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The Effect of Melody and Rhythm in Music-Based Therapy for Nonfluent Aphasics: A Literature Review

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Abstract

The aim of this review is to examine studies which explored whether melody or rhythm played a more integral role in the facilitation of music-based speech and language rehabilitation for the population of individuals with nonfluent aphasia. This paper is intended to serve as a succinct synthesis of the myriad articles covering the efficacy of the treatment program called Melodic Intonation Therapy (MIT) and the impact of its primary musical mechanisms. Secondarily, it may assist in a deeper examination into speech and language-based music cognition and neurologic music therapy research. The speech and language disorder of aphasia; the relationships between music, speech and the brain; and the mechanisms of neuroplasticity and entrainment are explained. Additionally, the history, components, protocol, and efficacy of MIT are discussed. Furthermore, the musical qualities of melody and rhythm in regards to MIT and speech and language rehabilitation are analyzed. The findings suggest that it is the combination of melody and rhythm that best facilitates the recovery of speech in music-based aphasia treatment. Moreover, attempting to separate the qualities of melody and rhythm may be a reductionist viewpoint that fails to advance this particular realm of music cognition research. Finally, the individual merits of melody and rhythm within MIT may be impossible to distinguish. Suggestions for future research in this area are provided.

Keywords: aphasia, melodic intonation therapy, melody, neurologic music therapy, rhythm, stroke

The Effect of Melody and Rhythm in Music-Based Therapy for Nonfluent Aphasics: A Literature Review

Aphasia is “an acquired language disorder that can arise as a consequence of stroke” (Thompson et al., 2016, p. 122). Ren da Fontoura et al. (2012) added that it is an “impairment of expressive and/or receptive language, caused by brain damage, usually to the left hemisphere” (p. 233). According to the National Institute of Health and the National Aphasia Association, roughly “one million people in the United States currently have aphasia, and nearly 180,000 Americans acquire it each year” (Aphasia, 2017). While there are multiple types of aphasia, Schlaug et al. (2009) specified that they fall under two categories: nonfluent and fluent. Individuals with nonfluent aphasia “usually have the ability to comprehend the speech of others, but are unable to produce words themselves,” while those with fluent aphasia “may have a prominent comprehension deficit and their jargon-like and/or nonsensical speech is often incomprehensible” (p. 1).

Currently, there is no universal treatment for aphasia (Schlaug et al., 2008; Akanuma et al., 2015). Based on the wide understanding that individuals with nonfluent aphasia can sing better than they can speak (Albert et al., 1973; Belin et al., 1996; Hébert et al., 2003; Wilson et al., 2006; Schlaug et al., 2008; Stahl et al., 2011; Tomaino, 2012; Stahl & Kotz, 2014; Merrett et al., 2014; Akanuma et al., 2015), an intervention for the recovery of propositional speech and language called Melodic Intonation Therapy (MIT) has increased in practice over the last several decades. MIT incorporates both melodic and rhythmic aspects of music (Albert et al., 1973; Boucher et al., 2001; Schlaug et al., 2008).

It was originally theorized that MIT facilitated language in the left hemisphere by activating the right-hemisphere’s ability to process music (Albert et al., 1973; Naeser & Helm-

Estabrooks, 1985). However, this notion has been challenged in subsequent years (Belin et al., 1996; Boucher et al., 2001; Racette et al., 2006; Merrett et al., 2014; Stahl & Kotz, 2014). There remains much discussion surrounding the efficacy of MIT (Hébert et al., 2003; Wilson et al., 2006; Merrett et al., 2014; Stahl & Kotz, 2014; Zumbansen et al., 2014a; Akanuma et al., 2015), and the specific way in which the right hemisphere operates within MIT is still a mystery (Stahl & Kotz, 2014; van de Meulen et al., 2014). Furthermore, the specific role of melody remains unclear (Merrett et al., 2014). Some have suggested that singing may help speech production by slowing articulatory tempo (Hébert et al., 2003; Wilson et al., 2006; Schlaug et al., 2008; Tomaino, 2012; Stahl & Kotz, 2014) and that singing is beneficial for long-term speech production (Wilson et al., 2006; Racette et al., 2006), while others have contended that rhythm alone may be responsible for MIT's effectiveness (Boucher et al., 2001; Stahl et al., 2011, 2013; Merrett et al., 2014).

In this review, the efficacy of MIT and singing-based interventions for speech and language recovery in individuals with nonfluent aphasia are examined. Additionally, the specific musical qualities of melody and rhythm as they pertain to MIT are discussed, and treatment outcomes based on whether one musical quality is more integral than the other are noted. Finally, relevant gaps in the research to date are noted in this inquiry, and proposals for future studies to address these gaps are included. Music can be interpreted in many ways. Music therapists believe that music possesses the ability to heal and, depending on how music is used, that healing can be measurable. Just as music has traditionally been viewed abstractly from an emotional or spiritual perspective, it can now, with the advent of sophisticated imaging techniques and devices in conjunction with subjective and objective clinical measurements, be examined concretely from a neurological one.

Literature Review

What is Aphasia?

According to Norton et al. (2009), aphasia is “the loss of ability to produce and/or comprehend language” (p. 431). In the United States and Europe, aphasia following a stroke occurs in nearly 60 out of every 100,000 people, and that as the elderly grow in numbers, so does the frequency of occurrence (Lim et al., 2013, p. 556). Aphasia can affect different aspects of speech such as comprehension, expression, naming and repetition (Ren da Fontoura, 2012, p. 223). Consequently, aphasia presents differently in each individual because speech production and language comprehension occur in different brain regions. Located in the left frontal lobe, Broca’s area is “associated with speech production and articulation” while Wernicke’s area, in the left temporal lobe, “processes word sounds” and language comprehension (Taylor, 2010, p. 215). Fujii and Wan (2014) explained that when a lesion in Broca’s area is detected and the production of speech is compromised, individuals are then typically categorized as having ‘non-fluent aphasia’ (p. 9).

The Relationship of Music and the Brain

In order to understand how music works to treat aphasia, it is important to comprehend the relationship of music and the brain. In 1987, research compiled by neuro-musicologist Dr. Arthur W. Harvey became the basis for the three assumptions supporting the Biomedical Theory of Music Therapy:

a. The center of control for the human organism is the brain.
b. Music is processed by the brain and through the brain, after which it can then affect us in many ways.

c. Music can have a positive effect upon both neural functions and hormonal activity and, as such, can facilitate the healthy functioning of the body's own immune and regenerative processes. (Harvey, 1987, p. 73–74)

There is no central music processing center in the brain (Vik et al., 2019, p. 2). Accordingly, almost every identified region of the brain is influenced by music (Levitin, 2007, p. 86). In a concise explanation detailing the neurophysiological progression of music processing, as well as the many neural centers activated by music, Taylor (2010) summarized:

> Once sensory stimuli in the form of musical sounds are received in the ear, they activate use of the auditory tract, enter the central nervous system via the medulla, and after passing through the thalamus, they are processed in the cerebral cortex. The brain develops its capacities in part because sense organs, such as the ears which accomplish transduction of sound waves, transmit the energy that generates brain development. The brain decodes and converts information and experience entering in the form of nerve impulses into sensations. It subsequently organizes and identifies stimuli, selects and directs reactions, stores information about the whole process, and recalls it as needed. (pp. 80–81)

By undergoing these processes, the brain can utilize music in many ways for various purposes, including those related to speech and language.

The Link Between Music and Speech and Language

There is no single language processing center; some neural regions are responsible for individual functions, while others organize the connectivity of those components (Levitin, 2007, p. 87). However, many studies demonstrate association between music and language (Patel et al., 1998; Koelsch & Siebel, 2005; Parsons et al., 2005; Brown et al., 2006). In addition, Thaut and

Hoemberg (2014) stated that “music and speech, especially in singing, share multiple control processes with regard to auditory, acoustical, temporal, neuromuscular, neural, communicative, and expressive parameters” (p. 5). Furthermore, Hausen et al. (2013) indicated with fMRI studies that music and speech perception occur in interrelated brain regions, including those once assumed to be language-specific, such as Broca’s area and Wernicke’s area. Regarding the brain’s ability to process melody and rhythm, Taylor (2010) specified that simple and repetitive songs in popular genres such as folk “lend themselves very well to the integration of perceptual, stimulus-response, relational, and motor learning as well as to including both informative and affective aspects of cognition” (p. 106). In the context of singing, the therapist prompts the systematic engagement of both the primary auditory and motor cortexes, as well as Broca’s and Wernicke’s areas, whenever a client sings a song (Taylor, 2010, p. 109).

Neuroplasticity

While the neurological basis for language recovery is still unknown (Schlaug et al., 2008; Norton et al., 2009; Akanuma et al., 2015), it is ultimately the mechanism of neuroplasticity that allows damaged brain tissue to heal. Baker (2011) asserted that neuroplasticity “is the term used to describe the process that the brain undergoes during recovering from injury” (p. 282). More specifically, Neugebauer et al. (2004) defined it as the modification of the operation or biological structure of neurons. Essentially, the brain is able to reorganize itself following an injury so that another part of the brain can undertake the duties of the damaged region (Baker, 2011, p. 283). It has been theorized that neuroplastic reorganization relating to language recovery may rely on multiple characteristics such as lesion size and location, and the severity of the aphasia itself (Merrett et al., 2014; Marchina et al., 2011; Wang et al., 2013). Relating neuroplasticity and music, playing a musical instrument may engage and strengthen connections between neural networks (Wan & Schlaug, 2010, p. 566). Recently, Vik et al. (2019) advanced this notion by suggesting that neurologic rehabilitation could be facilitated by music making. Pertaining to aphasia treatment specifically, the generation of fresh neural connections indicative of neuroplasticity's effect may be attributable to singing (Slavin & Fabus, 2018, p. 1353).

The advent of modern imaging techniques allowed scientists to study functional aspects of the brain for the first time. In regards to the mechanisms responsible for post-stroke recovery, Belin et al. (1996) stated that "such studies provide new insights into the plasticity of the mature cerebral cortex by showing that brain areas other than the ones normally used in certain cognitive tasks may be activated during functional recovery" (p. 1504). In their landmark study, Belin et al. (1996) utilized PET and fMRI technology to study the language recovery in seven right-handed aphasic patients by employing MIT. The authors indicated that, by exaggerating or altering the melodic and rhythmic properties of regular speech patterns, nondominant language-related areas of the brain may exhibit significant neuroplastic functionality (Belin et al., 1996, p. 1510). Their findings suggested that MIT helps to redirect the atypical, right-brain language activity and to restore the left hemisphere's damaged essential language functions, demonstrating not only the effect of neuroplasticity, but also the efficacy of MIT (Belin et al., 1996, p. 1509).

Entrainment

In 1666, Dutch physicist Christian Huygens identified entrainment as a phenomenon when he observed the synchronization of two clocks' pendulums while affixed to a board (Thaut et al., 2015, p. 1). This phenomenon is also observed in humans by their ability to synchronize movements to rhythm, defined by Thaut et al. (2015) as "a temporal locking process in which one system's motion or signal frequency entrains the frequency of another system" (p. 1). Essentially, externally produced rhythms can stimulate the brain's internal time-keeping mechanism. Between 1991 and 1993, Thaut and colleagues conducted experiments regarding rhythmic entrainment's efficacy in treating movement disorders by demonstrating that, in healthy individuals as well as those affected by stroke, musical rhythm can be used to regulate bodily movement by synchronizing to the human motor system (Thaut, 2013, p. 32). Later, entrainment was applied to speech and language disorders as well. Thaut (2013) stipulated that "speech rate control affecting intelligibility, oral motor control, articulation, voice quality, and respiratory strength may greatly benefit from rhythmic entrainment using rhythm and music" (p. 33). He further delineated that sound waves affect the speech and language centers in the brain by repeating cyclically, so that the auditory system can more readily detect and develop rhythmic sequences (Thaut et al., 2015, p. 6). Thaut et al.'s (2015) recognition that "timing and sequencing also have a critical function in cognitive abilities" led to research that supported the development of neurologic music therapy speech and language interventions, and a greater understanding of the mechanisms underlying previously established techniques and protocols like MIT (p. 4).

The Use of Music in Treating Aphasia

Music cognition research conducted in the 1990's confirmed music's ability to stimulate the brain's physiological processes, as well as its ability to "retrain and re-educate the injured brain" (Thaut & Hoemberg, 2014, p. 1). This research lead to the development and standardization of neurologically-informed, musically-specific clinical interventions that shaped the foundation of neurologic music therapy (NMT). Thaut and Hoemberg (2014) defined NMT as "the therapeutic application of music to cognitive, affective, sensory, language, and motor dysfunctions due to disease or injury of the human nervous system" (p. 2). Under the umbrella of NMT, an intervention called Melodic Intonation Therapy (MIT) "uses melodic and rhythmic elements of intoning (singing) phrases and words to assist in speech recovery for patients with aphasia" (Thaut & Hoemberg, 2014, p. 140). The authors stipulated that patients diagnosed with nonfluent Broca's aphasia will benefit from this treatment over individuals with other forms of aphasia since the ability to read and comprehend language is necessary for improvement (Thaut & Hoemberg, 2014, 140).

Origins and Protocol of MIT

MIT was first introduced in Albert et al.'s (1973) seminal study, where the authors described the effect of their newly developed method in three brief case studies. They hypothesized that language impaired by left hemisphere damage can be accessed through the right hemisphere (p. 130), and concluded that MIT had considerably improved the participants' expressive language production (p. 131). While the authors indicated that treatment with two other participants diagnosed with global aphasia and Wernicke's aphasia were not receptive to MIT, the circumstances of their injuries and the course of their treatment was not specified. Furthermore, the exact procedure of MIT was not detailed, nor would it be until subsequent studies.

MIT incorporates a specified order of operations. According to Naeser and Helm-Estabrooks (1985), MIT "is a hierarchically structured aphasia rehabilitation program [that] uses high probability phrases and sentences which are intoned and tapped out in a syllable-by-syllable manner" (p. 203). Stahl et al. (2013) contended that MIT included "three main components: singing, rhythmic speech, and common phrases" (p. 1). Additionally, Schlaug et al. (2008) maintained that it was the elements of melodic singing with continuous voicing, and the rhythmic tapping using the individual's left hand that "set it apart from other, non-intonation-based therapies" (p. 316). Thaut and Hoemberg (2014) outlined the steps of the procedure:

1. The therapist presents an intoned statement via humming while hand tapping with the patient. The patients listens to the presentation.
2. The therapist sings the intoned statement in several repetitions while hand tapping with the patient. The patient listens to the presentation.
3. The therapist sings and invites the patient to join in. The therapist and patient sing together with several repetitions. The therapist continues to aid the patient's hand tapping, but fades progressively as the patient shows more independent tapping motions.
4. The therapist fades during singing with the patient. Hand tapping continues.
5. The therapist sings first and then stops and cues the patient to respond by intoning independently. Hand tapping continues. The therapist may increase the "wait period" for the patient to respond after each repetition to exercise the ability to retrieve words.
6. The therapist asks one or more questions about the information in the exercise statement. The patient may respond by intoning or in normal speech. The therapist does not assist with hand tapping. The patient may or may not use tapping spontaneously. (p. 142)

Since its introduction nearly fifty years ago, the efficacy of MIT as a treatment protocol, as well as the relative effect of the individual components of melody and rhythm within it, have been explored by many researchers.

Melody and Singing in Melodic Intonation Therapy

Tomaino (2012) concluded that there are multiple benefits to singing for individuals with nonfluent aphasia, including "strengthened breathing and vocal ability, improved articulation and prosody of speech, and increased verbal and nonverbal communicative behaviors" (p. 312).

Slaving and Fabus (2018) expounded on this deduction to posit that "singing…may optimize the retraining of shared brain functions including memory, attention, perception, motor control, and language" (p. 1353). The original explanation of MIT's effectiveness was based on the notion that singing helps recruit the use of the right hemisphere for language production (Albert et al., 1973, p. 131). In a literature review discussing MIT's protocol and efficacy, Norton et al. (2009) proposed that "the goal is to uncover the inherent melody in speech to gain fluency and increase expressive output" (p. 433). Many studies have attempted to determine the roles of singing and melody within the treatment method. These are discussed more fully below and summarized in Tables 1-4.

Efficacy of Singing in MIT

Schlaug et al. (2008) conducted a study to determine the effectiveness of singing with MIT on speech and language recovery in patients with nonfluent aphasia by comparing MIT with Speech Repetition Therapy (SRT). SRT was "designed to control for the elements of MIT that are common to other speech therapies, and exclude its distinct features, the melodic intonation and rhythmic tapping with the left hand" (Schlaug et al., 2008, p. 317). The study included two participants, both of whom had nonfluent aphasia resulting from left-hemisphere ischemic stroke, were diagnosed with Broca's aphasia, sustained similar lesion sizes and locations, and had undergone a year of speech therapy prior to the study (Schlaug et al., 2008, p. 317). Both participants underwent 75 sessions of MIT and were assessed after sessions 40 and 75, respectively. However, participant #2 underwent 40 sessions of SRT prior to undertaking sessions of MIT. The two participants were randomly assigned treatment types, both worked one-on-one with a therapist for 1.5 hours per day, five days per week, and were provided materials for at-home practice (Schlaug et al., 2008, p. 318). The participants utilized 16 bisyllabic words and phrases. Two experimental conditions (spoken or sung bisyllabic words and phrases) and three control conditions (humming, phonation, and silence) were stipulated. “The participants heard an investigator saying/singing two-syllable words or phrases, then repeated exactly what they had heard after an auditory cue” (Schlaug et al., 2008, p. 318).

The results indicated that “the MIT-treated patient had greater improvement on all outcomes than the SRT-treated patient” regarding syllable and word production (Schlaug et al., 2008, p. 320). Furthermore, the authors indicated a connection between left-hand tapping and speech production capability through the mechanisms of rhythmic priming and entrainment (p. 320). However, the study presented several limitations. First, the small sample size may not generalize the treatment results to a broader population. Next, the amount and duration of at-home practice for either participant was not specified. Stahl and Kotz (2014) further criticized the study for controlling for singing but not for left-hand tapping:

> The treatments did not only differ in singing, but also in other aspects of vocal expression and sensorimotor feedback. What seems like a benefit from singing may actually be the effect of rhythm, prosody, tactile stimulation, or any of their combinations. (p. 2)

Nonetheless, Stahl and Kotz (2014) asserted that the authors were able to demonstrate MIT’s effectiveness over its non-melodic control (p. 2). In contrast, Merrett et al. (2014) asserted that the function of melody in MIT remains uncertain.

Singing Versus Speaking

Racette et al. (2006) attempted to determine whether singing is more effective than speaking in speech production in nonfluent aphasics. The authors conducted three separate experiments with eight participants. They were tested in the repetition and recall of sung and spoken words and phrases from familiar songs performed individually, novel songs performed individually, and novel songs performed in unison with an auditory model. In the first two experiments, the authors found that, regardless of familiar or novel songs, there was no advantage to singing over speaking pertaining to individual recall. However, the third experiment demonstrated that "singing in synchrony with an auditory model—choral singing—is more effective than choral speech" (p. 2571). This outcome directly supports the aid of entrainment within the treatment process. Referring to the third experiment's outcome, Zumbansen et al. (2014a) considered that "this is the condition that the authors of MIT deemed the most clinically facilitating for teaching the intoned-speech technique to patients" (p. 7).

Despite this encouraging result, there remain various factors to deliberate. First, while the authors asserted that "MIT treatments emphasizing rhythm lead to better syllable repetition than treatments emphasizing intonation," syllable duration was not controlled since the natural prosody of singing and speaking utilizes irregular rhythmic patterns (p. 2571). When critiquing this study, Zumbansen et al. (2014a) argued that "the superiority of choral singing over choral speech may actually depend on differences in syllable duration," emphasizing the very condition for which Racette and colleagues did not account (p. 8). Furthermore, Racette et al. (2006) clarified that rhythm was not analyzed due to the amount of pauses and hesitations (p. 2574). Secondly, while each participant had incurred a left hemispheric event, the location and size of the lesion, as well as the type and severity of the aphasia, all varied among the sample. Additionally, five of the eight participants had comorbidities of apraxia and dysarthria, potentially skewing the generalizability of results. Lastly, the study was undergone in French, potentially highlighting differences in language cadence and brain processing when compared to English.

Melody in MIT

Wilson et al. (2006) conducted a study on a male singer with Broca's aphasia to determine the efficacy of MIT, as well as to gauge the levels of language improvement based on the success of "unrehearsed verbal production, rehearsed verbal production (repetition), and rehearsed verbal production with melody (MIT)" using thirty novel phrases (p. 23). The authors explained that "the unrehearsed condition served as the control for the rehearsed conditions" while "rehearsed verbal production assessed the effects of practice using an accentuated rhythm as opposed to melody during training. The immediate and longer-term efficacy of MIT was assessed by comparing the patient's performance at baseline, 1 week, and 5 weeks after therapy" (p. 24). The findings suggested:

> Melodic prompts facilitated access to words that had been rehearsed with melody over those that had not. In the absence of any rehearsed articulation pattern, the MIT phrases dominated over the nonmelodic phrases. Overall, the MIT phrases showed the highest correct response rate without a prompt, whereas repetition phrases were more likely to be correct with a verbal cue. (p. 32)

Wilson et al. (2006) argued that "melodic rehearsal appeared to be the key component for effecting longer-term improvements in speech production" but also acknowledged the effect of rhythm to facilitate "slowing the tempo and providing greater accentuation of the speech sounds" (p. 32). Merrett et al. (2014) echoed this study's findings by suggesting that melody may have assisted in long-term memory retrieval (p. 6). However, Schlaug et al. (2008) were critical of Wilson and colleagues' findings regarding the long-term carryover of the participant's language capability. They suggested the results were skewed since the patient was only tested with practiced phrases administered by the therapist, and the usage of unrehearsed or unstructured phrases was not included (p. 316). Regardless of providing evidence of MIT's ability to recover speech through melodic rehearsal, the small sample size made it difficult to generalize the results, especially when the sole participant was a trained singer.

Modified MIT

Slavin and Fabus (2018) conducted a study of a 63-year-old man with nonfluent aphasia and apraxia of speech (AOS) using a modified version of MIT to include several different exercises as precursors to the original treatment program. The authors argued that "the basic MIT approach may be embellished to incorporate a variety of techniques designed to maximize the contribution of right brain centers in the recovery of language in people with aphasia" (p. 1354). The clinician first lead the participant in a breathing exercise, followed by singing a musical scale while tapping rhythmically. Next, the participant sustained a series of vowel sounds, and then engaged in modeling different rhythmic tapping patterns. Afterward, the clinician administered MIT, coupling the intervention with the singing of familiar songs (p. 1355). The participant was provided with 50-minute, biweekly sessions, for three 12-week intervals (p. 1357). At the beginning, the participant's AOS and subsequent word-finding and comprehension deficits contributed to their lack of expressive output (p. 1357). After 9 months of treatment, the participant's "auditory comprehension skills improved, as did his articulatory precision and expressive language skills" (pp. 1357–1358). While the authors were cognizant of the importance of rhythmic priming and consistent tapping, they stressed it was singing that "allowed him to enjoy a verbal fluency he had not experienced in years" (p. 1358).

Despite the attention to detail in this study, the authors submitted that "our findings… should be viewed in the context of a single-subject design with the limitation inherent in it" (p. 1360). Furthermore, the participant was ten years post-stroke and had undergone eight years of speech therapy prior to the study's initiation. Both of these factors, as well as the long duration of the treatment in the study, must be taken into account. Slavin and Fabus (2018) additionally conceded that their "procedures may have been strengthened through collaboration with a music therapist whose expertise in using more melodic complexity and improvisation, for example, might further enhance clinical outcomes" (p. 1360). Lastly, the impact of the participant's AOS on his results remains unclear due to the small sample size. While the results are promising, future studies employing this modified method with a larger sample size will be needed to support its efficacy moving forward.

Rhythm in Melodic Intonation Therapy

In the last twenty years, many studies have more closely examined the role of rhythm in speech and language rehabilitation (Boucher et al., 2001; Stahl et al., 2011, 2013; Fujii & Wan, 2014; Thompson et al., 2016; Beber et al., 2018). It is well established that hand-tapping and rhythmic pacing can improve syllabic articulation (Naeser & Helm-Estabrooks, 1985; Schlaug et al., 2008; Norton et al., 2009; Merrett et al., 2014). More comprehensively, it has been asserted that rhythmic entrainment can benefit multiple aspects of speech such as intelligibility, oral motor control, respiratory strength and vocal quality (Thaut, 2013; Lim et al., 2013; Thaut et al., 2015). Additionally it has been proposed that left-hand tapping may engage a right-hemispheric sensorimotor network (Schlaug et al., 2008; Norton et al., 2009; Stahl et al., 2011; Merrett et al., 2014). Furthermore, some researchers have claimed that rhythm may be the crucial factor in MIT's effectiveness (Boucher et al. 2001; Stahl et al., 2011, 2013; Merrett, et al., 2014).

Rhythm in Speech Prosody

In 2001, Boucher and colleagues led a study exploring the effect of melody and rhythm in melody-based speech and language interventions with two individuals diagnosed with nonfluent aphasia (p. 131). The authors focused on the subjects' prosody of speech, which included "rate, emphasis and syllabification" (p. 132). Both participants presented with left hemisphere lesions that had impaired their repetition abilities (p. 131). The participants had incurred their injuries 40 and 30 months prior to the study, respectively, and both were administered the Western Aphasia Battery (p. 133). However, their lesion types and specific locations, as well as their ages and the amount of speech therapy they had received prior to the study, varied widely (p. 134). The authors broke down treatment into four different categories (tone contour, verbal pacing, hand tapping, and melodic intonation) that each followed seven phases modelled after MIT's original protocol. The categories of hand tapping and melodic intonation were incorporated to account for MIT's combined melodic and rhythmic criteria, and were used as comparisons to their separated categorical counterparts of verbal pacing and tonal contour (p. 135).

The goal of Boucher et al. (2001) was not to challenge the efficacy of MIT, but to gauge that of its individual components based on the assumption of the brain's right hemispheric facilitation of melody (p. 134). The authors argued that "rhythm and intonation involve different aspects of speech that may be subserved by different neurological processes" (p. 132). Furthermore, they contended that rhythm, in regards to both speech-related and non-speech-related impetuses, is governed by the left hemisphere (p. 132).

While they acknowledged the facilitating effect of melody in regards to MIT, Boucher et al. (2001) concluded that "emphasis on the tonal attributes of utterances in protocols exploiting melody did not serve to improve the verbal productions of individuals presenting non-fluent speech as a result of left-hemisphere lesions" (p. 145). However, the authors admitted to the study's inherent limitations based on its "short intervention period", and that it failed to "address the question of the general efficacy of tonal or rhythmic components in melody-based therapies" (p. 145). Although they presented their case for the efficacy of rhythm's effect over that of melody's pertaining to the facilitation of speech in melody-based interventions, their results suggested that the emphasis of prosodic elements aided specifically in the participants' short-term repetition abilities and articulatory precision, but were not generalized to their overall speech functionality (p. 145).

Rhythm in Lyric Memory and Formulaic Expression

Stahl et al. (2011) conducted a study with similar questions surrounding melody and rhythm, but rather than applying them to speech prosody, they aimed to determine melody's and rhythm's importance in the context of "lyric memory and motor automaticity for speech production" (p. 3084). Using 17 right-handed German participants, aged 27-80, with Broca's or global aphasia, the authors sought to assess preserved automatic speech in formulaic phrases with MIT (p. 3085). All participants were assessed using the Aachen Aphasia Test; had sustained left hemispheric lesions; and demonstrated a combination of comorbidities such as AOS, dysarthria and dysphagia. However, 14 of the 17 subjects experienced injuries to the basal ganglia (p. 3086). The authors indicated that the majority of MIT research focuses on the left and right cortical areas of the brain, while ignoring subcortical areas such as the basal ganglia. They suggested that it is this region which controls rhythmic subdivision in the production of speech (p. 3084).

In the experiment, "melodic intoning, rhythmic speech and a spoken arrhythmic control" (Stahl et al., 2011, p. 3086) were assessed using "original, formulaic, and non-formulaic lyrics" (p. 3087). For the melodic intoning and rhythmic speech conditions, the participants sang or spoke to a chosen song from a pre-recorded playback containing a vocal track and a 4/4 percussive beat. For the arrhythmic speech control, the beat was switched to 3/4 time and shifted by an eighth note. “Rhythmic speech served as the control condition for melodic intoning, whereas the arrhythmic condition provided the control for rhythmic speech” (p. 3086).

Pertaining to melody, Stahl et al. (2011) found that “melodic intoning, frequency variation and pitch accuracy did not affect speech production in the current patient sample” and refused to “confirm an effect of singing on speech production in non-fluent aphasic patients” (p. 3089). Nevertheless, they supported prior research suggesting that singing may positively impact speech recovery by engaging the right hemisphere. Yet, they contended that rhythm provided a significant benefit, and “was found to be strongest in patients with lesions including the basal ganglia” (p. 3090). Ultimately, the authors alleged that “benefits typically attributed to melodic intoning in the past may actually have their roots in rhythm” (p. 3092). However, while the authors may have supported part of their hypothesis regarding the basal ganglia’s role in rhythm perception, their results of rhythm’s overall facilitating effect may prove difficult to generalize due to the sample’s highly specific lesion criteria and varying comorbidities.

Rhythm in Non-MIT-Based Interventions

Outside of MIT, the facilitating effect of rhythm has been studied under varying conditions and toward different purposes. Thompson et al. (2016) attempted to uncover rhythm’s significance utilizing Therapeutic Singing, while Beber et al. (2018) and Aichert et al. (2019) focused on its effect pertaining to AOS. In 2013, Hausen et al. argued that musical rhythm may have more influence on speech processing than melody (p. 11). In a series of computerized assessments, the authors assessed 61 individuals based on musical, pitch-related, prosodic, and visuospatial perceptions (p. 3). They hypothesized that rhythm is associated with speech prosody and word stress. Furthermore, while they advocated for the shared neural connection between speech and music, they suggested that the mechanisms of melody and rhythm perception may work more independently (p. 11). However, the generalizability of these findings may be impacted not only by the exclusion of non-musicians in the sample, but to other languages as well as due to the use of the Finnish language in the assessments.

In a study featuring a similar theoretical position, Raglio et al. (2016) compared the effect of free-improvisation music therapy combined with speech-language therapy versus speech-language therapy alone. The music therapy approach utilized melodic intoning with the playing of instruments to enhance non-verbal communication and the matching of rhythmic musical attunement between patient and therapist (p. 236). The authors' findings indicated that music therapy combined with speech-language therapy proved more effective than speech-language therapy on its own with regards to the production of spontaneous language (p. 240), and surmised that the coordination and fluency of expressive speech may be due to rhythm's effect (p. 241).

The Combination of Melody and Rhythm in Melodic Intonation Therapy

As many of the aforementioned articles examining the efficacy of MIT have concentrated on the relative importance of one musical mechanism over another, other studies have addressed the equal contributions of both. Arguing that the majority of existing MIT research considered chronic aphasia, van de Meulen et al. (2014) employed the protocol to determine its effect as an early intervention with nonfluent aphasics in the subacute phase, occurring between two to three months post-stroke (p. 537). A total of 27 Dutch-speaking individuals, aged 18-80, and suffering nonfluent aphasia from left-hemispheric injuries were originally included in the study (p. 538). Sixteen were placed in the experiment group who underwent MIT, four of whom withdrew after two weeks. Eleven were placed in the control group who underwent various linguistic tasks involving "written language production, language comprehension, and nonverbal communication strategies" (p. 537). Both groups received treatment five hours per week for six weeks, and were administered the Aachen Aphasia Test.

Van de Meulen et al. (2014) stipulated that they used the original protocol of MIT, as well as a predetermined set of trained and untrained utterances, beginning with shorter and more common phrases, and gradually increasing to more complex and less commonly used phrases (p. 538). Overall, their findings demonstrated MIT's effectiveness over the control group regarding language repetition and verbal communication. However, several limitations presented themselves including the authors' desired sample size, a lack of consistent information pertaining to the participants' lesion sizes and locations, and a failure to "examine patients' use of the trained utterances in their daily life communication" (p. 542).

Despite these limitations, the authors encouraged the use of MIT. While making mention of the longstanding research involving melody's activation of the right hemisphere's language-capable regions, they also pointed to Stahl et al.'s (2013) assertion of rhythm's role in MIT (p. 536). Most compellingly, they stated that "it was impossible to unravel the impact of the MIT components (melody, rhythm, hand-tapping, or reduction of speed in singing verses speaking), since we used the original MIT technique," ultimately lending support to the efficacy of the entirety of the treatment protocol (p. 542).

Zumbansen et al. (2014b) came to a similar conclusion in their study examining melody and pitch in trained, non-trained and connected speech. Applying conditions that echoed Stahl et al. (2011), the authors used a modified form of MIT containing "various sentences and intensive treatment delivery," and then compared it with a rhythmic speech control as well as a spoken therapy, devoid of pitch or rhythm (p. 2). Three French-speaking, right-handed men with Broca's aphasia acquired from left-hemisphere lesions were included in this study (p. 3) and underwent three one-hour treatment sessions per week for six weeks (p. 4).

Their results showed that the modified MIT had the most substantial effect on language improvement over the rhythmic and spoken controls (p. 7). Additionally, the authors claimed that their findings replicated those of Schlaug et al. (2008) concerning language improvements in MIT versus those in a non-musical control (Zumbansen et al., 2014b, p. 7). More specifically, Zumbasen et al. (2014b) stated that the combination of melody and pitch was most integral to language recovery in MIT. They further asserted that "the addition of musical pitch to the rhythmic element was associated with generalization effect to connected speech, whereas the use of rhythm only did not" (p. 7). Most remarkably, after citing research supporting rhythm's facilitating effect on left-hemispheric activation, the authors proposed that the use of melody may provide an additional cue to rhythm processing, thereby strengthening rhythm's effect in the reactivation of areas required for language production (p. 8). Consequently, this suggestion indicates even stronger connections between melody and rhythm in MIT, as well as its efficacy as a treatment method.

Table 1

Demographic and Assessment Data

Studies	Sample Size	Age	Gender	Language	Assessment
Schlaug et al. (2008)	2	47 and 58	Male	English	BDAE, BNT
Racette et al. (2006)	8	36-67	4 male, 4 female	French	BDAE (French version), MT-86, Token Test
Wilson et al. (2006)	1	57	Male	English	AME, BDAE, MMA, WAIS-III
Slavin & Fabus (2018)	1	63	Male	English	ABA, BDAE
Boucher et al. (2001)	2	39 and 66	Female	English	WAB
Stahl et al. (2011)	17	27-80	9 female, 8 male	German	AAT, Token Test

Hausen et al. (2013)	61	19-60	40 female, 21 male	58 = Finnish, 3 = Swedish	MBEA, WAIS-III
Raglio et al. (2016)	20	42-89	14 male, 6 female	Italian	AAT (Italian version), BNT, Milan Protocol, Token Test
Van de Meulen et al. (2014)	27	18-80	-	Dutch	AAT, ANELT, Sabadel, SAT
Zumbansen et al. (2014b)	3	48, 50, and 57	Male	French	MT-86, MBEMA, PEGV, WAIS-III, WMS

Note. - = data was not obtainable from, or not observed within, the study; AAT = Aachen Aphasia Test; ABA = Apraxia Battery for Adults; AME = Australian Music Examinations; ANELT = Amsterdam Nijmegen Everyday Language Test; BDAE = Boston Diagnostic Aphasia Examination; BNT = Boston Naming Test; MBEA = Montreal Battery of Evaluation of Amusia; MBEMA = Montreal Battery of Evaluation of Musical Abilities; MMA = Measures of Musical Abilities; MT-86 = Montreal-Toulouse Aphasia Battery; PEGV = Protocole D'évaluation des Gnosis Visuelles (Visual Agnosia Diagnostic Battery); SAT = Semantic Association Task; WAB = Western Aphasia Battery; WAIS-III = Wechsler Adult Intelligence Scale; WMS = Wechsler Memory Scale.

Table 2

Stroke and Aphasia Data

Studies	CVA Type	Lesion Location	Aphasia Type	Comorbidity
Schlaug et al. (2008)	Left ischemic	Superior division of MCA	Broca's	-
Racette et al. (2006)	6 = left sylvian, 1 = FP aneurysm, 1 = anterior and mid-left cerebral artery aneurysm	Varying LH locations	4 = Broca's, 3 = mixed, 1 = anomic	6 = dysarthria and AOS
Wilson et al. (2006)	Left MCA tertiary	Left FP	Global	AOS
Slavin & Fabus (2018)	LH	-	Nonfluent	AOS
Boucher et al. (2001)	LH	1 = left parietal, 1 = left MCA	Nonfluent	1 = AOS
Stahl et al. (2011)	15 = left ischemic MCA; 1 = left basal ganglia; 1 left basal ganglia, pons and medulla	14 = left basal ganglia, 1 = right cerebellum, 1 = right parietal, 1 = right basal ganglia and pons	10 = Broca's, 7 = global	15 = AOS, 3 = dysarthria, 2 = dysphagia
Hausen et al. (2013)	-	-	-	-
Raglio et al. (2016)	-	6 = left TP, 5 = left FT, 4 = left FP, 4 = left FTP,	13 = nonfluent, 4 = fluent, 3 = global	11 = AOS, 5 = dysphagia

		1 = left TPO		
Van de Meulen et al. (2014)	LH	-	Nonfluent	-
Zumbansen et al. (2014b)	Left ischemic	-	Broca's	AOS

Note. - = data was not obtainable from, or not observed within, the study; AOS = apraxia of speech; CVA = cerebral vascular accident; FP = frontal-parietal; FT = frontal-temporal; FTP = frontal-temporo-parietal; LH = left hemisphere; MCA = middle cerebral artery; TP = temporal-parietal; TPO = frontal-parietal-occipital.

Table 3

Musical Protocol, Evaluation of MIT Efficacy, and Research Limitations

Studies	Protocol	MIT Efficacy	Limitations
Schlaug et al. (2008)	MIT	Evaluated, found to be efficacious.	Small sample, controlled for singing but not left-hand tapping.
Racette et al. (2006)	Not MIT	Not evaluated, yet suggested that choral singing may account for efficacy of MIT.	Syllable duration not controlled, no rhythmic tapping.
Wilson et al. (2006)	MIT	Evaluated, found to be efficacious.	Small sample, sole participant was trained musician, based results on rehearsed content rather than transfer to unrehearsed language skills.
Slavin & Fabus (2018)	MMIT	Evaluated, found to be efficacious.	Small sample, impact of AOS and long duration of prior speech therapy unclear.
Boucher et al. (2001)	MMIT	Not evaluated	Short intervention period, failure to address general efficacy of tonal or rhythmic attributes in melody-based treatment.
Stahl et al. (2011)	Not MIT	Not evaluated	Sample's highly specific lesion criteria and varying comorbidities may not generalize results.
Hausen et al. (2013)	Not MIT	Not evaluated	MIT was not utilized, use of Finnish and Swedish languages may not generalize results, excluded non-musicians from study.
Raglio et al. (2016)	Improvisational MT	Not evaluated	Small sample, type of aphasia not analyzed, no MT control group.
Van de Meulen et al. (2014)	MIT	Evaluated, found to be efficacious.	Failure to reach desired sample size, lack of info regarding lesion size and location, no examination of carryover

			of controlled results to everyday speech.
Zumbansen et al. (2014b)	MMIT	Not evaluated, but mentioned MIT to be efficacious.	Sample size, impact of AOS unclear, use of French language may not generalize results.

Note. AOS = apraxia of speech; MIT = melodic intonation therapy; MMIT = modified melodic intonation therapy; MT = music therapy.

Table 4

Focus of, and Connections Between, Music and Speech-Language Mechanisms

Studies	Focus of Melodic/Rhythmic Mechanisms	Focus of Speech-Language Mechanisms	Connections Between Music and Speech-Language
Schlaug et al. (2008)	Equal emphasis on melody and rhythm	Spontaneous speech and naming	Left-hand tapping may facilitate speech production through rhythmic priming and entrainment.
Racette et al. (2006)	Singing/melody	Articulation, word recall and repetition	Suggest that sung and spoken speech both controlled by same neural mechanisms.
Wilson et al. (2006)	Melody	Articulation and phrase production	Melodic rehearsal may benefit long-term speech production.
Slavin & Fabus (2018)	Equal emphasis on melody and rhythm	Expressive language and articulatory precision	Singing and rhythm both utilize entrainment and priming, facilitate functions that underlie speech mechanisms.
Boucher et al. (2001)	Rhythm	Speech prosody	Melody and rhythm involve different aspects of speech and are utilized by different neurological processes.
Stahl et al. (2011)	Rhythm	Preserved automatic speech and prosody	Rhythm is integral to speech production.
Hausen et al. (2013)	Rhythm	Speech prosody and word stress	Advocate shared neural connection between speech and musical rhythm, suggest areas processing melody and rhythm work independently.
Raglio et al. (2016)	Utilized both, but emphasized rhythm	Expressive speech regularity and fluency	Musical rhythm may coordinate prosody and improve expressive speech.
Van de Meulen et al. (2014)	Equal emphasis on melody and rhythm	General language production and repetition	Suggest melody, rhythm, hand-tapping, and speed reduction may all impact language production.

Zumbansen et al. (2014b)	Equal emphasis on melody and rhythm	Connected speech	Addition of musical pitch to rhythmic element assisted in improvement to connected speech.

Note. MIT = melodic intonation therapy; MMIT = modified melodic intonation therapy; MT = music therapy; SLT = speech-language therapy.

Discussion

The aim of this literature review was to discuss the functions of melody and rhythm in MIT and other music-based aphasia treatments, and to determine if one musical mechanism provided more of a facilitating effect than the other in regards to the recovery of speech and language. The initial goal of this thesis was not to determine the efficacy of MIT as a treatment method. Nevertheless, the efficacy of MIT was examined for the purpose of gaining a more comprehensive understanding of the protocol's underlying musical components.

The Connection Between Music and Speech and Language

The vast majority of research indicates a correlation between music and speech and language processing centers. Tomaino (2012) suggested there exists a neural network with shared musical and language-oriented pathways. Similarly, Slavin and Fabus (2018) contended that melody and rhythm both facilitate functions that underlie speech mechanisms. More specifically, van de Meulen et al. (2014) claimed that melody, rhythm, hand-tapping and speed reduction all may impact language production.

Pertaining to melody, Racette et al. (2006) offered that sung and spoken speech are both controlled by the same neural mechanisms. Likewise, Wilson et al. (2006) suggested that melodic rehearsal may benefit long term speech production. Moreover, Zumbansen et al. (2014b) submitted that the addition of musical pitch to a rhythmic element could assist in the improvement of connected speech.

Pertaining to rhythm, Stahl et al. (2011) and Raglio et al. (2016) both maintained its importance to speech production. Furthermore, Schlaug et al. (2008) proposed that left-hand tapping facilitated speech production through rhythmic priming and entrainment. Finally, Hausen et al. (2013) echoed Tomaino (2012) by hypothesizing that music and speech perception are linked, yet agreed with Boucher et al. (2001) that melody and rhythm are not connected and may utilize separate neurological processes.

The Mechanisms of Melody and Rhythm in MIT

Of the ten articles that were analyzed, eight focused on a specific musical mechanism, while van de Meulen et al. (2014) and Zumbansen et al. (2014b) championed both rhythm and melody. Of the four that focused on melody, only two (Racette et al., 2006; Wilson et al., 2006) maintained that melody played a more important role over rhythm, while the remaining two (Schlaug et al., 2008; Slavin & Fabus, 2018) emphasized the equal contributions of melody and rhythm. Regarding the articles dedicated to examining rhythm, Boucher et al. (2001) openly acknowledged the facilitating effect of melody in MIT, and Stahl et al. (2011) recognized melody's role in speech recovery. Hausen et al. (2013) did not employ MIT, and their determination of rhythm's significance pertained specifically to word stress perception and not a general speech facilitation. Raglio et al. (2016) used an improvisational music therapy approach, and was the only rhythm-centric study to ignore melody in their conclusion.

The idea of separating and comparing the musical components of melody and rhythm in MIT and other music-based aphasia therapies may be a more complex question than this limited review is capable of fully answering, especially as there is disagreement among its researchers for the importance of the various components of MIT in improving aphasia. Stahl & Kotz (2014) offered that attempting to do so is an oversimplified way of considering the efficacy of singing-based aphasia therapy. Both Merrett et al. (2014) and Thompson et al. (2016) went further to suggest that melody and rhythm may be impossible to distinguish in regards to this form of treatment. Echoing their sentiments, van de Meulen et al. (2014) specifically stated that "it was impossible to unravel the impact of the MIT components (melody, rhythm, hand-tapping, or reduction of speed in singing verses singing)" (p. 542). Finally, Merrett et al. (2014) appeared to warn future researchers that they should avoid reductionist examinations of this type of research (p. 2).

MIT Efficacy

Six of the ten articles discussed in this thesis, not including Albert et al. (1973) or Belin et al. (1996), utilized a MIT or MMIT protocol. Four evaluated MIT's efficacy and found it to be efficacious (Wilson et al., 2006; Schlaug et al., 2008; van de Meulen et al., 2014; Slavin & Fabus, 2018). One article (Zumbansen et al., 2014b) that utilized a MMIT approach did not evaluate its efficacy, yet still determined the treatment to be effective. Additionally, one article that did not use a MIT or MMIT protocol (Racette et al., 2006) also championed its efficacy. With regards to the analysis of MIT efficacy, the relative severity of participants' aphasia type and their comorbidities were not examined in this literature review due to lack of space, as well as to maintain the focus of the review. Furthermore, some studies included hypothetical psychological (Ragio et al., 2016), emotional (Hausen et al. 2013), or mood-related (Zumbansen et al., 2014b) outcomes which were not evaluated.

Limitations to MIT Studies

There are many limitations in the MIT studies that impact their outcomes. For instance, it is difficult to replicate exact lesion size and location in samples, influencing the generalizability of certain results. Moreover, not all participants in different studies followed the same therapeutic regimen. Some studies failed to control for certain aspects of MIT, while other studies either did not include a control at all. Additionally, most of these studies featured small sample sizes. All of these issues affected the collective validity of the results. Moreover, despite MIT's specified order of operations, there appear to be assorted interpretations of the intervention throughout different studies based on modifications to the original protocol. Other criteria that varied among samples included the amount of time that had passed between study participants' stroke events and their participation in their corresponding studies, the various forms of assessments that were utilized, the comorbidities with which participants were diagnosed and their relative impact on their speech and language capabilities, and the amount of speech therapy they received prior to participation.

In terms of participant data, not all studies recorded the same demographic information. While most studies documented participants' levels of education, Boucher et al. (2001) and Stahl et al. (2011) did not. In addition, only Racette et al. (2006), Stahl et al. (2011) and Zumbansen et al. (2014b) reported the number of stroke events incurred by each individual prior to participation in the study. Many studies that mentioned participants' level of musical training or experience did not expound on what that training was or how much training had occurred, while van de Meulen et al. (2014) did not report that data at all.

Lastly, there are major differences among the languages used in certain studies, and their subsequent assessments' clinical procedures. Specific linguistic dissimilarities regarding articulation, syllabification, cadence, and grammatical structure were not explored within these studies, impacting the generalizability of their specific outcomes. Three studies did not report the language used, while Boucher et al. (2001) and Schlaug et al. (2008) stipulated that English was utilized. The remaining studies employed French (Racette et al., 2006; Zumbansen et al., 2014b), German (Stahl et al., 2011), Dutch (van de Meulen et al., 2014), and Italian (Raglio et al., 2016).

Gaps in the Literature

Two prominent gaps presented themselves throughout the course of this literature review. First, many of these studies made a clear distinction regarding their usage of musicians or non-musicians in their samples; either all the participants had some kind of prior singing or musical training, or the authors specifically excluded musicians from participating. Providing non-musical controls to musically-inclined samples, or vice versa, may assist with increasing the external validity of MIT research. Additionally, it may help to further examine whether or not musically-trained brains can recover speech and language following a stroke more effectively than non-musically trained brains while undergoing music-based aphasia therapy.

Secondly, some of the studies that focus on a single musical component's ability to provide the central facilitating effect for speech and language production actually concentrate on only one or two mechanisms of speech and language production, and cannot account for that particular musical component's generalizing effect on improved speech and language production as a whole. For instance, several of the studies that champion melody in MIT's speech and language facilitation target word articulation and repetition. Likewise, the studies that support rhythm's facilitating effect on speech and language focus predominantly on prosody.

Conclusion

While there remains debate in current research surrounding how melody and rhythm influence specific regions of the brain in relation to speech and language function and neuroplastic recovery, the evidence for the efficacy of MIT as a therapeutic intervention for nonfluent aphasics is wide-ranging. As previously suggested, it may be impossible to dissect the impact of melody and rhythm on speech and language production. Accordingly, it may also be impossible to assert that melody or rhythm alone can better facilitate a comprehensive recovery of speech and language mechanisms in music-based aphasia therapy. Future research into the effect of melody and rhythm on speech and language should attempt to address the individual musical components' impacts on a wide array of speech and language mechanisms, rather than focusing on a select mechanism, in order to form a more comprehensive assessment of their influence. Additionally, future research into music-based therapy for speech and language recovery in nonfluent aphasics should include larger sample sizes; musically-trained versus non-musically-trained controls; more examination of certain types of lesions, as well as their relative sizes and locations; further investigation on the impact of aphasia comorbidities; and the influence of different languages' phonetic and prosodic characteristics.

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In the judgment of the following signatory this thesis meets the academic standards that have been established for the above degree.

Thesis Advisor: Michelle Napoli