The impact of singing on human communication in aging:

From protection to rehabilitation

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Several studies have shown that speech production can deteriorate significantly with age. Results demonstrate strong sex-specific changes in speaking fundamental frequency (F0)[1], whereby the pitch of a woman's voice becomes lower with age and the pitch of a man's voice becomes higher (e.g. Honjo & Isshiki, 1980; Ramig, 1983). Other age-related changes include a decline vocal stability (e.g. Lortie et al., 2015; Wilcox & Horii, 1980) and loudness (Baker et al., 2001). Decreased speech rate (Fozo & Watson, 1998 ; Wohlert & Smith, 1998), increased duration of speech sounds (Ryan & Burk, 1974 ; Smith et al., 1987), and changes in speech timing (e.g. Tremblay & Deschamps, 2016 ; Tremblay et al., 2017) have also been reported, as well as a decline in articulation accuracy (Bilodeau-Mercure & Tremblay, 2016 ; Bilodeau-Mercure et al., 2015). Though limited, a few studies suggest that these changes originate, at least in part, in the central nervous system, suggesting a decline in motor control (e.g. Tremblay & Deschamps, 2016; Tremblay et al., 2017). Understanding changes in human communication and their impact on everyday situations is crucial, given that communication difficulties can negatively affect quality of life.

One promising strategy to maintain communication skills in normal and pathological aging is singing. Singing is a universal human activity that offers a broadly applicable low-cost strategy to protect against the negative effects of aging. Indeed, singing can easily be integrated into the daily routine of most adults at home, in rehabilitation centres, in retirement centres or in recreational facilities. Importantly, it is universal: everyone can sing, regardless of their age, sex, socioeconomic and cultural backgrounds. Identifying whether singing can positively affect voice, articulation, prosody and quality of life is important, as a variety of professionals including speech pathologists, gerontologists, family doctors, and educators, but also families and caregivers, can develop or implement low-cost interventions tailored to individual needs and characteristics, which, ultimately, could improve quality of life of the elderly.

The fact that singing has an impact on speaking is consistent with the Integrative Model of Speech Motor Control (Ballard et al., 2003). This model postulates that speech and non-speech orofacial functions are controlled, at least in part, through domain general brain networks, and that working on one behaviour (e.g., singing) may have beneficial effects on another (e.g., speaking). Given that singing and speaking share the same apparatus, which includes the respiratory system, the vocal tract, and the articulators (e.g., the tongue, soft palate and lips), the impact of one behaviour on the other is perhaps not surprising, but the potential clinical applications of this phenomenon have not been fully exploited. Importantly, singing also engages affective, motivational and memory systems and therefore may have broad applications.

In this chapter, we review the impact of singing on voice and speech production in normal and pathological aging. For the sake of brevity, here we focus on two common age-related disorders: non-fluent post-stroke aphasia and dysarthria. We also provide a brief discussion of future directions in this area of research.

The Protective Effect of Singing in Aging

Several studies have examined the positive impacts of singing on the human voice. Specifically, it is well established that singing has a huge impact on vocal quality and stability (e.g. Brown et al., 1993; Pabon et al., 2014), phonatory range (Åkerlund et al., 1992) and respiration (e.g. Mendes et al., 2006; Stegemöller et al., 2017). But can these benefits have long-lasting effects and outweigh the strong impact of age?

In a recent study on 47 professional singers, it was found that, with age, the highest frequency as well as the frequency range, measured from the sustained phonation of a vowel, decline significantly (Berghs et al., 2013). No significant age-related voice improvement was found. This suggests that the voice of a professional singer may undergo the negative effects of aging in the frequency domain (pitch); however, the absence of a control (non-singing) group makes it difficult to determine whether the intensity and the trajectory of these age-related changes is different across professional singers and non-singers. Importantly, a more recent study reported that older singers can benefit from a short vocal training program (Tay et al., 2012). In that study, the impact of a 7-week vocal training program, the Vocal Function Exercise (VFE) developed by Stemple (1993), on the voice of healthy nonprofessional older choral singers (68 to 83 years) was examined. A control group of singers was included which did not receive the VFE. The results show that the voice of the VFE group was perceived as less rough. The data also revealed longer phonation times, lower jitter[2], lower shimmer[3], and lower Harmonic-to-Noise ratio (HNR)[4] in the VFE group. These results suggest that voice acoustic and perceptual features can be improved in older singing adults quite rapidly.

A growing number of studies have examined the benefits of singing on vocal aging, in amateur and professional singers. Interestingly, some studies have shown that, in professional singers, the normal changes that occur in the human voice do not occur, and that the Speaking F0 of professional singers remain stable over time (e.g. Brown et al., 1991; Brown et al., 1990; Morris et al., 1995). Voice parameters other than pitch also appear to benefit from singing. For example, Brown and colleagues found a faster speech rate in older female professional singers compared to older female non-singers (Brown et al., 1990), which suggests that the decline in speech timing that is observed in normal aging is reduced in older professional singers. This could indicate an experience-dependent preservation of speech motor control in singers, though additional data are needed to evaluate whether the neural networks involved in speech motor control are preserved in older singers.

Prakup (2012), in an elegant study, found that the voices of 30 older female and male amateur choral singers aged between 65 and 80 years old were more stable in the frequency domain (measured as a lower jitter) compared to a group of 30 older non-singers. Vocal stability in the frequency domain is a measure of the synchrony of vocal fold vibrations. Lower stability is perceived as harshness. In the same study, it was also found that singers had an overall higher mean vocal intensity compared to the non-singers. No difference was found in vocal F0. Interestingly, it was also found that male and female singers were perceived as younger than non-singers. Jitter was correlated to perceived age in male and female singers and male non-singers. These data provide important cues into the impact of amateur singing on the human voice, at the physical and perceptual levels. However, the finding of a positive impact of singing on jitter is at odds with the results of earlier studies (Brown et al., 1990; Maruthy & Ravibabu, 2015). Specifically, Brown and colleagues (1990) found no difference in jitter ratio[5] between older female non-singers and professional female singers aged 63 to 85 years old. Participants in the Brown et al. study were slightly older than in the Prakup study, and, importantly, they were *professional* rather than *amateur* singers, which may account for the divergences. A difference in jitter also was not found by Maruthy and Ravibadu (2015) who compared groups of 15 young and older female professional Carnatic classical singers[6] to groups of 15 young and older female non-singers. The results revealed an interaction between group (singers and non-singers) and age on maximum F0 but not jitter. Maximum F0 was significantly higher in older singers compared to older non-singers, though the group difference was higher for the younger singers, suggesting that the benefit of singing on maximum F0 may decline with age.

<TABLE TREMBLAY.1 HERE>

In sum, though most studies document some form of age-related benefit of singing on voice production (see Table Tremblay.1), there is some variability in terms of the specific impact of singing. These partly discordant findings may be related to the type of singers that were recruited (amateurs vs. professionals) or to other characteristics of the singers such as how often people sing, how long and intense their average singing sessions are, but also general health factors, including respiratory health and weight. While one may have expected a strong positive moderation effect of professional singing on vocal aging because of greater vocal control and better vocal technique compared to amateur singers, it is possible that the positive impact of professional singing on vocal aging declines gradually with age. Potential explanations include more frequent and probably more intense vocal activities, which may have a deleterious effect on the vocal folds. Research comparing vocal aging in amateur and professional singers is needed to identify potentially specific impacts of different singing profiles.

A related concern is that, in most studies in the literature, singers' personal characteristics (beyond the amateur/professional dichotomy), such as respiratory health and weight, are not reported or not integrated to experimental designs. Singing-related factors are also largely ignored, such as the number of instances per week at which one sings, the context (e.g., group or solo singing) as well as the duration and intensity of singing sessions. This is potentially an important limitation because the impact of singing may vary as a function of both personal and singing-related characteristics, and singing may be an effective strategy against normal vocal aging only under certain circumstances. We started addressing this question in a recent study in which we examined whether the frequency of singing moderates the effect of age on several voice parameters in a group of 72 healthy adults (20–93 years) (Lortie et al., 2017). Our results suggest that the number of instances per week at which one sings moderates voice stability in aging, with frequent singers maintaining a more stable voice in the frequency domain (measured as F0 standard deviation). An interaction between age and singing frequency was also found on F0, with frequent singers showing a more stable voice than occasional singers and non-singers. Some of the effects of singing, however, were found to be detrimental at younger ages, such as voice amplitude variability, though this effect normalized later in life.

In sum, though a certain degree of divergence is noted, globally the studies suggest a positive (mitigating) impact of singing on vocal aging. Taken together, these studies indicate a positive effect of singing on the aging voice. However, the results appear quite variable across studies, which may be due to the small and not fully characterized samples. Thus, while this is a promising area of research, additional studies are necessary to fully understand the benefits of singing in the aging of voice but also articulation and prosody, taking into account the diversity of singing profiles. Understanding the impact that singing has on normal aging is necessary to fully take advantage of its positive impact in pathological aging.

The Therapeutic Effect of Singing in Non-Fluent Aphasia

Singing has been used as an intervention in different types of age-related diseases, including aphasia. Aphasia is an acquired, non-degenerative, language disorder often resulting from a cerebrovascular accident or a traumatic brain injury (TBI). Lesions resulting in aphasia are generally located on the left hemisphere (Verstichel & Cambier, 2005). Patients with *fluent aphasia* can produce sentences and speak spontaneously. In contrast, patients with *non-fluent aphasia* (NFA) are unable to produce sentences: they use a limited vocabulary and speak slowly (Hallowell & Chapey, 2008). Spontaneous speech is either completely absent or severely limited and prosody is altered (Verstichel & Cambier, 2005). Aphasia recovery is variable.

The capacity of NFA patients to sing has been reported by clinicians since the earliest published studies on the topic in the mid-19th century. In one of the first group studies on singing (Yamadori et al., 1977), 24 patients with moderate to severe NFA were asked to sing known popular songs. For 21 of these patients, the capacity to sing was partially or totally preserved, suggesting that the capacity to sing is, at least in part, independent from the capacity to speak. This suggests partly distinct control systems, with the dominant hemisphere for singing being the intact right hemisphere, while the dominant hemisphere for speaking is the left (which is damaged).

Melodic Intonation Therapy (MIT) was developed by Albert, Sparks & Helm (1973), as a treatment for patients with severe chronic NFA. MIT uses melodic intonations (not songs) which represent an exaggeration of natural prosody and is usually referred to as “intoning.” MIT uses a hierarchy of difficulty levels: (1) the patients begin by humming a melody; (2) then they intone sentences, first as a repetition (3) and then in response to a question. (4) Finally, the patients use a spoken prosody without melodic intonation. MIT also involves a hierarchy of facilitation. The clinician always starts by singing alone, then the patients and the clinician sing together. The clinician gradually stops singing to let the patients finish the melody alone. Throughout MIT, the patients are required to tap the rhythm using their left hand, first with the help of the clinician, then by themselves (Sparks, 2008). MIT was first tested on three patients with NFA who did not respond to other treatments; their speech production was found to improve following MIT (Albert et al., 1973).

Several studies have been conducted to test the effectiveness of MIT. Cortese et al. (2015) tested it in 6 Italian-speaking NFA patients who received four 40-minute sessions per week for 16 weeks. At the end of the intervention, patients showed improved spontaneous speech (semantic-lexical structure, phonemic structure, speech automatism, prosody and communication). Schlaug and colleagues (2008) compared MIT with another commonly used type of therapy, Speech Repetition Therapy (SRT), in two NFA patients. Both interventions were organized around five 90-minute sessions per week combined with home exercises (total of 75 sessions). The only differences between the interventions were the melodic intonation and the hand tapping of MIT. After the initial 40 sessions, both patients improved on naming and speech rate, but the patient who received MIT showed larger improvements. After 75 sessions, naming and speech rate were further improved. Moreover, the patient who completed MIT showed evidence of a reorganization in the right hemisphere, as revealed by functional magnetic resonance imaging (fMRI), while the patient who completed SRT showed evidence of a reorganization in the left hemisphere. Since the melodic intonation and the hand tapping were the only elements that differed from the SRT, the authors concluded that these elements contributed the most to the effectiveness of MIT by activating right-hemisphere brain regions more strongly. Wan and colleagues (Wan et al., 2014) observed that intensive MIT (five 90-minute sessions per week for 15 weeks) was associated with changes in the right hemisphere. They compared 11 NFA patients who underwent MIT sessions with 9 NFA patients who did not receive any treatment. Changes in the right hemisphere only occurred in the treatment group and were associated with improved fluency.

To determine whether rhythm or melodic intonation contributes the most to the effectiveness of MIT, two studies (Stahl et al., 2013; Zumbansen et al., 2014) compared three types of therapy: melodic or singing therapy (MT), rhythm therapy (RT), and standard spoken therapy (ST). The MT included melodic intonation and rhythm, the RT only included rhythm and the ST included neither melodic intonation nor rhythm. In both studies, participants underwent three one-hour individual sessions per week. Stahl et al. (2013) included 15 NFA patients assigned to one of the treatment groups (MT, RT or ST). Left hand tapping was not allowed to facilitate the comparison of the interventions. All participants improved their production of stereotyped phrases (e.g. “hello, everything alright?”) but the participants who underwent MT or RT showed greater improvements. However, only ST patients showed improvements on non-stereotyped phrases and generalization effects. Zumbansen et al. (2014) included three NFA patients who underwent all three therapies (MT, RT and ST) each for six weeks in different order. Patients practised 20 sentences of different lengths per session. Half of the sentences were practised every session, and the other half were new. The results showed improvement on trained sentences in all interventions, but a generalization effect was only observed for MT. This difference may be due to the presence of untrained sentences, which promotes generalization, which is a feature of the original MIT, but was absent in Stahl (2013).

MIT was originally developed for patients with chronic aphasia, but it was adapted for subacute (i.e., two to three months post stroke) NFA patients by Van der Meulen and colleagues (2014). In this study, 24 subacute NFA patients underwent a randomized controlled trial. The control therapy consisted of linguistics tasks not involving speaking, such as writing or oral comprehension. The experimental and control groups received five hours of therapy per week for six weeks and were asked to complete exercises at home. Similar to Schlaug's (2008), Van der Meulen et al. (2014) observed that the MIT group improved their speech production more than the control group in language repetition, in the Amsterdam Nijmegen Everyday Language Test (ANELT), which measures verbal communication in daily life, and in trained and untrained sentences. Furthermore, the authors observed that the sooner the treatment is started in the subacute phase, the larger the improvements.

In sum, the MIT seems to have the potential to rehabilitate, at least to some extent, NFA patients at both the chronic and subacute phases. All the studies reviewed here found a positive impact of singing on at least one measure of speech production (e.g., naming, fluency repetition). The unique elements of the MIT are the rhythm, the melodic intonation and the tapping, but it is unclear whether one of these elements is most beneficial. Finally, while some researchers have examined the generalization effect of MIT on untrained sentences (Stahl et al., 2013; Zumbansen et al., 2014), no study thus far has examined the generalization to everyday life situations, which is the ultimate goal of any intervention targeting human communication.

The Therapeutic Effect of Singing in Dysarthria

In addition to being used as a treatment for aphasia, singing-based interventions have also been used as an alternative treatment for dysarthria. Dysarthria refers to a group of neurogenic acquired speech disorders characterized by altered speech movements. Depending on the lesion site, dysarthria may involve one or several pathophysiology (e.g. spasticity, flaccidity, or rigidity), which may impair speech processes [e.g., respiration, phonation (pitch, intensity, voice quality), articulation, resonance or prosody (stress, rate of speech)] to different extents (Yorkston et al., 2010). Most studies on singing intervention in dysarthria have focused on patients with Parkinson's disease (PD). However, few studies have also explored singing interventions in patients with dysarthria in non-degenerative brain diseases, such as stroke or TBI. In this section, we first review studies of PD patients and then we discuss other kinds of dysarthria.

PD is a neurodegenerative disorder associated with hypokinetic dysarthria (HD), which is characterized by reduced respiratory function, altered articulation, reduced speech intelligibility, prosody and pitch (F0), and changes in voice quality and intensity (Yorkston et al., 2010). The Music Therapy Voice Protocol (MTVP) was one of the first singing-based interventions for PD patients (Haneishi, 2001). The protocol was first introduced as an individual treatment (Haneishi, 2001), and then it was adapted as a group intervention (Yinger & Lapointe, 2012). Both individual and group interventions reported gains in vocal intensity (Table 2). Another intervention, the Voice and Choral Singing Treatment (VCST), which involves weekly choral sessions as well as two, one-hour speech therapy sessions, was also found to have positive outcomes (respiratory function, maximum phonation time and speech prosody) (Di Benedetto et al., 2009). In a more recent study using a similar choral intervention, Evans and colleagues reported improvements in respiration, vocal intensity, and F0 but not intelligibility (Evans et al., 2012). Other studies, however, have failed to find positive outcomes following singing interventions in PD patients (Elefant et al., 2012; Shih et al., 2012), but also found no deterioration, despite the degenerative nature of PD (Elefant et al., 2012; Evans et al., 2012), even after 2 years (Evans et al., 2012). This lack of deterioration was considered a positive outcome (Yinger & Lapointe, 2012). However, none of these studies mentioned the typical rate of speech deterioration in PD patients, and the only study that investigated longitudinal changes, to our knowledge, reported that the speech of patients with no or mild cognitive impairment did not deteriorate over a period of one year (Ash et al., 2017). Thus, it is not clear whether interventions in these studies were effective at all. Importantly, these studies used a less intense protocol (see Table Tremblay.2), involving only one session per week, which may account for the discrepancy. However, Stegemöller et al. (2017) compared two choral treatments differing only in intensity and found no difference, suggesting that intensity may not be the key factor.

Contrary to PD patients, patients with non-degenerative brain damage, such as TBI or stroke, usually suffers from a combination of two or more types of dysarthria (Yorkston et al., 2010). Two individual singing-based therapies have been developed specifically for patients with dysarthria following TBI or stroke (Kim & Jo, 2013; Tamplin, 2008). Both therapies are similar to the one used with PD patients and include vocal exercises and singing familiar songs. In the first study, patients improved in speech intelligibility, rate, and speech naturalness (Tamplin, 2008), while in the second, patients improved mostly on voice measures including vocal intensity, F0, stability, maximum phonation time, and speech rate in a phoneme repetition task (Kim & Jo, 2013).

Two other singing therapies have been developed for neurological patients with various speech disorders, including dysarthria, following TBI (Baker et al., 2005) or other neurological conditions (Cohen & Masse, 1993). In an individual singing therapy for TBI patients, participants improved their voice range and their emotional prosody (the ability to change intonation patterns with emotions) (Baker et al., 2005). In a group singing therapy targeting patients with neurogenic communication disorders, such as cerebrovascular accident, multiple sclerosis, cerebral palsy, or PD, an improvement in speech rate and intelligibility was found (Cohen & Masse, 1993). An important limitation of these two studies is that the number of dysarthric participants was not specified and the positive outcomes were not reported as a function of whether the patients had a diagnostic of dysarthria.

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In sum, singing may be beneficial to dysarthric patients but the results are less consistent than for aphasia. One potentially important limitation is that disease and speech severity is rarely reported. Those two important limitations render between-study comparisons difficult and make it hard to interpret null findings. Finally, very few studies used conversational speech as an outcome measure (Di Benedetto et al., 2009; Yinger & Lapointe, 2012), which makes it difficult to determine whether post-singing-intervention improvements can be generalized to everyday conversation. Hence, though singing interventions appear to have a positive effect in some dysarthric patients on some outcome measures, future research is needed to evaluate the effectiveness of singing therapy on dysarthria symptoms as a function of patients' characteristics (e.g. severity).

Conclusions

In this chapter, we provide a non-exhaustive overview of the scientific evidence for a beneficial impact of singing in normal and pathological aging, focusing on NFA and dysarthria. The results of our review suggest that singing can improve communication-related outcomes in both clinical populations, but that it may be more effective in aphasic patients, as the results appear to be more consistent across studies. However, the outcome measures vary significantly across studies and often are not detailed. Moreover, the outcome measures are usually not selected based on clear hypotheses about underlying mechanisms. Given the various types of dysarthria, and also aphasia, it is possible that singing-based interventions are most effective either at certain severity levels, or for certain types of disorders. Importantly, we also found that singing has a protective impact on different aspects of human communication, particularly on voice production, though the voice parameters most sensitive to singing remain to be identified, and the potential impact of singing on speaking has been largely ignored. While benefits are reported in all studies, there is divergence in terms of the nature and extent of these benefits. Here again, a lack of proper characterization of participants, particularly the singers, prevents the identification of the most robust singing-related outcomes in the elderly. Understanding normal aging as well as the impact of singing on normal aging will provide a better baseline against which to examine the clinical impact of singing in age-related diseases such as NFA and PD. It will also inform the development of science-based singing interventions. Thus, while this field of research is still emerging and much work is needed to fully understand the protective and curative effects of singing on communication, the available evidence shows promising results.

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Tables

Table 1 - *Normal aging articles reviewed (full references provided in the main text)*

#	Reference	Sample	Outcome measures	Main findings
1	Morris et al. (1995)	Young (25–35): 18 non-singers, 5 tenors and 9 bass/baritones; Middle-aged (49-55): 14 non-singers, 5 tenors and 6 bass/baritones; Older (65+): 18 non-singers, 5 tenors and 4 bass/baritones	SFF, frequency range, intensity, intensity range and average peak vocal intensity	Singing benefit on SFF and frequency range in aging.
2	Prakup (2012)	65–80(M=N/A): 30 singers and 30 non-singers	F0, pitch stability, intensity, intensity stability and perceptual ratings	Singing benefit on jitter and intensity in older singers. Older singers perceived as younger.
3	Lortie et al. (2017)	Young (20–39, M=28): 12 non-singers, 8 occasional singers and 6 frequent singers; Middle-aged (40–65, M=56): 13 non-singers, 8 occasional singers and 5 singers; Older (66–93, M=75): 14 non-singers, 2 occasional singers and 4 frequent singers	F0, frequency range, pitch stability, intensity, intensity range, intensity stability and HNR	Singing benefit on F0, SFF, F0 variability and amplitude variability in aging.
4	Brown et al. (1991)	Young (20–35, M=26): 20 professional singers and 35 non-singers; Middle-aged (40–55. M=44): 20 professional singers and 35 non-singers; Older (65–85, M=76): 20 singers and 34 non-singers	SFF	Singing benefit on SFF in aging.
5	Berghs et al. (2013)	Young (21–30, M=N/A): 13 professional singers; Middle-aged a (31-30, M=N/A): 9 professional singers; Middle-aged b (41–50, M=N/A): 12 singers; Older (51–60, M=N/A): 13 professional singers	Frequency range, pitch stability, intensity range, vibrato parameters, MPT, and DSI	Age-related decline in highest frequency overall and DSI. For additional female decline in F0 range and SD vibrato amplitude.
6	Brown et al. (1990)	25 young non-singers (20–32, M=27), 19 older singers (63–85, M=73), 25 older non-singers (75–90, M=79)	F0, frequency range, intensity, pitch stability, reading time	Singing benefit on SFF and reading time in aging.
7	Sundberg et al. (1998)	20 professional singers (20–70, M=N/A)	Rated age, vibrato rate and vibrato extent	Rated age correlates with real age. Vibrato rate and extent correlate negatively with rated age.

8	Tay et al. (2012)	22 singers (68–83, M=76), half received a voice treatment (VFE) and the other half did not.	F0, frequency range, pitch stability, intensity stability, HNR, maximum phonation time, perceptual parameters of the voice, perceived effectiveness of the program and compliance with home practice	The VFE is associated with lower perceived roughness, lower shimmer, and lower HNR.
9	Hazlett & Ball (1996)	1 young singer (20) and 1 older smoking singer (60)	F0, F0 range, pitch stability, intensity, intensity stability, HNR, maximum phonation time, voice onset time	No statistics reported. Tendency for a benefit of singing on jitter and frequency range and HNR.
10	Maruthy et al. (2015)	15 young non-singers (19–48, M=28), 15 older non-singers (51–68, M=59), 15 young singers (19–48, M=28), 15 older singers (51–72 M=59)	F0 maximum, lower intensity, jitter, MPT, DSI	Singing benefit on F0 maximum and DSI in aging.

Legend:
F0 = fundamental frequency
DSI = Dysphonia severity index
HNR = harmonic-to-noise ratio
MPT = maximal phonation time
SD = standard deviation
SFF = speaking F0

Table 2 - *Aphasia and dysarthria articles reviewed (full references provided in the main text).*

#	Reference	N	Age	Diag.	Intervention	Outcome measure	Main findings
1	Albert et al. (1973)	3	48-67 (M=60)	NFA	MIT (N/A)	Speech fluency	Improvement (speech fluency)
2	Yamadori et al. (1977)	24	21–74 (M=48)	NFA	Singing or humming	Capacity to sing popular song	Preserved on 21/24 patients
3	Schlaug et al. (2008)	2	47–58 (M=53)	NFA	MIT (Individual, five 90-minute sessions/week for 15 weeks) and Speech Repetition Therapy (Individual, five 90-minute sessions/week for 8 weeks)	Structural brain changes and speech fluency	Improvement (speech production measure) for MIT and Speech Repetition Therapy, but greater improvements for MIT, Structural brain changes (right hemisphere for MIT and left hemisphere for Speech Repetition Therapy)
4	Stahl et al. (2013)	8	40–72 (M=56)	NFA	Melodic therapy, Rhythmic therapy or Spoken therapy (Individual, three 60-minute session/week for 6 weeks)	Speech accuracy	Improvement (speech accuracy) for singing and rhythmic therapy
5	Van Der Meulen et al. (2014)	23	18–80 (M=53)	NFA	MIT (Individual, five 90-minute sessions/week for 15 weeks) and Speech Repetition Therapy (Individual, five 90-minute sessions/week for 8 weeks)	Verbal communication, repetition and semantic association	Improvement (verbal communication, repetition, semantic association)
6	Zumbansem et al. (2014)	3	48-57 (M=52)	NFA	Melodic therapy, Rhythmic therapy or Spoken therapy (Individual, three 60-minute sessions/week for 6 weeks)	Speech fluency and speech accuracy of trained and untrained material	Improvement (speech fluency and speech accuracy of untrained material) for melodic therapy Improvement (speech accuracy of trained material) for all the therapies
7	Wan et al. (2014)	20	45–70 (M=56)	NFA	MIT (Individual, five 90-minute sessions/week for 15 weeks)	Structural brain changes and speech fluency	Structural brain changes (right hemisphere) and Improvement (speech fluency)

8	Cortese et al. (2015)	6	53–71 (M=60)	NFA	MIT (Invidual four 40-minute sessions/week for 16 weeks)	Semantic-lexical structure, speech accuracy, speech automatism, prosody and communication, repetition, naming, comprehension and speech fluency	Improvement (Semantic-lexical structure, speech accuracy, speech automatism, prosody and communication, repetition, naming, comprehension and speech fluency)
9	Van der Meulen et al. (2016)	17	N/A (M=60)	NFA	MIT (Individual, 5h/week for 6 weeks)	Verbal communication, repetition, naming, auditory verbal comprehension	Improvement (repetition of trained and untrained items)
10	Haneishi (2001)	4	67-77 (M N/A)	PD	Music Therapy Voice Protocol Individual, three 60-minute sessions/week for 4 weeks)	Speech intelligibility, vocal intensity and voice parameters	Improvement (speech intelligibility and vocal intensity)
11	Yinger et Lapointe (2012)	10	59–84 (M=72)	PD	Group Music Therapy Voice Protocol (Group, two 50-minute sessions/week for 6 weeks)	Vocal intensity and voice parameters	Improvement (vocal intensity)
12	Di Benedetto et al. (2009)	20	N/A (M=66)	PD	Voice and Choral Singing Treatment (one 120-minute session/week, N/A) with speech therapy (two 60-minute sessions/week)	Respiratory function, voice parameters and speech prosody	Improvement (Respiratory function, some voice parameters and speech prosody)
13	Evans et al. (2012)	10	48–81 (M=67)	PD	Choral (Group, one 120-minute session/fortnight for 2 years)	Speech intelligibility, respiratory function, vocal intensity voice parameters and facial musculature	Improvement (respiratory function, vocal intensity, voice parameters and facial musculature)
14	Shih et al. (2012)	13	54–79 (M=66)	PD	Singing in groups (Group, one 90-minute session/week for 12 weeks)	Vocal intensity and voice parameters	No improvement
15	Elefant (2012)	10	55–84 (M=64)	PD	Choral (Group, one 60-minute session/week for 20 weeks)	Vocal intensity, voice parameters and singing components	Improvement (singing components)
16	Stegemöller et al. (2017)	27	N/A (M=67)	PD	Choral (Group, one or two 60-minute	Respiratory function, vocal intensity and voice parameters	Improvement (respiratory function, voice parameters

					session/week for 8 weeks)		
17	Tamplin (2008)	4	19-51 (M=28)	Dysarthria	Singing therapy (Individual, three 30-minute sessions/week for 8 weeks) and Speech therapy	Speech intelligibility, rate of speech, communication efficiency and naturalness of speech)	Improvement (speech intelligibility, rate of speech and naturalness of speech)
18	Kim & Jo (2013)	6	52-65 (M=59)	Dysarthria	Accent-based Music Speech Protocol (Individual, 5 sessions/week for 2 weeks)	Vocal intensity, voice parameters and articulation	Improvement (vocal intensity, voice parameters and articulation)
19	Baker et al. (2005)	4	24-29 (M=27)	Unspecified speech disorders following TBI	Singing Therapy (Individual, three 45-minute sessions/week for 5 weeks)	Prosody and voice parameters	Improvement (prosody and voice parameters)
20	Cohen & Masse (1993)	32	N/A	Speech disorders following brain damage	Singing or rhythmic therapy (Group, two 30-minute sessions/week for 9 weeks)	Rate of speech and speech intelligibility	Improvement (rate of speech) for singing and rhythmic therapy Improvement (speech intelligibility) for singing therapy

Legend:
Diag. = diagnostic
M = mean
MIT = Melodic Intonation Therapy
N = Sample size
NFA = Non-fluent aphasia
PD = Parkinson's Disease
Voice parameters: Fundamental frequency (F0), F0 variability, vocal range, maximum phonation time, jitter and shimme

[1] The fundamental frequency (F0) of the human voice is a measure of how high or low the frequency of a voice is. It is the frequency of vocal fold vibration. F0 can be measured using a sustained vowel or a connected speech, in which case it is referred to as Speaking F0.

[2] Jitter corresponds to the amount of instability in vocal pitch, with higher jitter indicating a higher instability in the frequency domain.

[3] Shimmer corresponds to the amount of instability in vocal intensity, with higher shimmer indicating a higher instability in the intensity domain.

[4] HNR is an assessment of the ratio between periodic components and non-periodic component comprising a segment of voiced speech. A normal voice is characterized by a high HNR. A low HNR denotes an asthenic voice and dysphonia.

[5] The jitter ratio is a measure that takes into account the relationship between jitter and F0: mean jitter (in milliseconds) / mean period (in milliseconds) * by 100.

[6] Carnatic classical singing is the traditional South Indian classical singing style.