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Structural Processing Of Language Components: Detection And Comprehension

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CHAPTER 1: REVIEW OF LITERATURE

1.1 Introduction: Language and Music Characteristics

Language and music are functionally and cognitively similar in many ways. First, both music and language use sound as a medium to convey information, contain ubiquitous elements in all cultures, and are intentional acts requiring proficient theory of mind and memory use developed through specific learning. Second, they are both rule-based systems composed of basic elements combined into higher-order structures using harmony and syntax rules. Third, language and music consist of two similar components: rhythm or formalized segmented time and discrete pitches. Sharing of these basic characteristics has led researchers to examine other possible overlaps.

Furthering our understanding of the relationship between language and music, researchers began examining these communication modalities through potential parallel subcategories. Depending on the source, language consists of four or five processing levels including phonetic-phonological, morphosyntactic, syntactic, lexicosemantic, and/or pragmatic. Music consists of three processing levels including temporal, melodic, and harmonic (Besson & Schön, 2001). Although language and music do not have the same number of processing levels, the levels are not well defined, requiring further investigation to define the boundaries between each. Patel (2003) hypothesized that both linguistic and musical syntax potentially share specific syntactic processes that then apply to separate and different domain-specific syntactic representations, particularly in the posterior brain regions. The 'Shared Syntactic Integration Resource Hypothesis' (SSIRH) is the current working hypothesis used when studying the effects of syntax on music and language processing (Patel, 2003). Delineation of the intricacies existing between language and music requires that researchers search for specific areas in the brain dedicated to processing language components, music components, and components of both domains.

1.1.1 Relating Music and Language

Recent studies have discovered an interconnectivity of language and music, indicating a relationship between these two domains. According to Koelsch (2005), language and music are intimately connected in early life and musical elements may act as a bridge to understanding and deciphering linguistic capacities. In utero, infants hear the prosodic or melodic aspects of speech, similar to an adult speaker listening to extremely muffled speech. This may indicate the earliest associations an infant has between sound patterns and meaning, or sound patterns and syntactic structure (Koelsch, 2005). Later in life, researchers have discovered that the prosody of a cultures' spoken language has a significant effect on the structural and expressive components of that cultures' music (Patel & Daniele, 2003). In essence, a culture’s music mimics and exaggerates the typical fluctuations observed in the culture’s pitch and rhythm of speech. If these two domains unique to humans can have such immense effects on the perception, expression, and interpretation of the other, then language and music must share some of the same underlying processes.

1.2 Localizing Brain Function for Auditory Stimulus Processing

Researchers have made great strides in the field of neuroscience identifying varying responsibilities of different areas of the brain based on functionality. Cytoarchitecture has been the most commonly used differentiation technique for the past century. Invented by Korbinian Brodmann, cytoarchitecture defines areas of the brain with numerical representation based on the cellular composition of the cortex layers. Named after the inventor, the Brodmann Areas (BA) were hypothesized to support similar functions within each designated numbered region based on the assumption that similar cortex cellular compositions would indicate similar function performance. These identifications have led to knowledge of typical outcomes if brain lesions occur in specific areas and, consequently, helped shape therapy interventions to improve patient compensation and recovery from trauma.

While details about the brain and the localization of specific functions continue emerging, a massive amount of information regarding function specificity in the brain remains unknown. Delineating specific areas of the brain for specific types of functions continues to increase current knowledge and understanding of different disorders in numerous fields. Language localization studies (e.g. Broca and Wernicke) provide excellent examples of recent discoveries in areas designated for specific functions as well as answering some of the remaining questions. With these areas isolated, multiple divisions of the medical field have been able to tailor diagnostic and intervention efforts to patients with lesions in these particular areas. While these areas were previously associated with specific language acts, new research has indicated that these areas are possibly associated with specific tasks that commonly occur within several skills. Up-and-coming research has also indicated activation of other brain areas during the processing of these linguistic skills.

1.2.1 Brain Structures Associated with Language

Previous research has indicated that lesions in the inferior frontal gyrus, or Broca’s area (BA 45), can result in effortful and telegraphic speech, impairment in articulation and melodic line, and semantic or phonemic paraphasias. Recently, Amunts et al. (2010) began further parcellating BA 45 and functionally similar surrounding areas into smaller, more specific areas by receptor-based architecture as opposed to cytoarchitecture. The authors concluded that a simple subdivision based solely on the cellular consistency of a brain region was not sufficient.

By examining different neurotransmitters and their associated receptor sites, Amunts and colleagues found that areas performing similar functions also contained similar receptor patterns, which differed from other areas performing other different and independent functions.

Specifically, the authors identified that the frontal operculum (BA 44) had a particular sensitivity to syntactic processing (Amunts et al., 2010). The authors also found that the BA 44 and BA 45 were structurally and functionally closely related, containing the same receptor types and responding to similar functions. While further research in the area of receptor-based architectonic separation is warranted to better delineate boundaries, this new leading research provides great support for the notion that specific aspects of syntactic processing occurs in the inferior frontal lobe, more commonly known as Broca's area and may include the frontal operculum.

1.2.2 Brain Structures Associated with Music

The processing of music has also undergone investigation by researchers interested in both functional isolation of musical skills and functional isolation of language skills (Stewart et al., 2006). The ability to play a musical instrument has the capacity to involve all known human cognitive processes, making music an ideal medium for investigating cognition and underlying brain mechanisms (Koelsch, 2005). Previous literature on musical processing has indicated specialization of the left hemisphere in rhythm and access to semantic representations, while the right hemisphere engages in melodic perception and timbre (Platel, 1997). Usually, language tends to favor left hemisphere lateralization. However, if the left hemisphere also engages in rhythm and semantic representation for music, then it is possible that language and music share an underlying functional process. Recent research has even gone as far as to suggest that language encompasses musical processes as well as cognitive function and we engage this process in every communicative interaction (Loewy, 2004). These predictions provide support for the ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH), indicating similar processing pathways.

1.2.3 Linguistic and Musical Shared Structures

Prosody encompasses the suprasegmental information conveyed in speech and thought to be a musical component of language. Suprasegmental information implies that the information supplied by these components is superimposed on top of the lexical components (i.e., main “segment”) of information. The suprasegments convey non-linguistic information including emotional state, talker identity, intensity, and duration (Arimitsu et al., 2011). Previous studies have found that music and language overlap in areas of brain activation, particularly when examining prosodic components of speech or tonal components of music (Arimitsu et al., 2011; Brown, Martinez, & Parsons, 2006; Gandour et al., 2002; Koelsch, 2005; Schultz et al., 2010; Tervaniemi et al., 2000; Tillmann, Janata, & Bharucha, 2003; Watanabe, Yagishita, & Kikyo, 2008; Zatorre & Gandour, 2008; Zhang et al., 2010). Theories about this overlap include the notion that language and music share common structural elements requiring the involvement of functionally similar brain areas, especially with attentional and auditory components (Schellenberg & Peretz, 2007).

In a phonological units experiment, participants were asked to focus attention on either segmental or suprasegmental information during each trial. Using functional magnetic resonance imaging (fMRI) scans, Li et al. (2010) examined speech prosody perception when contrasting segmental and suprasegmental components of phonological units. The authors found a consistent rightward asymmetry in frontoparietal regions when focusing specifically on suprasegmental information. Therefore, the authors concluded that during phonological processing the neural circuitry involved in the perception of speech prosody differentially engages depending on attentional demands and perceptual cues (Li et al., 2010). Interestingly, this brain region's functionality and location in the right hemisphere could imply a counterpart relationship to the left hemisphere Broca's area.

The notion that language and music occupy homologous regions of opposite hemispheres encourages the idea that these two domains are features of a single function rather than completely different or unrelated functions. Further research along the line of thought delineating hemispheric dominance and homologous regions of activation led Brown, Martinez, and Parsons (2006) to examine the activation of specific cortical regions associated with language and music generation tasks. Sentence generation tasks observed a strong preference to left-lateralization regarding both motor and sensory areas. Music generation tasks observed a strong preference to the anterior superior temporal pole (BA 22) and the right frontal operculum (BA 44). Evidenced areas of overlap included: premotor cortex, sensory-motor area, presensory-motor area, anterior insula, somatosensory cortex, putamen, globus pallidus, ventral thalamus, and posterior cerebellum. The authors believed these areas represent a sharing of neural resources for control of phonation and articulation during both singing and speaking, concluding that phonological generation uses parallel cognitive operations occurring on different semantic bases (Brown, Martinez, & Parsons, 2006). Therefore, recent research efforts support the 'Shared Syntactic Integration Resource Hypothesis' (SSIRH) hypothesizing that music and language are functionally similar and share similar early resources before diverging to different brain areas for further specialization.

Continuing along this line of thought, Sammler et al. (2010) further investigated the involvement of the corpus callosum in the processing of prosody and syntax. The authors described a division of the corpus callosum into thirds based on topographical organization of fiber tracts. The anterior two-thirds of the corpus callosum are believed to connect the orbital and frontal lobes, while the posterior one-third is assumed to connect the temporal, parietal, and occipital lobes. Sammler et al. (2010) discovered the lateralized prosody and syntax processing streams are able to communicate through the posterior corpus callosum fiber tracts in the auditory areas of the temporal lobes. This interaction between the left and right hemispheres through the posterior corpus callosum extends current research by exploring the integration and coordination of syntactic and prosodic elements during auditory comprehension of speech.

1.2.4 Brain Structures Associated with Working Memory

Auditory sensory memory is connected with working memory and long-term memory. Regarding structure building, auditory memory requires both for discerning syntactic regularities and for the use of mental and musical lexicons. However, the extent of the interconnectedness between the memory functions requires further investigation (Koelsch & Siebel, 2005). Specifically, the lateral prefrontal cortex bilaterally has been identified as a main region of activation in working memory studies involving language (Schulze, Mueller, & Koelsch, 2011). Stronger activation of this area was witnessed with structured sequences of stimuli, indicating that the presented stimuli were remembered more easily when grouped together in specific ways. Schulze, Mueller, and Koelsch (2011) designed a study explicitly isolating the areas of working memory associated with musical tonal tasks. The authors found that the lateral prefrontal-parietal cortex was strongly associated with strategy-based working memory processing for non-verbal auditory stimuli. Providing further support for the ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH) and indicating a modality-independent network designed for strategy-based working memory function.

1.3 Cue and Task Dependent Hypotheses

Previous research on prosody has focused on experiments testing two specific processing hypotheses (Hsieh, Gandour, Wong, & Hutchins, 2001). The task-dependent hypothesis focuses on the functional properties associated with prosody, tone versus intonation. The cue-dependent hypothesis focuses on the physical properties associated with prosody, temporal versus spectral information. Determining a type of hypothesis that explains music and language processing would benefit future research by unifying the experimental designs and methods.

1.3.1 Cue-Dependent Hypothesis

Aligning with the cue-dependent hypothesis, Arimitsu et al. (2011) investigated potential innate hemispheric lateralization of suprasegmental information in neonates according to changes in spectral frequency of acoustic information. The authors found a functional lateralization to the right temporal area regarding prosodic processing. Specifically examining vowel contrast, the authors discovered bilateral engagement of auditory areas when discerning suprasegmental elements. Arimitsu et al. (2011) also noted activation around the inferior parietal region, which they attributed to the processing of auditory-verbal short-term memory. According to this research with neonatal infants, prosodic information is innately processed in the right hemisphere prior to the development of language abilities.

1.3.2 Task-Dependent Hypothesis

Other research has examined the intricacies of prosody within speech using the task-dependent hypothesis. Tracy et al. (2011) further subdivided prosody into linguistic and emotional subcomponents and examined studies associated with this hypothesis. Emotional prosody is the mechanism used by individuals to convey attitudes and emotions in speech. Linguistic prosody is the medium used to convey information about semantic meaning including pragmatic category and syntactic relations. Focusing on linguistic prosody, the authors' research found that the left frontotemporal regions of the brain are heavily involved in simple short syntactic and lexical segments of speech, while the right frontotemporal regions are involved in larger suprasegmental elements at the sentence level (Tracy et al., 2011). Further support for the task-dependent hypothesis comes from Tong et al. (2005). The authors determined that speech prosody involves multiple hemispheric and regional asymmetries that enable different weighting of brain areas based upon language experience, auditory stimulus properties, and cognitive processes evoked by the task demands (Tong et al., 2005; Angenstein, Schiech, & Brechmann, 2012).

Tracy et al. (2011) examined internal pitch changes, or emphasis shifts, occurring within the middle of a sentence using fMRI. The authors found that pitch processing across both sentence and tone-sequence stimuli activated bilaterally the medial temporal gyrus (MTG) and the superior temporal gyrus (STG), with more prominent activation in the right inferior frontal cortex. Bilateral activation in the inferior parietal lobule was associated with storage within the working memory system. The sentence stimuli, or prosodic pitch perception, had significant activation bilaterally in the frontal and temporal cortices. The degree of involvement of the STG, inferior frontal gyrus (IFG), and medial frontal gyrus (MFG) was dependent on the task, as predicted by the hypothesis. Therefore, Tracy et al. (2011) provided support for the conclusion of the task-dependent hypothesis indicating the left hemisphere specializes in lexical and short syntactic aspects of pitch, whereas the right hemisphere specializes in processing of suprasegmental pitch.

Gandour et al. (2004) focused on the task-dependent hypothesis and attempted to determine whether the type of auditory stimulus (tone or intonation) influenced prosodic processing. The authors also attempted to compare homologous regions in both hemispheres to assess the extent of lateralization regarding stimulus type, prosodic unit, or both. Generally, the study found the left hemisphere appeared more sensitive to linguistic levels of processing (intonation), while the right hemisphere appeared more sensitive to acoustical processing (tone). Speech prosody perception appeared to be primarily mediated by right hemisphere regions when analyzing complex sounds (tone); but switches to left hemisphere lateralization when language processing is required for task-dependent regions (Gandour et al., 2004). However, the authors hypothesize a close interaction between the two hemispheres by connection of the corpus callosum, later supported by Sammler et al. (2010).

1.4 Language and Music: Event-Related Potentials

Event-related potentials (ERPs) are commonly used in brain localization research to identify functionally similar brain areas by degree of activation or response to specified stimuli. These potentials are measured from brain waves collected by electrodes placed at precise locations on the scalp, corresponding to specific areas of the brain. In previous research, several late-occurring ERPs appear consistently during specific language and music tasks. More recently, research has also identified early-occurring ERPs that appear consistently during specific language and music tasks.

1.4.1 ERPs and Semantics

Two well-known and heavily researched late-occurring ERPs are related to linguistic tasks involving semantics. A negative potential occurring approximately 400 msec after the presentation of a stimulus containing semantic violations is more commonly known as the N400. A positive potential occurring approximately 600 msec after the presentation of a stimulus containing harmonic violations is more commonly known as the P600. Besson and Schön (2001) came across research that cross-examined the processing of lexicosemantic components against melodic components. The researchers found that semantically unexpected and incongruous words elicited the N400, while musical incongruity with unexpected and nondiatonic wrong notes elicited the P600. Due to the different potentials elicited, researchers proposed that these results argue in favor of processing specificity in relation to semantic aspects of language and melodic aspects of music (Besson & Schön, 2001). However, melody of music is typically considered a parallel process of syntax in language and harmony of music is typically considered a parallel process of semantics in language.

Another study looked at the processing relation between semantics and harmony. Researchers discovered that when semantically wrong words were sung and certain words were sung out of tune, both a N400 and a P600 were elicited. This finding indicated that words are processed faster than music and provided evidence that independent computations are required for semantic aspects of language and for harmonic aspects of music (Besson & Schön, 2001). Remarkably, these recorded ERPs diminished when participants paid attention to the non-target aspect of the presented stimuli (i.e. focused attention on the music when presented with incongruous word stimuli). Contrarily, syntax and harmony evoked similar ERPs indicating they may share the same underlying processes. Similarly, the temporal structure of language and music also appear to share similar neuronal processes, supported by the biphasic ERPs elicited in both conditions (Besson & Schön, 2001).

While investigating all these comparisons between language and music, one major question arose around the issue of semantics. Although language has a definite semantic component, researchers are still unsure of whether music contains this component. Musical research has focused on discerning certain ERPs associated with the syntax or the melodic structure of the music, rather than the semantic or the harmonic meaning of the music. Using the N400 ERP to identify semantic transference, the authors played musical excerpts in an effort to elicit associations with specific words. Results of the study indicated that auditory perception of language and music had the same effect on the processes of semantic analysis. Therefore, both music and language can affect the meaning of a word and that music can manipulate and shape semantic processing (Koelsch et al., 2004).

1.4.2 ERPs and Structure

Earlier examination of the P600 component revealed some contrasting findings to the more recent research. Patel et al. (1998) found an inverse relationship between the P600 component and the ease of integration of linguistic elements into an existing set of syntactic relations. The authors also found that out-of-key target chords in a musical sequence also elicited a P600 potential, which suggests that the P600 potential is unlikely to be language specific. More likely, the P600 potential reflects the more general processes of knowledge-based structure integration.

Consistently, musically-syntactic irregular chords have produced an early right anterior negative (ERAN) potential that has a maximal peak around 200 msec after the onset of a chord and is strongest over the right frontal electrode leads (Koelsch, 2005; Koelsch, 2009). Current research has shifted to focusing on an early left anterior negative (ELAN) potential that has a maximal peak around 170 msec after the onset of a word and is strongest over the left frontal electrode leads. With these ERPs identified, it would provide support for the ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH) and indicate that both components receive information from the same brain regions in the inferior frontal cortex with an overlap of neural resources engaged in early processing of syntax in music and language (Koelsch, 2005).

The ERAN reflects music-syntactic processing of acoustic information according to abstract and complex regularities that usually have representation in long-term memory. Although the ERAN resembles the mismatch negativity (MMN) potential, there are several differences between the two potentials (Koelsch, 2009). The MMN compares regularities that are established on an intersound relationship, which are extracted online from the acoustic environment. While the ERAN compares syntactic regularities extracted from the acoustic environment to a reference existing in long-term memory. Therefore, the MMN appears to involve more temporal activation with a focus on sensory aspects in speech, whereas the ERAN appears to involve more frontal activations with a focus on cognitive aspects in speech. Recent brain-imaging studies located a different ERP related to language and music function (Koelsch et al., 2005). The left anterior negative (LAN) potential emerged when subjects experienced syntactically incorrect words in a syntactically irregular chord. Therefore, linguistic syntax interacts with the processing of musical syntax. This postulated overlap of language and music provides support for the ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH) (Koelsch et al., 2005).

Maidhof and Koelsch (2011) developed a study to examine the effects of selective attention to syntactic processing in a complex auditory environment. These effects were measured by specific time-coded ERPs during an electroencephalography (EEG) behavioral experiment. The ERAN was selected to measure the automaticity of music-syntactic processing. While the ELAN, was selected to measure the automaticity of linguistic-syntactic processing. The authors found that both the ERAN and the ELAN share overlapping neural resources; demonstrate a similar time course and comparable scalp distribution particularly in the inferior frontolateral cortex and the planum polare of the superior temporal gyrus. Both the ERAN and

ELAN were found to be partially automatic, indicating that both potentials are influenced by attentional demands. However, the ELAN is influenced by attentional demands to a lesser degree than the ERAN. Therefore, syntactic structure of music is processed even when attention is focused on another auditory stimulus, and syntactic structure of language is processed even when attention is focused on another auditory stimulus.

Syntactic knowledge is implicitly acquired and formal training is not required for either music or language. Few studies have investigated an interaction during simultaneous processing of music and language. Carrus, Koelsch, and Bhattacharya (2011) examined EEG oscillatory patterns during presentation of musical and linguistically syntactic stimuli. The authors found that theta power decreased for syntactically irregular chord sequences presented on syntactically correct sentences during the ERAN time window. Low frequency bands were predominantly involved during language syntactic and semantic processing. Therefore, the authors were able to conclude that large-scale oscillatory brain responses are complementary to ERP responses providing a more comprehensive view of syntactic processing of music and language. This study supports the efficacy and validity of conducting EEG studies using either ERPs or oscillatory brain responses (Carrus, Koelsch, & Bhattacharya, 2011).

1.5 Present Study

The first purpose of this study was to determine whether prosodic elements of spoken language effect syntactic language detection. We predict that the melodic intonation productions will have the most significant effect on syntactic language detection. In theory, the melodic intonation trials should partially automatically engage both inferior frontolateral brain regions associated with structural processing. The second purpose of this study was to determine whether prosodic elements of spoken language effect working memory of language. We predict that the melodic intonation productions will again have the most significant effect on working memory of language. With two types of auditory input theoretically activating homologous bilateral areas of the frontal lobe, the retention of stimuli in the working memory of language should increase. The third purpose of this study was to determine whether a possible interaction between syntactic language detection and working memory of language exists. Finally, when the detection of syntactic structure of language is aided by prosodic elements of spoken language, we predict this will in turn aid the working memory of language. We expect that, efforts from this study will provide further support for the 'Shared Syntactic Integration Resource Hypothesis' (SSIRH).

1.6 Clinical Application

If sentential prosody has significant effects on early structural syntactic processing and working memory of language, then therapy could incorporate the most beneficial sentential prosody to increase the generalizability of new speech and language skills acquired during the rehabilitation process. Previous research has shown that musical training can influence the perception of pitch contour in spoken language; indicating that there is a direct link between some music and language skills that could directly influence the outcomes of therapy (Schön, Magne, & Besson, 2004). According to Zoller (1991), music can be an added touch of creativity that serves as a crucial link between a therapist and client to achieve communication even when the individual may seem unreachable through multiple barriers including physical, intellectual, social, or emotional.

Music is a natural medium evident in many cultures and does not require explicit understanding in order to connect with others and enjoy. In a review performed by Wigram and Gold (2006), the authors concluded that music therapy promotes interpersonal communication, social reciprocity, and relationship skills. The underlying similarity of musical understanding across individuals provides an optimal foundation for development of pragmatic skills. Further support for musical integration in speech therapy arises from the possibility that musical and linguistic stimuli are processed differently for these individuals. Mottron, Peretz, & Ménard (2000) suggest that a portion of those individuals with autism spectrum disorders possessing special "savant" musical abilities demonstrate outstanding pitch-processing skills. Therefore, music integrated into speech therapy may aid the language impaired by building skills in another related domain.

CHAPTER 2: METHODOLOGY

2.1 Subjects

Sixteen subjects (8 female, 8 male, average 24.4 years of age) participated in the experiment. All participants completed a questionnaire indicating their age, gender, handedness, vision and hearing function, native language, and extent of musical training (both vocal and instrumental). Informed written consent was obtained and questionnaire completed before participation in the EEG study.

2.2 Recordings and Data Analysis

Behavioral data (i.e., reaction times and accuracy) and electroencephalography (EEG) data were recorded from subjects in the Speech Language Neuroscience Lab at Wayne State University (WSU) using a 64-channel Waveguard cap referenced by a ground electrode in the cap. This system uses an average of all 64 channels at the reference. The participants arrived in the lab and a cap was placed over their hair. Gel was injected into each channel location to ensure contact between skull and EEG electrode. Impedances were checked to ensure they were below 50k ohms. If they were above this threshold, the subjects skin was abraded with the blunt end of the needle used to inject the gel. Subjects were seated at a desk in front of a computer screen.

Participants completed a practice trial before beginning the experimental blocks. Raw EEG data was collected and recorded for analysis without any filtering or artifact correction performed. After completion of all data collection, the EEG data were filtered using a bandpass filter of 15-100 Hz with a notch at 60 Hz to filter out any artifact from the power lines. Behavioral data was measured as the time elapsed between stimuli offset and participant button press. Using hit trials and excluding miss trials, the response times and accuracies were divided by detection (grammatical vs. ungrammatical) and prosodic condition (monotone, child-directed, melodic). Any stimuli that yielded less than 50% accuracy across participants (i.e. less than eight individuals answered correctly) was eliminated from the analysis process. In addition, any individual accuracy, response time, or amplitude in either the syntax detection or language memory task that exceeded three standard deviations were removed before performing statistical analysis on the collected data. Table 1 provides a summary of the total number of behavioral data stimuli used in the analysis, the average of the stimuli, and the standard deviation.

For statistical analysis, subject behavioral data and ERPs were analyzed using Analysis of Variance Tests (ANOVAs), univariate tests of hypotheses for within-subject effects. Brain electrical signals were analyzed across brain locations and by grouping six separate regions of interest (ROI). These ROIs included: left anterior (AF7, AF3, F7, F5, F3, FC3, FC1, Fp1), right anterior (AF8, AF4, F8, F6, F4, FC4, FC2, Fp2), left middle (C5, C3, C1, CP5, FC5, FT7, T7, TP7), right middle (C6, C4, C2, CP6, FC6, FT8, T8, TP8), left posterior (CP3, CP1, P7, P5, P3, P1, PO7, PO5, PO3), and right posterior (CP4, CP2, P8, P6, P4, P2, PO8, PO6, PO4). The time window for statistical analysis of the ERPs *was* 130-170 msec, based on time windows used in previous studies (Carrus, Koelsch, & Bhattacharya, 2011; Friederici, von Cramon, & Kotz, 1999, Hahne & Friederici, 1999; and Maidhof & Koelsch, 2011;). Independent variables analyzed in the ANOVAs were: grammar (Grammatical x Ungrammatical), group (In-group x Out-group), prosody (Monotone x Child-directed x Melodic), position (Anterior ROIs x Middle ROIs x Posterior ROIs), and hemisphere (Left ROIs x Right ROIs).

2.3 Stimuli

The stimuli were recorded using Wavosaur Audio Editing program and a Shure SM58 high-grade low-noise microphone attached to a desk stand. The recording cell by Creative

Professional was an audio/MIDI interface consistently set at a power of 4 and an intensity level of +60 dB. Once recording was completed, the stimuli were edited using Cool Edit Pro 2.1 software by Syntrillium Software Corporation. The experimental stimuli were normalized individually, matched for volume by each prosodic condition, and enveloped for smooth onset and offset of auditory stimulus. The following are the average auditory stimuli length in seconds for each prosodic condition: monotone (M = 1.094, SD = 0.093), exaggerated (M = 1.101, SD = 0.145), and melodic (M = 1.990, SD = 0.245).

The experiment manipulated syntactic correctness using phrase structure violations occurring at the penultimate position of the phrase (second-to-last word). The language materials consisted of 240 total stimuli separated into 120 pairs of syntactically grammatical (e.g. "Jim bought her a gift") and ungrammatical (e.g. "Jim bought her to gift") phrases. Each phrase consisted of five monosyllabic words of simple construction, ensuring ease of prosodic manipulation. The phrase pairs were evenly distributed among three differing sentential prosody conditions: none (monotone), exaggerated (child-directed speech), and melodic (melodic intonation). Monotone productions consisted of one unvaried tone without harmony or pitch variation. Exaggerated productions consisted of excessive pitch variation and a normal speech rate; henceforth, exaggerated productions are referred to as child-directed productions. Melodic intonation productions consisted of fluid, connected speech with harmony and normal pitch variations with a slowed speech rate (similar to sung speech).

(1) 40 syntactically grammatical monotone prosody sentences
(2) 40 syntactically ungrammatical monotone prosody sentences
(3) 40 syntactically grammatical child-directed prosody sentences
(4) 40 syntactically ungrammatical child-directed prosody sentences
(5) 40 syntactically grammatical melodic prosody sentences
(6) 40 syntactically ungrammatical melodic prosody sentences

There were six experimental blocks to account for two presentations of each prosodic condition that were randomly ordered for each participant, while syntactic detection stimuli were pseudo-randomized to ensure each participant only heard one of the phrase pairs in one block. Each block contained phrases distributed in a 50/50 division between grammatical and ungrammatical syntax.

(1) Block 1
   a. 20 syntactically grammatical monotone prosody sentences
   b. 20 syntactically ungrammatical monotone prosody sentences
(2) Block 2
   a. 20 syntactically grammatical child-directed prosody sentences
   b. 20 syntactically ungrammatical child-directed prosody sentences
(3) Block 3
   a. 20 syntactically grammatical melodic prosody sentences
   b. 20 syntactically ungrammatical melodic prosody sentences
(4) Block 4
   a. 20 syntactically grammatical monotone prosody sentences
   b. 20 syntactically ungrammatical monotone prosody sentences
(5) Block 5
   a. 20 syntactically grammatical child-directed prosody sentences
   b. 20 syntactically ungrammatical child-directed prosody sentences
(6) Block 6
   a. 20 syntactically grammatical melodic prosody sentences
   b. 20 syntactically ungrammatical melodic prosody sentences

The experiment examined working memory of language using comprehension questions presented visually after completion of four syntactic detection phrase tasks. This pattern of four syntactic detection tasks followed by a language comprehension task occurred ten times within each block. For example, after the participant heard and responded to four syntactic detection phrases presented over the speakers, the phrase “Jim bought her a gift” would appear on the screen without any auditory accompaniment. The participant had to discern whether the visually presented phrase was one of the four auditory syntax detection phrases presented prior. Once the participant answered the comprehension question, another set of four auditory syntax detection tasks and one visual language comprehension task began. Participants were instructed to focus only on the immediately previous four auditory stimuli when completing each language comprehension task.

Each visually presented phrase was the counterpart of an auditorily presented phrase at some point in the experiment. However, the pseudo-randomization of the syntax detection stimuli within each set and condition enabled appropriate manipulation of the language memory stimuli. The language memory stimuli were also pseudo-randomized to ensure that memory trials in one block were not either all in-group or all out-group stimuli. Each block contained random distribution between in-group and out-group phrases. Between each block, there was a short break and participants continued the experiment by button press whenever ready.

2.4 Procedure

Stimuli were presented via desktop speakers at a comfortable listening level (55 dB). Participants were informed about irregular phrases, varying sentential prosody, familiarized with the task, and instructed to focus their attention on the syntax of the presented phrases regardless of the sentential prosody. The task blocks were self-paced and timed to continue with the participant's button press. Using the Presentation 16.3 software by Neurobehavioral Systems (NBS) (available at http://www.neurobs.com), the experiment was presented to the participants. Each participant heard both versions, grammatical and ungrammatical, of each phrase; however, the paired phrases occurred in separate blocks as well as separate prosodic conditions. The stimuli were pseudorandomized separately for each participant.

Each trial began with the experiment instructions on the computer screen. Participants pressed the left arrow key to begin a block of the experiment. For the syntactic detection portion, the participants were asked to indicate whether an auditorily presented phrase was syntactically grammatical or ungrammatical by button press. For the language memory portion, the participants were asked to indicate whether a visually presented phrase was one of the previous set of four phrases by button press. Participants were instructed to press one of two keys indicating “yes” or “no” in response to phrases they heard or saw while answering the questions as quickly and accurately as possible. A “yes” response indicated either “syntactically grammatical” or “part of the previous stimuli set”. A “no” response indicated either “syntactically ungrammatical” or “not part of the previous stimuli set”.

CHAPTER 3: RESULTS

Table 1 displays the total number, average, and standard deviation of stimuli including accuracy and response time for both the syntax detection task and the language memory task.

Table 1. Descriptive Statistics Summary of Behavioral Data

Task	*n*	*M*	*SD*
Syntax Detection			
Accuracy	48	0.93	0.04
Response Time	3491	637.23	1070.05
Language Memory			
Accuracy	45	0.92	0.06
Response Time	824	1649.28	1041.07

3.1 Syntax Detection Task Behavioral Data

Overall, participants answered the syntactic detection questions correctly 93.0% of the time. Figure 1 presents the mean accuracies across the six conditions. The grammatical condition yielded an average of 91.0% accuracy across prosodic conditions. Accuracy improved during the ungrammatical condition yielding an average of 95.0%. Regardless of grammar condition, the melodic intonation prosodic condition elicited the lowest accuracy. Figure 2 displays the mean response times across the six conditions. Typically, the grammatical condition generated a slower response time than the ungrammatical condition across prosodic conditions. However, the melodic intonation prosodic condition elicited an opposite effect. Table 2 displays the ANOVA values used for both accuracy and response time from the syntax detection task.

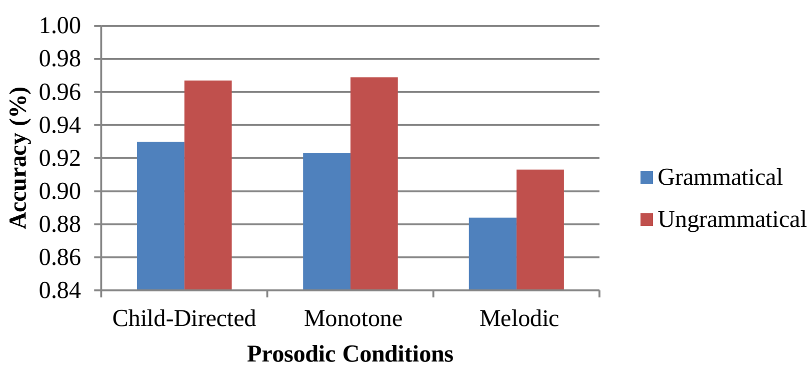

Figure 1. Comparison of prosodic condition accuracy of syntax detection task.

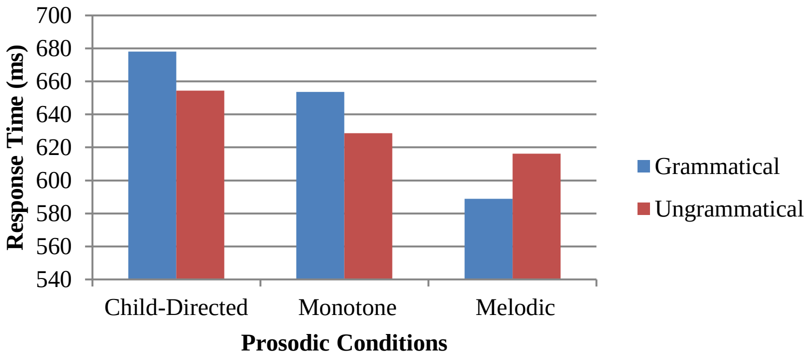

Figure 2. Comparison of prosodic condition response time of syntax detection task.

3.1.1 Syntax Detection Task Accuracy Results

Multiple ANOVAs were performed in an effort to identify the effects of accuracy on the detection task. The between-subjects analyses revealed significant results for prosodic condition [$F = 18.454$, $p < 0.01$], grammar condition [$F = 5.017$, $p < 0.05$], and the interaction between subject and grammar condition [$F = 4.608$, $p < 0.01$]. Across all subjects, this indicates that the prosodic condition and the grammar condition each individually influenced the accuracies achieved on the syntax detection task. The interaction effect generated indicates that the differences in accuracy observed were due to subject variability and grammatical stimuli. The within-subjects analyses revealed significant results for prosodic condition [$F = 18.260$, $p < 0.01$], grammar condition [$F = 4.993$, $p < 0.05$], between monotone and melodic prosodic conditions [$F = 26.690$, $p < 0.01$], and between child-directed and melodic prosodic conditions [$F = 26.950$, $p < 0.01$]. Both the prosodic and grammatical stimuli individually influenced the accuracies achieved on the syntax detection task. Examining the effects between prosodic conditions indicated significant differences in accuracy when comparing monotone and melodic conditions, and when comparing child-directed and melodic prosodic conditions.

3.1.2 Syntax Detection Task Response Time Results

Multiple ANOVAs were performed in an effort to identify the effects of response time on the detection task. The between-subjects analyses revealed significant results for subject [F = 3.561, $p < 0.01$], the interaction between prosodic condition and subject [F = 2.032, $p < 0.05$], and the interaction between grammar condition and subject [F = 2.249, $p < 0.05$]. Overall, this indicates that subject variability influenced the response time achieved on the syntax detection task. The interaction effects indicate that the differences in response time observed were due to subject variability regarding both prosodic and grammatical stimuli. The within-subjects analyses revealed significant results between the child-directed and melodic prosodic conditions [F = 4.703, $p < 0.05$]. Examining the effects between prosodic conditions indicated significant differences in response time when comparing child-directed and melodic prosodic conditions.

Table 2. Behavioral Data for Syntactic Detection Task

Variable		**Accuracy**			**Response Time**		
	df	***MS***	***F***	***p***	***MS***	***F***	***p***
Between-Subjects							
Prosody	2	0.022	18.454	0.000**	22102.139	1.172	0.324
Grammar	1	0.034	5.017	0.041*	5314.075	0.254	0.621
Subject	15	0.002	0.381	0.962	108466.559	3.561	0.004**
Prosody*Grammar	2	0.000	0.329	0.722	7871.483	0.848	0.438
Prosody*Subject	30	0.001	0.827	0.696	18863.277	2.032	0.028*
Grammar*Subject	15	0.007	4.608	0.000**	20880.860	2.249	0.029*
Within-Subjects							
Prosody	2	0.894	18.260	0.000**	18.306	2.808	0.076
Grammar	1	1.355	4.993	0.042*	1.052	0.162	0.693
Prosody*Grammar	2	0.019	0.326	0.724	2.534	0.971	0.390
Monotone vs. Melodic	1	1.318	26.690	0.000**	26.483	3.685	0.074
Child-Directed vs. Melodic	1	1.364	26.950	0.000**	28.400	4.703	0.047*
Child-Directed vs. Monotone	1	0.000	0.009	0.927	0.034	0.005	0.943

Note: $^{*}p < 0.05$, $^{**}p < 0.01$

3.2 Language Memory Task Behavioral Data

Overall, participants answered the language memory questions correctly 92.3% of the time. Figure 3 presents the mean accuracies across the six conditions. The in-group condition yielded an average of 89.0% accuracy across prosodic conditions. Accuracy improved during the out-group condition yielding an average of 96.0%. Regardless of grammar condition, the monotone prosodic condition elicited the lowest accuracy. Figure 4 displays the mean response times across the six conditions. Typically, the out-group condition generated a slower response time than the in-group condition across prosodic conditions. However, the melodic intonation prosodic condition elicited an opposite effect. In addition, the out-group condition appeared to elicit similar response time durations across all prosodic conditions. Table 3 displays the ANOVA values used for both accuracy and response time from the language memory task.

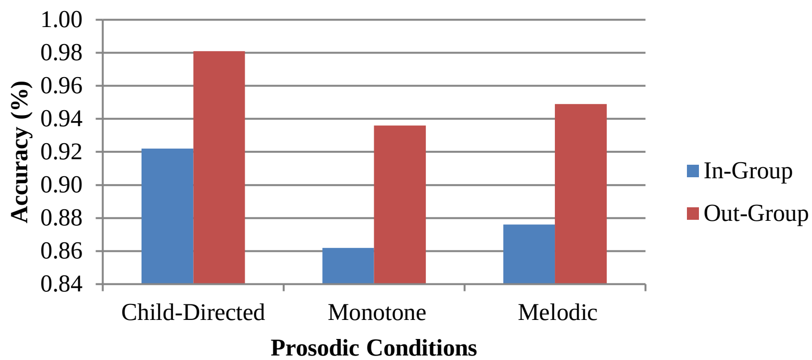

Figure 3. Comparison of prosodic condition accuracy of language memory task.

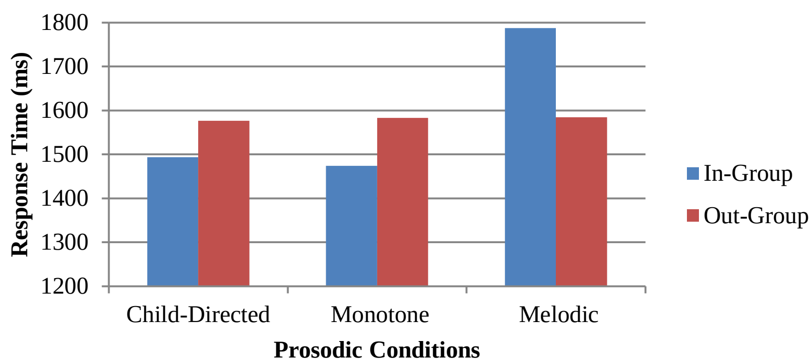

Figure 4. Comparison of prosodic condition response time of language memory task.

3.2.1 Language Memory Task Accuracy Results

Multiple ANOVAs were performed in an effort to identify the effects of accuracy on the memory task. The between-subjects analyses revealed significant results for prosodic condition

[$F = 4.432$, $p < 0.05$] and group condition [$F = 10.032$, $p < 0.01$]. Indicating that prosodic condition and group condition individually influenced the accuracies achieved on the language memory task. The within-subjects analyses revealed significant results for group condition [$F = 10.030$, $p < 0.01$], and between the monotone and child-directed prosodic conditions [$F = 12.860$, $p < 0.01$]. The group stimuli influenced the accuracies achieved on the language memory task. Examining the effects between prosodic conditions indicated significant differences in accuracy when comparing monotone and child-directed prosodic conditions.

3.2.2 Language Memory Task Response Time Results

Multiple ANOVAs were performed in an effort to identify the effects of response time on the memory task. The between-subjects analyses revealed significant results for subject [$F = 5.681$, $p < 0.01$], the interaction between prosodic condition and group condition [$F = 8.558$, $p < 0.01$], and the interaction between prosodic condition and subject [$F = 2.998$, $p < 0.01$]. Overall, subject variability influenced the response times achieved on the language memory task. The interaction effects observed for response time indicate the results are due to prosodic condition variability regarding both group condition and subject variability. The within-subjects analyses revealed significant results for prosodic condition [$F = 7.200$, $p < 0.05$], the interaction between prosodic condition and group condition [$F = 11.990$, $p < 0.01$], in-group condition [$F = 12.270$, $p < 0.01$], between the monotone and melodic prosodic conditions [$F = 12.270$, $p < 0.01$], and between the child-directed and melodic prosodic conditions [$F = 11.230$, $p < 0.01$]. The prosodic and in-group stimuli both individually influenced the response times achieved on the language memory task. The interaction effects observed indicated that the response time differences were due to the prosodic and group stimuli simultaneously. Examining the effects between prosodic conditions indicated significant differences in accuracy when comparing monotone and melodic conditions, and when comparing child-directed and melodic prosodic conditions.

Table 3. Behavioral Data for Language Memory Task

Variable		Accuracy			Response Time		
	df	***MS***	***F***	***p***	***MS***	***F***	***p***
Between-Subjects							
Prosody	2	0.022	4.432	0.021*	279569.668	2.737	0.082
Group	1	0.105	10.032	0.007**	7172.711	0.197	0.664
Subject	14	0.015	1.610	0.249	593115.528	5.681	0.000**
Prosody*Group	2	0.000	0.079	0.925	291501.392	8.558	0.001**
Prosody*Subject	28	0.005	0.797	0.724	102134.043	2.998	0.002**
Group*Subject	14	0.010	1.648	0.127	36334.463	1.067	0.425
Within-Subjects							
Prosody	1	0.003	0.587	0.456	472313	7.200	0.018*
Group	1	0.105	10.030	0.007**	7173	0.197	0.664
Prosody*Group	1	0.000	0.000	0.985	514089	11.990	0.004**
In-Group	1	0.001	0.226	0.642	985959	12.270	0.004**
Out-Group	1	0.001	0.472	0.503	443	0.016	0.902
Monotone vs. Melodic [a]	1	0.003	0.587	0.456	985959	12.270	0.004**
Child-Directed vs. Melodic [a]	1	0.023	3.127	0.099	701704	11.230	0.005**
Child-Directed vs. Monotone [a]	1	0.041	12.860	0.003**	24111	0.267	0.613

*$p < 0.05$, **$p < 0.01$

[a] Response time statistics were compared using only in-group data

3.3 Syntax Detection Task EEG Data

Table 4 displays the average minimum peak score for the N150 ERP. Broken down by ROI, prosody condition, and grammar condition, this table provides several insights useful for determining further potential analyses and future research directions. Table 5 displays the ANOVA results of the EEG peak scores for the N150 ERP examining potential interactions between the experimental variables. The N1 ERP was examined first as assurance that the stimuli elicited the basic auditory response expected in EEG auditory studies. Figure 5 illustrates the average peak occurring around 90 msec for each condition, indicating that all subjects on average were appropriately responding to the presented auditory stimulus. Figure 6 depicts the three ungrammatical prosodic conditions forming an obvious consistent peak around 150 msec.

The EEG waveform confirms the existence of the N150 potential in response to syntactic violations.

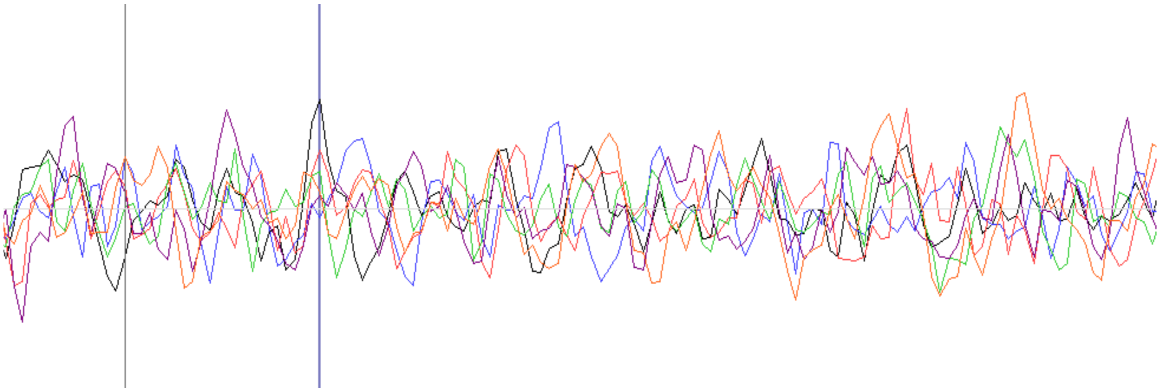

Figure 5. Waveform depicting peak 90 msec after stimulus onset across all six experimental conditions. The gray vertical line delineates the zero-cross for the waveform. The blue vertical line delineates the 90 msec mark illustrating the auditory response. This figure shows the averaged six experimental conditions across all subjects.

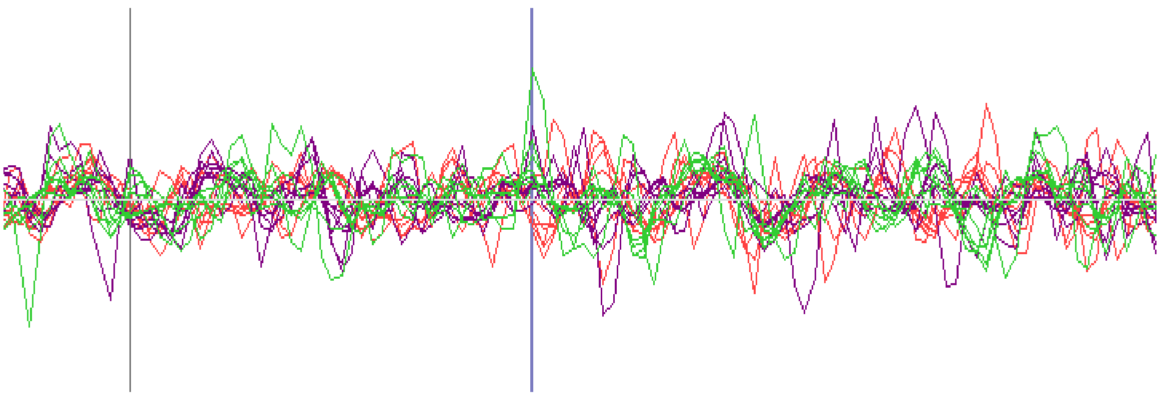

Figure 6. Waveform depicting peak 150 msec after stimulus onset in the left anterior ROI. The gray vertical line delineates the zero-cross for the waveform. The blue vertical line delineates the 150 msec mark illustrating the N150 response. This figure shows the averaged three ungrammatical experimental conditions across all subjects with multiple EEG channels activated. The green waveform depicts the melodic intonation prosodic condition, the purple waveform depicts the child-directed prosodic condition, and the red waveform depicts the monotone prosodic condition.

Table 4. Average EEG Peak Score Amplitudes for Specified ERPs based on ROI

Variable			Amplitude			Latency		
ROI	**Prosody**	**Grammar**	***M***	***SD***	***SE***	***M***	***SD***	***SE***
Left Anterior	Mono	G	-0.661	0.547	0.137	151.607	4.635	1.159
		U	-0.884	0.657	0.164	150.203	5.458	1.364
	Child	G	-0.815	0.370	0.093	150.354	6.494	1.623
		U	-0.727	0.542	0.135	149.704	4.892	1.223
	Melodic	G	-0.822	0.443	0.111	149.675	5.157	1.289
		U	-0.757	0.378	0.094	151.321	3.264	0.816
Left Middle	Mono	G	-0.899	0.602	0.150	149.993	5.654	1.414
		U	-0.626	0.412	0.103	148.882	3.632	0.908
	Child	G	-0.798	0.409	0.102	149.451	6.270	1.568
		U	-0.791	0.503	0.126	149.711	4.531	1.133
	Melodic	G	-0.730	0.379	0.095	147.661	4.710	1.177
		U	-0.772	0.522	0.130	149.957	5.230	1.308
Left Posterior	Mono	G	-0.812	0.762	0.190	150.348	5.236	1.309
		U	-0.590	0.262	0.066	149.468	5.178	1.294
	Child	G	-0.837	0.483	0.121	147.059	5.247	1.312
		U	-0.638	0.478	0.119	148.895	5.242	1.311
	Melodic	G	-0.692	0.520	0.130	148.637	5.363	1.341
		U	-0.652	0.385	0.096	148.454	6.311	1.578
Right Anterior	Mono	G	-0.727	0.607	0.152	150.840	5.362	1.341
		U	-0.906	0.504	0.126	148.264	4.343	1.086
	Child	G	-0.676	0.512	0.128	152.096	4.841	1.210
		U	-0.684	0.409	0.102	150.710	4.624	1.156
	Melodic	G	-0.942	0.424	0.106	151.388	4.726	1.182
		U	-0.720	0.295	0.074	148.698	4.539	1.135
Right Middle	Mono	G	-0.837	0.511	0.128	148.870	5.749	1.437
		U	-0.714	0.508	0.127	149.847	3.569	0.892
	Child	G	-0.594	0.441	0.110	150.886	4.545	1.136
		U	-0.716	0.394	0.098	151.966	4.596	1.149
	Melodic	G	-0.834	0.467	0.117	150.844	4.463	1.116
		U	-0.640	0.422	0.106	148.487	4.516	1.129
Right Posterior	Mono	G	-0.746	0.783	0.196	149.059	5.104	1.276
		U	-0.620	0.339	0.085	149.879	5.834	1.459
	Child	G	-0.625	0.381	0.095	148.352	5.315	1.329
		U	-0.648	0.286	0.071	152.349	6.239	1.560
	Melodic	G	-0.692	0.352	0.088	149.581	6.485	1.621
		U	-0.525	0.638	0.160	150.592	6.077	1.519

Note: "Mono" indicates monotone, "Child" indicates child-directed, "Melodic" indicates melodic intonation, "G" indicates grammatical, and "U" indicates ungrammatical

3.3.1 N150 Latency Results

Multiple ANOVAs were performed in an effort to identify the effects of prosody on ERP latency during the syntax detection task. The within-subjects analyses revealed marginally significant results for an interaction effect between grammar, hemisphere, and position [F =

2.684, $p < 0.10$]. The interaction effect indicates that the differences in ERP latency observed for the N150 were due to grammatical stimuli and dependent on the electrode hemisphere placement and channel position. As a comparison, we examined each subject's EEG data individually by experiment condition and recorded the latency where the majority of the electrodes formed a cohesive peak on the waveform. From this data in Table 6, another ANOVA was performed and a significant interaction effect was found between prosody and grammar [$F = 4.178$, $p < 0.05$]. This interaction effect indicated that both the prosody and grammar stimuli resulted in the ERP latency differences observed for the N150 response.

3.3.2 N150 Amplitude Results

Multiple ANOVAs were performed in an effort to identify the effects of prosody on ERP amplitude during the syntax detection task. The within-subjects analyses revealed significant results for grammar [$F = 5.251$, $p < 0.05$]. This significant result was expected with the N150 response as this ERP is suggested to be highly sensitive to syntax violations. Therefore, significant differences in ERP amplitude due to grammar conditions would be a logical result and is in agreement with previous research on the N150 ERP. A marginally significant result was found for the interaction between prosody, grammar, and hemisphere [$F = 2.866$, $p < 0.10$]. This slight interaction suggests that the amplitude differences observed for the N150 ERP may be more sensitive in one hemisphere and dependent on the prosody stimuli and grammar stimuli. As a comparison, we examined each subject's EEG data individually by experiment condition and recorded the peak score of the electrode with the largest amplitude on the waveform. However, no significant results were found using this hand-measured data.

Table 5. Computer Generated Peak Score EEG Data for Syntax Detection

Variable	*df*	Latency			Amplitude		
		MS	***F***	***p***	***MS***	***F***	***p***
Prosody	2	16.255	0.730	0.491	0.299	0.218	0.805
Grammar	1	20.136	0.009	0.926	0.095	5.251	0.039*
Hemisphere	1	48.442	1.030	0.329	0.208	0.814	0.384
Position	1	35.366	1.279	0.295	0.474	1.003	0.381
Prosody*Grammar	2	13.254	1.925	0.166	0.056	1.338	0.280
Prosody*Hemisphere	2	47.262	1.376	0.270	0.178	1.006	0.380
Grammar*Hemisphere	1	25.470	0.132	0.723	0.216	0.030	0.866
Prosody*Position	4	20.406	0.561	0.692	0.155	0.390	0.815
Grammar*Position	2	23.538	2.344	0.116	0.228	0.764	0.476
Hemisphere*Position	2	18.754	1.052	0.364	0.180	0.219	0.805
Prosody*Grammar*Hemisphere	2	48.578	0.838	0.444	0.103	2.866	0.075
Prosody*Grammar*Position	4	17.220	0.582	0.677	0.144	2.152	0.088
Prosody*Hemisphere*Position	4	12.428	0.170	0.953	0.086	0.125	0.973
Grammar*Hemisphere*Position	2	14.069	2.684	0.087	0.069	0.375	0.691
Prosody*Grammar*Hemisphere*Position	4	15.827	0.586	0.674	0.048	0.362	0.835
Condition	5	15.831	0.947	0.457	0.161	0.965	0.446
ROI	5	31.336	1.147	0.345	0.303	0.790	0.560
Condition*ROI	25	22.235	0.957	0.525	0.124	0.951	0.534

Table 6. Hand Measured Peak Data for Syntax Detection

Variable	*df*	Latency			Amplitude		
		MS	***F***	***p***	***MS***	***F***	***p***
Prosody	2	5.7E-05	0.087	0.917	0.615	0.312	0.737
Grammar	1	5.0E-05	0.483	0.509	0.397	1.785	0.223
Prosody*Grammar	2	2.5E-05	4.178	0.038*	0.221	1.449	0.268

Note: These data were found by individually examining each subject's waveform and isolating the largest peak amplitude in the allotted time window for the designated ERP. This ensured that the computer was indeed isolating an obvious peak on the waveform.

CHAPTER 4: DISCUSSION

4.1 Effects of Sentential Prosody on Syntax Detection

The first purpose of this study was to determine whether prosodic elements of spoken language effect syntactic language detection.

4.1.1 Syntax Detection Behavioral Data Interpretation

Regarding accuracy, both prosody and grammar conditions significantly influenced performance on the syntax detection task. Illustrated in Figure 1, participants achieved greater accuracy on ungrammatical stimuli trials, and on monotone and child-directed stimuli trials. If the ELAN is sensitive to syntax violations, then the activation of this potential should increase awareness of violation events resulting in greater identification. Trials with either child-directed or monotone prosody yielded similar accuracies regardless of grammar condition and likely yielded higher accuracies due to the closer resemblance to typical speech patterns. Child-directed prosody trials intentionally resembled regular speech; therefore, the achievement of higher accuracy on these trials intuitively made sense.

Regarding response time, both prosody and grammar conditions influenced performance on the syntax detection task individually, as evidenced by the interaction effects of subject variability on prosody and grammar condition. Illustrated in Figure 2, participants achieved faster reaction times during the melodic stimuli trials, and within this prosodic condition, exhibited faster reaction times during grammatical stimuli trials. The opposite effect was observed within the other two prosodic conditions, indicating that higher accuracy typically occurred with longer response times. Although the melodic prosody condition yielded the lowest accuracy, it also produced the quickest reaction times regardless of grammar condition. This would lead us to accept that increased sentential prosody is processed faster; yet, it masks the syntax of language resulting in lower accuracy.

4.1.2 Syntax Detection EEG Data Interpretation

Regarding latency, prosody and grammar conditions significantly influenced ERP elicitation on the syntax detection task, while the interaction between grammar, hemisphere, and position had a marginal effect. The earliest N150 response elicited occurred during the ungrammatical monotone prosody trials and the latest N150 response elicited occurred during the ungrammatical child-directed prosody trials. As the ELAN is sensitive to syntax violations, the earliest and latest occurring ERPs should only include the ungrammatical trials. Typically, the ELAN occurs earlier than the ERAN indicating that linguistic syntax is processed slightly faster than musical syntax. If language and musical syntax violations are initially processed in homologous areas of the hemispheres with shared neural resources, then the trials with minimal sentential prosody should yield the earliest occurring ERP. Therefore, the earliest occurring N150 ERP during the ungrammatical monotone prosody trials supports the ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH).

Regarding amplitude, the grammar condition significantly influenced ERP elicitation on the syntax detection task, while the interaction between prosody, grammar, and hemisphere had a marginal effect. The largest peak amplitude elicited in the left anterior ROI occurred during the ungrammatical melodic intonation prosody trials and the smallest peak amplitude elicited in the left anterior ROI occurred during the ungrammatical child-directed prosody trials. As the ELAN is sensitive to syntax violations, the smallest and largest occurring N150 amplitude response should only include the ungrammatical trials. These findings support the ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH); the largest N150 ERP amplitude occurred during the ungrammatical melodic intonation prosody trials indicating that the shared neural resources of homologous areas in both hemispheres strengthens the peak response.

4.1.3 Syntax Detection Overall Significance

Overall, the monotone prosody trials elicited higher accuracies and earlier occurring N150 responses. The child-directed prosody trials produced higher accuracies, while the melodic intonation prosody trials yielded faster response times and larger peak amplitudes. The monotone prosody trials appear to begin processing quicker and generate more accurate responses to syntax violations than the other prosody conditions. With the lack of prosodic information incorporated in the monotone prosody trials, these findings further support the notion that language and music syntax are initially processed in homologous brain areas with shared neural resources. Although the melodic intonation prosody trials elicited lower accuracies, they did produce faster response times and generated the largest peak amplitudes for syntax violations than the other prosody conditions. With the increased prosodic information incorporated in the melodic prosody trials, these findings provide support for bilateral activation of homologous brain areas increasing responsiveness and generating stronger signals.

4.2 Effects of Sentential Prosody on Language Memory

The second purpose of this study was to determine whether prosodic elements of spoken language effect working memory of language. Regarding accuracy, both prosody and group conditions significantly influenced performance on the language memory task. Illustrated in Figure 3, participants achieved greater accuracy on out-group stimuli trials and child-directed prosody stimuli trials. Again, the child-directed prosody trials most closely resemble speech; therefore, it is logical to assume that this trial would yield the highest accuracy. Interestingly, the out-group condition yielded the highest accuracies, which could be attributable to the oddball paradigm. A novel unrelated stimulus is much easier to rule out of a group than a novel related stimulus is to rule into a group. Although the melodic intonation prosody condition did not generate the highest accuracy, it did not generate the lowest accuracy either. The monotone prosody condition achieved the lowest accuracy providing support to the notion that prosody aids working memory of language to some extent.

Regarding response time, prosody conditions influenced performance on the language memory task depending on group conditions and subject variability. Illustrated in Figure 4, participants achieved faster response times during the in-group condition with either monotone or child-directed prosodic trials. The opposite effect was observed for the melodic prosody condition, indicating that sentential prosody taxes language memory resulting in longer response time. However, this effect was only observed during the in-group conditions. The out-group conditions yielded similar response times across all three prosody conditions, indicating that incongruous stimuli are processed similarly regardless of prosody.

Even though the monotone prosody condition yielded the fastest reaction time, it also achieved the lowest accuracy. On the other hand, the melodic intonation condition yielded the slowest reaction time and a higher accuracy. It would appear that lack of prosody improves reaction time at the expense of decreased accuracy. Therefore, prosody has a positive effect on the accuracy of retention in the working memory of language.

4.3 Interaction Effects of Sentential Prosody on Syntax Detection and Language Memory

The third purpose of this study was to determine whether prosodic elements of spoken language facilitate an interaction between syntactic language detection and working memory of language. The proposed ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH) suggests that similar areas of the inferior frontal lobe activated in both hemispheres share similar neural resources, which then diverge to differing specific areas in the posterior brain regions for further structural processing. The monotone prosody condition elicited greater accuracy in detecting syntax violations because the shared neural resources had limited prosodic information to process. In contrast, the melodic intonation prosody condition generated faster response times and larger peak amplitudes when detecting syntax violations because the shared neural resources enable quick evaluation of the stimuli and combined responsiveness in peak amplitude.

Juxtaposed to these findings, the monotone prosody condition elicited the quickest response time and lowest accuracy during the language memory task because there was less prosodic information to process, which led to lower retention of presented stimuli. The melodic intonation prosody condition generated a slower response time and higher accuracy during the language memory task because there was more prosodic information to process, which led to greater retention of presented stimuli. Therefore, prosodic elements of spoken language facilitate an interaction between syntactic language detection and working memory of language. Sentential prosody facilitates syntactic language detection, which in turn facilitates working memory of language.

Interestingly, the results revealed the child-directed prosodic condition enhanced syntactic judgment and language memory, whereas the melodic intonation prosodic condition appeared to have a conflicting effect on language processing. This conundrum of reduced detection accuracy and increased memory response time elicited by the melodic intonation prosodic condition may be explained by several deductions. First, the attentional demand increased for simultaneously processing music and language in the melodic intonation prosodic condition mimicking a divided attention task and thereby taxing the brain’s limited resources from the shared neural network. Second, the idiosyncratic results may arise due to conflicting responses in the processing of auditory information from the melodic intonation prosodic condition. Third, competition for limited processing resources of language and music stimuli in the melodic intonation prosodic condition may produce conflicting outcomes. Fourth and final, a familiarity effect may factor in to the results of this study. It is possible the subjects were not familiar with the melodic intonation condition or sung-speech. Therefore, accurate results for this experiment may require additional or longer practice periods for the melodic intonation prosodic condition as opposed to the monotone and child-directed prosodic conditions. Further studies are necessary to determine the true underlying nature of these findings.

Another possible alternative explanation for the observed contradictory results involves examination of a different hypothesis. Perhaps the ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH) limits the ability to explain the complex neural processing of music and language stimuli. The shift towards a multi-modal processing hypothesis may generate more complete result analysis of the behavioral and EEG data collected. A ‘Multi-Modal Syntactic Processing Hypothesis’ (MMSPH) would support current clinical research involving specific populations. In the study investing local and global processing of music in individuals with autism spectrum disorders, Mottron, Peretz, & Menard (2000) examined a bias in processing as the explanation for individuals with these exceptional musical abilities. The authors confirmed the presence of enhanced local processing and a potential multi-modal processing of auditory stimuli. Further research is warranted to examine the efficacy of the MMSPH and the SSIRH.

4.4 Limitations

The largest limitation for this experiment was the small number of subjects. Although 16 total subjects should provide enough power for EEG data analysis, the behavioral data may have been skewed in one direction due to a subject outlier. Even with elimination of data points exceeding three standard deviations, the variability in responses covered a wide range. Another limitation in this experiment stemmed from the simplicity of the stimuli recording instruments. While the recording methods were satisfactory, better recording equipment and environment as well as a musically trained professional would have greatly enhanced the congruity of stimuli within each prosodic condition. However, having an untrained vocalist record the stimuli may have provided more natural representations of a therapy setting and better support generalization of results to a real therapy setting.

Regarding the stimuli length, one other limitation that may have attributed to the experimental outcomes was the variability of the auditory duration. While duration editing may have enabled equal stimuli length across the prosodic conditions, it also would have distorted the playback of the recordings. In an effort to preserve the naturalness of the auditory stimuli, we decided to forgo splicing and condensing the audio files. Data recording was another area of limitation in this experiment. Due to financial constraints, EEG data was the best option for ERP analysis. Although the data does yield some interesting results, another data collection method such as magnetoencephalography (MEG) may have produced results that are more accurate and the localization of the underlying function neural network.

4.5 Future Research

Further research involving language and musical syntax should incorporate accurate and direct localization of underlying ELAN and ERAN potential networks. Use of MEG would greatly enhance the analysis of this type of data by providing the functional localization of the underlying neural ERP network information alongside the EEG waveform. Another alternative for source localization would include use of a 128-channel EEG cap to improve the temporal and spatial resolutions of the brain electrical signals. Use of fMRI would also provide interesting insight into the underlying anatomical neural network used for syntactic detection and integration as well as the prosodic condition effects on working memory.

Consideration of incorporating a trained musical professional in the stimuli creation and recording would add to the reliability and stability across the stimuli. Accounting for the stimuli duration across prosodic conditions may also add to the reliability and validity of the results. Adjusting the stimuli to incorporate an entirely new variable of musical syntax involving correct and violation trials would add another level to the analysis and further investigate the shared neural networks for early syntax detection of language and music. A comparison study involving trained and untrained participants on the prosodic conditions in the experiment may yield interesting results. Based on participant feedback, the melodic intonation prosodic condition was the most difficult become accustomed to hearing and accurately judging. Therefore, there may be an inadvertent learning effect for the melodic intonation prosodic condition and a study investing this learning curve with interval evaluations over several training sessions may produce further insight into the use of music in speech therapy.

CHAPTER 5: CONCLUSION

This study has determined that investigations of the prosodic elements of spoken language do effect syntactic language detection as well as working memory of language. We also found that prosodic elements of spoken language facilitate a positive interaction between syntactic language detection and working memory of language. The ‘Shared Syntactic Integration Resource Hypothesis’ (SSIRH) (Patel, 2003) was supported by our EEG brain neural response study when examining the effects of musical components on the processing of linguistic syntax. The larger scope of how this study contributed to the literature shows that music integrated into speech therapy may aid the language impaired by building skills in the related domain of music.

REFERENCES

Amunts, K., Lenzen, M., Friederici, A., Schleicher, A., Morosan, P., Palomero-Gallagher, N., & Zilles, K. (2010). Broca's Region: Novel organizational principles and multiple receptor mapping. *PLoS Biol, 8*(9): e1000489. doi: 10.1371/journal.pbio.1000489.

Angenstein, N., Scheich, H., & Brechmann, A. (2012). Interaction between bottom-up and top-down effects during the processing of pitch intervals in sequences of spoken and sung syllables. *NeuroImage, 61*, 715-722.

Arimitsu, T., Uchida-Ota, M., Yagihashi, T., Kojima, S., Watanabe, S., Hokuto, I., Ikeda, K., Takahashi, T., & Minagawa-Kawai, Y. (2011). Functional hemispheric specialization in processing phonemic and prosodic auditory changes in neonates. *Frontiers in Psychology*, *2*, 1-10.

Brown, S., Martinez, M., & Parsons, L. (2006). Music and language side by side in the brain: A PET study of the generation of melodies and sentences. *European Journal of Neuroscience, 23*, 2791-2803.

Besson, M. & Schön, D. (2001). Comparison between Language and Music. *The Biological Foundations of Music, 930*, 232-258.

Carrus, E., Koelsch, S., & Bhattacharya, J. (2011). Shadows of music-language interaction on low frequency brain oscillatory patterns. *Brain & Language*, *119,* 50-57.

Fedorenko, E., Patel, A., Casasanto, D., Winawer, J., & Gibson, E. (2009). Structural integration in language and music: Evidence for a shared system. *Memory & Cognition*, *37*(1), 1-9.

Friederici, A., von Cramon, D.Y., & Kotz, S. (1999). Language related brain potentials in patients with cortical and subcortical left hemisphere lesions. *Brain*, *122*, 1033-1047.

Gandour, J., Tong, Y., Wong, D., Talavage, T., Dzemidzic, M., Xu, Y., Li, X., & Lowe, M. (2004). Hemispheric roles in the perception of speech prosody. *NeuroImage, 23*, 344-357.

Gandour, J., Wong, D., Lowe, M., Dzemidzic, M., Satthamnuwong, N., Tong, Y., & Li, X. (2002). A cross-linguistic fMRI study of spectral and temporal cues underlying phonological processing. *Journal of Cognitive Neuroscience, 14*(7), 1076-1087.

Hahne, A. & Friederici, A. (1999). Electrophysiological evidence for two steps in syntactic analysis: Early automatic and late controlled processes. *Journal of Cognitive Neuroscience, 11(2)*, 194-205.

Hsieh, L., Gandour, J., Wong, D., & Hutchins, G. (2001). Functional heterogeneity of inferior frontal gyrus is shaped by linguistic experience. *Brain and Language, 76*, 227-252.

Koelsch, S. (2009). Music-syntactic processing and auditory memory: Similarities and differences between ERAN and MMN. *Psychophysiology, 46*, 179-190.

Koelsch, S. (2011). Toward a neural basis of music perception-A review and updated model. *Frontiers in Psychology, 2*, 1-20.

Koelsch, S. (2005). Neural substrates of processing syntax and semantics in music. *Current Opinion in Neurobiology, 15*, 207-212.

Koelsch, S. & Siebel, W. (2005). Towards a neural basis of music perception. *TRENDS in Cognitive Sciences, 9(12)*, 578-584.

Koelsch, S., Gunter, T., Wittfoth, M., & Sammler, D. (2005). Interaction between syntax processing in language and in music: An ERP study. *Journal of Cognitive Neuroscience, 17(10)*, 1565-1577.

Koelsch, S., Kasper, E., Sammler, D., Schulze, K., Gunter, T., & Friederici, A. (2004). Music, language and meaning: Brain signatures of semantic processing. *Nature Neuroscience, 7(3),* 102-107.

Li, X., Gandour, J., Talavage, T., Wong, D., Hoffa, A., Lowe, M., & Dzemidzic, M. (2010). Hemispheric asymmetries in phonological processing of tones vs. segmental units. *Neuroreport*, *21*(10), 690-694.

Loewy, J. (2004). Integrating music, language and the voice in music therapy. *Voices: A World Forum for Music Therapy, 4(1).*

Longoni, F., Grande, M., Hendrich, V., Kastrau, F., & Huber, W. (2005). An fMRI study on conceptual, grammatical, and morpho-phonological processing. *Brain and Cognition, 57*, 131-134.

Maidhof, C. & Koelsch, S. (2011). Effects of selective attention on syntax processing in music and language. *Journal of Cognitive Neuroscience, 23(9)*, 2252-2267.

Mottron, L., Peretz, I., & Ménard, E. (2000). Local and global processing of music in high-functioning persons with autism: Beyond central coherence? *Journal of Child Psychology and Psychiatry*, *41*(8), 1057-1065.

Patel, A. (2003). Language, music, syntax and the brain. *Nature Neuroscience, 6(7),* 674-681.

Patel, A., & Daniele, J. (2003). An empirical comparison of rhythm in language and music. *Cognition, 87,* 35-45.

Patel, A., Gibson, E., Ratner, J., Besson, M., & Holcomb, P. (1998). Processing Syntactic Relations in language and music: An event-related potential study. *Journal of Cognitive Neuroscience, 10(6),* 717-733.

Platel, H., Price, C., Baron, J.-C., Wise, R., Lambert, J., Frackowiak, R., Lechevalier, B., & Eustache, F. (1997). The structural components of music perception: A functional anatomical study. *Brain, 120,* 229-243.

Sammler, D., Kotz, S., Eckstein, Ott, D., & Friederici, A. (2010). Prosody meets syntax: The role of the corpus callosum. *Brain, 133*, 2643-2655.

Schellenberg, E., & Peretz, I. (2007). Music, language and cognition: Unresolved issues. *Trends in Cognitive Sciences, 12(2),* 45-46.

Schön, D., Magne, C., & Besson, M. (2004). The music of speech: Music training facilitates pitch processing in both music and language. *Psychophysiology, 41,* 341-349.

Schulze, K., Zysset, S., Mueller, K., Friederici, A., & Koelsch, S. (2011). Neuroarchitecture of verbal and tonal working memory in nonmusicians and musicians. *Human Brain Mapping*, *32*(5), 771-783.

Schulze, K., Mueller, K., & Koelsch, S. (2011). Neural correlates of strategy use during auditory working memory in musicians and non-musicians. *European Journal of Neuroscience, 33*, 189-196.

Sloboda, J. (1986). *The Musical Mind: The Cognitive Psychology of Music*. New York: Oxford University Press.

Steinbeis, N. & Koelsch, S. (2008). Shared neural resources between music and language indicate semantic processing of musical tension-resolution patterns. *Cerebral Cortex, 18,* 1169-1178.

Stewart, L., von Kriegstein, K., Warren, J., & Griffiths, T. (2006). Music and the brain: Disorders of musical listening. *Brain, 129,* 2533-2553.

Tervaniemi, M., Medvedev, S., Alho, K., Pakhomov, S., Roudas, M., van Zuijen, T., & Näätänen, R. (2000). Lateralized automatic auditory processing of phonetic versus musical information: A PET study. *Human Brain Mapping, 10*, 74-79.

Tillmann, B., Janata, P., & Bharucha, J. (2003). Activation of the inferior frontal cortex in musical priming. *Cognitive Brain Research, 16*, 145-161.

Tong, Y., Gandour, J., Talavage, T., Wong, D., Dzemidzic, M., Xu, Y., Li, X., & Lowe, M. (2005). Neural circuitry underlying sentence-level linguistic prosody. *NeuroImage, 28*, 417-428.

Tracy, D., Ho, D., O'Daly, O., Michalopoulou, P., Lloyd, L., Dimond, E., Matsumoto, K., & Shergill, S. (2011). It's not what you say but the way that you say it: An fMRI study of differential lexical and non-lexical prosodic pitch processing. *Bio Med Central Neuroscience, 12*, 128-135.

Watanabe, T., Yagishita, S., & Kikyo, H. (2008). Memory of music: Roles of right hippocampus and left inferior frontal gyrus. *NeuroImage, 39*, 483-491.

Wigram, T. & Gold, C. (2006). Music therapy in the assessment and treatment of autistic spectrum disorder: Clinical application and research evidence. *Child: Care, health and development*, *32*(5), 535-542.

Xu, Y. (2011). Speech prosody: A methodological review. *Journal of Speech Sciences, 1*, 85-115.

Zatorre, R., & Gandour, J. (2008). Neural specializations for speech and pitch: Moving beyond the dichotomies. *Philosophical Transactions of The Royal Society B, 363*, 1087-1104.

Zhang, L., Shu, H., Zhou, F., Wang, X., & Li, P. (2010). Common and distinct neural substrates for the perception of speech rhythm and intonation. *Human Brain Mapping, 31*, 1106-1116.

Zoller, M. (1991). Use of music activities in speech-language therapy. *Language, Speech, and Hearing Services in Schools, 22*, 272-276.

ABSTRACT

STRUCTURAL COMPONENTS OF LANGUAGE: DETECTION AND COMPREHENSION

by

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Although music and language share many perceptually functional characteristics, research endeavors are still focusing on the underlying neural circuitry. Past research has indicated a distinction of hemispheric lateralization between music and language processing. Recently, efforts have shifted to the notion of an initial general shared pathway in the brain with auditory stimuli differentiated in later processing to specialized regions. Therefore, both linguistic and musical components have been examined in numerous experiments to discern the possible influence of music and language components on auditory perception and comprehension, including their potential interaction. However, the effects of sentential prosody on early language structural processing and short-term working memory have yet to be examined from a linguistic perspective. Sixteen subjects participated in an experiment using behavioral and electroencephalography (EEG) data to assess the effects of sentential prosody variation on syntactic detection and language memory. Findings from this experiment could support current therapy techniques in speech-language pathology and provide an avenue for the development of new therapy techniques using multiple communication modalities.

AUTOBIOGRAPHICAL STATEMENT

In December 2010, I received my B.S. in Psychology from Michigan State University with a minor in Linguistics, and specializations in Cognitive Science and Bioethics, Humanities, and Societies. At Michigan State, I assisted in the neuropsychological research at the Consortium for Neurodevelopmental Studies conducted by Dr. Margaret Semrud-Clikeman and Dr. Jodene Fine. The focus of research involved potential identification of specific brain regions in children associated with attention deficit/hyperactivity disorder (ADHD) using functional magnetic resonance imaging (fMRI). My work in the neuropsychology lab increased my desire to provide assistive services for the pediatric population while integrating my interest in language development.

In January 2011, I began working with Dr. Li Hsieh in the Speech-Language Neuroscience Lab (SLNSL) at Wayne State University while completing post-bachelor coursework. The lab was involved in projects concerning visual tracking and distraction during attentionally demanding tasks. I assisted Dr. Hsieh, in scheduling participants, experiment and participant set-up, and data analysis. I entered the graduate program in Speech-Language Pathology at Wayne State University in August 2011. Throughout my graduate career, I completed many different clinical rotations and noticed that music was a constant medium that most patients receiving speech and language services responded to, regardless of the presenting disorder. Therefore, I attempted to observe an interaction between music and language to propose future experiments and potential therapy practices. My psychology and research background coupled with my language interest, led me to continue researching in the hopes of contributing to the speech and language evidence base.