

2018

Neuroanatomical Correlates Of Speech And Melody Repetition In Chronic Stroke

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NEUROANATOMICAL CORRELATES OF SPEECH AND MELODY REPETITION IN
CHRONIC STROKE

by

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Bachelor of Science
University of South Carolina, 2016

Submitted in Partial Fulfillment of the Requirements

For the Degree of Master of Speech Pathology in

Speech Pathology

The Norman J. Arnold School of Public Health

University of South Carolina

2018

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DEDICATION

This document is dedicated to the speech-language pathologists and early interventionists who gave me the chance to succeed in this life. Your kindness and dedication to my family and myself has inspired a career of giving others the chance to communicate again. Thank you for giving me the skills I needed to write this document and making all of what I love about this life possible.

ABSTRACT

The ability to repeat speech is impaired in most individuals with aphasia. Recent evidence suggests damage to area Spt (boundary of the parietal and temporal lobes at the Sylvian fissure) may cause the repetition difficulties commonly seen in aphasia. This study examined if such repetition impairments are specific to speech or reflect a more general repetition deficit, and determined how regional and network brain damage predict repetition impairments. Participants in the chronic phase of stroke (N=47) listened to a series of ten five-second melodies that consisted of six tones and repeated the melody (by humming) following its presentation. The participants' audio samples were rated based on their similarity to the target melody, using a sentiment scale. The sentiment scale included the following ratings: strongly negative, negative, neutral, positive, and strongly positive. The audio samples were given one of these ratings based on their accuracy compared to the target melody. These scores were compared with the Western Aphasia Battery (WAB) repetition subscores to relate real word repetition to melody repetition. Melody repetition scores were also compared to nonword repetition by using a nonword word repetition task. A moderate association between melodic repetition and speech (real word and nonword) repetition was observed. Several connections were implicated as predicting poorer performance on the three behavioral tasks. A common shared connection between melodic repetition and word repetition was between the left inferior frontal gyrus pars opercularis and the left precentral gyrus. Damage to the left supramarginal gyrus, an area commonly damaged in conduction aphasia, predicted poor

performance on melodic, real word, and nonword repetition. Melodic repetition was also predicted by damage to the precentral gyrus. These results suggest that performance on melodic repetition and speech repetition are predicted by mostly distinct areas of damage with some overlap in dorsal stream areas.

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CHAPTER 1

INTRODUCTION

Aphasia is an acquired language disorder that results from brain injury, most commonly stroke. Individuals with aphasia have difficulty with spoken language, reading, and/or writing (Helm-Estabrooks & Albert, 2004). Individuals with aphasia often have relatively intact nonlinguistic cognitive skills, such as memory and executive functioning, but due to the communication deficits that are associated with aphasia, many of these individuals' quality of life, ability to work, and participation in daily activities is impacted. Difficulty with repetition of words and phrases is a characteristic of most aphasia types (Davis, 2000). However, some types of aphasia are more frequently discussed in relation to speech repetition difficulties than other types. These classifications include Broca's aphasia, conduction aphasia, and Wernicke's aphasia (Dronkers & Baldo, 2010). Conduction aphasia is most commonly described as a disconnection between structurally intact cortical centers – Broca's and Wernicke's areas (Geschwind, 1965). In the case of conduction aphasia, the disruption in repetition is disproportionately more severe when compared to comprehension ability and spontaneous speech (Davis, 2007).

It has traditionally been thought that impaired repetition in aphasia was the result of damage to a white matter pathway known as the arcuate fasciculus. The arcuate fasciculus connects auditory areas (Wernicke's area) and motor speech areas (Broca's

area) (Catani et al., 2005). More recent evidence suggests that some cortical regions may also be implicated in the ability to repeat speech by individuals with conduction aphasia. A review of the evidence related to the relationship between the arcuate fasciculus and conduction aphasia indicates auditory presentation of speech plays a direct role in verbal motor planning (Bernal et al., 2009). This emphasizes that the arcuate fasciculus connects posterior brain areas with Broca's area by a relay station located in the precentral gyrus, which would involve the motor planning areas in the ability to repeat speech (Bernal et al., 2009). This supports the idea that cortical structures, in addition to the arcuate fasciculus, are necessary for repeating speech. However, other evidence suggests that there is little or no involvement of the arcuate fasciculus in repetition. Baldo and colleagues investigated the neuroanatomical correlates of repetition and auditory-verbal short-term memory (AVSTM) (2012). It was revealed that the left posterior temporo-parietal cortex, not the arcuate fasciculus, was implicated in both repetition and AVSTM (Baldo et al., 2012). Areas involved in repetition and AVSTM were part of partially overlapping networks (Baldo et al., 2012).

Involvement of posterior brain regions in repetition supports aspects of the Hierarchical State Feedback Control (HSFC; Hickok, 2012 & 2014) model, a contemporary model of speech production. The HSFC describes a hierarchical production model with two levels; a lower level (dorsal stream) that programs articulatory motor movements, and a higher level (ventral stream) responsible for identifying the sensory targets of stored auditory representations (Hickok, 2012 & 2014). Consistent with the dual stream model (Hickock & Poeppel, 2000, 2004, 2007), the ventral stream interfaces sensory/phonological networks with conceptual-semantic systems, and the dorsal stream

interfaces sensory/phonological networks with motor-articulatory systems (Hickok & Poeppel, 2000, 2004, 2007). These two levels are mediated by different neuroanatomical regions. The lower level dorsal stream is comprised of the primary motor cortex, premotor cortex, medially the supplementary motor area, and the supramarginal gyrus, while the higher level ventral stream is mediated by areas in the superior temporal gyrus and superior temporal sulcus (Hickok, 2012 & 2014). Spt (the boundary of the parietal and temporal lobes at the Sylvian fissure) is thought to coordinate the two processing streams. In this way area Spt functions as an auditory-motor transformation area that translates an auditory representation of a word or phrase into a motor output.

This model helps to explain some of the deficits found in aphasia, as neuroimaging studies are beginning to reveal patterns of damage to the dorsal and ventral streams that correspond to different aphasia types (Fridriksson, 2016 & Kümmerer, 2013). Area Spt has been found to serve as an auditory-motor transformation area for melodies (Hickok, 2003), as it also responds during tonal melodic perception and production (humming) (Pa & Hickock, 2008). Interestingly, some studies have found that area Spt responds differently to speech than it does to music (Hickok, 2003). Relying on pattern classification methods, which involve using fMRI data to observe activity patterns in the brain, researchers found that the response in Spt was different during sensory stimulation than motor activation. Based thereon, it seems that Spt activity is not all sensory or all motor; rather that it is indeed a sensory-motor area (Pa & Hickock, 2008). This would confirm other findings suggesting that area Spt is commonly damaged in conduction aphasia, and that this cortical damage may be the cause of speech repetition impairments (Buschsbaum, 2011). When using voxel-lesion symptom mapping (VLSM)

to determine areas significant to non-word and real word repetition, damage to area Spt was significantly correlated with both poor real word and non-word repetition (Rogalsky et al., 2015). Repetition of melodies is a sensory-motor task, requiring an interface between the perception of auditory stimuli and the motor production of the same stimuli for repetition. Therefore, it is plausible that poor melodic repetition is also related to Spt damage.

Studies have found some association between the neural correlates of singing and speaking. A common area implicated in these studies is the superior temporal gyrus (STG), which has been found to have a role in both singing and speaking (Koelsch et al., 2005; Özdemir et al., 2006). fMRI studies also suggest music and language syntax processing interact in Broca's area (Kunert et al., 2015). Persons with aphasia have shown impaired processing of musical syntactic relations (Patel et al., 2008). Studies of healthy individuals also support the presence of temporal activation in melodic perception with bilateral activation of superior temporal areas extending from the primary auditory cortex (Griffiths et al., 1998). Callan et al. (2008) found that areas activated in both perception and production of singing as well as speech included the left planum temporale/superior temporal parietal regions and anterior superior temporal gyrus, with greater activation for singing in the right planum temporale. These findings suggest greater involvement of the right hemisphere in singing perception and production (Callan et al., 2008).

These studies attempt to address the underlying question of whether language and melody processing can be supported by separate or distinguishable neuroanatomical areas or if these processes share a neural substrate. This is of particular interest to this study

when comparing processing areas that support the processing of speech and melody repetition. Is speech unique in where it is processed or does it share processing areas with other auditory-motor tasks, specifically repetition of melodies? Price et al. (2005) addressed these questions when they proposed that there are no macroanatomical structures devoted solely to speech in the human brain. Rather, speech processing emerges from differential demands placed on areas implicated in both verbal and non-verbal stimuli (Price et al., 2005).

By assessing both word and melodic repetition in post-stroke individuals, we will obtain a greater understanding of the neuroanatomical correlates of general repetition deficits. Accordingly, the purpose of the current study is to answer the following questions: What cortical regions are necessary for melodic repetition, and are there regions of overlap for speech and melodic repetition? In light of the evidence that supports that language and speech processing are not localized to a specific region (Price et al. 2005), we hypothesize that the cortical areas involved in speech and melodic repetition will have some, but not complete, overlap.

CHAPTER 2

MATERIALS AND METHODS

2.1 SUBJECTS

This study included individuals in the chronic phase after a left hemisphere stroke (6 months or more post stroke). Participants are included regardless of aphasia diagnosis or type. 47 participants (12 females, mean age of evaluation= 57.3 ± 8.5 , mean months post stroke= 47.9 ± 50.9) with the following distribution of aphasia types: anomic $n=10$; Broca's $n=11$; conduction $n=6$; global $n=3$; transcortical sensory $n=1$; no aphasia $n=16$. Aphasia severity for all participants is indicated by the Western Aphasia Battery Aphasia Quotient (WAB AQ, group mean= 72.7 ± 29.1). The mean aphasia severity for the participants with aphasia was 59.1 ± 27.8 .

2.2 EXPERIMENTAL DESIGN

2.2.1. Behavioral Measures. To assess the repetition of melodic stimuli, participants listened to a series of ten melodies consisting of six tones (Pa & Hickok, 2007) and hummed each melody immediately following presentation of the tune. Participants were given three trials per melody. The melody was presented on a Dell laptop computer at a comfortable hearing level. Task completion was video recorded for offline scoring of melodic repetition. Responses were rated based on similarity to the target melody, using a 1-5 rating scale (5 being the best). See Table 2.1 for details of each sentiment rating. Inter-rater reliability was established using a two-way random, absolute

agreement single-measures intraclass correlation coefficient with the primary rater (the author) and an ASHA-certified speech-language pathologist. 20% of the sample was scored for reliability measures. The intraclass correlation coefficient was .95, indicating "excellent" rater agreement (Cicchetti, 1994).

2.2.2. Real Word and Nonword Assessment To assess real word repetition, participants' repetition subscore were taken from the WAB. To assess non-word repetition, a subgroup of 33 participants completed a non-word repetition task. Nonwords were presented auditorily and participants repeated the nonword word aloud. Responses were video recorded and later transcribed using standard IPA (international phonetic alphabet) transcription. Each nonword was scored for number of syllables correct, where a score of 30 corresponded to 100% accuracy.

Table 2.1

Descriptors associated with each sentiment for the purpose of scoring hummed melodies.

Sentiment Ratings for Melody Scoring				
1	2	3	4	5
Select this if the hummed melody does not represent the played piano melody at all. If none of the notes of the hummed melody are	Select this if the hummed melody does not sound like the played piano melody. If the hummed melody has one or two notes that are	Select this if the hummed melody is somewhat like the played piano melody. If half of the notes of the hummed melody are	Select this if the hummed melody is almost identical to the played piano melody. If only two to three notes of the hummed melody deviate	Select this if the hummed melody is identical to the played piano melody. If all of the notes of the hummed melody are identical to that

identical to that	identical to that	identical to	from that of the	of the played
of the piano	of the played	those of the	played piano	piano melody
melody select	piano melody	played piano	melody select	select this
this sentiment.	select this	melody select	this sentiment.	sentiment.
	sentiment.	this sentiment.		

2.2.3. Neuroimaging Data Acquisition. All participants underwent high-resolution neuroimaging T1 and T2 weighted MRI scans for the purpose of lesion-symptom mapping, as well as diffusion tensor imaging (DTI) scans to construct the white matter structural connectome. A lesion overlay map for all participants is found in Figure 2.1. At the time of analysis, four participants did not have MRI data.

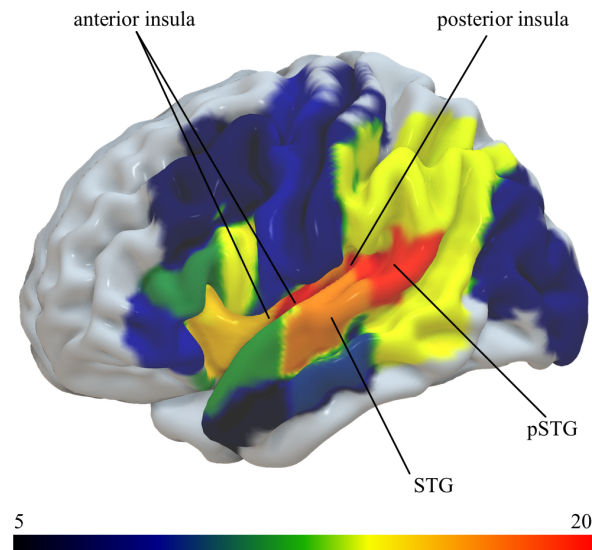


Figure 2.1. Lesion overlay map for all participants. Areas in red indicate more overlap in damage and areas in blue indicate less overlap in damage. The anterior insula, posterior insula, STG, and pSTG are regions in red that indicate the most overlap.

2.2.4. Neuroimaging Analysis. A region of interest analysis for each behavior was completed. Real word repetition, non-word repetition, and melody repetition were entered as independent variables in each analysis. All analyses were completed with 4000 permutations to avoid type 1 error due to multiple comparisons, with p -values set to 0.05. DTI analyses included both right and left hemisphere areas.

The regions of interest are shown in Table 2.2 and are areas implicated in linguistic processing related to the dual stream model of speech production (Fridriksson et al., 2016). Right hemisphere homologues were included in the DTI analysis.

Table 2.2

Regions implicated in the dual stream model of speech production used for the region of interest analyses. Note that the right hemisphere homologues of each of these regions were included for the DTI analyses.

Regions implicated in the dual stream model of speech production	
MFG_L	middle frontal gyrus (posterior segment) left
IFG_opercularis_L	inferior frontal gyrus pars opercularis left
IFG_orbitalis_L	inferior frontal gyrus pars orbitalis
IFG_triangularis_L	gyrus pars triangularis
PoCG_L	postcentral gyrus left
PrCG_L	precentral gyrus left
SMG_L	supramarginal gyrus left
AG_L	angular gyrus left
STG_L	superior temporal gyrus left
STG_L_pole	pole of superior temporal gyrus
MTG_L	middle temporal gyrus left
MTG_L_pole	pole of middle temporal gyrus
ITG_L	inferior temporal gyrus left
MOG_L	middle occipital gyrus left

Ins_L	insular left
Put_L	putamen left
GP_L	globus pallidus left
Plns_L	posterior insula left
PTSG_L	posterior superior temporal gyrus
PMTG_L	posterior middle temporal gyrus left

CHAPTER 3

RESULTS

3.1 BEHAVIORAL DATA RESULTS

3.1.1. Average Behavioral Task Scores. Behavioral data were summarized based on the average melodic repetition scores, average WAB repetition score, and average nonword repetition scores. Each trial of each melody is scored with ratings averaged across all ten melodies (mean = 2.9 ± 1.03)/max=5. The WAB repetition subtest was used to assess real word repetition (mean = 6.75 ± 3.5 /max=10). The nonword repetition test was used to assess nonword repetition (mean = 17.2 ± 9.5 /max=30).

3.1.2. Correlation Coefficients. The correlation coefficient calculated between the average of the highest of all ten melodies and the WAB repetition subtest was $r=0.52$ ($p<0.001$), reflecting a moderately strong relationship between melodic repetition and real word repetition. The correlation coefficient calculated between the average of the highest of all ten melodies and non-word repetition was $r=0.53$ ($p<0.002$) also reflecting a moderately strong relationship between melodic repetition and nonword repetition with a stronger relationship between real word and nonword repetition. Finally, the correlation coefficient calculated between real word and nonword repetition was $r=0.85$ ($p<.001$), reflecting the strongest relationship amongst behavioral variables.

3.2 NEUROIMAGING DATA RESULTS

3.2.1. Region of Interest Analysis Results. A region of interest analysis was completed and restricted to the areas in the left hemisphere listed in Table 2.2. When controlling for lesion volume, no regions survived thresholding. For the univariate analysis of real word and non-word repetition, fifteen regions survived thresholding for both real word and non-word repetition. All regions implicated in the univariate ROI analysis for melodic repetition, real word repetition, and nonword repetition and their respective z-scores are listed in Table 3.1. Lesion maps for the regions implicated for each behavioral variable can be seen in Figure 3.1.

Table 3.1

Significant regions and z-scores for each behavioral variable.

Regions implicated in the analysis for each behavioral variable	
Regions implicated in the univariate ROI analysis for non-word repetition	
posterior superior temporal gyrus left (pSTG_L)	-5.16
supramarginal gyrus left (SMG_L)	-4.74
superior temporal gyrus left (STG_L)	-4.49
posterior insula left (pIns_L)	-4.25
pole of superior temporal gyrus left (STG_pole_L)	-4.11
inferior frontal gyrus pars opercularis (IFG_opercularis_L)	-3.83
precentral gyrus (PrCG_L)	-3.50
posterior middle temporal gyrus left (PSMG_L)	-3.43
insular (Ins_L)	-3.34
postcentral gyrus left (PoCG_L)	-3.10
pole of middle temporal gyrus (MTG_L_pole)	-3.04
middle frontal gyrus (posterior segment) (MFG_L)	-2.94

inferior temporal gyrus left (ITG_L)	-2.87
middle temporal gyrus left (MTG_L)	-2.82
Regions implicated in the univariate ROI analysis for real word repetition	
posterior superior temporal gyrus left (pSTG_L)	-6.23
supramarginal gyrus left (SMG_L)	-5.87
inferior frontal gyrus pars opercularis (IFG_opercularis_L)	-5.25
angular gyrus left (AG_L)	-5.22
superior temporal gyrus (STG_L)	-4.95
posterior insula left (pIns_L)	-4.66
insular (Ins_L)	-4.20
gyrus pars triangularis (IFG_triangularis_L)	-4.09
posterior middle temporal gyrus left (PSMG_L)	-3.87
precentral gyrus (PrCG_L)	-3.84
middle frontal gyrus (posterior segment) (MFG_L)	-3.67
pole of superior temporal gyrus left (STG_pole_L)	-3.61
postcentral gyrus left (PoCG_L)	-3.26
middle occipital gyrus left (MOG_L)	-2.92
putamen left (Put_L)	-2.76
Regions implicated in the univariate ROI analysis for Melodic Repetition	
inferior frontal gyrus pars opercularis (IFG_opercularis_L)	-2.91
middle frontal gyrus (posterior segment) (MFG_L)	-2.817
inferior frontal gyrus pars triangularis (IFG_triangularis_L)	-2.815
supramarginal gyrus (SMG_L)	-2.70
insular (Ins_L)	-2.67
precentral gyrus (PrCG_L)	-2.58

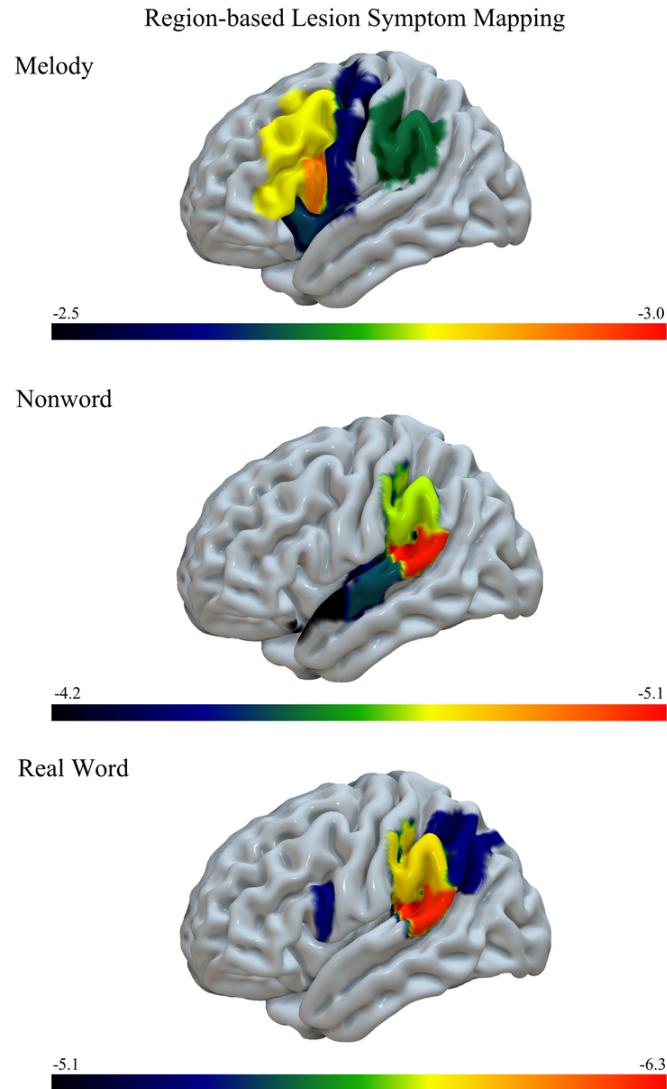


Figure 3.1. Lesion Overlay Maps for Behavioral Tasks. Lesion maps showing lesions predictive of impairment for each behavioral variable. Red indicates more overlap in that region while blue indicates less overlap in that region for the behavior.

Results indicate some, but not complete overlap of regions involved in word, nonword, and melody repetition. Of the regions listed for each task, the left middle frontal gyrus (MFG_L), inferior frontal gyrus pars opercularis (IFG_opercularis_L), left precentral gyrus (PrCG_L), left insula (Ins_L), and supramarginal gyrus (SMG_L)

survived thresholding for all three behavioral tasks. Word and nonword repetition had more regions in common; for example, the left postcentral gyrus (PoCG_L), left angular gyrus (AG_L), left superior temporal gyrus (STG_L), left posterior insula (PIns_L), left posterior superior temporal gyrus (PSTG_L), left posterior middle temporal gyrus left (PSMG_L), and the left pole of superior temporal gyrus (STG_L_pole). Overlap was present at the left inferior frontal gyrus pars triangularis (IFG_triangularis_L) for both the real word repetition and melodic repetition tasks. See Figure 3.2 for maps of overlapping areas for each word repetition task with melodic repetition.

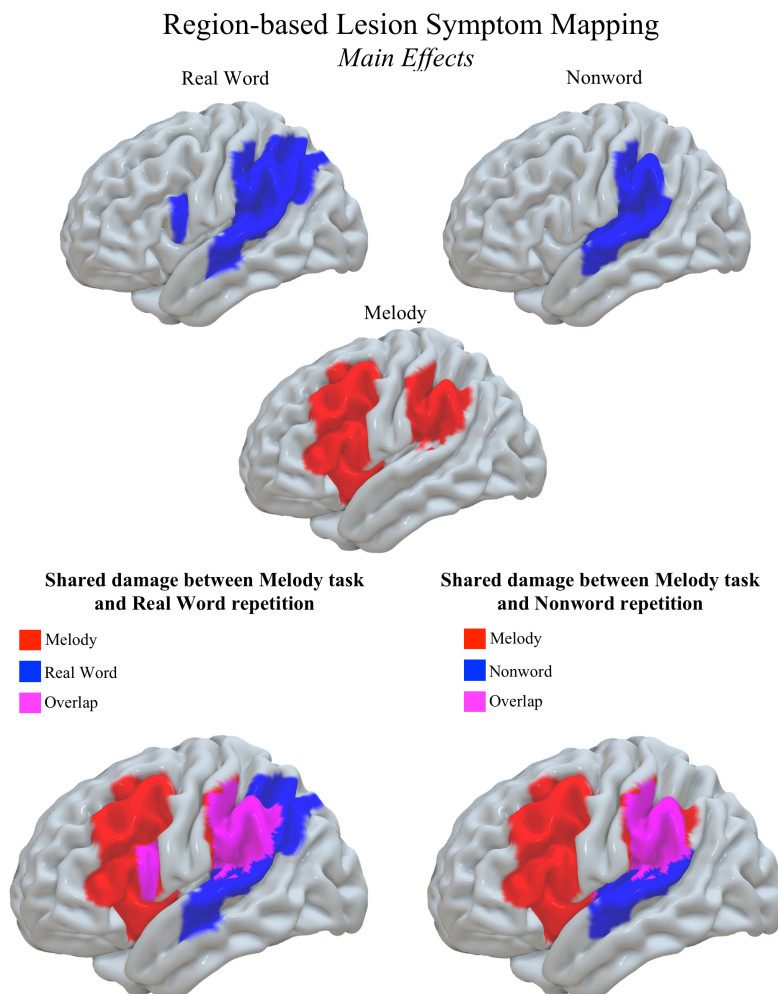


Figure 3.2. Lesion Overlap Maps for Behavioral Tasks. Regions indicated in main effects for each behavioral variable and lesion overlap map indicating areas predictive of poor performance on repetition tasks.

3.2.2. Connectome Analysis Results. For the whole brain connectome analysis, multiple interregional connections survived thresholding. When controlling for lesion volume, no regions survived thresholding and no right hemisphere connections survived thresholding for melodic repetition. Only three connections survived thresholding for melodic repetition when not controlling for lesion volume. The top connections for each behavior can be seen in Table 3.2.

Table 3.2

Connections implicated in the connectome analysis and their respective z-scores for each behavioral variable.

Connections implicated for each behavioral variable	
Connections implicated in the connectome analysis for nonword repetition	
PoCG_R↔MTG_L	4.14
IFG_opercularis_L↔PrCG_L	4.06
IFG_opercularis_L↔AG_L	3.76
PoCG_L↔MTG_L	3.72
STG_L_pole↔Ins_R (insular right)	3.62
Connections implicated in the connectome analysis for real repetition	
IFG_opercularis_L↔PrCG_L	4.06
IFG_opercularis_L↔IFG_triangularis_L	3.81
SMG_L↔AG_L	3.80
PoCG_L↔STG_L	3.76
IFG_opercularis_L↔STG_R	3.62
Connections implicated in the connectome analysis for melodic repetition	
PrCG_L↔pSTG_L	3.99
MFG_L↔pSTG_L	3.67

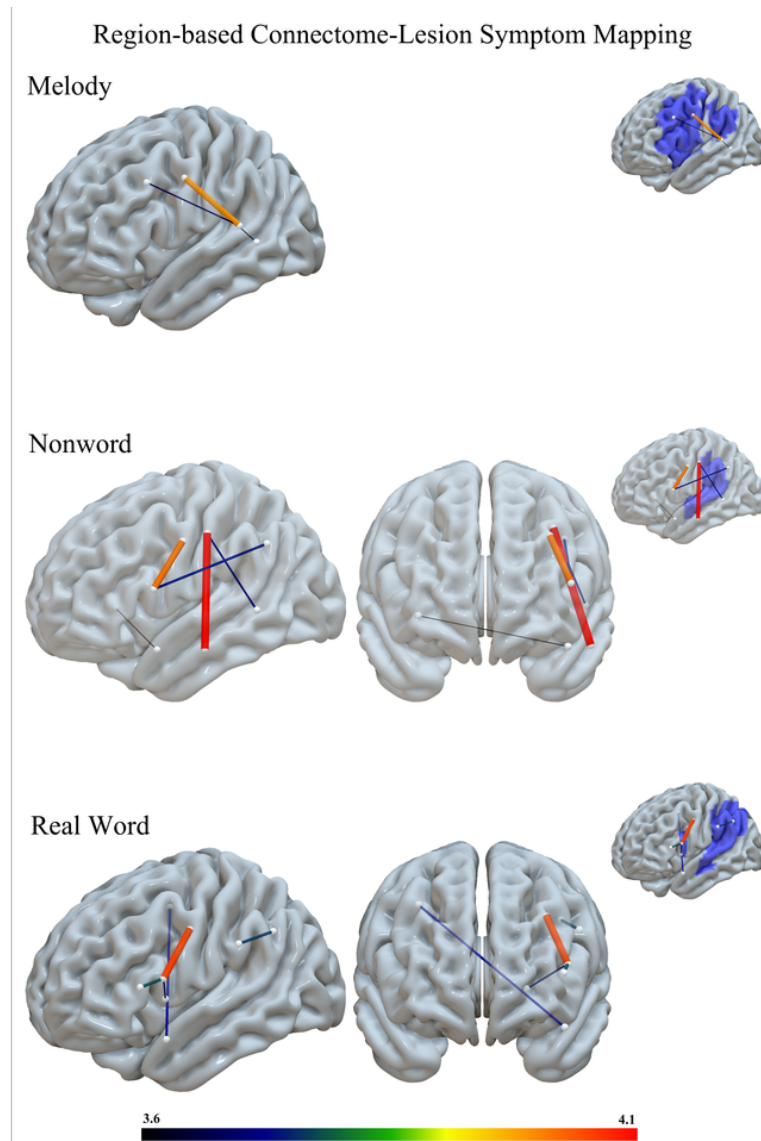


Figure 3.3. Connectome Maps. Maps indicating significant right and left hemisphere connections for each behavioral variable. Top right inset maps are significant connections mapped on top of lesion map for each behavioral variable.

Melodic repetition shared no connections with word or nonword repetition and reflected no right hemisphere connections surviving thresholding. Word repetition and nonword repetition shared one common connection, IFG_opercularis_L \leftrightarrow PrCG_L.

CHAPTER 4

DISCUSSION

4.1 DISCUSSION OF RESULTS

4.1.1 Dual Stream Correlates. The primary question addressed in the present investigation was whether melodic repetition and speech repetition are subserved by shared brain regions commonly implicated in linguistic processing. Performance on all three behavioral variables was predicted to some extent by damage to the left supramarginal gyrus. Since this area involves the posterior end of the arcuate fasciculus, we would expect that performance on all repetition tasks would be predicted by damage to this area, which is commonly implicated in conduction aphasia (Damasio & Damasio, 1980). All three behavioral variables shared some neuroanatomical substrates.

From observing the region of interest analysis results, real word repetition is associated with areas implicated in the dual stream model, and includes areas such as the inferior frontal gyrus *pars opercularis* that are involved with speech production that are associated with the dorsal stream areas. Nonword repetition is also associated with similar areas of the dorsal stream involved in lexical processing, such as the left supramarginal gyrus, but not with the higher-level linguistic processing areas that are implicated in the real word repetition analysis. This highlights the larger area of overlap between real word and non-word repetition compared to the degree of overlap between these two behavioral variables with melodic repetition. Our results support that melodic

repetition uses both articulatory and sensory/phonological connections. The region of interest results show that melodic repetition does not involve any ventral lexical areas but does include dorsal stream areas such as the left inferior frontal gyrus *pars opercularis* and the left precentral gyrus. The inferior frontal gyrus *pars opercularis* is a language area that plays a role in speech production. The left middle frontal gyrus is a distinct supplementary motor area, which was an area significant to melodic repetition. Two areas significant to the melodic repetition task, the *pars opercularis* and the *pars triangularis*, are implicated as important parts of the dorsal stream in form-to-articulation processing (Fridriksson et al., 2016). Connections between the left precentral gyrus and the posterior middle temporal gyrus, as well as the left precentral gyrus with the left posterior superior temporal gyrus were observed for melodic repetition. This supports that area Spt serves as an auditory-motor transformation area, where area Spt connects articulatory centers with temporal auditory areas.

4.1.2 Correlation between Behavioral Tasks. When compared to the other tasks, melodic repetition was only moderately associated with both real word and nonword repetition showing how these tasks are behaviorally and structurally different. Correlation coefficients in the behavioral data support the minimal overlap between areas implicated in real word, nonword, and melodic repetition. Therefore, melodic repetition performance may not be the strongest predictor of speech repetition performance, as we observed variability in individual participant performance on melodic repetition and speech repetition tasks. These weak correlation coefficients highlight the distinct nature of speech repetition and melodic repetition tasks.

4.1.3. Clinical Implications. There are several treatment considerations related to these results. A well-known approach, Melodic Intonation Therapy (MIT), attempts to address language deficits through the use of repetition of melody and intonation (like in singing or humming) to activate the nondominant hemisphere's latent language capacity (Albert et al., 1973). The use of MIT is most often effective with nonfluent individuals with severe expressive language deficits. Despite its effectiveness, many clinical questions still surround the use of MIT. One of the larger questions surrounding the use of MIT is the neural processes that underlie the effectiveness of this approach (Norton et al., 2009). Several theories of what neural regions are involved in MIT suggest mostly right hemispheric involvement (Norton et al., 2009; Schlaug et al., 2010; Sparks et al., 1974). The basis of MIT is that there are two distinct routes for word articulation: a route for spoken words in the left hemisphere and a route for sung words that use either the right hemisphere or both hemispheres (Norton et al., 2009). While examining the images for patients (N=6) who had received MIT treatment, diffusion tensor imaging revealed a treatment related increase in the size of the right arcuate fasciculus (both the number of fibers and the volume of the tract) for one of the patients (Schlaug et al., 2009). It was concluded that in individuals with large left hemispheric lesions, the right arcuate fasciculus might play an important role in facilitating the planning of motor movements (Schlaug et al., 2009). Though none of the connections we observed for melodic repetition in this study were right hemisphere connections, the connections for both real word and nonword repetition had right hemisphere connections. Given the results of Schlaug et al.'s study, it would be worth investigating further the extent to which MIT restores normal functioning to the left hemisphere regions, especially those regions found

to be important in melodic repetition in the current study. Since these regions are also implicated in speech production, whether or not MIT targets these regions for improved speech production would be of interest.

There is some work to suggest that MIT recruits the left hemisphere during the course of treatment. In a study where MIT was administered to patients in the chronic phase of recovery, positron emission topography (PET) was used to observe areas of activation during hearing and repetition of simple words (Belin et al., 1996). Broca's area and the left prefrontal cortex were activated during MIT administration while the right hemisphere counterpart to Wernicke's area was deactivated (Belin et al., 1996). This suggests that the left hemisphere may indeed be implicated in MIT's efficacy. Similar patterns of activation have been observed in another study by Breier and colleagues (2010). In their study, Breier and colleagues used magnetoencephalography to observe areas of activation before and after administration of two blocks of MIT treatment. These blocks consisted of two 30-minute treatment sessions per day, two days a week for three weeks, for a total of 12 hours of treatment (Breier et al., 2010). When compared to their baseline activation map, one of the two participants included in the study showed improvement in phrase production following MIT treatment. This participant had increased activation in left hemisphere language areas including the superior, middle, and occasionally inferior temporal gyri, angular gyrus, temporal pole, and inferior frontal gyrus with decreased activation in the right hemisphere counterparts of these areas following treatment (Breier et al., 2010). Collectively, these results support left hemisphere involvement during MIT treatment, and importantly, that this left hemisphere involvement appears to support positive gains during MIT.

This evidence supports the notion that the preservation of certain left hemisphere cortical structures facilitates recovery of language functioning. In studying which preserved cortical structures are important for positive language recovery outcomes, the left middle temporal lobe and the temporal occipital junction have been implicated in better treatment outcomes (Fridriksson et al., 2010). Particularly related to speech repetition, the left inferior portion of the supramarginal gyrus, an area indicated in the region of interest analysis for every behavioral variable in this study, has previously been indicated as a structure that is associated with performance on speech repetition tasks (Fridriksson et al., 2010). Damage or preservation to these particular cortical structures may predict if a person with aphasia might have positive treatment outcomes. Our results do provide some clinical utility by indicating which connections and areas are most significant for repetition tasks that are similar to those used by clinicians for the purpose of assessing and treating aphasia.

4.1.4. Limitations. Several limitations are present in this study. Though interrater reliability was judged to be “excellent” (Cicchetti, 1994), scoring the participants’ repeated melodies was considered subjective based on how the melody sounded when compared to the target melody. For future studies, standardization of the scoring method is recommended, which may include more individuals scoring the hummed melodies or using an acoustic-based computer analysis to determine similarity between the target melody and the repeated melody. In addition, not all participants completed the nonword repetition task. Thus, the results indicating neuroanatomical correlates for nonword repetition may be underpowered when compared to the analyses of melodic repetition and real word repetition. Finally, our sample size is considered small. Though

participants performed at different levels of accuracy on the melodic repetition task, a larger sample size would be needed to determine aphasia-type-specific neuroanatomical correlates of melodic repetition.

4.1.5. Future Directions and Conclusions. An aspect of the melodic repetition task that was not measured was rhythm. Some suggest that singing does not promote recovery in aphasia, but rather the rhythm at which speech is presented is what is the foundation of MIT's success (Stahl et al., 2011). A study that included 17 persons with nonfluent aphasia used a presentation of music that examined what role lyrics, intonation, and rhythm played in the use of singing for aphasia recovery. Results indicated that rhythm was more crucial than intonation, especially for patients who had lesions that involved the basal ganglia (Stahl et al., 2011). In addition, the study also revealed that preserved long term memory and motor automaticity appeared to strongly mediate speech production. Though our sample did not include any individuals with progressive memory disorders (i.e., dementia or Alzheimer's disease), this study did not account for the role of working memory on the performance of repetition tasks. Though rhythm was not measured in this study, future investigations of the neural correlates of singing could involve the use of tasks that require the participant to tap a certain rhythm along with signing or intoning the syllables. When examining repetition deficits in aphasia, the level of involvement of rhythm in treatment gains should be examined.

Overall, the findings of this study provide an overview of brain regions involved in repetition of speech and nonspeech stimuli in the chronic phase of a left hemisphere stroke. Speech (both word and nonword repetition) and melodic repetition involve mostly distinct areas with limited overlap in left temporal areas. Language is a skill that requires

higher-level linguistic areas as well as motor areas that are also important for non-language tasks such as melodic repetition.

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