CORTICAL SPECIALIZATION FOR MUSIC IN PREVERBAL INFANTS

A Thesis

by

ESWEN ELIZABETH FAVA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2008

Major Subject: Psychology

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Approved by:

Chair of Committee,	Heather Bortfeld
Committee Members,	Gerianne Alexander
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ABSTRACT

Cortical Specialization for Music in Preverbal Infants. (May 2008)
Eswen Elizabeth Fava, B.S., University of Arizona
Chair of Advisory Committee: Dr. Heather Bortfeld

Audition is perhaps the most developed and acute sense available to infants at birth. One theory supported by speech and music researchers alike proposes that the auditory system is biased to salient properties such as pitch and allocates processing of such stimuli to specialized areas. In the current study, we sought to investigate whether infants would show similar patterns for processing music and language, as they both contain predictable changes in pitch. In a previous study, we established that language processing is lateralized to the left temporal region in the infant brain. We hypothesized music would be processed in the right temporal area. Although it contains a rule-based structure somewhat akin to language, it is heavily dependent on fine distinctions in pitch. Preverbal infants watched a video of animated shapes (visual stimuli) coupled with either speech (1 of 10 different stories in infant-direct speech) or music (Scriabbin's Ballade No. 3 in A flat) while hemodynamic activity in bilateral temporal sites was recording using near-infrared spectroscopy. Results indicated significant right temporal decreases in HbO2 concentration in comparison with baseline measures during music trials relative to the left temporal area. These results suggest that even at the preverbal stage, infants process speech differently than other similarly structured auditory stimuli.

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CHAPTER I

INTRODUCTION: THE IMPORTANCE OF PITCH

Infants begin life with a well-developed sense of audition and are almost immediately able to discriminate and tune themselves to the auditory information in their environment. For example, newborns are sensitive to the phonological cues of their native language (Christophe & Dupoux, 1996) and can discriminate languages that are rhythmically dissimilar (Mehler et al., 1988). As early as 6 months of age, infants also show signs of developing specialized networks for language with an adult-like left temporal bias for speech stimuli (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Dehaene-Lambertz et al., 2006). Thus, data from infant perception point to an already mature auditory processing system that is in place and specifically tuned to language within the first half of the first year of life.

General Auditory System

It is less clear what sound qualities are processed and how variability in sound quality influences auditory sensitivity. Peretz (2006) has proposed that infants possess a *general* auditory system. This system capitalizes on the qualities of sound, whether they are present in language or music, and uses this information to further analyze sound structure. This general auditory system may develop within days of birth or be innately

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This thesis follows the style of *Developmental Science.*

endowed. In support of this model, Saffran, Johnson, Aslin & Newport (1999) found that infants are sensitive to the structure in the auditory signal, even when the material takes a non-linguistic form (musical tones). Research suggests that infants are able to discriminate music using the very same cues they use in language, namely, tempo (Baruch & Drake, 1997; Drake & Bertrand, 2001; Trehub & Thorpe, 1989), meter (T.R. Bergeson, 2002; Halit, de Haan, & Johnson, 2003; Hannon & Trehub, 2003), timbre (Trehub, Endman, & Thorpe, 1990) pitch (Trehub, 2000, 2001), consonance and dissonance (Schellenberg & Trainor, 1996; Schellenberg & Trehub, 1996; Trainor & Heinmiller, 1998; Zenter & Kagan, 1996). Indeed, Magne, Schön, & Besson (2006) demonstrated that these important overlaps in the auditory properties of speech and music are facilitating perception in both domains.

One specific source of experience in using the common properties of speech and music for infants is the use of pitch changes in Infant Directed Speech (IDS) and singing lullabies. As aptly put by Tramos, Cariani, Koh, Markis & Braida (2005), pitch with regard to speech conveys voicing distinction, emphasis and speaker identity while with regard to music, in serial creates melodic intervals and in parallel, gives rise to intervals and chords. Bergeson and Trehub (2002) found that both IDS and lullabies had higher pitch and slower tempos than adult directed speech or song. At a higher level of processing, both IDs and lullabies feature a decline in pitch that typically indicates the end of a phrase (Hirsh-Pasek K et al., 1987; Juscyzk & Krumhansl, 1993; Krumhansl & Juscyzk, 1990). From behavioral research of lullaby singing over time, Bergeson and Trehub (2002) found mothers' repetitions of lullabies deviated less in terms of pitch and tempo than their infant directed speech. Thus, lullabies are more reliable across repetitions in certain properties (pitch and tempo) critical in language acquisition (signaling end of phrase), and may facilitate development because of these consistencies. Similarly, Juscyzk (1999) and Trehub (2003) independently noted that infants learn much about word and phrase boundaries and possibly semantics through other musical cues such as melody, rhythm, timbre, recursion, transformations and meter. Using both behavioral and electrophysiological measures, Magne, Schön and Besson (2006) observed that children with musical training were better able to detect pitch changes in language and music than non-musician children. Thus, the benefits of listening to music in regard to language perception continue well into childhood.

Recent converging fMRI evidence from children and adults processing music (Koelsch, Fritz, Schulze, Alsop, & Schlaug, 2005) has revealed right hemisphere lateralization for processing this stimulus in children. In contrast, adult musicians revealed left hemisphere activity in auditory cortical areas, including Broca's Area. These researchers have also observed less left prefrontal left activity in children than in non-musician adults. These findings are also supported by Brown, Martinez and Parsons (2006), who propose that language and music share some processing areas, namely the primary processing sites of the auditory and motor cortices. Furthermore, these authors suggest that the superior temporal gyrus and Broca's Area are used for both language and music processing, with music lateralized to the right and language to the left.

These findings for the right temporal lateralization of music are consistent with the more specific area of pitch processing research. From animal models, we know that old world monkeys (Wright, 2000), birds (Hulse, Bernard, & Braaten, 1995) and rats (Borchgrevink, 1975) can perceive cues of consonance and dissonance. This demonstrates a common mechanism across animals for the processing of multiple pitches in parallel. In addition, animal and human lesion research has demonstrated that the right auditory cortex is critical in pitch discrimination tasks (Liegeois-Chauvel, Peretz, Babai, Laguitton, & Chauvel, 1998; Samson & Zatorre, 1988). More specifically, across studies right temporal and frontal activations are common processing areas seen in pitch processing tasks (Holcomb et al., 1998; Perry et al., 1999; R. J. Zatorre, Evans, & Meyer, 1994). Patterson, Uppenkamp at el. (2002) conducted a thorough study using fMRI of hierarchy pitch processing, and used contrasts such as pitch/no-pitch, varied pitch, pitch tracking and melody extraction. They concluded that the network of areas activated by pitch-related processing move anterolaterally from the primary auditory cortex side as the complexity of the stimulus increases. For example, Patterson (2002) found the presence of pitch elicited processing from the lateral half of Heschl's gyrus, varied pitched added Planum Temporale and Superior Temporal Gyrus activation. They found the most asymmetry in auditory thalamus activity (right lateralized) when pitch was contrasted with noise. These results have been confirmed many times over, with stimuli that contrast pitch saliency (Penagos, Melcher, & Oxenham, 2004) and melodies (changes in pitch) with fixed pitch stimuli (Griffiths et al., 1997; Johnsrude, Penhune, & Zatorre, 2000; Samson & Zatorre, 1988; R. J. Zatorre et al., 1994). A review article of human and nonhuman primate research in 2005 stated that at present we know Heschl's and the superior temporal gyri bilaterally play important roles in the detection of small pitch changes, the critical processing of direction of pitch change is likely right lateralized as is spectral (frequency distinctions) processing (as opposed to temporal processing which is likely left lateralized) (Tramos et al., 2005).

These data have led researchers to develop models in an attempt to explain the processing networks that consistently respond to spectral or temporal aspects of speech and music stimuli. Current opinion, as best discussed by Zatorre, Belin and Penhune (2002), places temporal processing predominantly on the left temporal side, with spectral processing occurring in the right temporal area. Evidence from the language literature also supports this claim, as Tallal, Miller and Fitch (1993) found that language acquisition suffers if children are found to have basic difficulties in processing temporal information. Imaging and lesion research has provided additional evidence supporting differential lateralization of spectral and temporal processing (Johnsrude et al., 2000; Patel & Balaban, 2001; Peretz, 1993).

Current Project

The current project aimed to determine whether such a dissociation could be established in the neural underpinnings of language and music processing in infants. Based on Patel's (2003)original proposal, I hypothesized that processing of music will be delegated to the right temporal area and that of language will be delegated to the left temporal area in preverbal infants.

The neuroimaging and electrophysiology literatures have relied upon dissociation and double dissociation methodologies in order to assign functional interpretation to cortical areas. One problem with this methodology is that it assumes certain mechanisms themselves (e.g. language processing mechanisms such as syntax and semantics) are taking place (Bub, 2000). Another issue is that samples selected to participate in dissociation experiments to examine the localization of function or dysfunction are not homogenous themselves (McCloskey, 1993; Van Orden, Pennington, & Stone, 2001). Moreover, researchers note that individuals selected based on a particular impairment may also be tested using a manipulation that could render the group heterogenous (Van Orden, Pennington, & Stone, 2001). Finally, a particular problem with double dissociation experiments is that they inherently assume that isolatable subsystems exist (Shallice, 2003). The experiment reported here has been designed explicitly to limit inferences; that means that its implications are likewise limited, as the infant brain is perhaps more poorly understood than its adult counterpart. We predict that we will observe a more robust hemodynamic response in the right relative to the left temporal region in response to music, a finding that would inform theories addressing the complex and highly connected systems likely found in the infant brain. If such cerebral lateralization specific to music is demonstrated, it would provide another piece of evidence that an entire network of areas is devoted to a range of auditory processes.

CHAPTER II

METHODS

In the present study, volume changes in oxygenated hemoglobin were assessed in 6-9 month-old infants. Infants were tested in two conditions: during exposure to music coupled with visual stimuli (audiovisual music condition) and during exposure to language coupled with visual stimuli (audiovisual language condition). Regions of interest were the right and left temporal cortices. Two hypotheses were tested. First, neural activation as measured by an increase in HbO_2 would be observed in area T_3 (left temporal region) in response to the audiovisual language condition would represent a replication of Bortfeld, Fava & Boas (under review). Second, neural activation as measured by an increase in T_4 (right temporal region) would be observed in response to the audiovisual music condition. These predictions were made based on the logic that only the audiovisual music condition would involve processing in the right temporal region, and that the musical nature of the stimuli would lead to greater activation of the right relative to left temporal region.

Participants

Data were collected from n =24 participants from the language condition and n =20 participants from the music condition. The mean age of the infants was 234 days or 7 months 24 days of age). Infants considered “lost” were tested but eliminated from the analyses because of large artifacts in the optical signal throughout the experimental run due to motion or hair obstruction (n =4 for the language condition, n=9 from the music condition). Furthermore, all infants whose data were analyzed completed more than one useable block of experimental trials. Infants' names were obtained from birth announcements in the local newspaper and commercially produced lists, and infants and parents were offered a new toy as compensation for their participation. Informed consent was obtained from the parents before testing began.

Paradigm

During data collection, each infant sat on a caretaker's lap in a testing booth. Infants were positioned facing a 53-cm flat panel computer monitor (Macintosh G4) 76 cm away (28.1° visual angle at infants' viewing distance based on a 36 cm wide screen). The monitor was positioned on a shelf, immediately under which audio speakers and a low-light video camera were positioned, orients towards infants. The monitor was framed by a façade that functioned to conceal the rest of the equipment. The façade was made of three sections. The upper third was a dark black curtain that covered the wall from side to side, and dropped down 84 cm from the ceiling. The middle section, measuring 152 cm (wall to wall horizontally) x 69 cm high, was constructed of plywood and covered with dark black cloth. The plywood had a rectangular hole cut out of its center that coincided with the size of the viewing surface of computer monitor (48 cm diagonal). A dark curtain hung from the bottom edge of the section to the floor. The testing area was separated by a curtain from a control area, where an experimenter controlled the NIRS instrument out of the infant's view. Fiber optic cables (15 m each) extended from the instrument to the testing booth and into a custom headband on the infant’s head. The cables were bundled into a single strand secured on the wall just over the parent’s right shoulder.

The NIRS instrument consisted of three major components: two fiber optic cables that delivered near-infrared light to the scalp of the participant (i.e., emitters); (2) four fiber optic cables that detected the diffusely reflected light at the scalp and transmitted it to the receiver (i.e., detectors); and (3) an electronic control box that served both as the source of the near-infrared light and the receiver of the refracted light. The signals received by the electronic control box were processed and relayed to a Dell Inspiron 7000™ laptop computer. A custom computer program recorded and analyzed the signal.

The imaging device used in these studies produced light at 690 and 830 nm wavelengths with two laser-emitting diodes (Boas, Franceschini, Dunn, & Strangman, 2002). Laser power emitted from the end of the fiber was 4 mW. Light was square wave modulated at audio frequencies of approximately 4 to 12 kHz. Each laser had a unique frequency so that synchronous detection could uniquely identify each laser source from the photodetector signal. Any ambient illumination that occurred during the experiment (e.g., from the visual stimuli) did not interfere with the laser signals because environmental light sources modulate at a significantly different frequency. No detector saturation occurred during the experiment.

The light was delivered via fiber optic cables, each 1 mm in diameter and 15 m in length. These originated at the imaging device and terminated in the headband that was placed on the infant’s head. The headband was made of elastic terry-cloth and was fitted with the two light-emitting and four light-detecting emitters and detectors. These were grouped into two emitter/detector sets, each containing two detectors placed at 2 cm distance on either side from the central emitter. One set delivered light to the left temporal region at approximately position T_3 according to the International 10-20 system, and the right temporal region at approximately position T_4 according to the International 10-20 system.

The stimuli in the pilot analysis consisted of classical music recordings, speech recordings and visual animations. Infants first saw a blank (dark) screen for 20 seconds before stimulus presentation began. Stimulus presentation proceeded as follows: 20 seconds of music with visual animation, 10 seconds of silence with a blank screen, 20 seconds of speech with visual animation, 10 seconds of silence with a blank screen. This sequence repeated five times over the course of the experiment. The initial audiovisual music trial and the baseline period preceding it served to familiarize the infant with the procedure and were not included in analyses. Likewise, the final audiovisual language trial and baseline period were excluded. This design resulted in four, 60-second blocks per infant, with each block consisting of an audiovisual music trial (20s), the subsequent baseline interval (10s), an audiovisual speech trial (20s), and the subsequent baseline interval (10s).

The content of each speech segment was different, but all contained speech from the same speaker with the same general intonation variation and affective tone. The voice recordings were made by a female speaker, relaying a children’s story using highly animated, infant-directed speech. Recordings were made using a Sony digital camcorder, and then converted to .wav sound files using Sound Forge 6.0™ audio editing software. The music stimuli were excerpts taken from Scriabbin Ballade No. 3 in A-Flat, segmented according to the 20s stimulus requirements and the best musical phrasing allowed. The visual stimuli were distinct across trials, but each consisted of animations that were similar in color contrast and motion parameters. They consisted of simple, 3-dimensional objects (e.g., spirals, circles, and rectangles) that rotated and moved slowly in front of a high-contrast, colored background. The animations were produced using 3-D Studio Max™ computer graphics software. The auditory and animated digital files were combined using Adobe Premier 6.5™ video editing software, which produced .avi movie files that were then recorded onto a blank DVD. The recorded DVD was then played for through the computer monitor and speakers. The hidden speakers were 82 cm from infants, facing them and producing audio stimuli at 75 decibels when measured from the approximate location of the infant.

After the parent and infant were seated, a head circumference measurement was taken from the infant using a standard cloth tape measure. Each parent was instructed to refrain from talking and interacting with the infant during the course of the experiment, and to hold the infant up so that they were able to comfortably view the screen. Parents were also asked to guide infants' hands down and away from the headband if they began to reach up during the experiment. The experimenter then placed the NIRS headband on the infant. Following the 10-20 system, the two optodes were adjusted over the left and right temporal areas, centered above and slightly anterior to the T_3 position (on the left) and T_4 (on the right). The experimenter moved to the control area. The room lights in both the experimental and control areas were turned off, leaving only a low intensity light to sufficiently illuminate the experimental area, and light from the computer monitor to light the control area. The emitter source lights of the imaging device were turned on, and optical recordings began. At this time, stimulus presentation began as well. Infants were video recorded for the duration of the experimental session for off-line coding of looking-times.

CHAPTER III

RESULTS

Optical Data

NIRS data collected from the two regions of interest for each of the two stimulus conditions were analyzed the same way. The two detectors located over each cortical region recorded raw optical signals for subsequent digitization at 200 Hz for each of the four channels. The NIRS apparatus then converted the signals to optical density units, digitally low-pass filtered at 10.0 Hz for noise reduction, and decimated to 20 samples per second to further reduce noise. The control computer converted the data to relative concentrations of oxygenated (HbO_2) and deoxygenated (HbR) hemoglobin using the modified Beer-Lambert law(Strangman, Boas, & Sutton, 2002), which calculates the relationship between light absorbance and concentration of particles within a medium. HbO_2 and HbR were first plotted across the four 60 s time blocks composed of the following components: the entire 20 s audiovisual music trial, the 10 s baseline period, the entire 20 s audiovisual language trial, and the 10 s baseline period. Artifacts originating in infant physiology and movement were spatially filtered using a principal components analysis (PCA) of the signals across the four channels (Zhang, Brooks, Franceschini, & Boas, 2005). This approach is based on the assumption that systemic components of interference are spatially global and have higher energy than the signal changes evoked by the perceptual stimuli themselves (Zhang et al., 2005). Additional filtering was conducted to eliminate “motion artifacts,” objectively defined as a signal change greater than 5% in a tenth of second. Optical signals were averaged across blocks for each infant, and then grand averaged across infants.

Hemodynamic Response Functions and Analyses

Optical data were averaged across the two channels per region with Channels 1 and 2 averaged for the right temporal region, and Channels 3 and 4 averaged for the left temporal region. Concentration changes across useable trials for the two types of stimuli were then calculated to allow for statistical comparisons of the average response to each stimulus condition (audiovisual music and audiovisual language) in each cortical region (left and right temporal cortex). Analyses were performed on average changes in concentration of HbO_2 within a cortical region during exposure to the music stimuli, as well as during exposure to language stimuli. Because changes in concentration began manifesting 2-3 seconds after stimulus onset and showed signs of abating near the stimulus offset, concentration changes were calculated by measuring the average relative Hb concentration during the 10-20 second period for each stimulus trial and comparing it the relative Hb concentration at time -2 to 0 seconds (baseline) prior to the trial.

A 2 (cortical region:) x 2 (stimulus condition) within-subjects ANOVA revealed non-significant effects for stimulus condition $F(1,16) = 1.45$, $p=0.25$, and a non-significant effect for cortical region $F(1, 16) = 1.45$, $p=0.25$, however the cortical region by condition interaction was significant oxygenated hemoglobin $F (1, 16) = 5.286$, $p=0.035$. Thus, we conducted two planned comparisons, results indicated the left cortical region for language was significantly different from the right cortical region for the music condition, $t (21) = 2.08$, $p<0.05$. Further, results indicated right cortical region for language was not significantly different than left cortical region for the music condition, t(21) =0.26 , $p>0.05$. As illustrated by the bar graph (Figure 1) there was a significant difference in activity in the left temporal area during the language (M= 0.25641, SD= 0.171215) and music conditions (M=-0.08491, SD=0.445957), and between the left and right (M=-.011298, SD=0.782944) areas during the language condition.

This means that the left temporal area in 5-10 month-old infants is allocating processing resources, namely oxygenated hemoglobin, significantly differently when infants are listening to music than when they are listening to language. Thus, infants as young as 5 months of age are distinguishing between speech and non-speech stimuli and are allocating resources differently when processing stimuli from these two groups. Moreover, the significant difference reflected in the left and right temporal areas when speech is processed compared with the non-significant difference between these same areas when music is processed demonstrates a more pronounced and specific processing mechanism in the T_3 and T_4 sites for language than for music. Furthermore, these data are consistent with results from our earlier work (e.g., Bortfeld, Fava & Boas, revision under review) that observed in left temporal lateralization to language during an audiovisual language and visual only stimuli contrast.

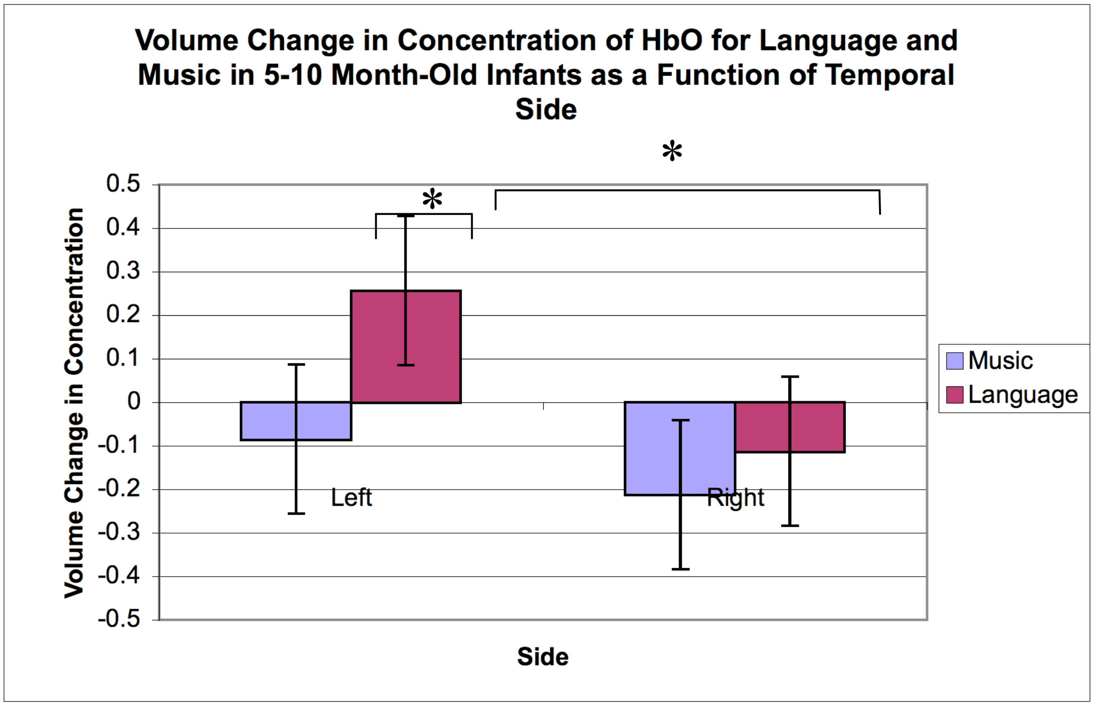


Fig. 1 Volume Concentration Change of HbO_2 for Language and Music in 5-10 month-old Infants as a Function of Temporal Side

CHAPTER IV

DISCUSSION

The present study provides specific evidence that infants ranging from 5 to 10 months in age are processing different auditory material differentially (i.e., differential hemodynamic resource allocation to bilateral temporal areas). The data reported here demonstrate two forms of auditory stimuli, music and language, are processed in different bilateral patterns. Our data demonstrate a significant decrease in change in concentration volume of HbO_2 in the right temporal area when compared with baseline for infants attending to music stimuli. In contrast, infants attending to speech stimuli experienced a significant increase in change in concentration volume of HbO_2 in the left temporal area relative to the same area during language processing. Moreover, these data duplicate our previous findings (Bortfeld, Fava, & Boas, revision under review) that infants show a significant increase in volume concentration of HbO_2 in the left compared with the right temporal area while attending to linguistic stimuli. The current study also found a significant difference in the left temporal area's volume change concentration of HbO_2 of music in comparison with language stimuli. Therefore, with the alternating presentation of the two auditory stimuli, we were able to dissociate the regions specifically involved with processing each class of stimuli within this sensory modality in particular within the left temporal area. It may be that using a blocked design, whereby stimulus type is consistent across trials, we would find even stronger effects. Regardless, based on these initial data, we argue that infants present evidence in their significantly different left temporal area allocation of hemodynamic resources that music and language stimuli are processed differently. The demonstration that music causes a significant decrease in change of concentration in HbO_2 may indicated that the site of our NIRS recording was inappropriate and that a different temporal area was involved in the processing, thus the allocation of hemodynamic resources was elsewhere when the music stimuli were presented. In the future, different 10-20 temporal recording sites should be used in order to locate the specific source of the hemodynamic resource allocation in this area, consistent with past research using fMRI and other imaging techniques.

These results are consistent with EEG data indicating that areas such as the posterior temporal cortex, the superior temporal gyrus, and Broca's Area are active during the processing of music (Koelsch et al., 2002). Conboy and Mills (2006) have demonstrated with ERP that infants just over 1 year in age show distributed bilateral temporal processing for non-native compared with native language stimuli. Pilot data of 5-10 month-old infants when listening to audiovisual music stimuli compared with visual only stimuli have demonstrated similar results of decreases in the change in concentration of oxygenated hemoglobin for both the left and right temporal areas. While these preliminary data support future research in music processing in the temporal area to record in areas other than T_3 and T_4, they also bring up the question of resource allocation and the proposition that perhaps music presents an increased amount of cognitive load. This proposition posits that when a stimulus requires extra processing, homologous areas of the brain in the alternate hemisphere are recruited for additional processing help. This idea that added cognitive load can lead to the recruitment of additional neural structures is an interesting one and such an account is consistent with the current study's findings of areas other than those already dealing with language pitch processing (left temporal area).

Limitations of the current study can be discussed in terms of the experimental design and the method of physiological investigation (NIRS). The infant population requires certain concessions and creative adaptations to experiment design due to lack of attention span and likelihood of movement during trial presentations. In the current study, we used blocked alternating trials (music/language) and then averaged across music trials. However a more powerful paradigm would employ randomized trial types and would be event-related in nature. One of the benefits of an event-related design is the inherent precision of predictions and conclusions in regards to processing at certain points in and over time. This would be especially helpful in infant research, as we are always trying to assess how developmental changes change processing (and cognition) over time. A blocked design was used in the current project because it provided an appropriate comparison for previously collected data, in which audiovisual processing was compared to visual processing. We hope to extend our research to event-related paradigms in future studies.

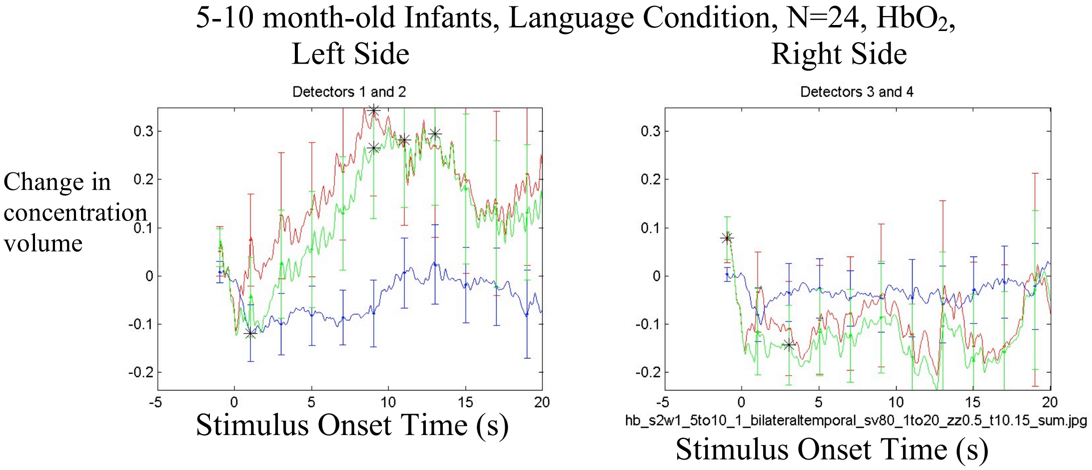
A second limitation in this experiment is the use of NIRS as an imaging tool. While other techniques such as functional Magnetic Resonance Imaging (fMRI) are more spatially precise, they require participants to remain in a motionless state for minutes at a time. Moreover, the exposure to the strength of magnetic field used in fMRI and MRI scans is not recommended for healthy infants. Other imaging techniques such as Positron Emission Tomography (PET) use the rapid decay of radioactive isotopes injected into the body to monitor the distribution of oxygen resources throughout the body. Unfortunately, the recommended amount of exposure to such isotope injections is once per year, moreover this technique is significantly more invasive than NIRS. Finally, techniques such as ERP and EEG can be used to map electrical signals that infer action potentials perpendicular to the surface of the scalp. Although these techniques are extremely accurate temporally, their spatial acuity is in the range of quarter hemisphere sections. As this project required a more spatially precise recording of the bilateral temporal areas, NIRS was selected as the method of choice.

Although there is no conclusive indication in the literature of the precise locations or networks of areas involved in music processing, the evidence provided in our own study can help us to narrow down the possible candidate areas that are the primary sources of HbO_2 allocation. Zatorre, Belin et al. (2002) conclude that, although core cortical areas such as Heschl's Gyrus are likely involved in low level processing of music (i.e. extraction and ordering of pitch information, 'belt' and 'parabelt' respectively), the organization of this class of sound across time involves right frontal-lobe activity (Peretz, 1994; R. Zatorre, Evans, Meyer, & Gjedde, 1992; R. Zatorre & Samson, 1991; R. J. Zatorre et al., 1994). Therefore, given that our stimuli included 20 second long excerpts from a piano concerto, it is likely that this involved activity in the right frontal region. This pattern of processing would explain the significant decrease in of the amount of oxygenated blood in the left and right temporal areas during the music condition. Future studies are needed in which data collection focuses on the right frontal and temporal sites to establish whether a significant increase in the change of oxygenated hemoglobin occurs in frontal region that corresponds with the decrease currently observed in the temporal region.

CHAPTER V

SUMMARY AND CONCLUSION

In conclusion, the current study has shed light on the auditory processing patterns of preverbal infants, particularly with regard to their processing of non-speech stimuli. Our results showed that. Our findings also demonstrated that in the same infants, the left temporal area was involved when they were listening to speech. These results lend support to the view that there is regional specialization unique to different forms of auditory processing. The data presented here (see Figures 2-4) demonstrate a dissociation in the processing of speech and non-speech auditory stimuli that also contain syntactic structure. Future studies will be needed to compare how preverbal infants process highly structured linguistic stimuli (e.g. a second or non-native language) relative to their native language. Results from the present study demonstrate that, even at a very young age, processing different classes of syntactic structure requires recruitment of distinct neural systems.

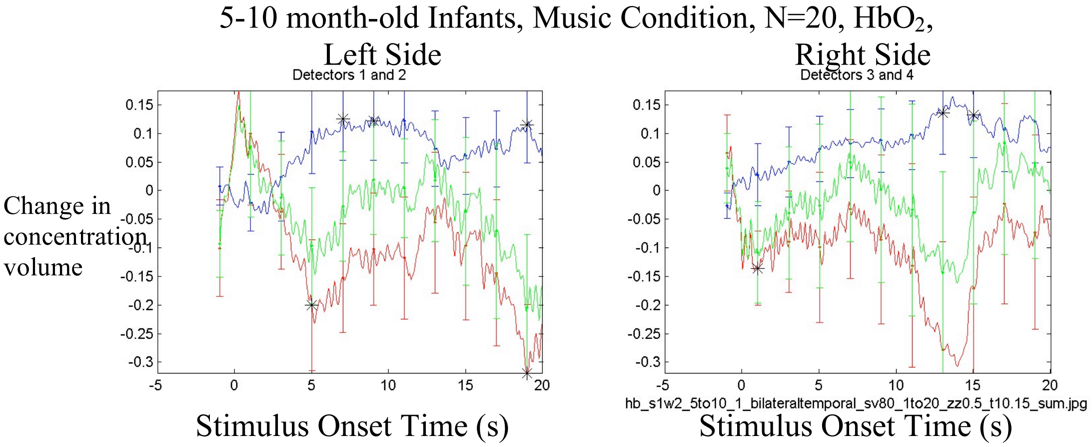


5-10 month-old Infants, Language Condition, N=24, HbO_2,

Left Side

Right Side

Fig 2. Hemodynamic Response Function of Music Stimuli



5-10 month-old Infants, Music Condition, N=20, HbO_2,

Left Side

Right Side

Fig. 3 Hemodynamic Response Function of Language Stimuli

4-11 month-old Infants, Music *Control* Condition, N=16, HbO_2,
Left Side Right Side

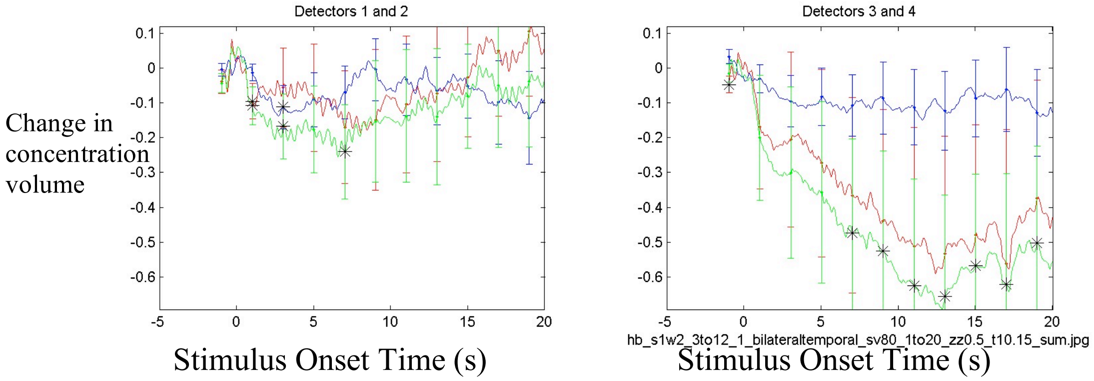


Fig. 4 Hemodynamic Response Function of Control Music Stimuli

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