

4-2017

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Bostler, Victoria A., "Neural Correlates of Multisensory Integration and the Role of Musical Experience" (2017). *Undergraduate Honors Theses*. Paper 1077.
<http://publish.wm.edu/honorsthesis/1077>

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Neural Correlates of Multisensory Integration and the Role of Musical Experience

A thesis submitted in partial fulfillment of the requirement
for the degree of Bachelor of Science in Neuroscience from
The College of William and Mary

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April 27, 2017

COMPLIANCE PAGE

Research approved by:

The Protection of Human Subjects Committee

Protocol number(s): PHSC-2016-11-08-11565-pdkieffaber

Date(s) of approval: November 8, 2016

Abstract

A large body of experimental research demonstrates that environments and behavioral experiences can affect cognitive performance. There has been increasing interest in the influence of musical experience on normal neuronal functioning over the past decade. However, much of this research has failed to target specific neural activity as indicators of cognitive function. One such measure of neural activity is the mismatch negativity (MMN), an event-related potential (ERP) that occurs in response to the presentation of a deviant stimulus in a sequence of repeated stimuli. The primary aim of the current study was to explore the influence of musical experience on sensory integration as measured using the MMN ERP. It was predicted that (1) the MMN could be used as a measure of multisensory integration and (2) that this measure of multisensory integration would correlate with an individual's level of musical experience (as determined by pre-study measurements).

Neural Correlates of Multisensory Integration and the Role of Musical Experience

A wide body of research has evaluated the effects of music on cognition and mental processes. The benefits of engaging with music are numerous, from recreational listening and self expression to targeted therapy and attention attunement (Fink-Jensen, 2007). Performing music intrinsically demands the coordination of several neural processes including visual, auditory, and motor mechanisms. The coordinating effects of music are so powerful that performing music without auditory feedback still elicits auditory system activity, just as listening to music still elicits motor system activity (Zatorre, Chen, & Penhune, 2007). Music also stimulates many of the limbic and paralimbic brain regions, explaining the intense emotional modulation music often produces (Koelsch, 2010). Music has also been shown to stimulate the release of oxytocin, a hormone associated with positive social behavior (Riedl, Javor, Gefen, Felten, & Reuter, 2017). Neural coordination, emotion modulation, and motor and visuo-auditory system refinement all contribute to neural plasticity, or the brain's ability to repair or compensate for deterioration and damage (Liou, 2010). Studies have traced enhanced neural plasticity in musicians to physical changes in the brain, namely increased white matter fibers in the corpus callosum in proportion to gray matter regions. Music training provides stimulation across neural regions, resulting in stronger neural connections and higher synchronicity in multi-region neuron firing (Steele, Bailey, Zatorre, & Penhune, 2013; Vaquero et al., 2016). Studies have also shown that the age that musicians begin training correlates to the amount of gray matter, connectivity in the corpus callosum, and sensorimotor synchronization (Steele, Bailey, Zatorre, & Penhune, 2013). Furthermore, the relationship between music and neural enhancement seems to be

bi-directional. That is, while increased practice predicts increased neural refinement, increased refinement can contribute to improved musical performance (Vaquero et al., 2016).

The neural enhancements associated with musical engagement have spurred a new field of professional rehabilitation known as music therapy. The first mentions of music as a clinical treatment appeared in the mid twentieth century, mostly in newspapers and magazines, with rare references in scientific journals (Aigen, 1991, p. 115). Investigation of the interaction between music and cognitive processes was primarily based in observation and popular anecdotal stories, with little reference to replicable experimental methods or controlled conditions (Aigen, 1991, p. 115). Since then, music therapy has continued as a popular clinical practice. Today, the focus of music therapy is primarily finding innovative modes of communication and contact between the patient or client and the social world (Fink-Jensen, 2007). Contemporary studies have successfully bolstered a base of research behind this practice and legitimized it in medical and scientific communities through empirical data collection (Aigen, 1991, p. 122). However, because of the field's recent inception, there is still much to understand about why this format of rehabilitation is so effective. Due to recent movements from pharmaceutical medications towards alternative forms of treatment, effectively incorporating music therapy into a patient's prescribed regimen is of ever increasing interest.

Many studies have evaluated music therapy as both a pharmaceutical alternative and supplement for patients with depression. Improvements in mood and cognitive function (particularly short-term memory recall) of individuals diagnosed with depression have been scientifically found as a result of music therapy, both listening and production based (Erkkilä et al., 2008). These results have also been widely demonstrated in geriatric populations suffering

from dementia. One study found that group music therapy significantly reduced depression and improved cognition in dementia patients during and up to thirty days after therapy concluded (Chu et al., 2014). Other studies have found significant improvements in dementia patients' behavioral symptoms (including agitation, delusions, and atypical motor movements) when patients underwent 20 weeks of music therapy as compared to patients receiving educational support and entertainment activity (Raglio et al., 2008).

Music therapy can be effective for persons with autism as well. According to the American Psychiatric Association, a common symptom of autism is difficulty with self expression and communication (2013). Music therapy is useful in treating this symptom because of its ability to provide an approachable medium through which to communicate emotion and moods (Fink-Jensen, 2007). It seems that music therapy offers improvements for another symptom of autism: difficulty maintaining attention (American Psychiatric Association, 2013). In a study comparing improvisational music therapy and play therapy in children with autism, it was found that music therapy was significantly more effective at improving the frequency and duration of both eye contact and sharing between the child and the therapist (Kim, Wigram, & Gold, 2008). This research and its counterparts provide a promising basis of understanding music therapy as an approach to disorders affecting social behaviors.

In light of these findings, it seems that an important area of current research is furthering the understanding of neural mechanisms underlying the effects of therapy. By discovering explanations for the cognitive effects of music and targeting treatments for specific neural systems, patients will be able to benefit from new forms of comprehensive care.

One method of promising research in this area is electroencephalography. This technique is used to study neural activity and cognitive processes by measuring the electrical activity (known as the electroencephalogram, or EEG) of the brain through electrode amplification (Luck, 2014, p. 4). Electrodes secured to the scalp record small neurologically generated voltages and depict them through computer processing systems. A succinct explanation can be found in Steven Luck's *An Introduction to Event-Related Potential Technique* (2014):

The EEG is recorded from electrodes on the scalp, with a conductive gel or liquid between each electrode and the skin to make a stable electrical connection. The electrical potential (voltage) can then be recorded from each electrode, resulting in a separate waveform for each electrode site. This waveform will be a mixture of actual brain activity, biological electrical potentials produced outside of the brain (by the skin, the eyes, the muscles, etc.), and induced electrical activity from external electrical devices that is picked up by the head, the electrodes, or the electrode wires. If precautions are taken to minimize the non-neural potentials, the voltages produced by the brain (the EEG) will be relatively large compared to the non-neurological voltages. (p. 21)

Because EEG data draws directly from brain activity, it is highly reliable for understanding neural activity and may be useful in exploring the mental processes involved in music. However due to the electrodes' sensitivities to irrelevant biological contributors (such as eye blinks, muscle movements, and drowsiness), raw EEG recordings can be very imprecise in localizing task-specific neural activity to specific brain regions, making it difficult to isolate and understand distinct neural processes (Luck, 2014, p. 4). To compensate for this, researchers can apply filters and averaging techniques to EEG data that work to subtract excess noise in the waveforms, thus

minimizing any non-neural confounds. By averaging voltages across many trials and correlating them with timed markers of when stimuli were presented, researchers are able to extract waveforms that are highly indicative of neural responses to specific events in a task, known as event-related potentials, or ERPs. ERPs are time locked neural events that can be used to understand responses to controlled stimuli in an experimental setting (Luck, 2014).

The mismatch negativity (MMN) is a specific component of the ERP waveform that can be defined by its polarity, latency, and general scalp distribution (Luck, 2014, p. 66). It is usually represented by a negatively peaking voltage occurring between 160 and 220 ms after an incongruent stimulus is presented. This voltage is most strongly recorded from electrodes distributed across the fronto-central midline of the scalp. The MMN typically occurs as an automatic response to an incongruity in a series of repeated stimuli. In order to elicit this component, many studies are designed in what is known as an oddball paradigm. In this paradigm, a subject will experience a series of trials, with 80% of trials consisting of a standard stimulus condition and 20% of trials consisting of a deviant stimulus condition. The MMN is observed in response to deviant conditions, and is attributed to the brain's ability to contrast presented stimuli with short term memories of previously presented data (Luck, 2014, p. 85).

Although the MMN is observed in response to physical stimulus inconsistencies, there is some research to suggest that the response is influenced by subjective perspective. The "McGurk illusion" is an excellent example of this influence. The McGurk illusion occurs when an auditory phoneme is simultaneously paired with a visual depiction of a different phoneme being articulated (Saint-Amour, De Sanctis, Molholm, Ritter, & Foxe, 2007). Subjects often combine the two stimuli and report perceiving a third phoneme-- some combination of the visual and

auditory syllables-- even though this perceived phoneme was not actually presented visually or auditorily (Saint-Amour, De Sanctis, Molholm, Ritter, & Foxe, 2007). Psychologists tend to attribute this perceptual illusion, known as the McGurk effect, to the multisensory integration processes of our brains (Saint-Amour, De Sanctis, Molholm, Ritter, & Foxe, 2007). One study done by the Nathan S. Kline Institute for Psychiatric Research evaluated the MMN response under McGurk illusion conditions and determined that the response was elicited when visual stimuli did not match auditory stimuli, indicating that sensory integration processes contributed to the MMN component (Saint-Amour, De Sanctis, Molholm, Ritter, & Foxe, 2007).

Because of the automatic nature of the MMN (that is, the presence of the MMN despite a subject's attention on a deviant stimulus), as well as its sensitivity to multisensory integration, the MMN is an ideal means for studying the multisensory integration effects of musical production. Several studies have already used the MMN to explore this effect. In a study by Proverbio et al. (2014) comparing musicians with nonmusicians, participants watched a series of videos of either a violinist or a clarinetist playing tones on their respective instruments. However occasionally the tones presented auditorily would not match the tones played in the videos (either in pitch or number). The study primarily found the N400 response generated in musicians to be significantly different than the response generated in nonmusicians. The study went on to correlate this N400 response (typically understood as a response to processing the meaning of a stimulus) with a visual MMN (vMMN) response, reminiscent of those found in McGurk effect studies (Proverbio, Calbi, Manfredi, & Zani, 2014).

Another study, titled "Auditory-Somatosensory Integration and Cortical Plasticity in Musical Training" (2009), evaluated multisensory integration in musical training by comparing a

group of participants trained in motor and auditory modalities to a group trained in the auditory modality alone. 23 participants with no music training were randomly assigned into a multimodal group and an auditory group. The multimodal group was trained to play a short and musically incomplex one-line piano melody. The auditory group was auditorily trained by listening to one of the multimodal group's training sessions. Participants' neural activity was assessed before and after training. In both pre and post assessments, participants listened to a series of broken C major chords (played from root note to fifth note). Occasionally the final tone in the chord was lowered by a semitone. In the pre-assessment, no difference between the two groups was detected in MMN response to the deviant final tone of the chord. In the post-assessment however, significantly increased MMN amplitudes were found in multimodally trained participants, whereas these effects were much smaller in auditorily trained participants. Researchers concluded that training through multisensory integration results in more robust neuroplastic changes than does single sensory training (Pantev, Lappe, Herholz, & Trainor, 2009).

Another study by Pantev et al. (2003), evaluated cortical representation of tones and found that musicians devote greater cortical regions to piano notes than to pure, electronically produced, tones. This enlargement was also correlated to the age the musician began training. The study extended its findings by comparing MMNs of musicians to nonmusicians in response to simple melodies. It found that musicians had greater MMN mean peak amplitudes in response to changes in melodic contour than did nonmusicians (Pantev et al., 2003).

The primary purpose of the current study was to contribute to the understanding of neural mechanisms underlying the cognitive enhancements that result from experience playing music.

Specifically, the study aimed to address whether experience playing music (and thus measurable experience combining several neural processes) improved abilities to integrate visual and auditory stimuli.

The current study evaluated participants' responses to four stimuli (two visual and two auditory) presented in iterations and pairings that comprised an oddball paradigm. The neural responses to these standard and deviant pairings were correlated in data analysis with participants' self-reported musical experience, as obtained through a pre-assessment survey. The goal of the research was to determine (a) how multisensory integration is reflected in neural activity using the MMN and (b) if the integration and MMN activity are correlated with a subject's musical experience. Consistent with prior research, this study hypothesized that participants with extensive musical experience (as determined by pre-study measurements) would have significantly different multisensory integration and MMN responses than participants without this experience.

Methods

Participants

Thirty-seven participants from the College of William and Mary volunteered to participate in this research. Because of a gender bias introduced by recruiting volunteers in tandem with another study, only female participants were included. Six male participants were excluded from the data. Two additional participants were excluded due to failure to complete the study. The average age of the remaining 29 participants was 19.9 (SD = 1.36) years old. Each

participant provided informed consent and the study was performed in accordance to the rules and regulations of the College of William and Mary's IRB.

Measures

Prior to the commencement of the task, each participant was asked to read and sign an informed consent form approved by the IRB at the College of William and Mary. The participant then completed a computerized survey assessing musical experience in a private room. The survey asked questions regarding how many years of formal training in an instrument (including voice training) the participant had completed, the fluency of the participant in music notation, the age of onset of formal training, the type and quantity of instruments the participant had extended experience with, and self-determined overall musical ability on a 100 point scale. The participant also completed a standard demographics survey at this time. The completed surveys were filed according to the participant's subject number and were never stored with the signed informed consent forms to ensure confidentiality.

Procedures

Participants were seated roughly 24 inches from a 19 inch LCD monitor inside an electrically shielded booth called a Faraday chamber with the lights off. They were fitted with a pair of Eartone 3a insert earphones. Participants were told that they would be presented with a series of shapes and tones, sometimes presented in pairs and sometimes independently. Participants were instructed to fixate on the center of the screen and to remain alert for the duration of the study.

Each trial consisted of an "alone" and a "paired" trial block of four stimuli (two visual and two auditory). The visual stimuli included a circle and a square, represented by the letters

“N” and “G” respectively, in Webding font. The auditory stimuli consisted of two tones, a 1000Hz tone (referred to as the “high” tone) and a 500Hz tone (referred to as the “low” tone). In the alone trial block each stimulus was presented by itself 20 times in random order. This was so that the neural activity associated with each stimulus independently could later be subtracted from the activity associated with each stimulus pairing, leaving the activity associated with integrating the stimuli as the difference. After the alone trial block completed, the paired trial block commenced. This trial block consisted of 200 trials of the audio and visual stimuli being presented together as pairs. There were four pairings of stimuli that were presented in pseudo-randomized order, according to an oddball paradigm. In the standard pairings, the square and low tone were presented simultaneously, as were the circle and the high tone. Each of these pairings was presented 80 times in the trial block. In the deviant pairings, the square and high tone were presented together, as were the circle and the low tone. Each of these pairings was presented 20 times in the trial block. In both the alone and paired trial blocks, each image was on the monitor for 250ms and each tone sounded for 250ms.. The inter-stimulus interval was randomized between two and seven seconds (mean=4.5s). The inter-block interval was self directed by participants according to how long it took them to read the instructions. A second version of the task was created with inverted standard and deviant pairings in the paired trial block. The versions, denoted as an “A” version and a “B” version were randomly assigned to each participant at the beginning of the study (See Tables 1, 2, and 3 for a visual breakdown of the pairings and versions).

Data Acquisition/Analysis

Electrophysiological data were recorded continuously at 2000 samples per second using a DBPA-1 Sensorium bio-amplifier (Sensorium Inc., Charlotte, VT) with an analog high-pass filter of 0.01 Hz and a low-pass filter of 500 Hz. Recordings were made using a fabric cap bearing 72 Ag-AgCl sintered electrodes while participants were seated in a Faraday chamber. EEG recordings were made using a forehead ground and a reference at the tip of the nose. Vertical and horizontal eye movements were recorded from electrodes placed above and below the eyes and from electrodes placed at the lateral canthi respectively. All impedances were adjusted to within 0-20 k Ω at the start of the recording session. EEG data were analyzed off-line using EEGLab or MatLab. Channels that contained excessive artifacts were interpolated using a spherical spline. Data were then corrected for both horizontal and vertical ocular artifacts using independent component analysis. Following the removal of ocular artifacts, the data were segmented between -300ms and 1000ms with respect to stimulus onset. Following segmentation, data were baseline corrected and filtered using an IIR Butterworth filter with a high-pass frequency cutoff of .1Hz and a low-pass frequency cut-off of 20Hz. A simple voltage threshold artifact detection was run for each subject with the voltage limit set to 100 100 μ V. Participants with more than twenty-five percent of the trials rejected on this basis were excluded from further analysis (N=0). Segmented data were then averaged over trials for each of the standard and deviant stimulus presentations. Unisensory neural activity was estimated by summing the ERPs elicited by auditory and visual stimuli when presented alone. Multisensory neural activity was measured using the ERPs elicited by paired auditory and visual stimuli. Thus, the effects of multisensory integration can be evaluated in the differences observed between ERPs associated with unisensory and multisensory signals. Finally, the Multisensory MMN was measured using

the difference between multisensory effect waveforms (i.e., multisensory - unisensory) for the “standard” and “deviant” multisensory pairings. The grand average ERPs for each of these comparisons was used to identify the time course and topographical distribution of multisensory integration effects and the MMN. Mean amplitude and peak latency of the MMN component were exported and used for the statistical analysis. ERP components were measured at parietal, central, and frontal electrodes (FCZ, CZ, PZ). A two-tailed one sample T-test was used for statistical analysis of the multisensory integration (MSI) and MMN waveform differences, and a correlation analysis was used to compare pre-assessment survey results to the ERP data. All statistical analysis was done in SPSS.

Results

Component Identification

Grand average waveforms for each of the conditions are presented in Figure 1. In order to test for the effects of MSI, differences between the ERP mean amplitudes of paired stimuli (both in standard and deviant conditions) and the sum of mean amplitudes for individually presented stimuli were generated (see Figure 1 column B). Non-zero values in this difference waveform represent alterations in activity generated when multisensory stimuli are integrated, compared with when they are processed independently. The MMN was measured by calculating the difference between MSI measures for the deviant and standard pairs (i.e., a difference of differences). Non-zero values in this difference waveform represent alterations in MSI for deviant, compared with standard pairs. Waveforms and component differences were generated from FCZ, CZ, and PZ electrode sites (presented in Figure 1). Components N1 (75-150ms), P1 (150-300ms), and P2 (300-600ms) were identified in the raw ERP waveforms and corresponding

full scalp topographies were mapped (see Figure 1 column A). Three components were identified in the MSI difference waveforms: C1 (75-150ms), C2(150-300ms), and C3 (300-600ms). Their corresponding topographies are also depicted (see Figure 1 column B). Component C1 was identified in the MMN difference between 300 and 600 ms (see Figure 1 column C).

MSI

In order to determine how MSI was reflected in the ERP, grand averaged waveforms following the common paired stimuli were compared with the sum of the grand averaged waveforms for visual and auditory stimuli when presented individually. If there are no differences between the paired and summed waveforms, then one can conclude that there is not an effect of the pairing on the recorded electrical activity. However, inspection of these waveforms revealed a significant difference between ERP waveforms generated when stimuli were presented alone and ERP waveforms generated when stimuli were paired. Component C1 corresponded with a decreased amplitude of the N1 ERP and was significantly different from zero, $t(28)$, $p < .01$. Component C2 corresponded with a decreased amplitude of the P1 ERP and was significantly different than zero, $t(28)$, $p < .01$. Component C3 corresponded with a decreased amplitude of the P2 ERP and was significantly different than zero, $t(28)$, $p < .01$. As can be seen in Figure 1 column B, MSI differences were seen across the fronto-central regions of the scalp. Figure 2 also depicts mean amplitudes and standard errors for these components.

MMN

The MMN activation was evaluated by subtracting the MSI difference for deviant stimuli pairings from the MSI difference for standard pairings (see Figure 1 column C). The difference

between these adjusted standard and deviant paired block waveforms was calculated at the FCZ, CZ, and PZ sites. This difference waveform was found to be significantly different than zero, $t(28)$, $p < .01$. The negativity was found to be greatest across upper occipital electrode sites. The head plot and graphical representation in Figure 1 row C display that MMN activity in multisensory integration is processed in the areas of the brain responsible for visual processing.

Correlations with Musical Experience

The second goal of this research was to determine whether reported data defining experience playing music was associated with the multisensory integration differences or the mismatch negativity ERP component. Self reported scores from the coded pre-assessment survey were compared to the mean amplitude differences in ERP waveforms generated at the FCZ, CZ, and PZ electrode sites. Formal training duration (in years), age of beginning formal training and self-defined musical ability were all scaled and run through a Pearson correlation test with mean amplitude differences. Other variables were also nominally evaluated such as note-reading literacy and number of instruments played. As seen in Figure 2, no statistical significance was found in correlated musical experience and waveform differences, inconsistent with our expectations.

Discussion

The purpose of this study was to evaluate the activity generated when combining multisensory information and to explore the relationship between this activity and musical experience. A standardized t-test confirmed that MSI activity was generated when processing visual and auditory stimuli together. The difference between summed independent amplitudes was statistically different than paired amplitudes, implying that the waveforms generated in the

paired trials could not be explained by only the activity associated with independent stimuli. That is, there must be some effect causing the distinction between the two conditions. Consistent with prior research, we can conclude with reasonable certainty that multisensory integration activity accounts for this difference.

Of particular interest is that the earlier components, C1 and C2, between 75ms and 300ms possess a topography that is consistent with the distribution of auditory ERP responses, while the later C3 component possess a topography that is consistent with visual ERPs. One potential explanation for this finding is that it is the auditory processing that is altered first during multisensory integration and that visual processing is not affected until the stimuli have been further processed. This may also reflect a general tendency to unevenly weight the allocation of neural resources during multisensory integration to favor the procession of visual information and may be consistent with the McGurk effect described earlier.

Similar findings can be discussed regarding the MMN waveforms. Because of the significance of differences between standard and deviant conditions, it can be concluded that there is an MMN response to deviant pairings, meaning that the unusual pairing of visual and auditory stimuli was recognized by the brain. Comparing the latency and duration of the MMN peaks in the waveforms with those described in previous research, it is clear that the MMN activity generated in the current study mirrored MMN responses discovered in similar studies, where MMNs generated occurred 95- 200ms after the stimulus was presented, further confirming this conclusion (Pantev et al., 2003).

It is also worthwhile to note that the topographical distribution of the MMN indicates that it is localized over the occipital cortex, suggesting involvement of the visual cortex. Considering

the findings related to multisensory integration, this result may again reflect an emphasis on the processing of visual information in multisensory contexts. In other words, when auditory and visual stimuli appear together in an unusual way, it is the visual cortex that processes the deviance from expectation.

Data relating musical experience with these waveforms did not support any meaningful correlations, inconsistent with the expectations of the study. There are a few potential explanations for this inconsistency that could be explored in future research. Music has been found to predict multisensory integration between motor and visual processing (Proverbio, Calbi, Manfredi, & Zani, 2014). It is possible that since the current study did not address motor system activity, this neural process confounded the relationship between visual and auditory systems. It is also possible that the participant pool studied did not have enough experience to demonstrate significant correlations. Previous studies have identified MMN distinctions between musicians and nonmusicians, recruiting only well renowned professional musicians (Proverbio, Calbi, Manfredi, & Zani, 2014). If the relationship between MMN activity and musical experience does not present itself until later in life or until achieving exceptional musical ability, the current study would not have accounted for the relationship in its population pool. The limitations of the study may provide additional explanations for the unsupported hypothesis.

Limitations

A limitation of the current study is the method of participant recruitment. This research was conducted in conjunction with a similar study, and for efficiency purposes the two studies merged their participant pools. This introduced a bias in the demographics of the participants being mostly caucasian females between 18 and 22 years of age. This participant bias narrowed

the current research's scope of study, such that it is not fully representative of the population. Future research would do well to recruit a more inclusive pool of subjects.

Another limitation of the current study is the implicit subjectivity in determining musical experience. Musical background is difficult to isolate, quantify, and measure, in part due to how integrated music is with everyday life. Even the very definition of music is arguable, as music differs from culture to culture and modern composition merges with everyday sounds (Kania, 2016). Because of this, the study's pre-assessment survey included implicit opportunities for subjective influence, leading to less reliable correlations. Further work could be done to identify objective measures of music and musical experience before drawing comparisons with neurological data.

A final limitation of the study is its lack of an active participation task. Without a specific activity to focus participant attention, participants may have felt drowsy or distracted. While this limitation does not detract from neurological evidence produced in the study (largely due to the automatic nature of the MMN response such that attention is not necessary to elicit activity), it is possible that this lack of motor integration could have introduced an influence into the research. Future studies should isolate a simple task for participants to complete while collecting data in order to better standardize participant attention.

Conclusions

The current study provides evidence that combining stimuli across sensory inputs activates central brain regions responsible for coordinating neural processing. Additionally this research defines a specific MMN response to pairing of stimuli across sensory inputs. This is significant because the MMN responses elicited in the study are not based on the stimuli

themselves. There is nothing physically unusual about the stimuli in the paired conditions when compared to the independent conditions. The only deviant component in the study was the ways in which the stimuli were paired. Further, this MMN response was found to be strongest in upper occipital regions. This implies that when deviances in multisensory data are presented, participants registered the deviances in reference to the visual stimuli, as opposed to the auditory stimuli.

As is often the case in neurological studies, more research is needed to fully understand the activation patterns evidenced in the data. However, these conclusions are useful in acting as a basis for future research regarding multisensory processing and could ultimately support developments of therapeutic techniques to address populations with difficulty coordinating and combining sensory input.

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Table 1 *Alone Trial Block*

Number of Trials	Stimulus
20	High Tone (1000 Hz)
20	Low Tone (500 Hz)
20	Square
20	Circle

Table 2 *Version A Paired Trial Block*

Number of Trials	Stimulus Pairing
80	Square with Low Tone
80	Circle with High Tone
20	Square with High Tone
20	Circle with Low Tone

Table 3 *Version B Paired Trial Block*

Number of Trials	Stimulus Pairing
80	Square with High Tone
80	Circle with Low Tone
20	Square with Low Tone
20	Circle with High Tone

Table 4
Correlations Between Survey Data and ERP Components as Measured at FCZ and PZ channels

	Component 1 FCZ Common	Component 2 FCZ Rare	Component 2 FCZ Common	Component 2 FCZ Rare	Component 3 PZ Common	Component 3 PZ Rare	Component 3 PZ Rare	Component 1 MMN PZ
Formal Training								
	.156	.004	-.042	-.108	-.311	-.305	-.058	
	.419	.983	.831	.578	.101	.108	.765	
	29	29	29	29	29	29	29	
	Pearson Correlation							
	Sig. (2-tailed)							
	N							
Music Ability								
	.194	.211	-.271	-.185	-.168	-.164	.268	
	.314	.271	.156	.337	.384	.395	.160	
	29	29	29	29	29	29	29	
	Pearson Correlation							
	Sig. (2-tailed)							
	N							
Age Of Onset								
	-.087	.021	-.130	-.205	-.167	-.183	-.120	
	.671	.920	.525	.315	.415	.371	.560	
	26	26	26	26	26	26	26	
	Pearson Correlation							
	Sig. (2-tailed)							
	N							

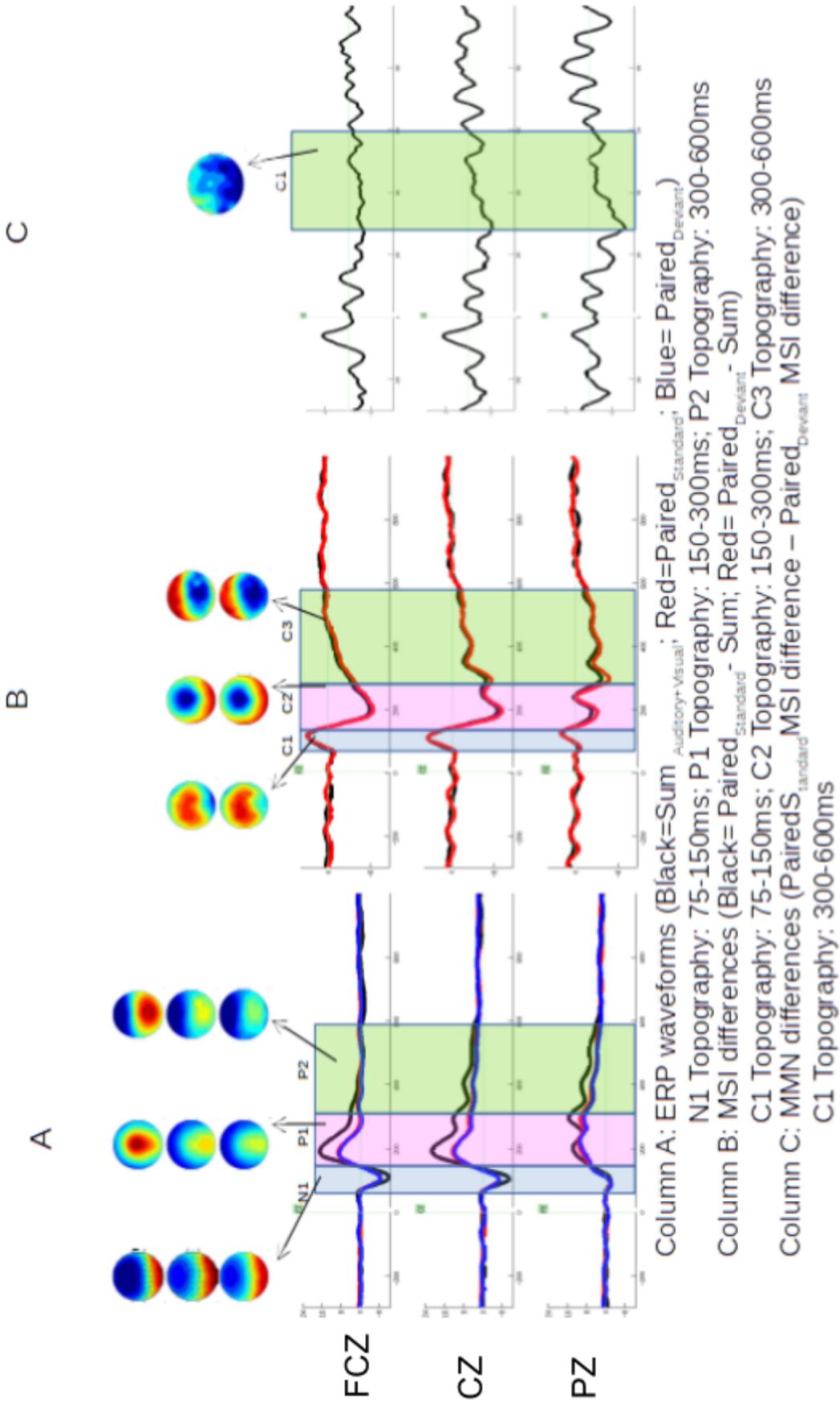


Figure 1 ERP waveforms, measurement windows, and corresponding topographies

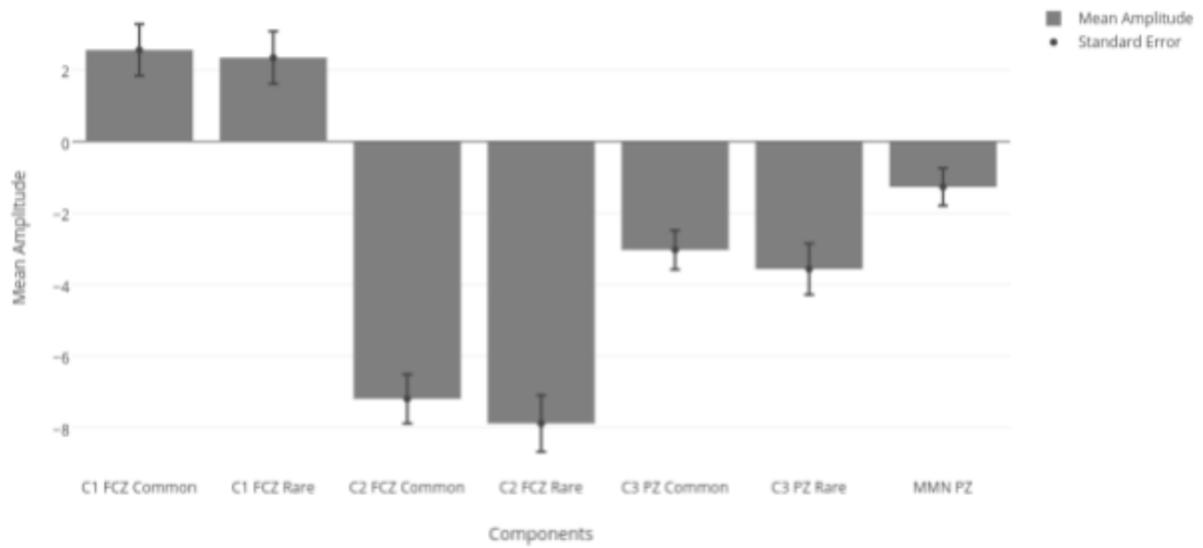


Figure 2 Mean Amplitudes of Multisensory Integration Differences