MULTISENSORY INTEGRATION THROUGH AUDITORY AND SOMATOSENSORY MISMATCH NEGATIVITY

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PLAGIARISM

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Bora Çelebi
08.10.2021

ABSTRACT

In everyday life, we rely on our sensory organs to gather information from the environment to take evolutionarily necessary actions. The most crucial of these information comes from the novelty in the stimulus we face. While a pattern of the same sensory cue repeats, it usually does not pose a danger to the self. However, a change in this pattern could mean a novelty in the environment that is needed to be processed to gain enough information about this new situation. In this aspect, mammal brains have a unique mechanism of mismatch responses which are elicited after a certain deviancy appears in the pattern of the stimuli. These responses have been observed with electroencephalography (EEG) in auditory, somatosensory and visual modalities as mismatch negativity (MMN). However, the effect of multisensory integration has not been studied in audiotactile mismatch responses. In this study, I examined the audiotactile novelty detection mechanisms using EEG. I found that, in the presence of auditory deviance, mismatch negativity (MMN) usually is within the auditory MMN range. Also, in presence of auditory standard stimuli, somatosensory mismatch negativity tends to be at the more negative side resembling its auditory counterpart.

Keywords: mismatch negativity, multisensory integration, audiotactile integration, novelty detection, mismatch responses

ÖZET

Günlük yaşamda, evrimsel olarak gerekli eylemleri yapmak için çevreden bilgi toplar ve duyu organlarımıza güveniriz. Bu bilgilerin en önemlisi, karşılaştığımız uyarandaki yenilikten gelir. Aynı duyusal uyaran bir örüntüyü tekrar ederken, genellikle kişi için bir tehlike oluşturmaz. Bununla birlikte, bu örüntüde bir değişiklik, bu yeni durum hakkında yeterli bilgi elde etmek için işlenmesi gereken ortamda bir yenilik anlamına gelebilir. Bu açıdan, memeli beyinleri, uyaran örüntüsünde belirli bir sapma ortaya çıktıktan sonra ortaya çıkan benzersiz bir uyumsuzluk mekanizmasına sahiptir. Bu mekanizma elektroensefalografi (EEG) ile işitsel, dokunsal ve görsel modalitelerde uyumsuzluk komponenti (Mismatch Negativity; MMN) olarak gözlemlenmiştir. Bununla birlikte, çoklu-duyusal entegrasyonun etkisi, işitsel-dokunsal uyumsuzluk durumlarında çalışılmamıştır. Bu çalışmada, EEG kullanarak işitsel dokunsal yenilik algılama mekanizmalarını inceledim. İşitsel sapma varlığında, uyumsuzluk komponentinin (MMN) genellikle işitsel MMN aralığında olduğunu buldum. Ayrıca, işitsel standart uyaranların varlığında, dokunsal uyumsuzluk komponenti, işitsel karşılığına benzer şekilde negatif tarafta olma eğilimindedir.

Anahtar kelimeler: uyumsuzluk komponenti, çoklu duyu entegrasyonu, işitsel dokunsal entegrasyon, yenilik algısı, uyumsuzluk tepkileri

ACKNOWLEDGMENTS

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1. INTRODUCTION

Conscious animals under different circumstances use their diverse sensory organs to receive crucial information about the environment they are in. In order to survive and comply with the evolutionary rules, various sensory information is processed in the brain and therefore included in the decision making and action processes. This processing system is foundational to every animal as it creates a complex system that allows the driving of conscious living. The human nervous system in this aspect, poses the crucial role in processing sensory cues to transform them into understandable objects. In simple, various sensory signals are accumulated by the nervous system, then in the brain these signals are processed and sent to the other regions that are responsible for different cognitive functions. (Hudspeth & Logotheis, 2000).

This process occurs primarily with receptors on different sensory organs receiving environmental signals. Different signals transmitted from diverse sensations are integrated synchronously in the brain and compared between each other or compared with the previous information regarding the aspects of the stimuli ,subject has faced (Gilbert & Sigman, 2007). These processes structuring human sensory system, extracts information from the environment in an optimal way in order to use this information in other cognitive processes. Moreover, detection of novel, unusual and out-of-pattern cues is a fundamental ability of sensory systems as that would ensure the survival of the mentioned animal (Titinen et., al., 1994). It has been known that,

brain has fundamental cognitive abilities that would allow the detection of these types of stimuli in every sensory modality.

1.1. Auditory Perception

Movement of air molecules in the environment creates mechanical energy. This is then captured by auditory system and transformed into neural signals that could be used to perceive certain kinds of sounds and objects (Purves et. al., 2008). In this aspect, peripheral auditory system was used to collect sound waves and then they are transitioned into neural signals. The external ear collects the energy created by sound waves by focusing the waves in the background to the inside of the ear. And then, ear canal amplifies and enhances these sounds according to the resonance of itself. This amplified sound waves then reach the tympanic membrane and they are also responsible for enhancing of the stimuli to be accessible by the inner ear that would be processing the sound. After these enhancements and preprocessing steps, the sound wave arrives at the oval window at the entrance of the cochlea. Then the basilar membrane and hair cells in the cochlea are responsible for transitioning these physical waves into neural information. Thus, the receptors in cochlea translate the sound

energy to neural dynamics (Rowe, et., al., 2014). (Figure 1)

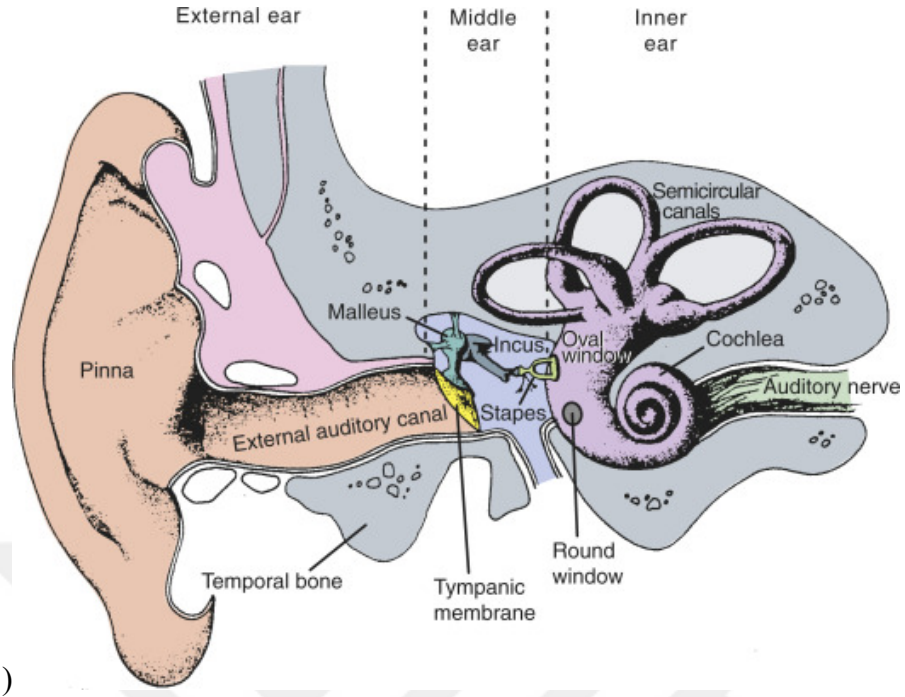


Figure 1: Auditory peripheral pathway. Lindsay, P. H., & Norman, D. A. (1972). *An introduction to psychology*. Academic.

These responses from the receptors are then projected into cochlear nucleus in the brain. The signal is then transmitted to inferior colliculus which is responsible for the auditory-motor integration in quick and reflexive movements to the sound stimuli. At the superior olivary complex, signals from both ears are converged together. Also, cochlear nucleus projects signals to nucleus of the lateral lemniscus which is responsible for the spatial perception of auditory stimuli. And then, these signals are transmitted into thalamus which is the last region before the sensory cortices for all of the modalities. These information are then sent to the primary auditory cortex which is responsible for processing low-level sensory information that is gathered by the environment (Lakatos, et., al., 2007). (Figure 2)

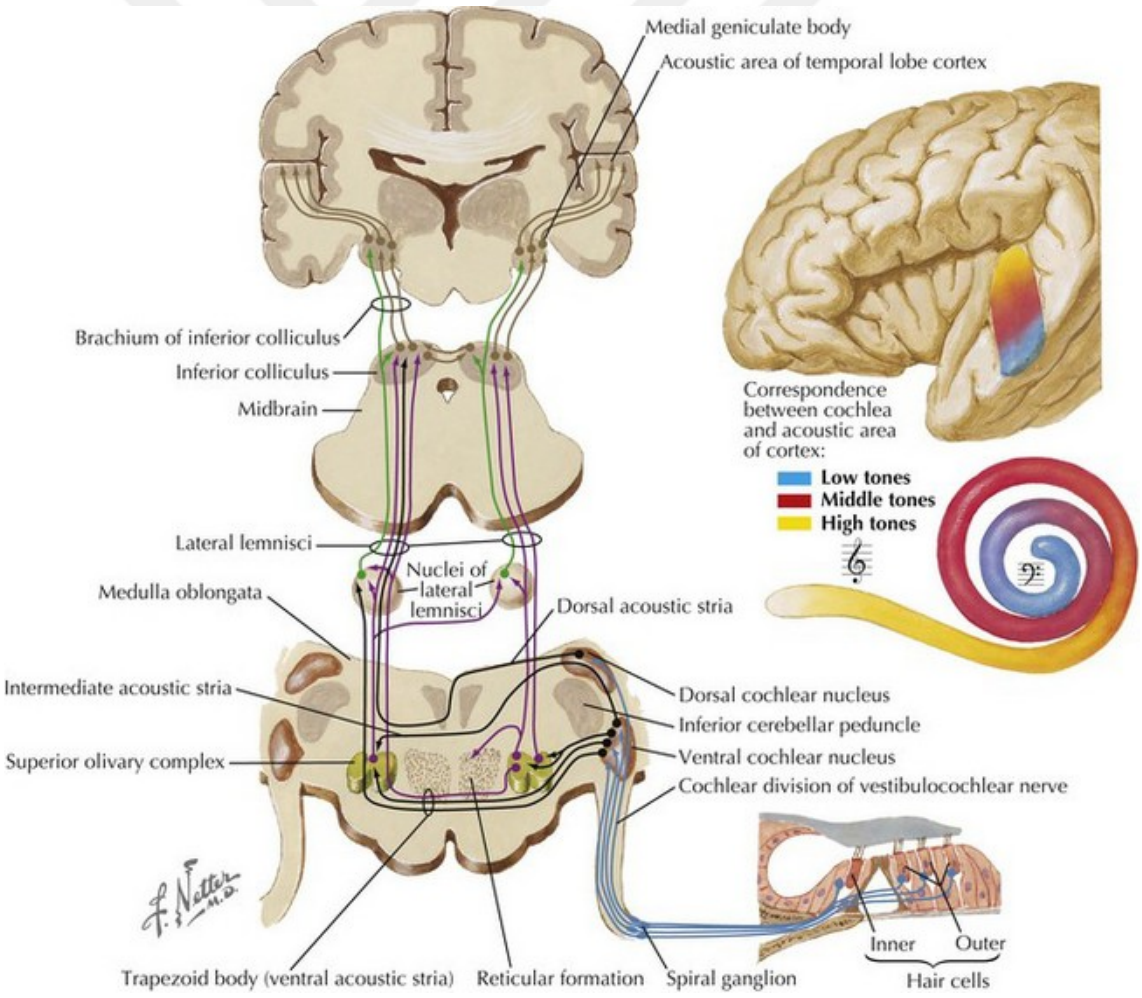


Figure 2: Auditory neural pathway (Cranial Nerve VIII | Clinical Gate (n.d.)

After the information was transmitted from the peripheral auditory system to the auditory neural pathway, the signal is then processed, classified and the meaning of the sound was extracted (Bizley & Cohen, 2013). This mechanism lets us perceive available auditory cues in the environment. This system is also responsible for detecting novelties and errors in the pattern of a sound which would be regarded as an important survival skill as it may classify non-dangerous stimuli from the novel and potentially dangerous ones (Malmeirca, et. al. , 2014).

1.2. Haptic Perception

Haptic system allows us to explore the objects around us and gather meaningful information about their properties. Material properties such as roughness, softness, viscosity, coldness, slipperiness of surfaces and objects are processed in order to understand the true nature of the stimuli. Also, some spatial properties of the material such as shape, curvature, size and orientation could be processed by the haptic system (Kappers & Bergmann Tiest, 2013).

Contrary to other sensory modalities, receptor distribution of the haptic system is wide across the surface of human skin, muscles and tendons and these receptors are activated through direct contact with the stimuli (Lederman & Klatzky, 1993). In this aspect, two general types of receptors exist in haptic system that gathers information from the environment; mechanoreceptors and thermoreceptors on the skin which process cutaneous inputs along with mechanoreceptors on tendons and muscles which process kinesthetic inputs (Lederman & Klatzky, 2009). Also, these receptors are not uniformly distributed around the skin thus, somatosensory receptive fields of different parts of the body differ in size and in the ability to gather information (Klatzky, & Lederman, 1992; Fitzgerald et. al., 2006).

The information gathered from the receptors on the skin and muscles are transferred into the sensory ganglia of the cranial nerves and then they enter the spinal cord and reach to the ventral posterior nuclear complex of thalamus. The signal is then projected into the primary somatosensory cortex which is responsible for processing the haptic information (Haggard, 2006). (Figure 3)

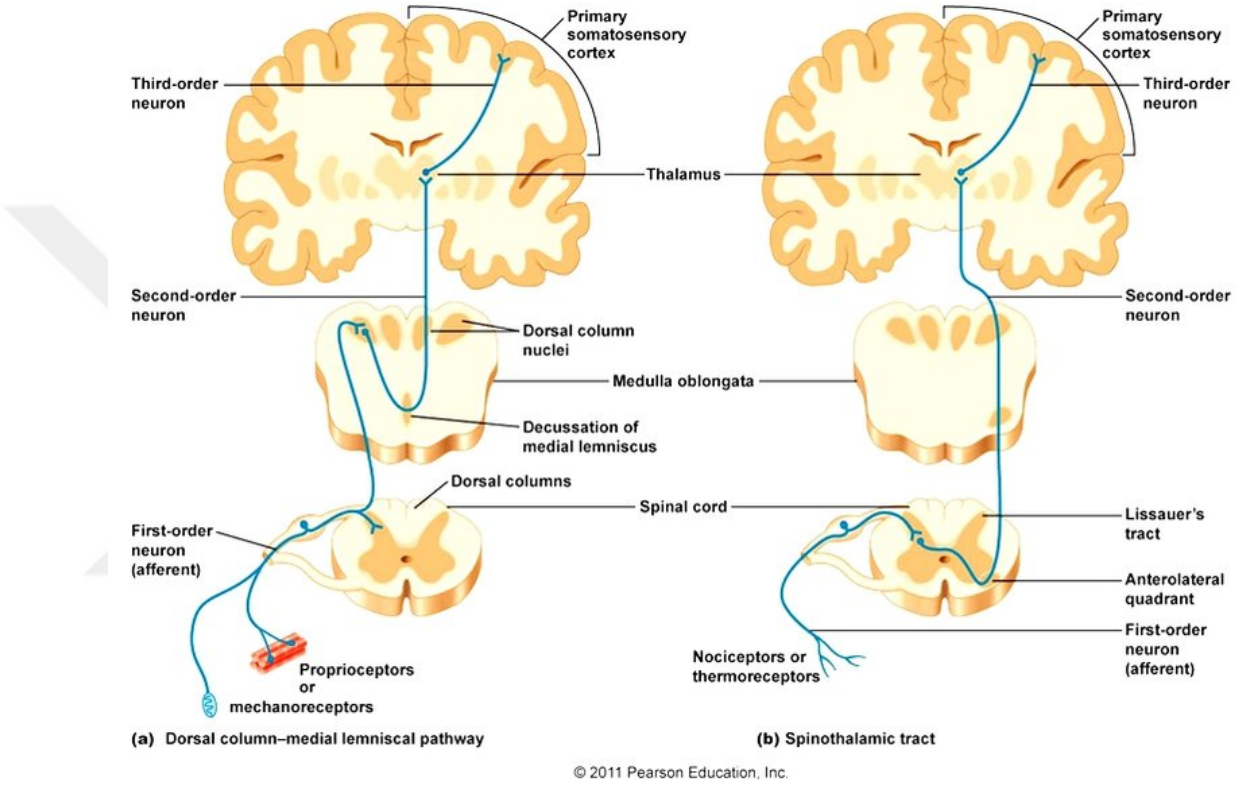


Figure 3: Somatosensory pathway

1.3. Multisensory Integration

In everyday life, we are often exposed to several different stimuli simultaneously. We hear a sound when we are visually contacting a target and also actively exploring an object by hand. Thus, these situations require convergence and

integrity of different sensory modalities in order to understand the environment around us. In this aspect, brain integrates these different resources from different sensory organs in order to perceive and understand the object of interest in a faster and more reliable manner (Stein & Stanford, 2008). This process could be regarded as an aid to capture the relevant information from the available signals in order to increase the speed of a response to a stimulus.This phenomenon of integration between different sensory modalities in order to get a better response is called multisensory enhancement (Diederich & Colonius, 2004). Multisensory enhancement has been found to be affecting the magnitude of the neural response to a fixed combination of stimuli and decreasing interval between stimulus onset and motor action resulting in a faster processing of sensory information and in a faster convergence into the response (Rowland, et. al., 2007). Multisensory enhancement has also been found to be affecting the latencies of physiological responses. This means that, it facilitates and speeds up the early processing steps needed to compute the signals from environmental stimuli (Rowland, et. al., 2007). Also, contrary to enchancement, multisensory depression could decrease the response to a crossmodal stimuli compared to the response to a unisensory one. This process incorporates some mechanisms which elicit attentional shifts between sensory modalities which would decrease the amount of resources conserved for each modality (Spence & Driver, 2004). Thus, in presence of different modalities, likelihood of a response is decreased along with higher latencies of detection of the cues.

In this aspect, it can be easily concluded that, there exist underlying mechanisms in the brain which incorporate different sensory modalities to make faster and more robust decisions. Also, multisensory enhancement speeds up the perception

process so that concrete information about the environment could be accessed with precision and ease.

Several regions in brain have been shown to be involved in processing multisensory integration by converging cues from different sensory modalities. Lateral-Occipital cortex (LO) has been primarily known to be extracting visual shape information of objects (Kourtzi & Kanwisher, 2001). Amedi et. al. (2002) found out that, the same region responds to the tactile shape perception while participants were actively exploring an object by their hands. The region showed similar activity to the somatosensory cortex meaning that an information processing mechanism exists in LO with regards to the object shape perception. These results indicate that a multisensory integration mechanism could exist in human lateral occipital cortex. Area MT (middle temporal visual cortex) has been known to be responsible in processing visual motion. It has also been found that the same region is responsive to the tactile perception of moving objects (Haggard, et., al. 2002; Blake et. al., 2004). However, these studies showed that the activation of MT to the moving tactile stimuli is significantly lower than the activation to a visual motion stimulus. . A large area called superior temporal sulcus (STS) has been shown to be responsible in integrating audio-visual information. Due to its size and complexity, different parts of these regions has been seen to be responsive to diverse kinds of audiovisual cues (Amedi, et., al., 2005). Also it has been shown that this region shows increased activation to meaningful stimuli such as movement of persons and objects (Beauchamp et. al. 2004). It has also been shown that, STS responds to tactile cues in sighted persons more than blind persons (Burton, et. al., 2004). However, the exact role of STS in visuotactile integration is still unknown. Beauchamp et. al. (2008) investigated the role of STS in auditory-tactile integration and in unisensory tactile stimulation. They

found out that, the region posterior to the human STS called STSms (multisensory) which has also been proven to be involved in multisensory integration between other modalities was responsive to tactile and audio-tactile stimuli. The region was shown to be responsive to the active and passive touch and it showed increased activation when auditory and tactile cues were presented simultaneously. These results show that STSms was involved in audio-tactile integration (Figure 4). In another study, Kayser et. al. (2005) investigated the effect of multisensory integration in auditory cortex using fMRI in macaque monkeys. They found the increased activation with multimodal stimuli in posterior and along the lateral side of the auditory cortex. Also, they concluded that the activation was higher with more simultaneous stimuli meaning that temporal coincidence of auditory and tactile cues enhances the activation in auditory cortex. These results indicate multisensory processing can occur in primary sensory areas along with other regions.

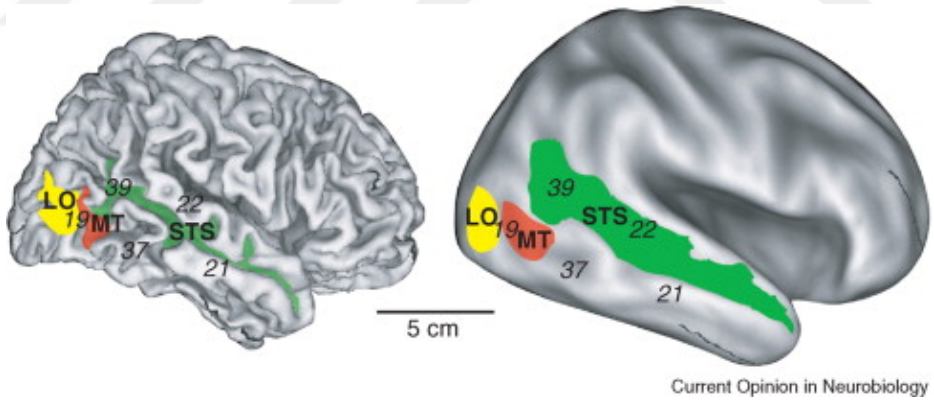


Figure 4: Anatomical regions indicating multisensory areas. Beauchamp, M. S. (2005). See me, hear me, touch me: multisensory integration in lateral occipital-temporal cortex. *Current opinion in neurobiology*, *15*(2), 145-153.

Audio-tactile integration was also studied in psychophysics in order to investigate the behavioral effects of multisensory integration in these modalities. Schürmann et. al. (2004) found out that, while there was a tactile cue mimicking the

auditory signal, the recognition of a faint tone was increased. They suggest that tactile cues help in the recognition process of auditory cues and enhance the effect of those. In another study, it has been shown that tactile cues help speed up to the suprathreshold stimuli (Murray et. al., 2015). Gillmeister & Eimer (2007) found out that, synchronous presentation of auditory and tactile stimuli increases the auditory detection performance in individuals. Also, they have shown that presence of tactile stimuli increases the perception of loudness of the auditory signal.

1.4. Mismatch Negativity

Miniscule changes in the cues available in the environment result in different brain mechanisms that would capture the novelty in this new scene. These small changes are generally in priority to be processed in the brain. The deviations from the environmental normality generally appear in situations of abnormality. Animals in nature generally try to estimate effectively the danger in the environment by the deviations in sensory cues in order to assess the safety of the scene they are exposed to (Casseday & Covey, 1996). In order to adapt and respond to novel environmental changes, mammals process the environmental cues in their sensory modalities. In this sense, an adaptive response could be created by processing the novel stimuli that could pose a survival risk (Ayala & Malmeirca, 2013). It was hypothesized that, in mammals, a mechanism was evolved to understand the difference in voices that could point to the presence of predators. This mechanism of detecting novelty in the acoustic environment was used to create early responses to the sudden manipulations of cues in order to increase the attention of the mammal to cope with the danger (Malmeirca, 2003). On the other hand, novel sensory cues in the environment have

been proven to distract the attention of mammals from the focused event (Parmentier, et. al., 2010). These distractions from the crucial event have been found in the implementation of other modalities apart from the main sensory modality (Yamaguchi & Knight, 1991). In the light of these studies, it has been concluded that, a mechanism that processes the novel stimuli that deviate from the standard ones in the environment exists in the mammal brain.

A specific component in the EEG data which responds to the changes in the auditory stimuli has been named Mismatch Negativity (Naatanen, et., al., 1978). The component was found in auditory-evoked potentials which are gathered by EEG recording (Naatanen & Mitchie, 1979). It has been found out that, MMN occurs as an automatic response in the brain when it is presented with a change exceeding a certain threshold in different attributes of an auditory stimuli (Naatanen, et., al., 1979). The discovery of MMN in auditory perception has revealed lots of new opportunities in understanding the mechanisms underlying the perception in brain especially in neurophysiology and biological processes that occur in central auditory processing (Naatanen, et., al,. 2007). The MMN component has been found to be peaked at about 100-250ms after change and stimulus onset topographically in frontal ,temporal and central areas (Sams et., al., 1985). It is calculated by subtracting the waveform of standard stimuli from the waveform of the deviant stimuli. In this context, standard stimuli had to be substantially more frequent than the deviant as it can be elicited in an oddball task (Herrmann & Knight, 2001). Oddball task refers to a paradigm that is generally used to measure the responses to a novelty in the stimuli. A feature of the stimulus is changed after a certain number of trials in a block. A large part of the trial is composed of standard stimuli like 80% and a smaller part of the trial is composed of the odd stimuli like 20% (Garcia-Larrea, et., al., 1992).

MMN has been generated by the frontal, temporal and central generators in presence of short term memory traces at least for a couple of seconds (Korzyukov, et., al., 1999). Thus, standard stimuli should be present for a certain time so that the preceding deviant could elicit the MMN. It has been found that, if the interval between stimuli is increased, instead of MMN, there exists an enhancement of N1,P1 and P2 waveforms (Naatanen & Picton, 1987). Thus, it could be concluded that MMN is elicited by quick changes in stimuli which requires a constant stream of the perceptive cue. The MMN has been found to be generated by two different intracranial processes. The supratemporal mechanism occurs according to the pre-perceptual change detection system which appears bilaterally in the brain. This process is related with the occurrence of MMN in prefrontal sites. The second process involves heavily the right hemisphere in frontal regions which refer to the involuntary attention switch between different stimuli (Giard, et., al., 1990 ; Rinne, et., al., 2000).

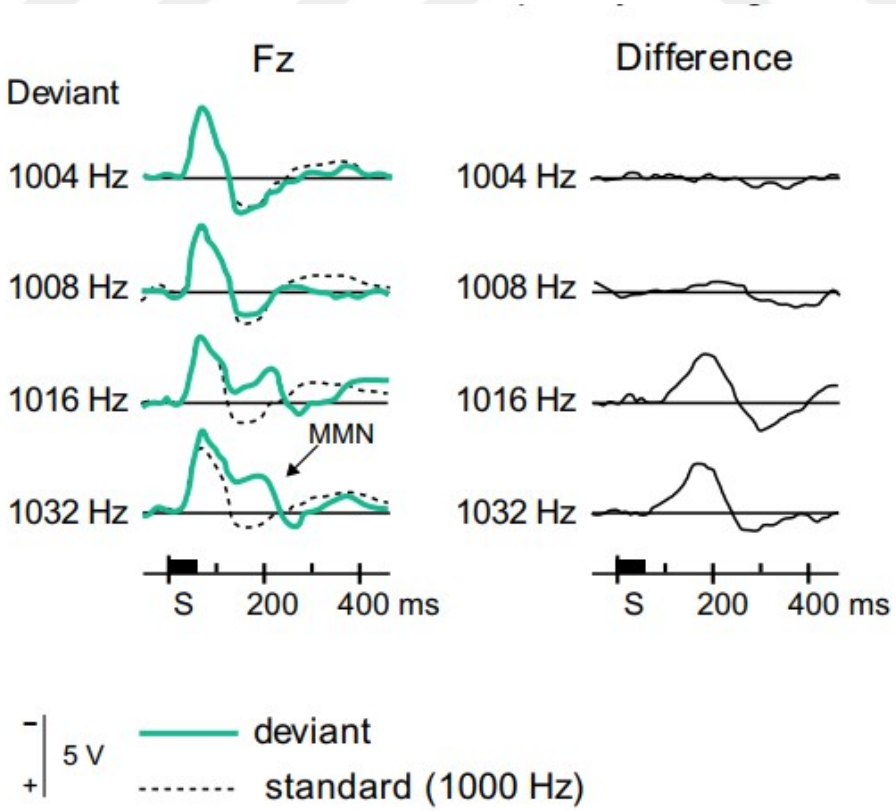


Figure 5: Auditory MMN as a function of frequency change (Naatanen, et., al., 2007)

The somatosensory counterpart of the mismatch negativity has been found in several studies. It has been found to be a positive component that generally peaks at about between 190ms to 290ms after change offset (Akatsuka, et., al., 2005). It has also been considered as analogous to the auditory MMN as it is generated in similar conditions regarding the deviance of the stimuli (Naeije, et., al., 2016). It has been studied in frequency, spatial location and duration. Spackman et., al., (2010) found that pediatric patients at the average age of 12 responded to the novelty in the frequency of the tactile stimulus with an ERP component which peaked at about this latency range. Akatsuka et., al. (2005) found this component in an oddball paradigm with durational deviance. Somatosensory mismatch negativity has also been found in spatial deviance conditions (Akatsuka, et., al., 2007 ; Naeije, et., al., 2018).

However, novelty detection mechanisms and mismatch responses have not been studied in a audiotactile environment. It has been known that auditory and tactile objects have been affecting the behavioral responses in humans (Guest, et., al., 2002; Zampini et., al., 2005). Multimodality enhances or inhibits the behavioral performance of individuals in presence of either of these senses. Thus, the perception of auditory and tactile cues has been intersecting and both of them rely on each other when multisensory environment is present (Schüman et., al., 2004). Also, there are several studies that show the enhancement and inhibition mechanisms of audiotactile stimuli in the brain. It has been known that N1 and P2 amplitudes increase with multisensory integration in an audiotactile environment (Zummer, et., al., 2020).

1.5. Aim of the Study

In the light of these studies, we believe that multisensory integration in an audiotactile stimulus environment would yield different mismatch responses than

their unisensroy parts. The main aim of this study is to find out the mismatch mechanisms in multisensory stimulus environments. It is expected that audiotactile novelty detection could trigger a different process than its unisensory modalities. However, because of the higher resolution of auditory processing, the dominance effect of this sensory modality would be effective in mismatch responses. This would indicate auditory MMN would be present when there is deviance in the auditory stimulus regardless of the tactile cues. Thus, auditory MMN would be the dominant mismatch response in these situations. Also, with regards to the same arguments, the presence of the auditory stimulation without deviance would change the somatosensory mismatch negativity. Therefore, we believe that somatosensory MMN would be affected by the audiotactile environment.

2. METHODS

2.1. Participants

Thirty three subjects between 20 and 33 years (mean = 23 years, SD= 3.2 years) attended the experiment. The participants reported no hearing problems and reported no problems with their somatosensory and sensorimotor systems. Experiment was approved by the Science-Ethics Committee of Yeditepe University.

2.2. Stimuli

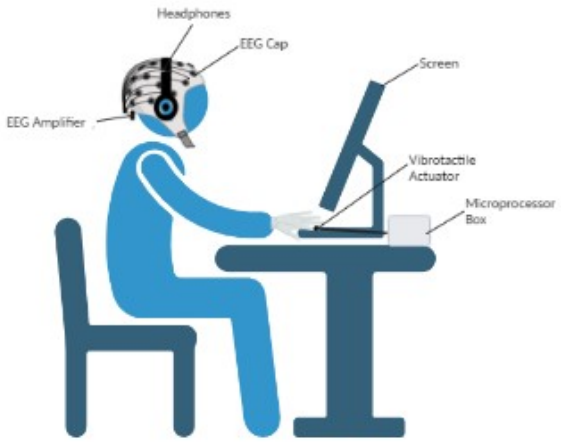
Four different stimuli were created using MATLAB and Arduino IDE. Auditory stimuli were created using MATLAB. Sine wave with 300 Hz of frequency was created with 44100 Hz sampling rate at 100ms and 200ms durations. These waves were converted to audio with WAV file type. The sounds were presented to the participants using SONY headphones at 60 dB sound pressure.

Vibrotactile stimuli were presented using an Eccentric Rotating Mass (ERM) haptic actuator at the resonant frequency of the specific unit (Maereg, et., al., 2017). The digital wave was transferred from a Windows PC to an Arduino UNO (Kushner, 2011) to the DRV2625L haptics motor driver from Texas Instruments. The digital waveform is then transferred as an analog output to the actuator. The duration of the vibrotactile stimuli was as the auditory ones; 100ms or 200ms. The vibrotactile stimuli were given to the right forefinger of the participants.

2.3. Procedure

Participants sit 60cm from the computer screen. They wear SONY headphones and the haptics actuator was fixated on their right hand forefinger with a rubber band

(Figure 4). They were told not to move their right hand and their hand was facing upwards. The hand movements were extracted from the EEG data. Participants watched an open source documentary without sound as it has been found that MMN was not affected by watching a soundless video (Michie, et., al., 2002). The video consisted of



aerial drone footage of different natural and urban aspects of Japan.

Figure 4: Experimental Setup

Participants were presented with an oddball paradigm in five sessions in succession; Auditory deviant only (A-), Somatosensory deviant only (S-), Auditory deviant somatosensory standard (A-S), Somatosensory deviant auditory standard (AS-), Auditory deviant somatosensory deviant (A-S-).

2.3.1. Auditory Deviant Only (A-)

Paricipants listened to 450 auditory stimuli with 800ms of interstimulus interval. 400 of these stimuli were standard at 100ms of duration and 50 of these stimuli were deviant at 200ms of duration. There were at least four standard stimuli before a deviant one is presented.

2.3.2 Somatosensory Deviant Only (S-)

450 vibrotactile stimuli were presented to the participants with 800ms of interstimulus interval. 400 of these stimuli were standard at 100ms of duration and 50 of these stimuli were deviant at 200ms of duration. There were at least four standard stimuli before a deviant one is presented.

2.3.3. Auditory Deviant Somatosensory Standard (A-S)

450 vibrotactile and 450 auditory stimuli were presented to the participants simultaneously. 450 of somatosensory stimuli were standard at 100ms. 400 of the auditory stimuli were standard at 100ms of duration and 50 of these stimuli were deviant at 200ms of duration. There were at least four standard stimuli before a deviant one is presented.

2.3.4. Somatosensory Deviant Auditory Standard (AS-)

450 vibrotactile and 450 vibrotactile stimuli were presented to the participants simultaneously. 450 of auditory stimuli were standard at 100ms. 400 of the vibrotactile stimuli were standard at 100ms of duration and 50 of these stimuli were deviant at 200ms of duration. There were at least four standard stimuli before a deviant one is presented.

2.3.5. Auditory Deviant Somatosensory Deviant (A-S-)

450 vibrotactile and 450 auditory stimuli were presented to the participants simultaneously. 400 of somatosensory stimuli were standard at 100ms of duration and 50 of these stimuli were deviant at 200ms of duration. 400 of the auditory stimuli were standard at 100ms of duration and 50 of these stimuli were deviant at 200ms of duration. There were at least four standard stimuli before a deviant one is presented.

2.4. EEG Recording and Analysis

Electroencephalogram (EEG) was recorded using Mitsar SmartBCI device. 19 electrodes were inserted in electrode sites Fp1, Fpz, Fp2, F7,F3, Fz, F4, F8, T7, C3, Cz, C4, P7, P3, Pz, P4, P8, O1, O2. The electrodes were placed using 10/20 system. Raw

EEG data was sampled at 1000 Hz with 70 Hz low pass filtering. Data was downsampled to 250 Hz due to the low bandwidth of the bluetooth communication between the amplifier and the recording computer. Average of the both reference electrodes at both ears were subtracted from the recording online.

EEG data was epoched and analyzed using FieldTrip toolbox (Ostenveld, et,. al,. 2011). Data were low pass filtered at 30 Hz and high pass filtered at 1 Hz. Trials with above 100 mV were discarded. Dependent Component Analysis (ICA) was applied and components with eye blink artifacts were removed. Detrending and baseline correction was applied with 200ms pre-stimulus determined as the baseline window.

The analysis was done using FieldTrip toolbox after these preprocessing steps. Event Related Potentials (ERP) were calculated using all clean trials. Difference waves were calculated by subtracting the standard stimulus condition by the deviant stimulus condition for every session for every participant in order to capture mismatch negativity waveforms (Naatanen, 2000).

I have applied dependent samples T-tests between condition pairs in order to investigate the significantly different patterns in these difference waveforms. Timeseries data of each electrode was compared between condition pairs to investigate if the difference between patterns were unlikely to occur by chance (Martin & Ostenveld, 2007).

- A- and S-
- A- and A-S
- A- and A-S-
- S- and AS-
- S- and A-S-
- AS- and A-S
- AS- and A-S-

- A-S and A-S-

Also, we subtracted the waveform of A- condition from A-S- to acquire calculated S- waveform. Then we applied dependent samples T-tests for every participant on every electrode between calculated S- and measured S- to investigate if there is a linear process that occurs in multisensory mismatch responses. Same procedure has been applied as we subtracted S- from A-S- to acquire the calculated A- waveform.

3. RESULTS

3.1. Dependent Samples T-Test Results

3.1.1 Single Modality Difference between A- and S-

Dependent samples T-test results between conditions (A-) and (S-) reveal that there was significantly different timepoints between these two conditions at electrodes F7, F3, F4, F8, T7 and Cz. The results were as follows;

There was a significant difference between (A-) and (S-) difference waves from 132ms to 148ms ($M=-0.298$, $SD=0.043$, $p<0.05$) and from 236ms to 248ms ($M=-1.10$, $SD=0.023$, $p<0.05$) after stimulus change onset at F7 electrode site.

There was a significant difference between (A-) and (S-) difference waves from 236ms to 264ms ($M=-0.75$, $SD=0.13$, $p<0.05$) after stimulus change onset at F3 electrode site.

There was a significant difference between (A-) and (S-) difference waves from 244ms to 260ms ($M=0.03$, 0.048, $p<0.05$) after stimulus change onset at F4 electrode site.

There was a significant difference between (A-) and (S-) difference waves from 180ms to 192ms ($M=-0.033$, $SD=0.94$, $p<0.05$) and from 244ms to 272ms($M=-0.022$, $SD=0.71$, $p<0.05$) after stimulus change onset at F8 electrode site.

There was a significant difference between (A-) and (S-) difference waves from 88ms to 100ms ($M=0.211$, $SD=0.213$, $p<0.05$) after stimulus change onset at T7 electrode site.

There was a significant difference between (A-) and (S-) difference waves from 236ms to 264ms (M=-0.57, SD= 0.20, $p<0.05$ after stimulus change onset at Cz electrode site.

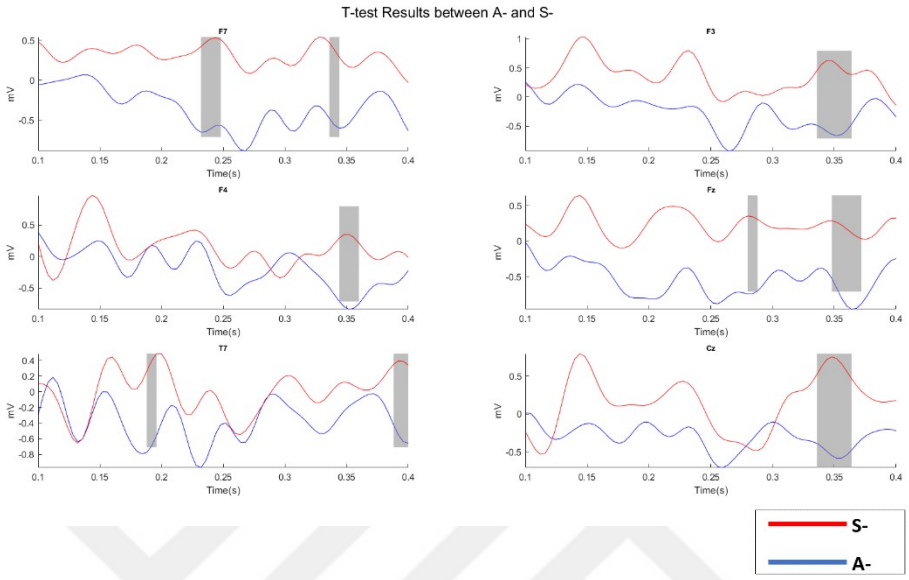


Figure 5: Dependent samples T-test significant timepoints between A- and S- Conditions

3.1.2. Single and Combined Modality Difference between A- and A-S

Dependent samples T-test results between conditions (A-) and (A-S) reveal that there was significantly different timepoints between these two conditions at electrodes F3, F4 and T7. The results were as follows;

There was a significant difference between (A-) and (A-S) difference waves from 32ms to 52ms (M=0.70, SD=0.30, $p<0.05$) and from 272ms to 288ms (M=-0.637, SD=0.205, $p<0.05$) after stimulus change onset at F3 electrode site.

There was a significant difference between (A-) and (A-S) difference waves from 36ms to 52ms (M=1.13, SD=0.18, $p<0.05$) after stimulus change onset at F4 electrode site which was not coincident with the usual MMN latency.

There was a significant difference between (A-) and (A-S) difference waves from 128ms to 160ms (M=-0.18, SD=0.10, p<0.05) after stimulus change onset at T7 electrode site.

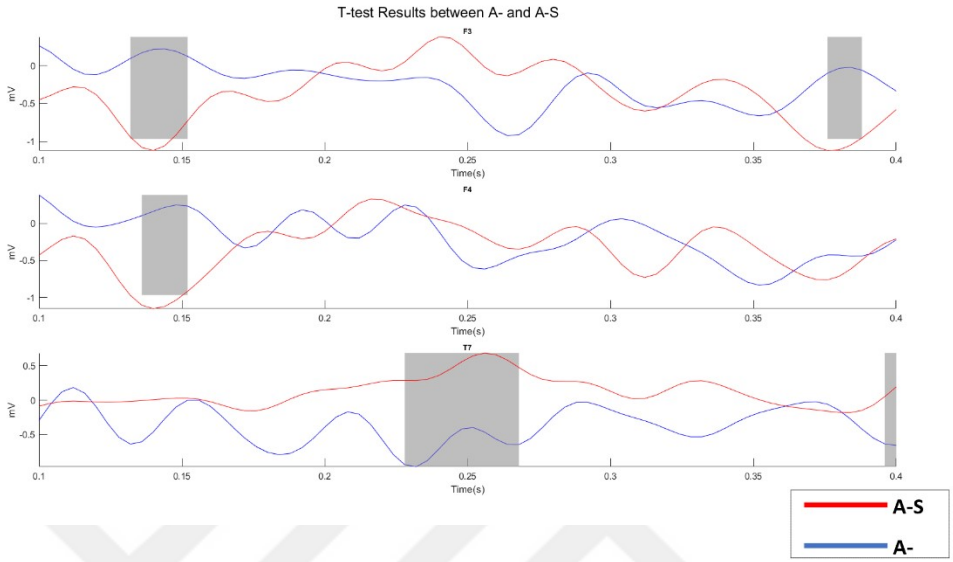


Figure 6: Dependent samples T-test significant timepoints between A- and A-S Conditions

3.1.3. Single and Combined Modality Difference between A- and A-S-

Dependent samples T-test results show that there was a significant difference between (A-) and (A-S-) difference waves from 252ms to 268ms (M=-0.96, SD = 0.22, p<0.05) after stimulus change onset at F8 electrode site. The results were as follows;

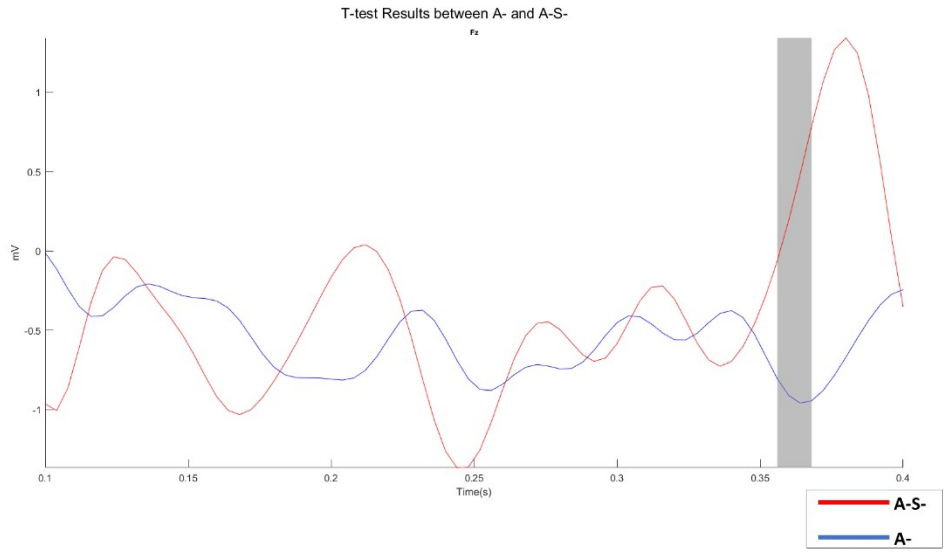


Figure 7: Dependent samples T-test significant timepoints between A- and A-S- Conditions

3.1.4. Single and Combined Modality Difference between S- and AS-

Dependent samples T-test results between conditions (S-) and (AS-) reveal that there was significantly different timepoints between these two conditions at electrodes F4, C3, Cz and C4. The results were as follows;

There was a significant difference between (S-) and (AS-) difference waves from 188ms to 200ms ($M=-0.95$, $SD=0.084$, $p<0.05$) after stimulus change onset at F4 electrode site.

There was a significant difference between (S-) and (AS-) difference waves from 160ms to 176ms ($M=-0.991$, $SD=0.103$, $p<0.05$) after stimulus change onset at C3 electrode site.

There was a significant difference between (S-) and (AS-) difference waves from 156ms to 164 ms ($M=-0.751$, $SD=0.222$, $p<0.05$) and from 180ms to 204ms ($M=-0.697$, $SD=0.43$, $p<0.05$) after stimulus change onset at Cz electrode site.

There was a significant difference between (S-) and (AS-) difference waves from 160ms to 180ms (M=-0.587, SD=0.191, p<0.005) after stimulus change onset at C4 electrode site.

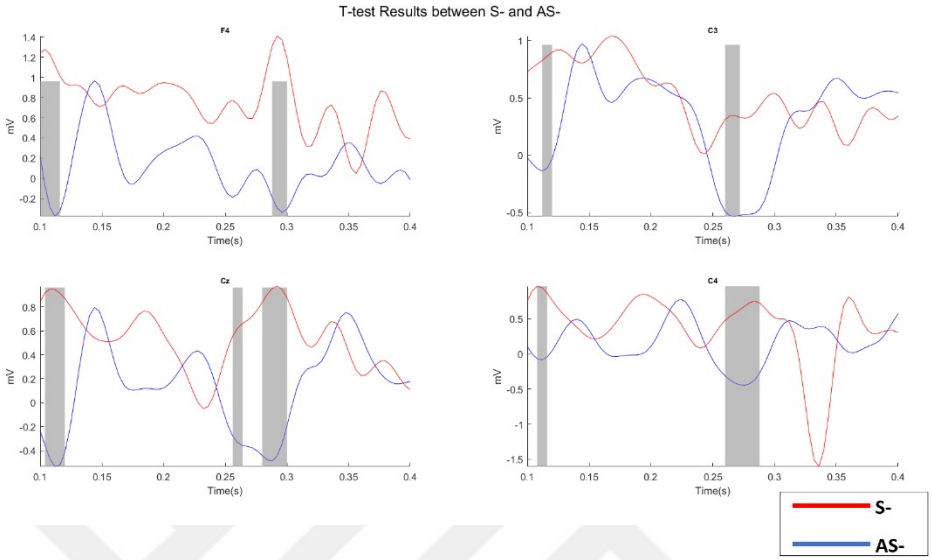


Figure 8: Dependent samples T-test significant timepoints between S- and AS- Conditions

3.1.5. Single and Combined Modality Difference between S- and A-S-

Dependent samples T-test results between conditions (S-) and (A-S-) reveal that there was significantly different timepoints between these two conditions at electrodes F7, F3, F4, F8, C3 and Cz. The results were as follows;

There was a significant difference between (S-) and (A-S-) difference waves from 68ms to 88 ms (M=0.944, SD=0.105, p<0.005) and from 220ms to 236ms (M=1.281, SD=0.0.87, p<0.005) after stimulus change onset at F7 electrode site.

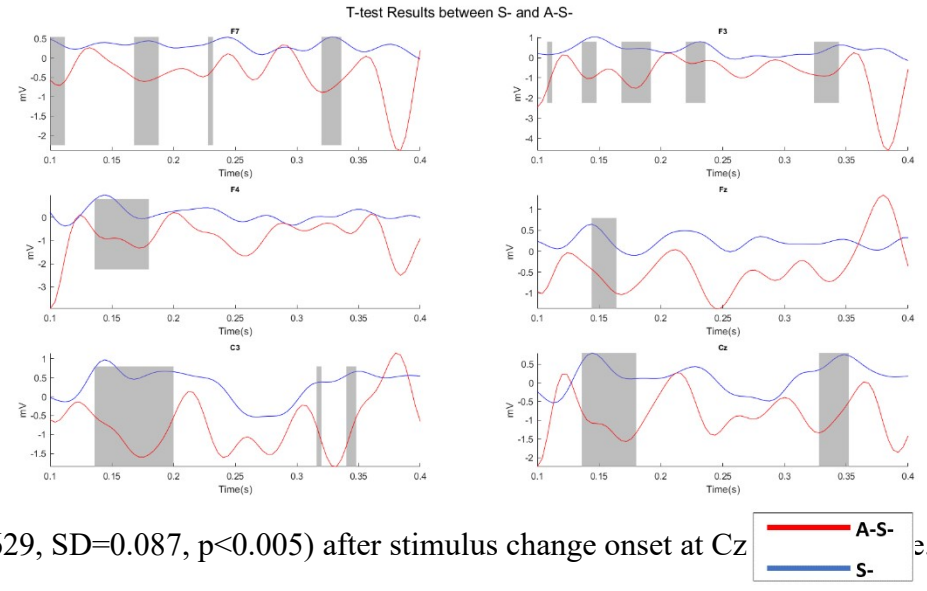
There was a significant difference between (S-) and (A-S-) difference waves from 68ms to 92ms (M=1.671, SD=0.256, p<0.005) , from 120ms to 136ms (M=0.842, SD=0.241, p<0.005) and from 226ms to 246ms(M=1.098, SD=0.329, p<0.005) after stimulus change onset at F3 electrode site.

There was a significant difference between (S-) and (A-S-) difference waves from 36ms to 82ms (M=1.557, SD= 0.352, p<0.005) after stimulus change onset at F4 electrode site.

There was a significant difference between (S-) and (A-S-) difference waves from 44ms to 64ms (M=1.091, SD= 0.072, p<0.005) after stimulus change onset at F8 electrode site.

There was a significant difference between (S-) and (A-S-) difference waves from 36ms to 100ms (M=1.749, SD= 0.318, p<0.005) after stimulus change onset at C3 electrode site.

There was a significant difference between (S-) and (A-S-) difference waves from 36ms to 80ms (M=1.542, SD= 0.442, p<0.005) and from 228ms to 252ms



(M=1.629, SD=0.087, p<0.005) after stimulus change onset at Cz e.

Figure 9: Dependent samples T-test significant timepoints between S- and A-S- Conditions

3.1.6. Combined Modality Difference between A-S and A-S-

Dependent samples T-test results show that there was a significant difference between (A-S) and (A-S-) difference waves from 156ms to 176ms (M=1.163, SD=0.187, p<0.005) after stimulus change onset at T7 electrode site. The results were as follows;

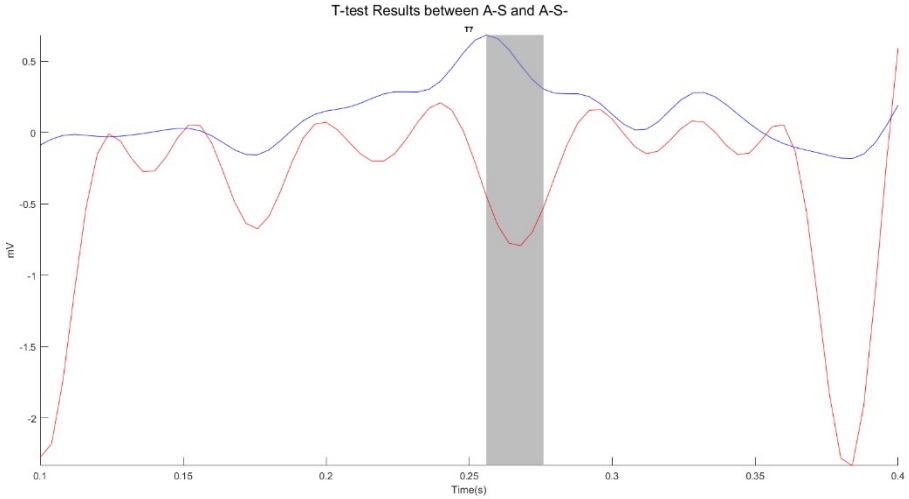


Figure 10: Dependent samples T-test significant timepoints between A-S and A-S- Conditions

3.1.7. Combined Modality Difference between AS- and A-S-

Dependent samples T-test results between conditions (AS-) and (A-S-) reveal that there was significantly different timepoints between these two conditions at electrodes F7, F3, F4, F8, C3 and Cz. The results were as follows;

There was a significant difference between (AS-) and (A-S-) difference waves from 60ms to 92ms (M= 1.163, SD=0.101, p<0.005), from 116ms to 132ms (M=1.073, SD=0.158, p<0.005) and from 228ms to 244ms(M=1.176, SD=0.089, p<0.005) after stimulus change onset at F7 electrode site.

There was a significant difference between (AS-) and (A-S-) difference waves from 64ms to 92ms (M=2.234, SD=0.244, p<0.005) and from 156ms to 244ms (M=1.487, SD=0.232, p<0.005) and after stimulus change onset at F3 electrode site.

There was a significant difference between (AS-) and (A-S-) difference waves from 40ms to 84ms (M=1.705, SD=0.166, p<0.005) and from 152ms to 168ms (M=2.280, SD=0.149, p<0.005) and after stimulus change onset at F4 electrode site.

There was a significant difference between (AS-) and (A-S-) difference waves from 52ms to 84ms (M=1.535, SD=0.368, p<0.005) after stimulus change onset at F8 electrode site.

There was a significant difference between (AS-) and (A-S-) difference waves from 28ms to 100ms (M=1.872, SD=0.521, p<0.05) after stimulus change onset at C3 electrode site.

There was a significant difference between (AS-) and (A-S-) difference waves from 36ms to 92ms (M=1.767, SD=0.308, p<0.005) and from 160ms to 192ms (M=1.641, SD=0.091, p<0.05) after stimulus change onset at Cz electrode site.

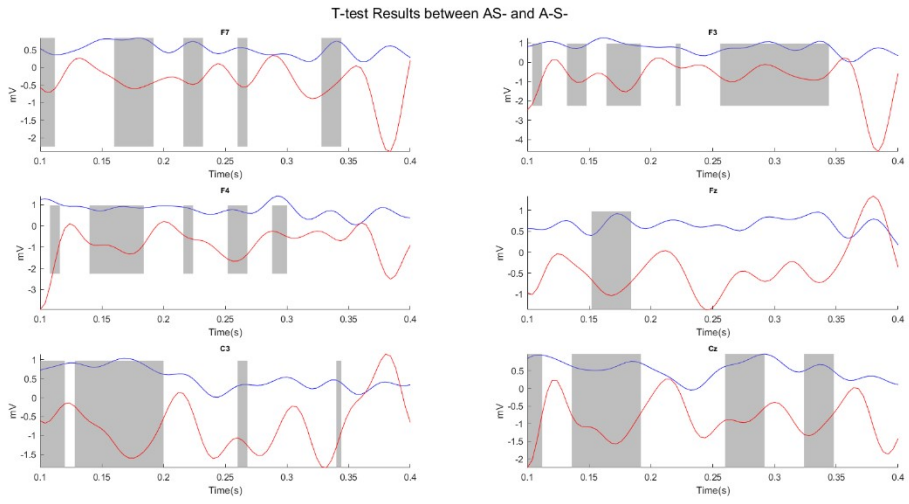


Figure 11: Dependent samples T-test significant timepoints between AS- and A-S- Conditions

3.1.8. Combined Modality Difference between A-S and AS-

Dependent samples T-test results between conditions (A-S) and (AS-) reveal that there was significantly different timepoints between these two conditions at electrodes F7, F3, F4, C3, Cz and C4. The results were as follows;

There was a significant difference between (A-S) and (AS-) difference waves from 100ms to 184ms ($M=-0.411$, $SD=0.193$, $p<0.005$) after stimulus change onset at F7 electrode site.

There was a significant difference between (A-S) and (AS-) difference waves from 1ms to 80ms ($M=-1.561$, $SD=0.214$, $p<0.05$) and from 192ms to 240ms ($M=-1.253$, $SD=0.115$, $p<0.05$) after stimulus change onset at F3 electrode site.

There was a significant difference between (A-S) and (AS-) difference waves from 1ms to 64ms ($M=-1.616$, $SD=0.23$, $p<0.05$) and from 188ms to 208ms ($M=-1.446$, $SD=0.159$, $p<0.005$) after stimulus change onset at F4 electrode site.

There was a significant difference between (A-S) and (AS-) difference waves from 1ms to 100ms ($M=-1.46$, $SD= 0.237$, $p<0.05$) and from 200ms to 212ms ($M=-92$, $SD= 0.05$, $p<0.05$) after stimulus change onset at C3 electrode site.

There was a significant difference between (A-S) and (AS-) difference waves from 1ms to 64ms ($M=-1.069$, $SD=0.130$, $p<0.05$) and from 180ms to 224ms ($M=-1.167$, $SD=0.174$, $p<0.05$) after stimulus change onset at Cz electrode site.

There was a significant difference between (A-S) and (AS-) difference waves from 1ms to 64ms ($M=-1.283$, $SD= 0.113$, $p<0.05$) and from 160ms to 192ms ($M=-0.868$, $SD=0.162$, $p<0.05$) after stimulus change onset at C4 electrode site.

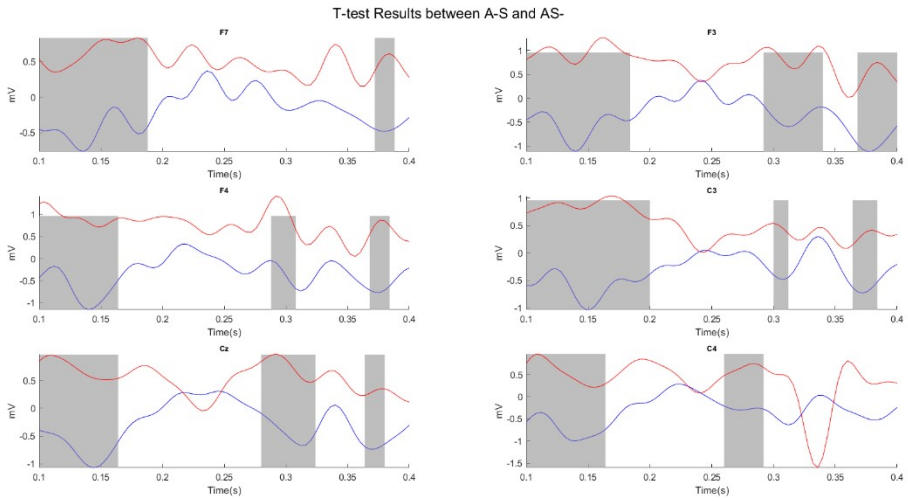


Figure 12: Dependent samples T-test significant timepoints between A-S and AS- Conditions

3.1.9. Difference between (A-S-)-(S-) and (A-)

Waveform of the condition S- was subtracted from the combined modality condition A-S- to obtain a calculated waveform of A-. Dependent samples T-tests results show that there was significant difference between (A-S-)-(S-) and (A-) waveforms in C3 and Cz electrode sites. The results were as follows;

There was significant difference between these two waveforms from 40ms to 104ms ($M=-2.064$, $SD=0.216$, $p<0.05$) at the C3 electrode site.

There was significant difference between these two waveforms from 48ms to 72ms ($M=-1.547$, $SD=0.14$, $p<0.005$).

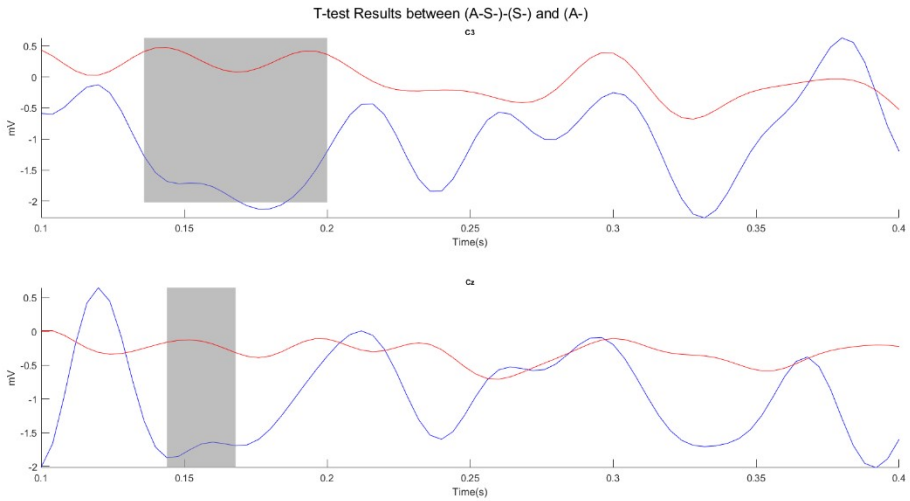


Figure 13: Dependent samples T-test significant timepoints between (A-S-)-(S-) and (A-) Conditions

3.1.10. Difference between (A-S-)-(A-) and (S-)

Waveform of the condition A- was subtracted from the combined modality condition A-S- to obtain a calculated waveform of S-. Dependent samples T-tests results show that there was significant difference between (A-S-)-(A-) and (S-) waveforms in F4 and C3 electrode sites. The results were as follows;

There was significant difference between these two waveforms from 40ms to 64ms ($M=-1.209$, $SD=0.28$, $p<0.05$) at the F4 electrode site.

There was significant difference between these two waveforms from 40ms to 100ms ($M=-2.095$, $SD=0.18$, $p<0.05$) at the C3 electrode site.

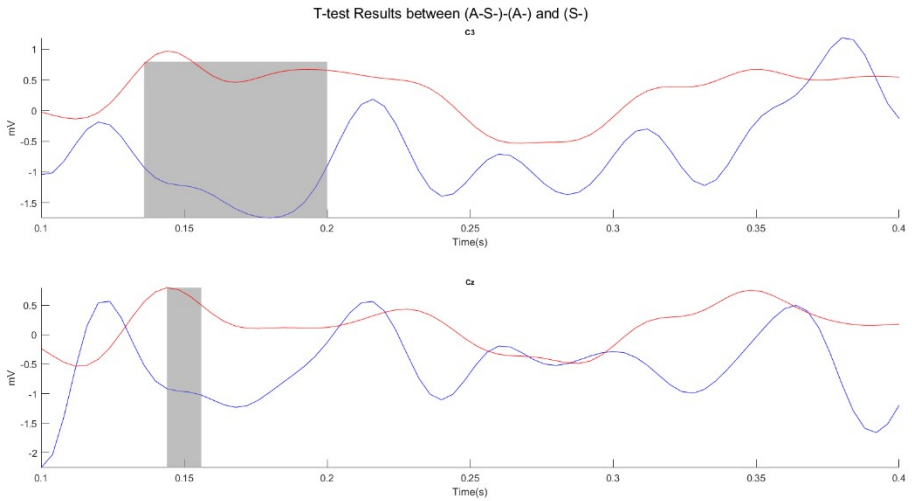


Figure 14: Dependent samples T-test significant timepoints between (A-S-)-(A-) and (S-) Conditions

Table 1

Dependent Samples T-Test Results between Condition Pairs

Electrode	A- / S-	A-/A-S	A-/A-S-	S-/AS-	S-/A-S-	A-S/A-S-	AS-/A-S-	A-S/AS-
F7	132-148ms, 236-248ms	-	-	-	68-88ms, 220-236ms	-	60-92ms, 116-132ms, 228-244ms	100-184ms
F3	236-264ms,	32-52ms, 272-288ms	-	-	68-92ms, 226-246ms	-	64-92ms, 156-244ms	1-80ms, 192-240ms
Fz	-	-	-	-	-	-		
F4	244-260ms	36-52ms	-	188-200ms	36-82ms	-	40-84ms, 152-168ms	1-64ms, 188-208ms
F8	180-192ms 244-272ms	-	252-268ms	-	44-64ms	-	52-84ms	-
T7	88-100ms	128-160ms	-	-	-	156-176ms	-	-

C3	-	-	-	160-176ms	36-100ms	-	28-100ms	1-100ms, 200-212ms
Cz	236-264ms	-	-	156-164ms, 180-204ms	36-80ms, 228-252ms	-	36-92ms, 160-192ms	1-64ms, 180-244ms
C4	-	-	-	160-180ms	-	-	-	1-64ms, 160-192ms
T8	-		-	-	-	-	-	-

3.2. Topographical Inspection of Mismatch Negativity

Mismatch negativity waveform was observed in all the 5 conditions with visual inspection.ss

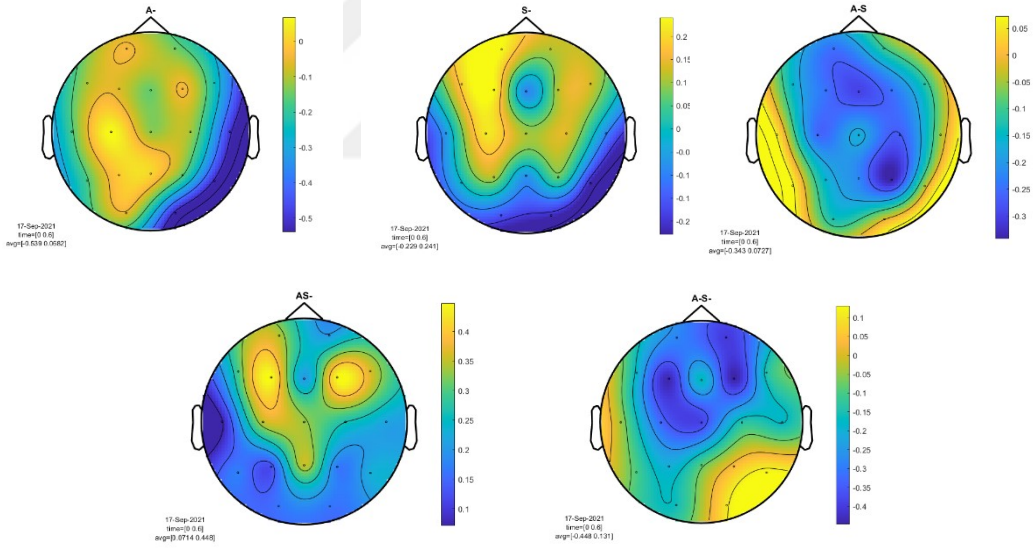


Figure 13: Topographical scalp maps from 0 ms to 300ms after change onset.

4.DISCUSSION

In our daily lives, we are always prone to detect changes in the environment. This change and novelty detection mechanism has been a crucial factor in survival. In this study, I examined the multisensory integration mechanisms in response to the changes in the auditory and tactile senses. Thus, human mismatch responses have been investigated in a more realistic scenario which includes the combination of two sensory modalities. I examined the response of the ERP component mismatch negativity (MMN) in multimodal scenes.

Auditory evoked mismatch negativity has been known to be peaked at about 150 to 250ms after change onset (Naatanen, et., al., 1979). Somatosensory evoked mismatch negativity has been known to be peaked at about 190 to 290ms after change onset (Spackman, et., al., 2010). In this experiment, I found out that auditory and somatosensory mismatch responses significantly differed from each other between both of these latencies. Also, descriptive investigation of the data showed that, somatosensory mismatch responses in these latencies were generally at the positive side compared to the auditory mismatch responses. The relative difference between these two modalities both in amplitude and latency has previously been shown in the literature (Jiang & Chen, 2013). These results indicate that, different mechanisms exist for the novelty detection in brain regarding these two modalities. Thus, mismatch responses in somatosensory and auditory sensory modalities are generated in different ways. Moreover, there were significant differences between auditory and somatosensory mismatch responses before the usual MMN latencies in T7 electrode site. This could be observed in all of the conditions. This difference relates to the N1-P1 component after change onset which would indicate the early processing

difference between these modalities. It has been studied that auditory evoked N1 component decreases by the habituation to the stimuli (Budd, et., al., 1998). However there was no related literature about the effect of habituation on the somatosensory evoked potential. This may indicate that habituation to the deviant auditory stimuli decreased the amplitude of N1 after the change onset but this effect has not occurred in the somatosensory modality. On the other hand, the difference in these latencies may indicate difference in responses to deviance in these modalities. Thus an earlier component before MMN could be present in processing deviant stimuli after being habituated to the standard ones.

The lateralization was spotted on the significant electrodes of the EEG data. T7 electrode site had more significant results in all the conditions than its right-hemispheric counterpart T8. This could be explained by the contralateral nature of the somatosensory and auditory sensory mechanisms (Staiens et., al., 2002). That is because we have presented the auditory stimuli in both ears but the vibrotactile stimulus was presented at the right forefinger.

4.1. Comparison between Auditory and Somatosensory MMN

Auditory and somatosensory mismatch negativity has been known to rely on different generators on the brain. In this experiment I found the difference between these two modalities on mismatch responses. There was a significant difference between difference waves on auditory and somatosensory only paradigms in the latency ranging from 250 to 300ms after change onset. This latency range of the component in Event-Related Potentials relates to the P300 component. In the auditory sense, it has been widely known that amplitude and latency changes on the P300 component is related to the deviancy of the stimuli (Polich, 1986). The attentional shift to the deviant cue affects the characteristics of the P300. It has been widely

studied in the somatosensory modality that P300 has been responsive to the deviancy and novelty in the tactile stimulation (Yamaguchi, & Knight, 1991). Thus, P300 has been observed in all of the five conditions. However, a significant difference in the patterns in that latency range between auditory and somatosensory modalities can indicate that neural mechanisms in these senses could be eliciting different P300 waveforms.

4.2. Effect of Multisensory Integration on Auditory MMN

Mainly, the difference between multisensory integrated and unisensory mismatch responses has been investigated. In this experiment, I also found that, there was a significant difference between difference waves in auditory only (A-) and auditory deviant somatosensory standard (A-S) conditions. In T7 electrode site, the significantly different patterns have been observed in the usual MMN latency range which is from 150 to 250ms after change onset. In this range, difference wave was at the positive side which is generally observed in the somatosensory MMN elicitation (Kekoni et., al., 1997). Analogously to the auditory MMN, this difference wave could be interpreted as an intersection between auditory and somatosensory modalities in response to the deviance in the stimuli. Generators on the human auditory cortex could be regarded as eliciting these waveforms (Romani, et., al., 1982). Thus, this result could be interpreted as the effect of early auditory processing which would naturally differ from the somatosensory processing as the presence of somatosensory stimuli could be regarded as an inhibition of the auditory mismatch processes which are created by multimodality of the stimuli. That is because, difference wave of the combined condition was positive in this range as it is observed in somatosensory mismatch negativity contrary to the single modality auditory difference wave. On the other hand, human superior temporal sulcus (STS) has been found to be effective in

processing multimodal sensory stimulation (Beuchamp et., al., 2008). Generators in STS could be the underlying these neural processes as it has been found that they affect the ERPs in the T7 electrode site (Pizzamiglio, et., al., 2005). The inhibition of the auditory MMN in the combined modality condition could relate to the multisensory integration processes being more primary than the novelty detection in this condition. This can show that STS does not process mismatch responses but generally compute the integration process of multimodal stimuli and the difference wave created should not be regarded as an MMN component. The role of STS on novelty detection in multisensory conditions should be thoroughly studied in order to shed light to the multisensory integration and mismatch response processes.

Statistical tests revealed only a significant difference between difference waves in conditions A- and A-S- in the latency range which is not consistent with the usual MMN. This result indicates that in a multimodal deviancy environment, the effect of auditory novelty is dominant over the addition of somatosensory input. This means that, underlying mechanisms in the brain generate mismatch responses according to the auditory system by eliminating the effect of somatosensory deviance. Thus, it could be interpreted as the situation of auditory dominance as it has been suggested in various multisensory environments (Burr, et., al., 2009).

4.3. Effect of Multisensory Integration on Somatosensory MMN

The novelty detection mechanisms have been investigated in somatosensory mismatch conditions in presence of an auditory standard stimulation. The difference waves between somatosensory only deviant (S-) and combined somatosensory deviant (AS-) conditions were significantly different in F4, C3, Cz and C4 electrode sites in the latency range of MMN. The difference waves for the combined condition also was generally at the negative side as opposed to the positivity in somatosensory only

condition. This result may indicate the presence of a auditory stimuli would alter the somatosensory MMN as negativity of the waveform was analogous to the auditory MMN. This could be interpreted as a dominance of auditory object as the somatosensory mismatch waveforms resembled its counterpart in the auditory sense. Also, it could be said that, auditory MMN, is the generic component of the mismatch responses as in the presence of an auditory stimuli, generators in the brain tends to process the sensory cue as it was an auditory event. Since these mismatch responses have been known to be created by higher areas and top-down processes the generality of the auditory MMN could be regarded as a foundational computational process in response to novelty and deviance in multisensory stimuli. Even though, auditory and somatosensory mismatch negativity has been known to be different than each other, there are several claims in the literature about their relevance and resemblance (Naatanen, 2009). In this aspect, it could be said that in a multimodally primed environment, generic MMN which is generally analogous to the auditory one was created in order to process deviancy in the sensory cues.

Difference waves of somatosensory only (S-) and auditory and somatosensory deviant (A-S-) conditions revealed different patterns both in MMN latency range and before it. As it was discovered in the difference between A- and S- conditions, N1-P1 components of both of these modalities affected the difference in the latency range until 100ms. This was explained due to the difference in elicitation of these waveforms and the habituation-inhibition phenomenon. In this aspect, it could be said that in this condition, these different patterns were elicited by the dominance of auditory mismatch processes. As it was discussed earlier that auditory and somatosensory deviant condition did not elicit too different waveforms than auditory only condition, this result could be interpreted as the dominance of auditory novelty

detection mechanisms over its somatosensory counterparts. For the usual MMN latency range, same conclusion could be drawn out as the difference wave was more similar to the auditory only condition. Thus, it could be said that in a multisensory integrated environment with novel stimuli, frontal and central generators generally tend to process auditory mismatch responses. This could be interpreted as the dominance of the auditory processes over the somatosensory novelty detection mechanisms as the brain relies on the auditory object while computing the mismatch in the environment.

4.4. Comparison of Multisensory Mismatch Conditions

A similar conclusion could be drawn from the statistical results between A-S and A-S- conditions. The difference between multisensory integrated conditions revealed mechanisms underlying mismatch conditions in a multimodal environment. There was a significant difference only on the T7 electrode site . This could be interpreted as the importance and dominance of the auditory mismatch processes as both of these conditions included auditory deviance. Thus, in the presence of auditory deviance in the sensory environment, neural processes generally tend to be similar to auditory processing. This means that, auditory novelty detection is dominant in multisensory integrated situations and the auditory object is processed primarily in the cortex when there is a deviance from the standard and habituated stimuli. As it was shown in a audiovisual oddball task (Robinson et., al., 2016) it could be said that similar mechanisms exist in audiotactile paradigms.

In a audiotactile multimodal environment, presence of auditory deviance revealed the importance of the auditory sensory system. Difference between AS- and A-S- conditions also revealed that auditory deviance processing is predominant in multimodal environments. The difference wave in the MMN latency range was more

resemblant to the auditory MMN as it peaked at negative side as opposed to the positivity in the AS- condition. Thus, the inclusion of auditory deviance creates a tendency towards a mismatch response which is analogous to the auditory MMN. Similar generators elicit these waveforms in multisensory integrated environments according to the dominant modality present. As the dominant modality could be said as the auditory object, elicitation of auditory MMN was observed in the A-S- condition. On the other hand, the presence of the standard auditory stimulation has been discussed to be shifting the MMN to its auditory part. However, from this result, it could be concluded that deviance in the auditory sense creates a bigger amplitude in the negative side of the waveform resulting in a greater dominance of the auditory modality in the multisensory integration of deviation.

Deviance in the somatosensory modality has been investigated in the presence of auditory deviance. The difference waves of A-S and A-S- conditions were significantly different on MMN latency range and before that. This result was expected as the deviant component of these sensory objects was in different modalities. This result indicates that auditory and somatosensory deviancies were processed in dissimilar ways in a multisensory integrated environment. Thus, the deviant modality has the utmost importance in a multimodal environment which indicates the cruciality of novelty detection and its sensory modality.

4.5. Limitations

Even though every condition in audiotacile integration has been covered in the scope of this study, mismatch responses in multimodality could be investigated in different paradigms using frequency, location and other complex measures. This result is only interpretable in the durational deviance situations. Also, to understand multisensory novelty detection mechanisms, audiovisual and visiotactile experiments

could be conducted. Moreover, as I conducted this experiment with an EEG device with 20 channels, an EEG device with more resolution and channels could be selected to understand the topographical aspects of these responses.

4.6. Future Studies

Future studies could include the investigation of MEG responses as MEG counterpart of the MMN has been found in different scenarios and modalities (Tiitinen, et., al., 1993), this study could be repeated with MEG recording. Furthermore, as MEG has more spatial resolution, localization of the MMN could be assessed in a more concrete way. Also, the same paradigm could be used to investigate the mismatch responses in sleep as MMN has been found to be elicited there with a lower amplitude (Loewy, et., al., 1996). Also, multisensory mismatch responses could be investigated in infants in order to understand the developmental effects of novelty detection mechanisms (Naatanen, et., al., 2000).

4.7. Conclusion

In this study, I found out that, there were crucial differences between auditory and somatosensory modalities as it was known in the literature (Butler et., al., 2011). Also, in presence of multiple sensory cues somatosensory mismatch responses did not entirely resemble their unisensory counterparts. However, in presence of the auditory deviance, the usual MMN latency range generally resembled auditory MMN. This meant that auditory sense could dominate the novelty detection mechanisms in human brain. Also, these results could be interpreted as auditory mismatch responses are the generic type of response that is elicited in response to deviance in the stimulation environment. These results indicate that in a multisensory environment, brain has different mechanisms in processing novel stimuli in order to capture the relevant information.

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APPENDIX A: EXPERIMENT CODE

MATLAB CODE

```
clear;
dlgstr =  inputdlg({'ID','Condition'},"Experiment Duration
MMN",[1 50]);
id_str = dlgstr{1};
condstr = dlgstr{2};
condition = str2num(condstr);



% fclose(instrfind);
s = fopen('trialsLAST.txt');
trials = textscan(s,'%f%f%f%f%f');
trials = trials(:,condition);
trials=cell2mat(trials);

normaldur = 0.2;
deviantdur = 0.4;
syncer = 0.01;
normals1 = sine_create(300,normaldur);
deviants1 = sine_create(300,deviantdur);

normalsf = [sine_create(300,0.2)];
deviantsf = [sine_create(400,0.2)];

soDur = {normals1, deviants1};
soFreq = {normalsf, deviantsf};
interstim = 0.8;
device = serial("COM7");
% syncdevice = serial("COM1");
% fopen(syncdevice);
fopen(device);
msgbox('The experiment will start. Click OK to continue');

pause(4);

tStart = tic;

if condition==1          % Duration Sound
    for i =1:numel(trials)
        obj=audioplayer(soDur{trials(i)},44000);
        time(i) = toc(tStart);
%         fwrite(syncdevice,char(num2str(trials(i))),'uchar');

        play(obj);
        pause(interstim);
    end
elseif condition==2     %Duration Haptic
```

```
    for i =1:numel(trials)
        time(i) = toc(tStart);
%         fwrite(syncdevice,char(num2str(trials(i))),'uchar');

        fprintf(device,num2str(trials(i)));
        pause(interstim);
    end

elseif condition==3     %Combined Deviant Sound

    for i =1:numel(trials)

        if(trials(i)==1)
            obj=audioplayer(soDur{1},44000);
            time(i) = toc(tStart);

fwrite(syncdevice,char(num2str(trials(i))),'uchar');

            fprintf(device,num2str(1));
            pause(syncer);
            play(obj);


        elseif(trials(i)==2)
            obj=audioplayer(soDur{2},44000);
            time(i) = toc(tStart);

fwrite(syncdevice,char(num2str(trials(i))),'uchar');

            fprintf(device,num2str(1));
            pause(syncer);
            play(obj);

        end
        pause(interstim);
    end
elseif condition==4   %Combined Deviant Haptic

    for i =1:numel(trials)

        if(trials(i)==1)
            obj=audioplayer(soDur{1},44000);
            time(i) = toc(tStart);

fwrite(syncdevice,char(num2str(trials(i))),'uchar');

            fprintf(device,num2str(1));
            pause(syncer);
            play(obj);


        elseif(trials(i)==2)
            obj=audioplayer(soDur{1},44000);
            time(i) = toc(tStart);
```

```
fwrite(syncdevice,char(num2str(trials(i))),'uchar');

            fprintf(device,num2str(2));
            pause(syncer);
            play(obj);

        end
        pause(interstim);
    end

elseif condition==5   %Combined Deviant Both

    for i =1:numel(trials)

        if(trials(i)==1)
            obj=audioplayer(soDur{1},44000);
            time(i) = toc(tStart);

fwrite(syncdevice,char(num2str(trials(i))),'uchar');

            fprintf(device,num2str(1));
            pause(syncer);
            play(obj);


        elseif(trials(i)==2)
            obj=audioplayer(soDur{2},44000);
            time(i) = toc(tStart);

fwrite(syncdevice,char(num2str(trials(i))),'uchar');

            fprintf(device,num2str(2));
            pause(syncer);
            play(obj);

        end
        pause(interstim);
    end


end

%
% stop = GetSecs;
% timesss = stop-start
save(['timestamps_Duration_ID_' id_str '_Condition_' condstr
'.mat'],'time');

fclose(device);
fclose(syncdevice);
```

ARDUINO CODE

```
// Control the vibration of an ERM motor
// using PWM and a photoresistor.

#include <Sparkfun_DRV2605L.h>
#include <Wire.h>

SFE_HMD_DRV2605L HMD;
const int analogInPin = A0;  // Analog input pin that the sensor is attached to
const int analogOutPin = 9; // Analog output pin that the Haptic Motor Driver is
attached to

int sensorValue = 0;        // value read from the sensor
int outputValue = 0;        // value output to the PWM (analog out)
int shiftdelay=200;
int matonset = 1;
void setup()
{
  HMD.begin();
  Serial.begin(9600);
  HMD.Mode(0x03); //PWM INPUT
  HMD.MotorSelect(0x0A);
  HMD.Library(7); //change to 6 for LRA motors

}
void loop()
{

// // read the analog in value:
```

```
//  sensorValue = analogRead(analogInPin);
//  // map it to the range of the analog out:
//  outputValue = outputValue+1;
//  // change the analog out value:
//  analogWrite(analogOutPin, outputValue);

  analogWrite(analogOutPin, 127);
  int command;
  command = Serial.parseInt();
  analogWrite(analogOutPin, 127);

  if(command==1){

    standard_time();

  }

    else if(command==2){

    deviant_time();

  }

    else if(command==3){

    standard_upper();

  }
```

```
  else if(command==4){

  deviant_upper_first();

}

  else if(command==5){

  deviant_upper_sec();

}

 else if(command==6){

  deviant_upper_third();

}

else{


  Serial.print("Not found command");
}



// print the results to the serial monitor:
```

```
//  Serial.print("sensor = ");
//  Serial.print(sensorValue);
//  Serial.print("\t output = ");
//  Serial.println(outputValue);

  // wait 2 milliseconds before the next loop
  // for the analog-to-digital converter to settle
  // after the last reading:
  analogWrite(analogOutPin, 127);
  delay(2);
 }


 void standard_time(){
  delay(matonset);
analogWrite(analogOutPin,220);
delay(200);
analogWrite(analogOutPin, 1);
Serial.print("Standard Time");

 }


 void deviant_time(){
    delay(matonset);
analogWrite(analogOutPin,220);
delay(400);
analogWrite(analogOutPin, 1);
```

```
Serial.print("Deviant Time");

}


void standard_upper(){
 delay(matonset);
 analogWrite(analogOutPin, 200);
 delay(shiftdelay);


  analogWrite(analogOutPin, 127);
Serial.print("standard_upper");


}


 void deviant_upper_first(){
 delay(matonset);
 analogWrite(analogOutPin, 254);
 delay(shiftdelay);


  analogWrite(analogOutPin, 127);
Serial.print("deviant_upper_first");
```

```
}



 void deviant_upper_sec(){
 delay(matonset);
 analogWrite(analogOutPin, 170);
    analogWrite(analogOutPin, 127);
 delay(100);
 delay(shiftdelay);
 analogWrite(analogOutPin, 252);
 delay(shiftdelay);

 analogWrite(analogOutPin, 127);
 Serial.print("deviant_upper_sec");



}

  void deviant_upper_third(){

 analogWrite(analogOutPin, 140);
 delay(shiftdelay);
 analogWrite(analogOutPin, 180);
 delay(shiftdelay);
 analogWrite(analogOutPin, 240);
 delay(shiftdelay);
 analogWrite(analogOutPin, 127);
```

```
Serial.print("deviant_upper_third");



}
```

APPENDIX B : PREPROCESSING AND ANALYSIS OF EEG DATA

```
userno = [9,10];
pathICA = strcat(pwd,'/Artifact_removed/');
pathTrials = strcat(pwd,'/Trials/');
for i = userno
    dataname1 = strcat('ID',num2str(i),'COND15.set');


    %     tsname1 =
strcat('timestamps_Duration_ID_',num2str(i),'_Condition_1.mat')
;
    %     tsname2 =
strcat('timestamps_Duration_ID_',num2str(i),'_Condition_2.mat')
;
    %     tsname3 =
strcat('timestamps_Duration_ID_',num2str(i),'_Condition_3.mat')
;
    %     tsname4 =
strcat('timestamps_Duration_ID_',num2str(i),'_Condition_4.mat')
;
    %     tsname5 =
strcat('timestamps_Duration_ID_',num2str(i),'_Condition_5.mat')
;
    cfg=[];
    cfg.dataset=dataname1;
    cfg.keepsampleinfo  = 'yes';
    %     cfg.method   = 'summary';
    %     cfg.channel  = [1:31];
    % 1 2 4 5 6 9 10 11 31
    cfg.dftfilter   ='yes';
    %     cfg.channel     =[1 2 3 4 5 6 7 13 14 15 16 17 23 24
25 26 27 28 29 30 31];
    cfg.dftfreq     =[50 100 150];
    cfg.hpfilter    ='yes';
    cfg.hpfiltord = 5;
    cfg.hpfreq      = 0.2;
    cfg.lpfilter    ='yes';
    cfg.lpfreq      = 30;
    %     cfg.continuous  = 'yes';              % force it to
be continuous
    cfg.keepchannel ='yes';
    cfg.latency  = 'all';
    data = ft_preprocessing(cfg);


labels={'Fp1','Fp2','F7','F3','Fz','F4','F8','T7','C3','Cz','C
4','T8','P7','P3','Pz','P4','P8','O1','O2','EOG'};
    data.label = labels;
    data.trial{1}([20 21 22],:) = [];
    data.label(20) =[];
    data              = ICA_art_remove(data);
```

```
save(strcat(pathICA,'cond15_artremoved_','ID_',num2str(i),'.ma
t'),'data');



    cfg=[];
    cfg.trialfun            = 'trialfun_std';
    cfg.condition           =1;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    std1                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'std1_','ID_',num2str(i),'.mat'),'std1')
;

    cfg=[];
    cfg.trialfun            = 'trialfun_dev';
    cfg.condition           =1;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    dev1                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'dev1_','ID_',num2str(i),'.mat'),'dev1')
;



    cfg=[];
    cfg.trialfun            = 'trialfun_std';
    cfg.condition           =2;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    std2                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'std2_','ID_',num2str(i),'.mat'),'std2')
;
    cfg=[];
    cfg.trialfun            = 'trialfun_dev';
    cfg.condition           =2;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
```

```
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    dev2                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'dev2_','ID_',num2str(i),'.mat'),'dev2')
;

    cfg=[];
    cfg.trialfun            = 'trialfun_std';
    cfg.condition           =3;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    std3                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'std3_','ID_',num2str(i),'.mat'),'std3')
;
    cfg=[];
    cfg.trialfun            = 'trialfun_dev';
    cfg.condition           =3;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    dev3                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'dev3_','ID_',num2str(i),'.mat'),'dev3')
;

    cfg=[];
    cfg.trialfun            = 'trialfun_std';
    cfg.condition           =4;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    std4                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'std4_','ID_',num2str(i),'.mat'),'std4')
;

    cfg=[];
    cfg.trialfun            = 'trialfun_dev';
```

```
    cfg.condition           =4;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    dev4                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'dev4_','ID_',num2str(i),'.mat'),'dev4')
;

    cfg=[];
    cfg.trialfun            = 'trialfun_std';
    cfg.condition           =5;
    cfg.dataset=dataname1;
    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    std5                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'std5_','ID_',num2str(i),'.mat'),'std5')
;
    cfg=[];
    cfg.trialfun            = 'trialfun_dev';
    cfg.condition           =5;
    cfg.dataset=dataname1;

    cfg.trialdef.pre    = 0.2;
    cfg.channel =[1:19];
    cfg.trialdef.post   = 0.6;

    cfg                     = ft_definetrial(cfg);

    dev5                    = ft_redefinetrial(cfg , data);

save(strcat(pathTrials,'dev5_','ID_',num2str(i),'.mat'),'dev5')
;
end


pathICA = strcat(pwd,'/Artifact_removed/');
pathTrials = strcat(pwd,'/Trials/');
c= 1;
for i = userno

load(strcat(pathTrials,'std1_','ID_',num2str(i),'.mat'),'std1')
;

load(strcat(pathTrials,'std2_','ID_',num2str(i),'.mat'),'std2')
;
```

```
load(strcat(pathTrials,'std3_','ID_',num2str(i),'.mat'),'std3')
;

load(strcat(pathTrials,'std4_','ID_',num2str(i),'.mat'),'std4')
;

load(strcat(pathTrials,'std5_','ID_',num2str(i),'.mat'),'std5')
;



load(strcat(pathTrials,'dev1_','ID_',num2str(i),'.mat'),'dev1')
;

load(strcat(pathTrials,'dev2_','ID_',num2str(i),'.mat'),'dev2')
;

load(strcat(pathTrials,'dev3_','ID_',num2str(i),'.mat'),'dev3')
;

load(strcat(pathTrials,'dev4_','ID_',num2str(i),'.mat'),'dev4')
;

load(strcat(pathTrials,'dev5_','ID_',num2str(i),'.mat'),'dev5')
;
```

```
    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    cfg.preproc.detrend = 'yes';
    temp=ft_preprocessing(cfg,std1);
    cfg.latency = [-0.2 0.6];
    cfg.removemean = 'yes';
    tlstd1{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlstd1{c} = ft_timelockbaseline(cfg,tlstd1{c});


    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    temp=ft_preprocessing(cfg,std2);
    cfg.latency = [-0.2 0.6];
```

```
    cfg.removemean = 'yes';
    tlstd2{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlstd2{c} = ft_timelockbaseline(cfg,tlstd2{c});


    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    temp=ft_preprocessing(cfg,std3);
    cfg.latency = [-0.2 0.6];
    cfg.removemean = 'yes';
    tlstd3{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlstd3{c} = ft_timelockbaseline(cfg,tlstd3{c});

    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    temp=ft_preprocessing(cfg,std4);
    cfg.latency = [-0.2 0.6];
    cfg.removemean = 'yes';
    tlstd4{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlstd4{c} = ft_timelockbaseline(cfg,tlstd4{c});

    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    temp=ft_preprocessing(cfg,std5);
    cfg.latency = [-0.2 0.6];
    cfg.removemean = 'yes';
    tlstd5{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlstd5{c} = ft_timelockbaseline(cfg,tlstd5{c});




    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
```

```
    temp=ft_preprocessing(cfg,dev1);
    cfg.latency = [-0.2 0.6];
    cfg.removemean = 'yes';
    tldev1{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlsdev1{c} = ft_timelockbaseline(cfg,tldev1{c});

    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    temp=ft_preprocessing(cfg,dev2);
    cfg.latency = [-0.2 0.6];
    cfg.removemean = 'yes';
    tldev2{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlsdev2{c} = ft_timelockbaseline(cfg,tldev2{c});


    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    temp=ft_preprocessing(cfg,dev3);
    cfg.latency = [-0.2 0.6];
    cfg.removemean = 'yes';
    tldev3{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlsdev3{c} = ft_timelockbaseline(cfg,tldev3{c});

    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    temp=ft_preprocessing(cfg,dev4);
    cfg.latency = [-0.2 0.6];
    cfg.removemean = 'yes';
    tldev4{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlsdev4{c} = ft_timelockbaseline(cfg,tldev4{c});


    cfg = [];
    cfg.preproc.demean= 'yes';     cfg.preproc.baselinewindow
= [-0.2 0];     cfg.preproc.detrend = 'yes';
    cfg.baseline  = [-0.2 0];
    cfg.continuous  = 'no';
    temp=ft_preprocessing(cfg,dev5);
    cfg.latency = [-0.2 0.6];
```

```
    cfg.removemean = 'yes';
    tldev5{c} = ft_timelockanalysis(cfg,temp);
    %     cfg=[];
    %     cfg.baseline = [-0.2 0];
    %     tlsdev5{c} = ft_timelockbaseline(cfg,tldev5{c});

    c=c+1;
end
cfg=[]
gastd1 = ft_timelockgrandaverage(cfg,tlstd1{:});
gastd2 = ft_timelockgrandaverage(cfg,tlstd2{:});
gastd3 = ft_timelockgrandaverage(cfg,tlstd3{:});
gastd4 = ft_timelockgrandaverage(cfg,tlstd4{:});
gastd5 = ft_timelockgrandaverage(cfg,tlstd5{:});

gadev1 = ft_timelockgrandaverage(cfg,tldev1{:});
gadev2 = ft_timelockgrandaverage(cfg,tldev2{:});
gadev3 = ft_timelockgrandaverage(cfg,tldev3{:});
gadev4 = ft_timelockgrandaverage(cfg,tldev4{:});
gadev5 = ft_timelockgrandaverage(cfg,tldev5{:});
c=1;

for i = userno
    cfg           = [];
    cfg.operation = 'x2-x1';
    cfg.parameter = 'avg';

    difference1 = ft_math(cfg, tlstd1{c}, tldev1{c});


save(strcat(pathTrials,'difference1_','ID_',num2str(i),'.mat'),
'difference1');


    cfg           = [];
    cfg.operation = 'x2-x1';
    cfg.parameter = 'avg';

    difference2 = ft_math(cfg, tlstd2{c}, tldev2{c});


save(strcat(pathTrials,'difference2_','ID_',num2str(i),'.mat'),
'difference2');

    cfg           = [];
    cfg.operation = 'x2-x1';
    cfg.parameter = 'avg';

    difference3 = ft_math(cfg, tlstd3{c}, tldev3{c});


save(strcat(pathTrials,'difference3_','ID_',num2str(i),'.mat'),
'difference3');

    cfg           = [];
    cfg.operation = 'x2-x1';
```

```
    cfg.parameter = 'avg';

    difference4 = ft_math(cfg, tlstd4{c}, tldev4{c});


save(strcat(pathTrials,'difference4_','ID_',num2str(i),'.mat'),
'difference4');

    cfg           = [];
    cfg.operation = 'x2-x1';
    cfg.parameter = 'avg';

    difference5 = ft_math(cfg, tlstd5{c}, tldev5{c});


save(strcat(pathTrials,'difference5_','ID_',num2str(i),'.mat'),
'difference5');
    c=c+1;

end

load('easycapM3_neighbours.mat','neighbours');
% cfg=[]
% cfg.latency   = [0 0.6];
% gadiff1 = ft_timelockgrandaverage(cfg,tldiff1{:});
% gadiff2 = ft_timelockgrandaverage(cfg,tldiff2{:});
% gadiff3 = ft_timelockgrandaverage(cfg,tldiff3{:});
% gadiff4 = ft_timelockgrandaverage(cfg,tldiff4{:});
% gadiff5 = ft_timelockgrandaverage(cfg,tldiff5{:});

Nsubj  = numel(userno);
design = zeros(2, Nsubj*2);
design(1,:) = [1:Nsubj 1:Nsubj];
design(2,:) = [ones(1,Nsubj) ones(1,Nsubj)*2];

cfg           = [];
cfg.method    = 'analytic'; % using a paarmetric test
cfg.channel   = [1:12];
cfg.statistic = 'ft_statfun_indepsamplesT'; % using dependent
samples
cfg.latency   = [0 0.6];
cfg.correctm  = 'no'; % no multiple comparisons correction
cfg.alpha     = 0.05;
% cfg.correcttail = 'prob';
% cfg.numrandomization = 1000;
% % cfg.clusteralpha= 0.05;
% cfg.neighbours = neighbours;
% cfg.minnbchan = 0;
cfg.design    = design; % indicating which trials belong ...
% to what category
cfg.ivar      = 2; % indicating that the dependent variable is
found in ...
% first row of cfg.design

stat_t = ft_timelockstatistics(cfg, tldiff2{:}, diffS{:});
temp_stat = stat_t;
```

```
%      gadiff3.mask = [];
gadiff1.mask = stat_t.mask;
gadiff2.mask = stat_t.mask;
gadiff3.mask = stat_t.mask;
gadiff4.mask = stat_t.mask;
gadiff5.mask = stat_t.mask;
% for i=1:12
%
%
%     cfg                = [];
%     cfg.layout         = 'easycapM3.mat';
%     cfg.maskparameter = 'mask';
%     cfg.maskstyle      = 'box';
%     cfg.maskfacealpha = 0.5; % transparency of mask
%     cfg.channel        = i;
% %     cfg.ylim           = [-5e-6 5e-6]; % Volts
%
%     cfg.showlegend = 'yes';
%     ft_singleplotER(cfg, gaordered, gaevent);
%     hold on
%     xlabel('Time (s)')
%     ylabel('Electric Potential (V)')
% %     plot([ga10ms.time(1), ga10ms.time(end)], [0 0], 'k--
') % hor. line
% %     plot([0 0], cfg.ylim, 'k--') % vert. l
%     axes = gca;
% %     legend(["10ms" "ordered"])
% end

cfg                = [];
cfg.layout         = 'easycapM3.mat';
cfg.maskparameter = 'mask';
cfg.maskstyle      = 'box';
cfg.maskfacealpha = 0.5; % transparency of mask
cfg.channel        = 1:12;
cfg.xlim=[0.1 0.4];
%     cfg.ylim           = [-5e-6 5e-6]; % Volts

cfg.showlegend = 'yes';
ft_multiplotER(cfg, gadiff2, gaS);
% save('tstats_1vs2.mat','stat_t');
```