that poor-pitch singing is often associated with memory disorders by studying pitch accuracy in individuals with congenital amusia. Note that this does not indicate that a faulty memory system is the primary cause of poor-pitch singing. Some congenital amusics (i.e., with dramatically impaired pitch perception), albeit they do not exhibit major memory disorders, are still poor-pitch singers.

Because poor-pitch singers often have weaker memory traces, providing a memory support (e.g., asking them to imitate a model) is expected to alleviate the retrieval of melodic information. We provided compelling evidence that this is true, by showing that singing after a model is presented, or in unison, enhances pitch accuracy in poor-pitch singers. Thus, a memory aid can act as a mediator for improving pitch accuracy in poor-pitch singers, a possibility that should be thoroughly examined in future studies.

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Conflicts of interest

The authors declare no conflicts of interest.

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