Making non-fluent aphasics speak: sing along!

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A classic observation in neurology is that aphasics can sing words they cannot pronounce otherwise. To further assess this claim, we investigated the production of sung and spoken utterances in eight brain-damaged patients suffering from a variety of speech disorders as a consequence of a left-hemisphere lesion. In Experiment 1, the patients were tested in the repetition and recall of words and notes of familiar material. Lyrics of familiar songs, as well as words of proverbs and prayers, were not better pronounced in singing than in speaking. Notes were better produced than words. In Experiment 2, the aphasic patients repeated and recalled lyrics from novel songs. Again, they did not produce more words in singing than in speaking. In Experiment 3, when allowed to sing or speak along with an auditory model while learning novel songs, aphasics repeated and recalled more words when singing than when speaking. Reduced speed or shadowing cannot account for this advantage of singing along over speaking in unison. The results suggest that singing in synchrony with an auditory model—choral singing—is more effective than choral speech, at least in French, in improving word intelligibility because choral singing may entrain more than one auditory–vocal interface. Thus, choral singing appears to be an effective means of speech therapy.

Introduction

Singing is considered to be an effective means for non-fluent aphasics to produce words that they are not able to pronounce otherwise (Keith and Aronson, 1975; Assal *et al.*, 1977; Yamadori *et al.*, 1977; Jacome, 1984). Singing may facilitate speech at different stages of processing: at the motor stage by reducing the speech rate in dysarthric patients (Yorkston and Beukelman, 1981; Yorkston *et al.*, 1990; Hustad *et al.*, 2003), at the level of word retrieval by providing structural constraints, such as the number of syllables per beat (Wallace, 1994; Rubin, 1995; Poulin-Charronnat *et al.*, 2005) or at a motivational level by engaging recreational skills. Identification of the factors that make singing an effective treatment for speech disorders is important to determine who can be helped by musical interventions and why.

The use of music as a therapy for speech has given birth to the Melodic Intonation Therapy (MIT). MIT is a 'rehabilitation program using high probability phrases and sentences which are intoned and tapped out in a syllable-by-syllable manner', mainly used with patients with severe expressive deficits (Sparks *et al.*, 1974; Naeser and Helm-Estabrooks, 1985). An early interpretation of successful recovery from aphasia with the MIT technique was that it facilitated the use of homologous language areas of the right hemisphere after damage to the language areas in the left hemisphere (Albert *et al.*, 1973). However, a study by Belin *et al.* (1996) challenged this notion in showing that repetition of words trained with MIT elicited a deactivation in the right-hemisphere structures while language-related left-hemisphere structures were active in seven non-fluent aphasic patients who were successfully treated with MIT. One possible explanation for this discrepancy is that the American use of the MIT emphasizes melodic cues whereas the French intervention stresses rhythm.

The rhythmic support seems to be key (Boucher *et al.*, 2001). MIT treatments emphasizing rhythm (with stressing points emphasized by the spoken syllable /tae/, and hand-tapping) lead to better syllable repetition than treatments emphasizing intonation (tone contour and melodic intonation). Another advantage related to rhythm is that singing slows down the rate of word production and thereby may improve intelligibility (Laughlin *et al.*, 1979; Pilon *et al.*, 1998). Intelligibility is tightly related to speech rate as

observed in three dysarthric patients with three different pacing methods (Pilon *et al.*, 1998). The slower the pace imposed on speech production, the better the intelligibility, but only when the speech reduction was severe. Because singing slows down word production by ∼50% as compared with speaking (Kilgour *et al.*, 2000), singing should be effective in improving intelligibility.

An additional reason why singing could improve speech is that words learned through music, as in familiar songs, are fixed or non-generative. Automatic or non-propositional speech, which includes not only song lyrics but also prayers and swearing, is usually preserved in non-fluent aphasia (Ryding, *et al.*, 1987; Speedie *et al.*, 1993; Blank *et al.*, 2002; Van Lancker-Sidtis, 2004). Moreover, in songs, words and melodies are learned together. Melody may facilitate access to words because they are tightly associated in memory (Serafine *et al.*, 1984, 1986; Crowder *et al.*, 1990; Peretz *et al.*, 2004*b*).

In sum, there are many reasons why singing can improve language production. Nevertheless, supporting evidence is scant. Cohen and Ford (1995) examined the production of songs by 12 patients who became aphasic after a unilateral left-hemisphere vascular accident, under three experimental conditions: naturally spoken, spoken with a steady drumbeat accompaniment and sung with the melody played on a keyboard. They found that speech content and error types did not differ across conditions, but that word intelligibility was higher when utterances were spoken without any support. However, it may be the case that the patients could not benefit from the musical aid because of associated musical disorders. Indeed, aphasia and amusia often occur together (Marin and Perry, 1999). Yet, even when music processing is preserved, we found that singing did not help speech recovery in two single-case studies (Hébert *et al.*, 2003; Peretz *et al.*, 2004*a*). The results suggest that verbal production, be it sung or spoken, is mediated by the same (impaired) language output system and that this speech route is distinct from the (spared) melodic route. Thus, the classic reports that non-fluent aphasics are able to sing may simply reflect the dissociation between automatic speech (in singing) and propositional speech (in spontaneous speech). However, our two aphasic patients (Hébert *et al.*, 2003; Peretz *et al.*, 2004*a*) presented atypical forms of aphasia (i.e. crossed aphasia and primary progressive aphasia, respectively). The goal of the present study was to examine this issue in common speech disorders.

To this aim, we conducted a multiple-case study with aphasic patients whose performance was compared when singing and reciting both familiar and novel utterances. A variety of speech deficits were considered to allow the exploration of a wide range of error types in production. In Experiment 1, we investigated patients' production of familiar material, such as traditional songs, prayers, proverbs and rhymes. If automatic access to words in memory is critical, then the aphasic patients should be fluent with all verbal material, be it spoken or sung. The patients not only

had to recite the lyrics of the songs, but they also had to sing the words of prayers and proverbs on a familiar melody. If singing helps word production, then sung words should be more accurate than spoken words in both lyrics and well-known expressions.

In order to assess the effect of singing on word production when access to the words is not automatic, we tested the patients with novel songs in Experiments 2 and 3. Furthermore, patients learned the novel songs either alone (Experiment 2) or in unison (Experiment 3). Unison production was performed at two different speeds in order to explore the role of speech rate on word intelligibility. Unison production should improve performance when compared with speaking or singing alone, simply because it provides online cues for the words to vocalize. 'Choral speech' is known to improve speech fluency in people who stutter (Saltuklaroglu *et al.*, 2004). The aid should be particularly effective at slow speed.
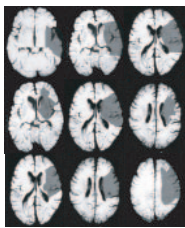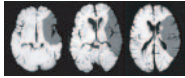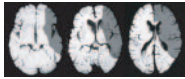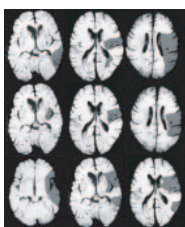
General method
Participants
Eight non-fluent aphasics were recruited through the Quebec Association of Persons with Aphasia (AQPA). A summary of the patients' characteristics is given in Table 1. All participants are right-handed, French-speaking and suffered a left cerebral vascular accident at least 2 years before the study. No patient had pre-morbid history of neurological or psychiatric problems. CT scans of four patients and MRI scans of three patients were obtained at the time of testing (summer 2002, except for JH's scan that was taken after his stroke in 1997). Informed consent was obtained from all patients and the study was approved by the Ethical Committee of the Montreal University Geriatric Institute.

The patients were assessed and tested in French, their native language. All patients had undergone speech therapy. At the time of testing, the patients were re-evaluated by two independent speech therapists, using the MT-86 (Nespoulous *et al.*, 1992), the short version of the Token Test (De Renzi and Vignolo, 1962) and subtests of the French version of the Boston Diagnostic Aphasia Examination (Mazaux and Orgogozo, 1981). On the basis of these tests, the patients were diagnosed as suffering from Broca's aphasia (JS, LB, RD), mixed aphasia with predominance of expressive deficits (RH, PP, CA, JH) and anomia (LD; *see* Table 1). In addition to the language problem, most cases (except JH and LD) suffered from dysarthria, an articulatory problem due to impaired coordination of speech muscles, and buccofacial apraxia, an inability to coordinate and carry out facial and lip movements. The main diagnostic scores are presented in Table 2. As can be seen, the speech disorders were mostly expressive, affecting both oral and written language. Simple comprehension was well preserved. Limited verbal expression, preserved comprehension and intact right hemisphere made all the patients eligible for MIT, even if some were better candidates (e.g.

Table I Characteristics of patient's diagnosis, aetiology and lesion location

Patient	Sex	Age	Education	Years since last infarct	Number of infarcts	Diagnosis	Aetiology	Lesion location
LB	F	56	10	5	1	Severe Broca's aphasia Severe dysarthria	Left sylvian CVA	
PP	M	45	11	6	2	Severe mixed aphasia	Left sylvian CVA	
JS	M	55	18	20	1	Severe Broca's aphasia	Left frontoparietal aneurysm Thalamic lacuna cerebri	
JH	M	62	20	5	1	Moderate to severe mixed aphasia; Predominantly expressive deficit	Left sylvian CVA	
CA	F	36	14	13	1	Moderate to severe mixed aphasia; Predominantly expressive deficit	Aneurysm of the anterior and mid-left cerebral artery	
RD	F	54	9	19	1	Moderate Broca's aphasia	Left sylvian CVA	
RH	M	67	7	9	2	Atypical Broca's aphasia; severe dysarthria	Left sylvian CVA	
LD	F	38	15	19	1	Mild to moderate anomia	Left sylvian CVA	

The right side of the brain is on the left; CVA = cerebral vascular accident.

Table 2 Language assessment

	LB	PP	JS	JH	CA	RD	RH	LD
MT-86 aphasia battery								
Expression								
Naming	0/6	11/31	26/31	17/31	30/31	31/31	28/31	28/31
Verbal fluency	3	0	13	15	35	38	32	36
							No agrammatism	
Automatized speech								
Digits 1 to 10	n	n	n	n	n	n	n	Slow
Days of the week	n–	d	n	n	n	n	n	Slow
Months of the year	–	d	n	n	n	n	n	Slow
Words of familiar songs	d	d	d	n	n–	n	n	n–
Melody of familiar songs	n	n	n	n	n–	n	n	n–
Repetition								
Syllables	5/20	19/20	3/20	20/20	16/20	18/20	11/20	20/20
Words and non-words	10/30	22/30	17/30	30/30	28/30	27/30	21/30	30/30
Sentences	0/3	0/3	0/3	2/3	1/3	1/3	0/3	1/3
Auditory comprehension								
Words	9/9	9/9	9/9	9/9	8/9	9/9	–	9/9
Simple sentences	6/6	6/6	5/6	6/6	6/6	6/6	6/6	6/6
Complex sentences	24/32	25/32	23/32	28/32	24/32	24/32	32/32	28/32
Body-part identification	8/8	7/8	8/8	8/8	8/8	8/8	8/8	9/9
Object manipulation	5/8	5/8	5/8	6/8	5/8	7/8	8/8	7.5/8
Reading comprehension	5/9	14/20	16/23	15/23	17/23	18/23	23/23	13/13
Dictation	–	3/7	4/9	0	2/4	1/6	23/35	n
Token test	16/36	10.5/36	13.5/27	22/36	16.5/28	28.5/36	29/36	26.5/36

n = normal performance; n- = with help; d = deficit; – = not assessed.

LB, JS, RD) than others (e.g. LD), because of their severe speech reduction. Individual scores are ordered in the Tables from the most to the less severe cases of speech reduction.

In order to assess prosody, the patients and three neurologically intact participants were required to produce three neutral sentences with four different intonations: statement, question, joy and sadness. The renditions were

randomly mixed and presented to five judges who had to guess and rate the intended intonation. The aphasic patients scored lower than controls for at least one intonation, especially joy. The fact that aphasics had pronunciation difficulties might have played a role.

Each participant was tested with a short neuropsychological battery of tests, including the digit span, the standard non-coloured Raven's matrices (1996) and the Tower of London (Shallice, 1982; *see* Table 3). Digit spans were limited, probably because of the alteration of verbal rehearsal (Burgio and Basso, 1997). Raven's matrices revealed good reasoning abilities in half of the participants. The other half was impaired. This is not too surprising since left-hemisphere lesions, especially in the frontal region, have been associated with difficulties in reasoning (Langdon and Warrington, 2000). Disorders of executive functions, as revealed by planning difficulties in the Tower of London, were present in JS, and to a lesser degree in PP.

Regarding musical abilities, it is worth mentioning that five aphasics (LB, PP, JS, CA, RH) participate in the choir activity organized by their association for 2 h a week. The choir activity consists in singing along familiar tunes. None of the participants had formal musical training. Their musical perception abilities were assessed with the Montreal Battery for Evaluation of Amusia (MBEA; Peretz *et al.*, 2003). The scores are presented in Table 4. Five participants

had normal scores, whereas two participants (PP and RD) were considered amusic because their composite scores were 2 SD below the mean of normal controls. PP's performance reflects a disorder in the temporal organization of music. RD's amusia is more severe; however, her residual pitch and temporal abilities, as revealed in the repetition of familiar melodies (*see* Experiment 1), seem sufficient to support singing.

General procedure and data analysis

The patients participated in about four sessions of 2 h each. Sessions were adapted to the patients' capacities with flexible durations, pauses and at-home testing. The testing sessions were recorded on a DAT Sony recorder via a Shure 565SD microphone. All productions were saved in digital sound files.

The experimenter (AR) and a university student in speech–language pathology transcribed all the produced words for scoring purpose. Words were considered correct or incorrect, irrespectively of their pitch and duration. Words were chosen over syllables because number of syllables sometimes differs across conditions; mute vowels are often sung but not pronounced. Contractions, such as articles or short words that were not produced on a distinct note, were considered as part of the word to which they were attached. A point was given for every word correctly produced in the right order. Recognizable (because of mild phonemic errors) words were given half a point. Omissions and substitutions were given no point. The number of correct words corresponded to the number of words for which both judges gave a point. The words on which they disagreed were discarded. The score corresponded to the number of words for which both judges gave a point or half a point, divided by the total number of words both judges agreed on and multiplied by 100, for each song line. A total of 4957, 1835 and 4960 words were analysed in Experiments 1, 2 and 3, with inter-rater agreements of 92, 96 and 88%, respectively.

The experimenter (AR) and a music faculty student transcribed by ear and scored the musical productions. Pitch intervals and directions were analysed, but not rhythm because of the numerous pauses or hesitations. The number of correct notes corresponded to the number of notes for

Table 3 Neuropsychological assessment

Patient	Digit span	Raven matrices (percentile)	Tower of London mean number of movements (mean total time in seconds)*
LB	3	48/60 (41 p.)	8.3 (26.3)
PP	2	52/60 (50 p.)	9.75 (30.75)
JS	3	27/60 (<5 p.)	10.7 (100.7)
JH	4	35/60 (10 p.)	5.2 (25.7)
CA	3	42/50 (11 p.)	6.4 (33.8)
RD	4	41/60 (12 p.)	7 (38.5)
RH	4	39/60 (25 p.)	5.4 (21.7)
LD	3	52/60 (50 p.)	5.1 (18)

*The standard norms for the Tower of London are $M = 5.75$, $SE = 1.49$ for the mean number of movements and $M = 24.67$, $SE = 24.5$ for the mean total time.

Table 4 Patients' score on the MBEA

Patient	Scale	Contour	Interval	Rhythm	Metre	Memory	Composite score
LB	29	25	26	26	26	25	26
PP	27	25	24	21*	18*	16*	22*
JS	26	24	24	26	27	20*	25
JH	24	29	21	30	22	25	25
CA	24	26	22	28	26	25	25
RD	19*	21*	18*	22*	20	15*	19*
RH	30	28	29	27	20	24	26
LD	27	24	25	30	23	26	26
Cut-off score	22	22	21	23	20	22	23

The maximal score on each test is 30 (chance is 15).
*Below cut-off.

which both judges gave a point. When there was a disagreement, the note was discarded. The musical score corresponded to the total of correct pitches divided by the total number of possible notes minus the notes both raters disagreed upon for these productions, multiplied by 100. A total of 7717, 1410 and 3398 musical notes were analysed in Experiments 1, 2 and 3, with inter-rater agreements of 95, 85 and 79%, respectively.

Because of the limited number of patients and the variability between subjects, non-parametric tests were used, with an alpha level of 0.05.

Experiment 1: Production of familiar material
Method
Patients were presented with two types of material. The first material consisted of 14 familiar songs selected from children and traditional songs (Peretz *et al.*, 1995). Song excerpts were, on average, 5 words (range: 3–7) and 9 notes (6–11) long. The second material was composed of two well-known prayers ('Our Father' and 'Holy Mary'), six proverbs (e.g. 'All roads lead to Rome') and one nursery rhyme (e.g. 'Eenie, meenie, minie, mo'). We will refer to these selected non-musical over-learned expressions as 'verbatim speech'. The sentences were, on average, 7 words (6–10) and 8.5 notes (7–12) long.

Patients had to perform two tasks on these materials: a repetition task and a recall from memory task. In the repetition task, the experimenter gave the first line and the participant had to repeat it in the same mode (for examples, *see* www.brams.umontreal.ca/peretz/). For sung repetition, the verbatim speech lines were sung to a familiar melody. Eight familiar songs that matched the number of syllables in the line were used. The second task implied recall from memory: the titles were presented to participants, who had to produce as much as they knew of the song, prayer or rhyme. For the proverbs, the beginning of the expression was given (e.g. An apple a day...) and the patient completed it (... keeps the doctor away). The recall of verbatim speech was always performed before the repetition task. Otherwise, order of presentation was counter-balanced across participants. At the end, spontaneous production and repetition of the songs' melodies on the syllable /la/ were assessed in one single block, in a counter-balanced order. Throughout the experiment, live presentation was used, hence enabling the use of visual as well as auditory cues. Patients could also ask the experimenter to repeat the title or the line in order to achieve his/her best performance (usually two to four times).

Results
Individual scores, corresponding to the percentage of correct words or notes produced and obtained for the different songs and for the different verbatim expressions, were averaged for each participant and for each task (repetition

and recall; *see* Table 5) and compared with Wilcoxon tests. The results will first be presented for songs and then for verbatim speech. For these two types of automatic productions, two conditions (isolated, combined) and two tasks (repetition, recall) will be compared for words and for musical notes. The isolated condition refers to the production of words only or musical notes only, while the combined condition refers to the sung production of both words and notes. Error types in word production were also assessed and compared between the sung and spoken conditions.

Songs
As can be seen in Table 5, the percentage of words correctly produced was not higher in singing than in speaking, in both repetition, $Z = 0.34$, n.s., and recall, $Z = 0.56$, n.s. This held true for each patient when considering song excerpts as the random variable (all $P > 0.05$, by Wilcoxon tests). Only one patient (LB) produced more words from memory in singing than in speaking, $Z = 1.96$, $P = 0.05$. The correlation between participants' word scores in singing and speaking was significant in repetition, $r(8) = 0.99$, $P < 0.001$, and in recall, $r(8) = 0.89$, $P < 0.01$.

The most frequent errors committed by the patients were non-words which share phonemes with the target word (phonemic paraphasias: 39%). The other errors

Table 5 Percentages of correct word and note production for familiar songs

Patient	Repetition		Recall	
	Combined	Isolated	Combined	Isolated
LB				
Words	54	56	50	34
Notes	90	98	90	85
PP				
Words	34	38	24	16
Notes	83	81	43	41
JS				
Words	13	10	6	10
Notes	98	91	80	24
JH				
Words	93	93	73	71
Notes	100	98	94	95
CA				
Words	91	83	66	69
Notes	93	85	70	72
RD				
Words	89	90	65	72
Notes	88	82	88	67
RH				
Words	85	89	66	72
Notes	96	92	83	64
LD				
Words	84	78	49	77
Notes	74	63	31	18
Mean				
Words	**67.9**	**67.1**	**49.9**	**52.6**
Notes	**90.3**	**86.3**	**72.4**	**58.3**

were omissions (31%), neologisms (12%) and real words semantically related to the target word (semantic paraphasia: 11%). There were very few real words with no semantic relation with the target word (lexical paraphasias: 6%). In repetition, the error types were similar in singing and speaking (all $P > 0.05$), except for the phonemic errors, which were more frequent in singing (45%) than in speaking (33%), $Z = 1.96$, $P < 0.05$. This was true for all but one participant (RH) who suffers from a severe dysarthric problem.

For all patients but LD, production of musical notes was much easier than words. This was confirmed statistically in singing songs in both repetition, $Z = 1.82$, $P = 0.07$, and recall, $Z = 2.10$, $P < 0.05$ (*see* Words versus Notes Combined in Table 5). A similar trend was apparent when participants were producing musical notes or words alone, although it did not reach significance. None of the correlations computed between word and note scores reached significance (all $P > 0.05$). LD's discrepancy between repetition and recall scores for notes seems to reflect a production deficiency rather than a perceptual or memory difficulty.

In general, word performance was higher in repetition than in recall, both in singing, $Z = 2.52$, $P < 0.05$, and in reciting, $Z = 2.38$, $P < 0.05$, although the three patients with the most severe form of aphasia (LB, PP, JS) had very low scores in both tasks. Similarly, the percentage of musical notes correctly produced was higher in repetition than in recall, both when produced alone, $Z = 2.52$, $P < 0.05$, and with words, $Z = 2.20$, $P < 0.05$. While sung words were not better performed than recited words, sung notes were more accurate when sung with words than on /la/ in recall, $Z = 2.03$, $P < 0.05$. The same tendency was present in repetition but failed to reach significance, $Z = 1.61$, n.s.

Verbatim speech

Comparing the sung and spoken production of popular expressions is interesting because it is usually the goal of speech therapy to improve production of functional sentences such as 'Thank you'. However, the present results suggest that using songs is not very effective (*see* Table 6). No effect of condition was obtained in repetition of verbatim speech, $Z = 0.98$, n.s. The only patient (LB) to show a positive effect of singing, with $Z = 2.06$, $P < 0.05$, is the same patient who benefited from singing songs. Here, LB was unable to recite a single word. However, two other patients (JS, RD) exhibited the reverse pattern, with spoken repetitions being better than sung repetitions, $Z = 2.03$ and 2.20, $P < 0.05$. JS was unable to repeat the expressions in singing. For these patients, executive impairments might explain the difficulty to sing conventionally spoken expressions to familiar melodies. The other participants had similar performance in the two modalities (all $P > 0.05$).

Here, omission was the most frequent error (53%). Phonemic paraphasias (21%) were again more frequent than semantic paraphasias (3%). Comparisons of the proportions of each error type in the sung and the spoken conditions

Table 6 Percentages of correct word and note production for verbatim speech

Patient	Repetition		Recall
	Combined	Isolated	Isolated
LB			
Words	28	0	7
Notes	77		
PP			
Words	18	9	0
Notes	75		
JS			
Words	0	11	28
Notes	22		
JH			
Words	59	78	48
Notes	77		
CA			
Words	50	72	83
Notes	38		
RD			
Words	50	84	71
Notes	27		
RH			
Words	84	82	48
Notes	84		
LD			
Words	76	84	51
Notes	55		
Mean			
Words	**45.6**	**52.5**	**39.8**
Notes	**56.9**		

revealed only one significant difference for neologisms (e.g. tantan for claire). These errors were more frequent in singing (14.3%) than in speaking (10.6%; $Z = 1.99$, $P < 0.05$). For both materials, the errors respected the number of syllables of the words in 92% of the phonemic paraphasias, thus preserving the rhythmic structure of the line, both in singing and in reciting. Vowels were correctly produced in 83% (range: 38–100%) of the phonemic paraphasias while the correct consonants were only preserved in 31% (0–75%) of the cases.

Finally, we compared performance obtained with songs and verbatim speech. Song lyrics were always better produced than verbatim speech, in both sung and spoken repetition, $Z = 2.52$ and 2.03, $P < 0.05$, respectively, and there was a trend in that direction in spoken recall, $Z = 1.68$, $P = 0.09$. The musical notes were also more accurate when sung with the original lyrics than when paired with verbatim speech, $Z = 2.52$, $P < 0.05$.

Discussion

Singing did not improve word production compared with speaking. Even in songs where lyrics are usually sung, there was no advantage of singing the words over speaking them. This was also true for verbatim speech, such as proverbs and prayers, which were not better repeated when sung on a familiar melody than when spoken.

Table 7 Illustration of the adaptive learning procedure with two trials

Lyrics presented	Lyrics repeated	Lyrics to be recalled
1 Dans cette petite boîte vide 1 Dans cette petite boîte vide	1 Dans cette petite boîte vide 1 Dans cette petite boîte vide	
2 Avec un ruban de velours 2 Avec un ruban de velours	2 Avec un ruban de velours 2 Avec un ruban de velours	
		1 Dans cette petite boîte vide 2 Avec un ruban de velours
3 Il y a tout mon cœur et mes rides 3 Il y a tout mon cœur et mes rides	3 Il y a tout mon cœur et mes rides 3 Il y a tout mon cœur et mes rides	
		1 Dans cette petite boîte vide 2 Avec un ruban de velours 3 Il y a tout mon cœur et mes rides
4 Mon sourire et tout mon amour 4 Mon sourire et tout mon amour	4 Mon sourire et tout mon amour 4 Mon sourire et tout mon amour	
		1 Dans cette petite boîte vide 2 Avec un ruban de velours 3 Il y a tout mon cœur et mes rides 4 Mon sourire et tout mon amour

Musical production was generally more preserved than speech. Interestingly, the melody was best performed when sung with the lyrics, except for one patient (LD). This result supports the fact that melody and text of songs are tightly associated in memory so that the words can facilitate melodic performance. The fact that this association is not as effective in the other direction, from melody to words, in aphasics suggests that the association is asymmetrical.

Finally, words in songs are more easily produced than words in prayers or proverbs. Different factors may account for this advantage. Songs may be more familiar, by being more often practised or heard, than prayers or proverbs. This difference in frequency of occurrence would make songs more accessible in memory than verbatim speech. Songs are also stored in memory in a dual code, that is, in a speech and a musical code (Samson and Zatorre, 1991). The melody might act as an additional cue that facilitates the word retrieval compared with prayers or proverbs. Thus, the automatic status of the material does not seem to account entirely for the advantage of song production over spontaneous speech in aphasic patients.

Experiment 2: Novel song learning

In novel songs, the sung version bears no advantage over the spoken version because they are both heard together for the first time. If singing does indeed facilitate word production in non-fluent aphasics, sung words should be better produced than spoken words when learning novel songs. The goal of the present experiment was to test this prediction with repetition and recall of novel words and notes. Furthermore, the putative influence of music at encoding words was

Table 8 Modes of presentation and production in each condition of Experiment 2

Presentation	Repetition/recall
Sung	Sung
Sung	Spoken
Spoken–sung on /la/	Spoken
Spoken–sung on /la/	Sung on /la/

also examined separately from its output influence. Presentation of the lines was either sung or spoken (with the melody in the background, referred to as the 'divided' presentation). Repetition was sung, spoken or sung on /la/ (*see* Table 8).

Material

Unfamiliar songs were chosen from the repertoire of Claude Gauthier, a popular French–Canadian folk-singer, author and composer. Four songs with few repetitions of words or melodic lines were selected (*see* Table 7 for an example). The 115 words used in the songs had a mean frequency of 2650 per million, including function words, based on a French lexical database (New *et al.*, 2001): 76% were highly frequent, with a frequency of usage >50 per million. Only 10% of the words had a low frequency, corresponding to <15 per million. The musical notes (nine per line on average) outnumbered words (six per line on average), $t(31) = 11.21$, SE = 0.22, $P < 0.001$.

The song excerpts were considered to be 'good' songs, as assessed by seven pilot participants who were unfamiliar with the singer. The judges were presented with the song excerpts in their original version and these were randomly mixed with

excerpts of hit songs from the same folk-singer. Each excerpt was presented twice, in a random order. For each song excerpt, the judges rated its musicality, its simplicity and its potential to be a hit, on three six-point scales where 1 meant poor, and 6 excellent. Very similar ratings were obtained for the hits and the experimental songs on each dimension (3.7 and 3.8 for musicality, 3.4 and 3.5 for simplicity and 3.2 and 3.4 for hit potential, with first and second ratings pooled together), supporting the idea that the selected material corresponded to well-formed songs.

In all songs, there was a one-to-one mapping between syllables and tones, with each syllable coupled with a single note. Lines respected the grouping preference rules proposed by Lerdahl and Jackendoff (1983). The alignment between the prosody of the text and the rhythm of the melody conformed to the rules of French songs (Dell, 1989). Regarding musical structure, the songs had a stable and standard metre. All the songs were in the major mode. Even if melodies were chosen for their diversity, the melody parts were highly coherent within a song.

Eight four-line excerpts (two per song) were included for the learning task (*see* Table 7). On average, an excerpt contained 25 words (range: 21–27) and 34 notes (range: 28–38). An additional four-line excerpt from an unfamiliar choir song (mean of five words and nine notes per line) by Johann Steuerlein served as a training song.

The four songs and the training song were produced *a capella* (without instrumental accompaniment) by a female singer, who learned the songs beforehand. The same singer also sang each song on /la/ and pronounced the lyrics with a natural intonation. The three versions of the same song served to create two types of stimuli, the sung and 'divided' songs. The latter were created by coupling each spoken line with its corresponding melody sung on /la/, in order to give the spoken presentation of words the same musical context as the sung presentation of words. In these divided songs, the intensity of the melody was decreased by 32%, on average, in order to make the spoken version intelligible. The intelligibility of songs' lyrics was equivalent in the sung and the 'divided' songs.

The length of the original spoken version was about half of the length of the sung version [$M = 2.48$ and 4.95 s per line, respectively, $t(31) = 13.44$, $P < 0.001$]. Because the divided condition combined both the spoken and the 'sung on /la/' versions ($M = 4.92$ s per line), divided and sung presentations had equivalent lengths. In the divided condition, the shorter spoken line was placed in the middle of the sung melody, so that it was preceded and followed by equivalent durations of the melody.

Procedure

The practice song was learned before each condition. It served to determine the number of attempts that each participant needed to achieve his/her best repetition of a line. Patients had always the same number of attempts to repeat a line throughout the experiment. The number of

trials varied between two for JH, RD, RH, LD; three for LB, JS, CA; and four for PP. Then, the patients heard the whole excerpt to be learned. Then, (s)he had to repeat (as many times as determined previously) one line at a time, following the procedure shown in Table 7. Each time a line was added, the patient had to recall them from the beginning, until all four lines had been presented, repeated and recalled.

In the sung–sung condition, the patient listened to the sung version of the lyrics and sang them back. In the sung–spoken condition, the patient listened to the sung version of the lines and repeated only the lyrics, by pronouncing them in a natural way. In the divided–spoken condition, the participant listened to the divided version of the lines and repeated again only the lyrics. In the last condition, divided-sung on /la/ the participant listened to the divided version and repeated only the melody, on the syllable /la/ (*see* Table 8). The patients learned one excerpt in each condition, for a total of four different songs. The order of presentation of the conditions that involved repetition of lyrics (sung–sung, sung–spoken, divided–spoken) was counter-balanced across participants. The divided-sung on /la/ condition was done last. Examples of stimuli and patients' productions are available at www.brams.umontreal.ca/peretz/.

Data scoring was performed as in Experiment 1, the best repetition performance and recall of the whole song (lines 1–4) being analysed for words and notes. The best

Table 9 Percentage of words correctly reproduced in Experiment 2

Patient	Word production		
	Sung–sung	Sung–spoken	Divided–spoken
LB			
Repetition	9	31	14
Recall	8	0	0
PP			
Repetition	5	0	0
Recall	0	0	0
JS			
Repetition	9	10	11
Recall	4	8	10
JH			
Repetition	54	51	50
Recall	13	9	14
CA			
Repetition	26	49	56
Recall	0	9	4
RD			
Repetition	69	50	70
Recall	25	4	44
RH			
Repetition	78	83	88
Recall	21	26	24
LD			
Repetition	85	70	83
Recall	36	29	63
Mean			
Repetition	**41.9**	**43.0**	**46.5**
Recall	**13.4**	**10.6**	**19.9**

Table 10 Percentage of notes correctly reproduced in Experiment 2

Patient	Note production	
	Sung–sung	Divided-sung on /la/
LB		
Repetition	28	89
Recall	6	58
PP		
Repetition	37	33
Recall	0	4
JS		
Repetition	43	69
Recall	0	0
JH		
Repetition	60	67
Recall	56	11
CA		
Repetition	30	34
Recall	0	0
RD		
Repetition	17	50
Recall	11	39
RH		
Repetition	70	48
Recall	21	16
LD		
Repetition	15	23
Recall	28	0
Mean		
Repetition	**37.5**	**51.6**
Recall	**15.3**	**16.0**

repetition for the sung production corresponded to the best word repetition performance. The scoring system thus favoured word production over musical note production in the combined production.

Results

As can be seen in Tables 9 and 10, there was a large variability in the scores obtained in each condition. Despite this important variability, none of the patients obtained a higher score in the sung–sung condition than in the spoken conditions. Singing did not help word repetition. The comparison of the three conditions involving words (sung–sung, sung–spoken, divided–spoken; Table 9) did not reveal any difference, $\chi^2(2) = 1.23$, n.s. (by Friedman test). Similar effects were obtained with recall scores [$\chi^2(2) = 2.74$, n.s.; *see* Table 9].

The rate of syllable production was calculated in order to examine if singing slowed down aphasic's speech relatively to speaking. The rate corresponded to the total duration of word articulation (independently of accuracy) divided by the number of syllables produced. Sung syllables ($M = 572$ ms) were slower than the spoken syllables ($M = 494$ ms), with $Z = 2.20$, $P < 0.05$.

The types of word errors were similar across the three conditions in repetition and there was no effect of condition (all $P > 0.05$). Omissions were the most common type of

error (40%). As for familiar songs, phonemic paraphasias were slightly more frequent in the sung condition (34% versus 17 and 20% for the sung–spoken and the divided–spoken conditions, respectively). Compared with university students, who only made omissions and substitutions (Racette and Peretz, 2006), aphasic patients made more omissions and slightly less substitutions (semantic and lexical paraphasias). Thus, phonemic paraphasias are specific to aphasic patients; they preserved the syllabic structure of the word in 85% of the cases, the vowels in 80% and the consonants in only 37%.

As can be seen in Table 10, the patients did not reproduce more musical notes when singing with words (sung–sung condition) than when singing on /la/ (divided-sung on /la/ condition), $Z = 1.61$, n.s. and $Z = 0$, n.s., in repetition and recall, respectively. The scores for notes repetition were actually higher without than with words for six patients. The proportions of correctly reproduced words and musical notes were also compared and did not yield any significant difference in the sung–sung condition, with $Z = 0$ and 0.67, both n.s., in repetition and recall, respectively. The same was true when notes and words were produced in isolation after the divided presentation, $Z = 0.14$ and 1.19, both n.s., in repetition and recall, respectively. There was no correlation between word and note scores (all $P > 0.05$). As expected, recall scores were always inferior to repetition scores, in each condition and for each component (all $P < 0.05$).

Discussion

Music did not improve intelligibility or verbal memory when aphasics learned a novel song. Moreover, the aphasic patients made the same type of errors when singing and when speaking, suggesting that the speech output, whether sung or spoken, was controlled by the same mechanisms. Music had no effect on presentation. Hearing a sung text (in the sung–spoken condition) did not lead to better word production than hearing the spoken text (in the divided–spoken condition). Thus, the results obtained here with unfamiliar songs parallel those found with familiar songs in Experiment 1.

Unlike Experiment 1, the aphasics did not reproduce more notes than words. However, here, the scoring system was biased towards words in the combined productions of words and notes to enable comparison across conditions. In our prior study with students, they performed much better on the verbal than musical component (Racette and Peretz, 2006). Here, in aphasics, the superiority of words over notes in production was reduced.

Experiment 3: Production in unison

In this last experiment, we examined another strategy that is often used in speech therapy, particularly the MIT, which consists in singing in unison with the therapist before trying to sing alone. We examined here how the patients benefit from singing and speaking along. Repetition and recall of
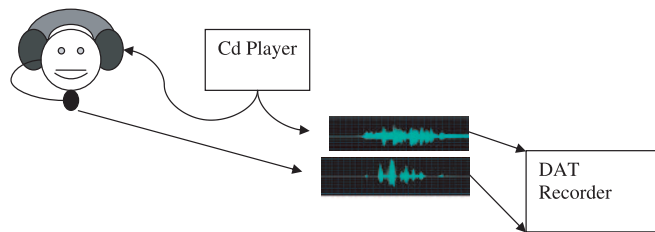
Fig. 1 Setting used in Experiment 3.

words and notes were done in unison. We also used two speeds of presentation—the original and a much slower one—to further assess the role of rate of articulation.

Method

Only the sung–sung and the divided–spoken conditions were used here at the same speed as used in Experiment 2. These versions were also slowed down by 50%, using the Cool Edit program (Syntrillium Software Corporation, 2000). This reduction of speed was chosen because it preserved the naturalness of the voice. During repetition and recall, the patients produced the words while listening to the target song lines. Otherwise, the same learning procedure as used in Experiment 2 was followed. The sung–sung and divided–spoken conditions were administered in the same order as used in Experiment 2 for a given patient. Two excerpts (four lines) were learned in each condition: one at the original speed first and then at the slow speed, and vice versa for the other. The speed was counter-balanced across conditions. A total of four excerpts, different from the ones learned in Experiment 2, were learned: two while singing and two while speaking.

The patients listened to the songs via a headset that was equipped with a microphone (*see* Fig. 1). The presented lines fed one channel of a DAT Sony recorder and were time-locked to the patient's production that was recorded on the other channel of the DAT recorder. Patients could hear themselves but the headphones might have altered the auditory–vocal feedback to some extent. Like in the previous experiments, the best repetition was analysed.

Results and comments

Two conditions (sung–sung, divided–spoken) and two speeds (original, slow) could be compared in repetition and recall. This time, singing was found to improve production. More words were correctly articulated when singing along (M = 63.2%) than when speaking along (M = 50.5%), with Z = 2.10, P < 0.05 for repetition scores averaged over the two speeds (*see* Table 11). Six of the eight patients (LB, PP, JS, CA, RD, LD) showed this effect in repetition and/or recall.

As for recall, before shadowing all the lines from the beginning, the patients were first invited to recall words *alone*, without the model. Patients' performance could thus be compared when recalling alone and along (*see* Table 11). In general, recall from the beginning of the song was better when shadowing than when producing alone without a

Table 11 Percentages of words correctly reproduced in Experiment 3 (shadowing-like task)

Patient		Words			
		Original speed		Slow speed	
		Sung–sung	Divided–spoken	Sung–sung	Divided–spoken
LB					
	Repetition	62	26	57	44
	Recall	41	22	60	30
	Alone	13	10	10	8
PP					
	Repetition	41	16	55	25
	Recall	38	7	38	18
	Alone	0	0	0	0
JS					
	Repetition	7	0	29	1
	Recall	13	1	22	0
	Alone	3	3	3	2
JH					
	Repetition	83	76	81	84
	Recall	64	55	70	74
	Alone	26	38	12	38
CA					
	Repetition	75	52	75	59
	Recall	52	36	59	35
	Alone	10	14	4	21
RD					
	Repetition	68	30	65	58
	Recall	34	27	41	44
	Alone	18	27	2	36
RH					
	Repetition	59	79	76	84
	Recall	22	37	39	35
	Alone	25	32	23	40
LD					
	Repetition	85	88	93	85
	Recall	67	54	78	70
	Alone	0	61	0	21
Mean					
	Repetition	**60.0**	**46.3**	**66.4**	**55.0**
	Recall	**41.4**	**31.4**	**50.9**	**38.3**

model, both when singing, Z = 2.52, P < 0.05, and when speaking, Z = 2.24, P < 0.05. Shadowing was also beneficial to pitch accuracy: repetition of musical notes was better in unison than alone, Z = 2.38, P < 0.05 (*see* Table 12). Yet, shadowing had a differential impact on singing and speaking. Singing tended to be superior to speaking when shadowing the four lines (with 46.2 versus 34.9%, for sung and spoken recall along the model, respectively; Z = 1.82, P = 0.07), as described above for each line. In contrast, speaking tended to be more advantageous than singing when recalling the four lines without shadowing (with 22 versus 8.1%, for spoken and sung recall alone, respectively; Z = 1.86, P = 0.06). Thus, singing *alone* does not facilitate word recall, only singing *along* does.

The rate of articulation was significantly slower in singing (696 ms/syllable) than in speaking (426 ms/syllable), with Z = 2.52, P < 0.05. In order to explore the possible

contribution of speed of articulation to the benefit of singing, the individual rates of articulation, obtained in each condition, were plotted as a function of the word score. This plot is presented in Fig. 2. As can be seen, four of the six patients (LB, PP, CA, RD) exhibited a significant correlation between syllable duration and word accuracy. However, most patients had small score differences in word accuracy between the slow and the original speeds in singing (with 66.4 versus 60%, on average; $Z = 1.35$, n.s.), even though the rates of articulation were significantly different between the two presentation speeds ($Z = 2.52$, $P < 0.05$, with $M = 796$

and 596 ms/syllable for the slow and original speed, respectively). In speaking, the effect of speed reaches significance (with 55 versus 45.9%; $Z = 2.24$, $P < 0.05$) and parallels the difference in rate of articulation ($Z = 2.39$, $P < 0.05$, with $M = 459$ and 393 ms/syllable for the slow and original speed, respectively). Thus, rate of articulation does contribute to intelligibility of aphasics' speech but cannot fully account for the superiority of singing over speaking. Moreover, in Experiment 2, patients were already producing sung syllables at a slower speed than spoken syllables, without exhibiting an advantage in word accuracy. Thus, the advantage of slowing down rate of articulation on speech production is neither constant nor general.

General discussion

The main finding from the present study is that singing *per se* does not help aphasics to improve their speech. When patients were producing words alone, without shadowing, singing did not facilitate word articulation whether the songs were familiar (Experiment 1) or unfamiliar (Experiment 2). The similarity in the proportion of intelligible words and in the types of error committed while singing and speaking suggests that there is a unique code for words, either sung or
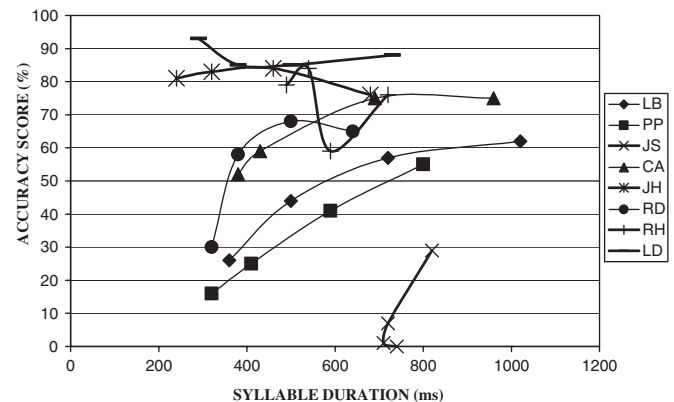
Table 12 Percentage of notes correctly reproduced in Experiment 3 (shadowing-like task)

Patient	Notes	
	Original speed	Slow speed
LB		
Repetition	81	76
Recall	80	87
PP		
Repetition	86	100
Recall	89	100
JS		
Repetition	62	69
Recall	56	65
JH		
Repetition	56	66
Recall	55	52
CA		
Repetition	76	80
Recall	64	66
RD		
Repetition	49	40
Recall	34	45
RH		
Repetition	83	89
Recall	37	55
LD		
Repetition	79	87
Recall	61	77
Mean		
Repetition	**71.5**	**75.9**
Recall	**59.5**	**68.4**

Fig. 2 Word accuracy according to syllable duration for each patient in the spoken–original speed, the spoken–slow speed, the sung–original speed and the sung–slow speed conditions in Experiment 3.

Table 13 Summary of the main results for word production in the three experiments

	Experiment 1	Experiment 2	Experiment 3
Material(s)	Familiar songs Verbatim speech	Unfamiliar songs	Unfamiliar songs
Tasks	Repetition Recall	Repetition Recall	Unison repetition Recall alone Unison recall
Conditions	Sung Spoken	Sung–sung Sung–spoken Divided–spoken	Sung–slow speed Sung–original speed Spoken–slow speed Spoken–original speed
Results	Sung = spoken Songs > verbatim speech	Sung = spoken Sung = divided	Sung > spoken (in unison) Spoken > sung (in recall alone) Slow speed ⩾ original speed

spoken. These results are consistent with two prior single case studies in which patients were suffering from atypical aphasia (Hébert *et al.*, 2003; Peretz *et al.*, 2004*a*) in showing that sung repetition is no better than spoken repetition. The present study extends this conclusion to a variety of speech disorders caused by a left-hemisphere lesion because each patient showed the same profile, at different levels of performance.

The novelty of the present study resides in the observation in Experiment 3 that singing with someone else is better than speaking in unison (*see* Table 13). Thus, singing has more potential than speaking to improve intelligibility when shadowing. Different factors may account for this 'singing along' advantage. As discussed earlier, the slower rate of articulation imposed by singing is not sufficient to account for this effect. In Experiment 2, rate of articulation was slower in singing than in speaking, and yet, there was no advantage of singing over speaking. In Experiment 3, a decrease in rate of articulation was experimentally induced by slowing down the speed of the model but it had little impact on performance.

The 'singing along' advantage probably arises from the opportunity to synchronize one's performance with a stable model. Vocal imitation alone is not sufficient to improve speech intelligibility, because vocal imitation after a model (via repetition) was involved in all three experiments. Even in the presence of visual cues provided by face-to-face vocal repetition, as was the case in Experiment 1 with familiar songs, patients did not improve their speech while singing. What seems to be critical is to be able to imitate in synchrony with an auditory model. The physical presence of the model is not necessary because the conditions of auditory–vocal synchrony, or 'choral singing', that we used in Experiment 3 were limited to the auditory channel. Moreover, the reduced memory load that the shadowing task affords applied to both singing and speaking in unison. Yet, shadowing only improved word production in singing along. Thus, on-line singing imitation is the critical condition to improve aphasic speech.

In singing along, the perception of the song is synchronous to the production of that same song. This principle can be related to the operation of mirror neurons (Rizzolatti and Arbib, 1998; Iacoboni *et al.*, 1999) or of an auditory–motor interface (Hickok *et al.*, 2003; Warren *et al.*, 2005; Callan *et al.*, 2006). Both models posit a direct link between perception and action for planning and performance. According to these auditory–motor integration models, there is a transformation of the auditory signal to a form that constrains its articulatory output via template-matching processes (Warren *et al.*, 2005). This mechanism would operate in language (Rizzolatti and Arbib, 1998; Hickok *et al.*, 2003) and in music (Callan *et al.*, 2006). Thus, in theory, this auditory–vocal interface (or mirror neurons system) could contribute to the learning of novel songs as tested here in aphasic patients, especially when singing at the same time as an auditory model.

In principle, the auditory–vocal interface would intervene in speaking, not only in singing. Indeed, choral speech has been shown to improve speech intelligibility in people who stutter (Kalinowski and Saltuklaroglu, 2003). Yet, we observed a benefit of synchronous vocal imitation in singing only. There are different factors that may account for this advantage of choral singing. First, all of the aphasic participants suffered from a left sylvian stroke that affected the brain areas that are involved in the auditory–vocal matching system in humans. That is, the lesions are located in the vicinity of the left temporal region that is normally active in both perception and covert production of sung and spoken lyrics (Callan *et al.*, 2006) and in both perception and covert production of novel sentences and melodies, as revealed by neuroimaging studies of normal subjects (Hickok *et al.*, 2003; Warren *et al.*, 2005). Therefore, the lesion may have damaged the auditory–vocal interfaces that are involved in both speech and music (Hickok *et al.*, 2003). However, these systems are not totally overlapping. For instance, the greater activation of the right planum temporale for sung over spoken perception and production of songs may reflect the contribution of a distinct auditory–vocal interface recruiting the right side of the brain (Callan *et al.*, 2006). Right-lateralized brain regions are generally more activated by singing than by speaking (Riecker *et al.*, 2000; Jeffries *et al.*, 2003; Brown *et al.*, 2006). Thus, the left-sided lesions that produced the observed speech disorders in our aphasic patients might have spared to some extent the auditory–vocal interface involved in singing. Indeed, all of our aphasic patients sang (without words) with normal proficiency. Thus, it is reasonable to assume that the auditory–vocal matching system involved in singing was relatively spared in the aphasic patients. Hence, this preserved auditory–vocal interface may account for the advantage of choral singing over choral speaking.

This musical auditory–vocal interface seems to best operate when singing is synchronous to a sung model. Both word and pitch accuracy were higher in singing along as compared with singing alone. Temporal accuracy could not be assessed here but timing is, in all likelihood, a major contributing factor because temporal regularity promotes synchrony (Large and Palmer, 2002) and because sung lyrics might be more regular than spoken lyrics, although this is currently an open issue (Patel *et al.*, 2006). In this respect, it is worth noting that the tested patients were tested in French. French is not a stress-based language while English is. Future studies should test whether the advantage of choral singing over choral speech is maintained in English-speaking aphasic patients. Finally, choral singing is more natural than choral speech. Participating in choir or singing at church are familiar and highly enjoyable activities.

The present findings point to choral singing as an effective therapy for various speech disorders. Choral singing may even account for the efficacy of the MIT in its initial stages, when patients sing in unison with the therapist. What might happen in subsequent stages was not assessed in the present study. Recent evidence suggests that singing is beneficial to speech production in the long term (Wilson *et al.*, 2006).

Future longitudinal studies should compare training with choral speech and choral singing to explore if the advantage of choral singing has more long-lasting effects on speech recovery.

More generally, we propose to use musical therapies in treatments of aphasic patients because there are additional benefits that may only be provided by music. Singing is a natural and pleasurable way to entrain and engage someone. Producing musical notes is also highly motivating because it provides a natural way to express oneself vocally. As mentioned previously, most patients had a profile of aphasia without amusia (Brust, 2001; Warren *et al.*, 2003). The patients who had a concomitant musical impairment in perception, memory or production did not show a different vocal pattern than the patients without amusia. Hence, singing can be used to motivate aphasic patients to engage in lengthy and laborious sessions by keeping their spirit high.

Acknowledgements

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