TO CLOSE THE EYES OR NOT: THE EFFECTS OF OCCIPITAL ALPHA POWER INDUCED BY EYE CLOSURE ON AUDITORY ENTRAINMENT

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Abstract

Neuronal oscillations facilitate extracting sensory information from the environment through optimization of rhythmic fluctuation in excitation and inhibition cycles of neurons; which is defined as neural entrainment. Although research suggests entrainment to frequency modulated (FM) speech-like rhythmic sounds, factors influencing entrainment are still open for discovery. With this purpose, the current work tackled the understudied daily strategy, eye closure, in auditory perception domain. Neural and behavioral effects of eye closure on auditory entrainment were investigated. Eleven participants detected near-threshold gaps (sound breaks) embedded in 2.8 Hz FM stimuli both eyes open and closed conditions. Electroencephalogram (EEG) data were also obtained from eight of the participants. Eye closure was hypothesized to induce occipital alpha oscillations, associated with decreased neural and behavioral effects of entrainment and results in enhanced gap detection performance compared with eyes open condition. Results revealed that, as hypothesized, eye closure increased occipital alpha power. Moreover, increased 2.8 Hz neural activity and participants' modulated behavioral gap detection performance suggested neural and behavioral auditory entrainment to 2.8 Hz FM sound stimuli both in eyes open and closed conditions. Contrary to the main hypothesis, closing the eyes did not influence the overall gap detection performance. However, first evidence of auditory entrainment under eye closure condition was provided. Although the current data have limitations, all in all, an interaction of two distinct auditory perception mechanisms -neural entrainment and cortical alpha band oscillations- are suggested to involve in perception of speech-like sound stimuli. Further, this interaction was proposed to influence auditory perception differently under eye open and closed periods, raising a firm background for further research on possible benefits of eye closure on sensory information processing.

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Teşekkürler sevgili ailem bana olan sonsuz desteğiniz ve öğretileriniz için.

CONTENTS

1.   INTRODUCTION

In auditory perception, there are several strategies that humans pursue in order to process specific auditory information over other. As the *Cocktail party effect* suggests, reading lips and gestures, and paying attention to acoustic details of the sound such as directional cues, pitch or speed information can help to comprehend relevant auditory stimuli over irrelevant ones (Cherry, 1953). Collection and simultaneously processing of different sensory cues from the environment is an automatic approach in sensory information processing and known as *multisensory integration* (Meredith, 2002). Combination of sensory inputs from multiple sensory systems substantiates information processing accuracy (Schroeder & Foxe, 2005). For instance, seeing the source of a sound improves auditory perception of the sound. The *McGurk effect*, when the pairing of an auditory component of one sound with the visual component of another sound results in the perception of a third sound, is a well-known example of how visual input affects speech perception accuracy (MacDonald & McGurk, 1978). Moreover, also at the cortical level, anatomical and functional connection between primary sensory cortices supports that multisensory integration facilitates sensory perception (Schroeder & Foxe, 2005).

Although the use of multiple senses for sensory information processing is common and automatic, multisensory integration does not always operate this way. Vision is dominant over other sensory systems during attentional (Bendixen et al., 2010) or somatosensory processes (Brodoehl, Klingner & Witte, 2015; Brodoehl, Klingner, Stieglitz & Witte, 2015). As the *Ventriloquism effect* suggests, visual inputs can also be misleading for auditory processing when an auditory stimulus is in synchrony with a visual input (Hershey & Movellan, 2000). In addition to misleading simultaneous presentation of multisensory inputs, human attention is suggested to be limited during sensory processing (Bendixen, et al., 2010). Thus irrelevant sensory inputs might jeopardize the relevant sensory information process even if attention is focused (Lavie, 2005).

Despite the above-mentioned problems in sensory perception, human perception usually operates accurately. Hence, further alternative internal mechanisms and external strategies must be considered to understand operation of effective sensory perception. For instance, in daily life, without paying much attention, a sound localization problem can be solved simply

by turning one's head (Middlebrooks & Green, 1991), or eyes might be directed towards a white wall or even be closed to improve comprehension in a conversation during a noisy phone call.

Although sensory perception is a vital topic of interest to neuroscientists, interaction of different sensory modalities and the effects of these interactions are still open to exploration. Specifically, there exists only one recent study on the effects of eye closure on auditory attention; Schmitt (2016) proposes eye closure as a possible mechanism to increase attentive listening accuracy. Thus, the main aim of this thesis was to investigate further about the underlying mechanisms and effectiveness of eye closure on auditory perception. For this purpose human participants' auditory near-threshold task performances were compared under open and closed eye conditions.

In order to uncover the effects of eye closure on auditory processing, the current work proceeds with the following structure: first relevant background research information is presented by describing how sensory information extraction from the environment takes place at a neuronal level, including the alpha-dominated brain state that results from eye closure and secondly, the current research is introduced with the experimental design and finally attained results are discussed.

2. BACKGROUND

2.1 Neural oscillations

Action potentials determine the neuronal activity in brain. Varying numbers of action potentials result in different excitability rates in brain oscillations. This re-arrangement in the brain oscillations result in rhythmic fluctuation; which is known as *neuronal oscillation* (Henry & Obleser, 2012; Lakatos, et al., 2016; Peelle & Davis, 2012; Schroeder, Lakatos, Kajikawa, Partan & Puce, 2008; Wöstmann, Herrmann, Maess & Obleser, 2016; Wöstmann, Fiedler & Obleser, 2017) where varying number of action potentials are associated with low and high excitability periods in brain oscillations (Figure 1).
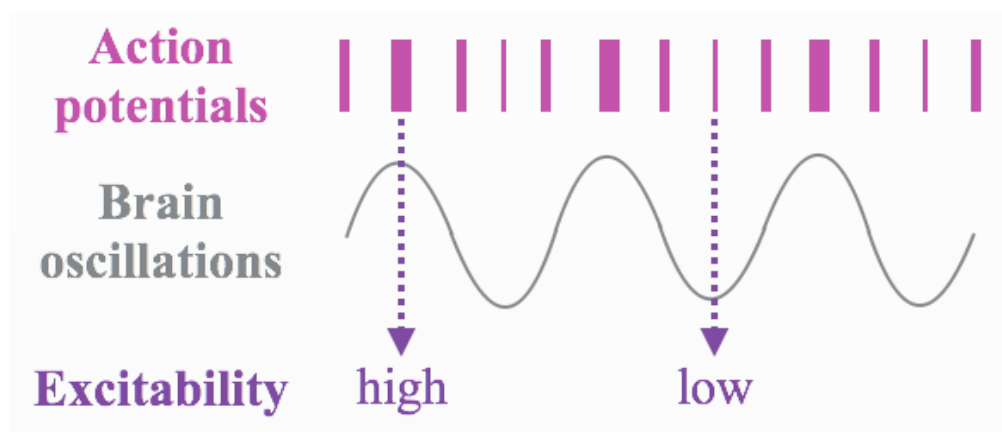
Figure 1. Neuronal activity is determined by action potentials. Number of action potentials lead to different levels of excitability; greater number of action potentials result in higher excitability periods and amplified brain oscillations, whereas smaller number of action potentials creates low excitability periods of brain oscillations.

2.1.1 Oscillatory entrainment

Neuronal oscillations facilitate perception of environmental information by optimizing rhythmic fluctuation in excitation and inhibition cycles of neurons; this is defined as *neural entrainment* (Henry & Obleser, 2012; Lakatos, et al., 2016; Peelle & Davis, 2012). Neural entrainment, for instance, takes part in speech comprehension (Schroeder et al., 2008; Peelle & Davis, 2012; Wöstmann, Fiedler & Obleser, 2017; Zoefel & VanRullen, 2015), selective attention (Calderone, Lakatos, Butler & Castellanos, 2014; Klimesch, 2012; Wöstmann et al., 2016) and memory (Klimesch, 2012).

The level of oscillatory activity is defined in terms of *phases*. Different excitability phases reflect the angle of the neural oscillation in a particular time period that is associated with processing efficiency (Schroeder, et al., 2008; Wöstmann, Fiedler & Obleser, 2017). During an unengaged or resting state, brain oscillations are random, but presentation of stimuli can reset the current brain oscillations and *phase reset* rearranges the neural oscillations according to the features of the sound stimuli. In this way, entrainment plays a role in arranging excitability phases for optimal processing efficiency of a sensory stimulus. Figure 2 demonstrates how phase angle of a current oscillatory activity reflects processing efficiency. When auditory input arrives, the stimuli are processed poorly in the low excitability periods, whereas the processing efficiency is high when the auditory information is processed in high excitability periods. (Peelle & Davis, 2012; Schroeder, et al., 2008)
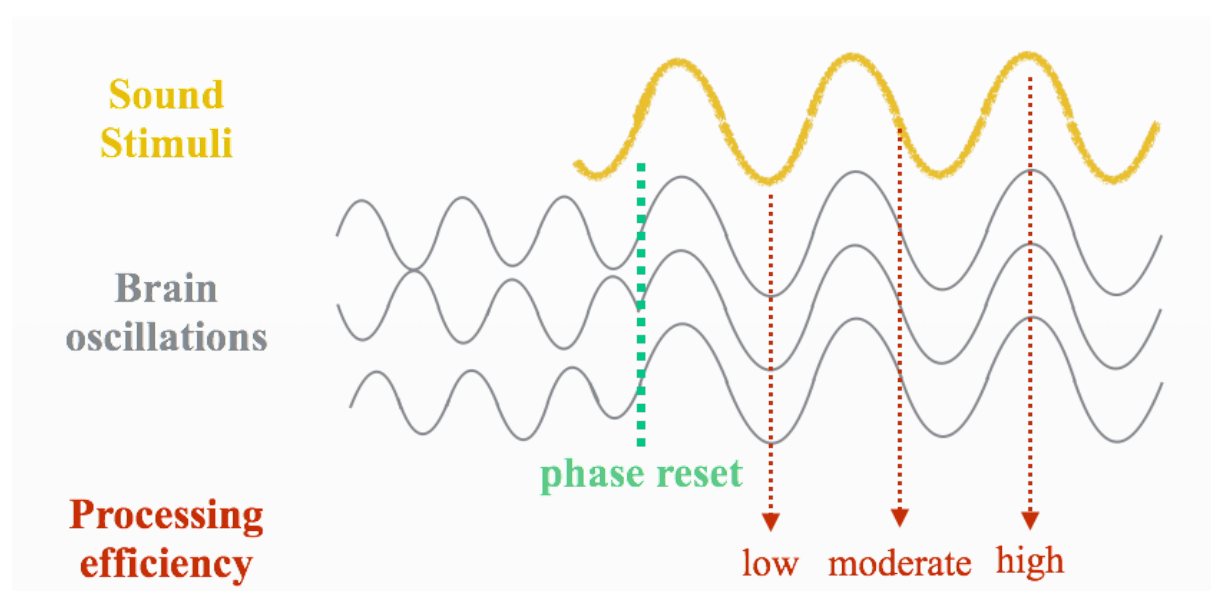
Figure 2. Random brain oscillations in a resting state are phase reset and become aligned with the stimuli onset, through entrainment, according to slow and rhythmic features of the sound stimuli. Processing efficiency of the stimuli varies depending on the arrival period of the stimuli. High excitability periods of neural oscillations facilitate high processing efficiency compared to low excitability periods. Thus, entrainment facilitates optimum sensory processing in neuronal level.

Degree of entrainment can be affected by mechanisms such as top-down attention (also known as endogenous or executive attention, as controlled by the person) (Henry & Obleser 2012; Henry, Herrmann, Kunke & Obleser, 2017; Lakatos et al., 2016) or the features of sensory input, for example being temporally predictable (rhythmicity), having a steady frequency and varying between low versus high information relevancy (Zoefel & VanRullen, 2015).

2.1.1.1   Speech and speech-like rhythmic entrainers

The variables, which are effecting entrainment, also involve in the process of speech perception and therefore several studies have been investigating the relation between speech perception and neural entrainment. The process of speech comprehension includes top-down attention. The frequency range of speech envelope varies between 1 and 8 cycles per second, which is similar to slow neural oscillations (1-8 Hz), and the speech structure consisting of syllables with silent breaks in between creates low versus high information, leading to rhythmicity (Wöstmann et al., 2016; Zoefel & VanRullen, 2015). Thus, it is not a coincidence that many of the auditory perception-entrainment studies focus on speech perception.

There are only a few other studies in the literature investigating auditory entrainment other than having a direct focus on speech perception. Henry and Obleser (2012) used slow frequency modulated (FM) stimuli in their research, which is related with "pitch and intonation counter" (Wöstmann et al., 2017, p.859) of speech. Results of this study suggest that the oscillatory neural phases around the sound-onset of the FM stimuli reflect detection rates of just-noticeable gaps embedded in FM sound (Henry & Obleser, 2012). A recent study (Bauer, Bleichner, Jaeger, Thorne & Debener, 2018) replicated the findings of Henry and Obleser (2012) and in order to investigate the phase reset mechanisms at the neural level, they varied the duration of 3 Hz the FM stimuli. The main finding of this research validates that neural oscillations dynamically rearrange their excitability to align with the external FM stimuli (Bauer et al., 2018). Importantly, detecting such just-noticeable gaps over (speech-like) FM stimuli requires a demanding level of top-down attention; thus entrainment to rhythmic auditory stimuli and its relation with attention was investigated in another recent study (Henry et el., 2017). These results revealed that decreased behavioral influence of entrainment is associated with increased alpha band oscillations in a near-perception level gap detection task over 2.8 Hz FM stimuli. Hence, it is suggested that there is a negative correlation between observed alpha power and neural entrainment (Henry et el., 2017).

2.2   Alpha oscillations and attention

Alpha range neural oscillations have a predictor role in sensory-attentional processes. In 1929 Hans Berger has firstly differentiated the alpha brain oscillations (8–12 Hz) with their distinct patterns in human electroencephalogram (EEG), a larger alpha band activation was observed

especially when the eyes were kept closed. In the subsequent years, Adrian and Matthews (1934) compared the brain oscillations by modifying eye closure and the alpha dominated brain state was reported as *idling* referring to an alert and resting state when no sensory processing is carried out.

Alpha brain oscillations have been widely studied since their discovery. Alpha power can be modulated by task difficulty, reflecting top-down and adaptive influence of attention and seen as task-irrelevant information suppression mechanism. Mainly alpha oscillations vanish with open eyes and increased attention in parieto-occipital regions (Adrian & Matthews, 1934; Berger, 1929) and moreover, parieto-occipital alpha activity is associated with auditory information processing and effortful listening (Henry et al., 2017).

2.2.1   Alpha theories

Building upon the knowledge since Berger, present works argue for the function of alpha dominated brain state in sensory processes. Currently there are two main viewpoints for the functions of alpha oscillations: *alpha inhibition hypothesis* (Jensen & Mazaheri, 2010; Klimesch, Sauseng, & Hanslmayr, 2007; Pfurtscheller, 2003; von Stein, Chiang, & König, 2000) and *active processing hypothesis* (Palva & Palva, 2007; Palva & Palva, 2011).

According to the inhibition hypothesis, amplitude of cortical alpha oscillations reflects inhibition of task-irrelevant sensory information (Jensen & Mazaheri, 2010). High alpha amplitudes in occipito-parietal regions indicate inhibition of task-irrelevant processes in order to boost attention in task relevant – auditory regions (Strauß, Wöstmann & Obleser, 2014). On the other hand, the active processing hypothesis considers an endogenous, stimulus-locked alpha phase dynamics suggesting that cortical alpha oscillations indicate a nonlinear association and thus proposing a direct role of alpha oscillations in sensory, attentional and memory processes (Palva & Palva, 2007).

The active alpha hypothesis further points out that task specificity such as task difficulty affects neural alpha fluctuations. In a near-threshold detection task, amplitude of ongoing cortical oscillations continuously fluctuate since the task demands top-down attentional control. Thus because of the active involvement of oscillatory alpha in information processing and since alpha oscillations fluctuate over time, a single trial analysis approach is proposed

instead of assuming a linear relationship like in alpha inhibition hypothesis and averaging across trials. (Linkenkaer-Hansen et al., 2004)

2.3   Eye closure and occipital alpha oscillations

After Hans Berger's first discovery of alpha brain oscillations during eyes closed EEG recording in 1929, Adrian and Matthews (1934) had observed larger alpha brain oscillations in a dark room-open and closed eye conditions compared with open eyes condition in a normal light environment. When the eyes kept closed, a pulse around 10 times in a second originating from occipital regions was noted. Furthermore, this pulse was disappearing with presentation of a sensory stimulus that demands attention (Adrian & Matthews, 1934).

Complimentary with earlier findings, eye closure is suggested to involve in attentional and sensory information processes as a result of having a distinct oscillatory activity compared with when eyes kept open. A magnetoencephalography (MEG) study showed separate alpha level oscillatory activity between eyes open and closed resting states after applying alpha frequency transcranial alternating current stimulation (tACS) (Ruhnau, et al., 2016). Eyes open resting state phase coherence of observed entrainment and results of strong tACS revealed a robust entrainment in visual areas, whereas the effects of entrainment by tACS alpha stimulation were less apparent during eyes closed periods. Furthermore, no entrainment was reported during weak tACS-eyes closed condition, suggesting a distinct oscillatory alpha activity due to eye closure (Ruhnau, et al., 2016). A functional magnetic resonant imaging (fMRI) study also demonstrated separate brain activation patterns for eyes open and closed conditions in a dark environment suggesting two distinct mental state: *interoceptive state* - during eyes closed- denotes imaginary and multisensory activation whereas *exteroceptive state* -during eyes open- is associated with attention and optical activity. Thus, eye closure is suggested to modulate visual and attentional processes differently compared with when eyes kept open (Marx, et al., 2003).

Although distinctive pattern of brain activity have been demonstrated for eyes open and closed conditions, to the best of our knowledge, there are only two studies systematically investigated the effects of eye closure on sensory information processing. An fMRI-eye closure study reported that participants' tactile perception threshold decreased during a tactile

discrimination task, when the dominance of vision was shut down both during eyes closed and in dark room conditions compared with keeping the eyes open and being in a lighted room. (Brodoehl, Klingner & Witte, 2015). Furthermore, effects of eye closure in somatosensory perception threshold were reported to be more prominent in younger participants compared to elders both in cortical and behavioral level (Brodoehl, et al., 2015). A recent study investigated the neural and behavioral effects of oscillatory alpha modulation on an attentive listening task as a result of eye closure (Schmitt, 2016). Although overall listening performance did not differ between eyes open and closed conditions, two different listener profiles were suggested: (1) profiteers of eye closure (whose attentive listening performance increased with eye closure) and (2) sufferers of eye closure (whose attentive listening performance decreased with eye closure). Increased alpha power modulations in parieto-occipital regions that occurred before the target onset are suggested to determine the profiteers of eye closure. Thus, eye closure is presented as a useful strategy in attentive listening, if only the neural alpha power fluctuated during the stimulation period (Schmitt, 2016). The results of these two studies propose eye closure as a strategy for improved sensory perception.

3. CURRENT RESEARCH

As discussed above, entrainment as well as alpha modulations facilitate auditory perception of rhythmic sound stimuli in relevant information processing. In order to achieve better auditory perception, human do not have a direct influence on becoming more entrained to sound stimuli or increasing the alpha modulation in our brain without an external stimulation like tACS at alpha level. However, there might be another possible approach in auditory perception accuracy, where one could boost cortical alpha oscillations by merely closing their eyes, which is indeed a daily strategy that humans do without even recognizing.

Although eye closure is a strategy that is frequently employed in daily life, the impacts of eye closure in auditory perception are lacking attention in the literature. Due to this lack of information about the cortical and behavioral results of eye closure in auditory perception, the current study aimed to investigate the effects of eye closure on speech-like, rhythmic sound stimuli.

In this respect to sum up what has been shown so far: FM stimuli at speech-like low frequencies lead oscillatory phase re-alignment (entrainment) (Bauer et al., 2018; Henry & Obleser, 2012; Henry et al., 2017). Eye closure creates a distinct brain state compared to open eye state; switches off the visual dominance, increases occipital alpha fluctuations and gives advantage to auditory processing (Brodoehl, Klingner & Witte 2015). Alpha oscillations are involved in attentional processes and associated mostly with no-entrainment periods (Henry et al., 2017; Lakatos et al., 2016; Ruhnaue et al., 2016). The power modulation of these alpha oscillations predicts auditory perception accuracy (Schmitt, 2016).

Hence, building upon the previous knowledge, main interests of this research were to understand whether neural oscillations entrain to frequency modulated auditory stimuli similarly during both eyes open and eyes closed conditions and whether eye closure decreases the effects of neural entrainment and enhances auditory attention; thus results in improved gap detection performance compared with eyes open condition.

Consistent with the previous research (Bauer et al., 2018; Henry & Obleser, 2012; Henry et al., 2017; Schmitt, 2016), entrainment to 2.8 Hz frequency-modulated sound was expected to correlate with the gap detection hit rates of participants. Since entrainment facilitates auditory perception, diminished effects of entrainment should be observed also in behavioral analysis of the gap detection task. Moreover, eye closure was expected to influence parieto-occipital alpha modulation, reducing the impacts of entrainment. Based on this, weaker entrainment during eyes closed periods was expected in the EEG results. Hence, gap detection performance should not vary according to the position of the gaps as strongly as in the eyes closed condition compared with the eyes open condition, thus resulting in increased auditory perception and bringing behavioral advantage. Therefore, eye closure may be suggested empirically as a strategy to improve auditory perception.
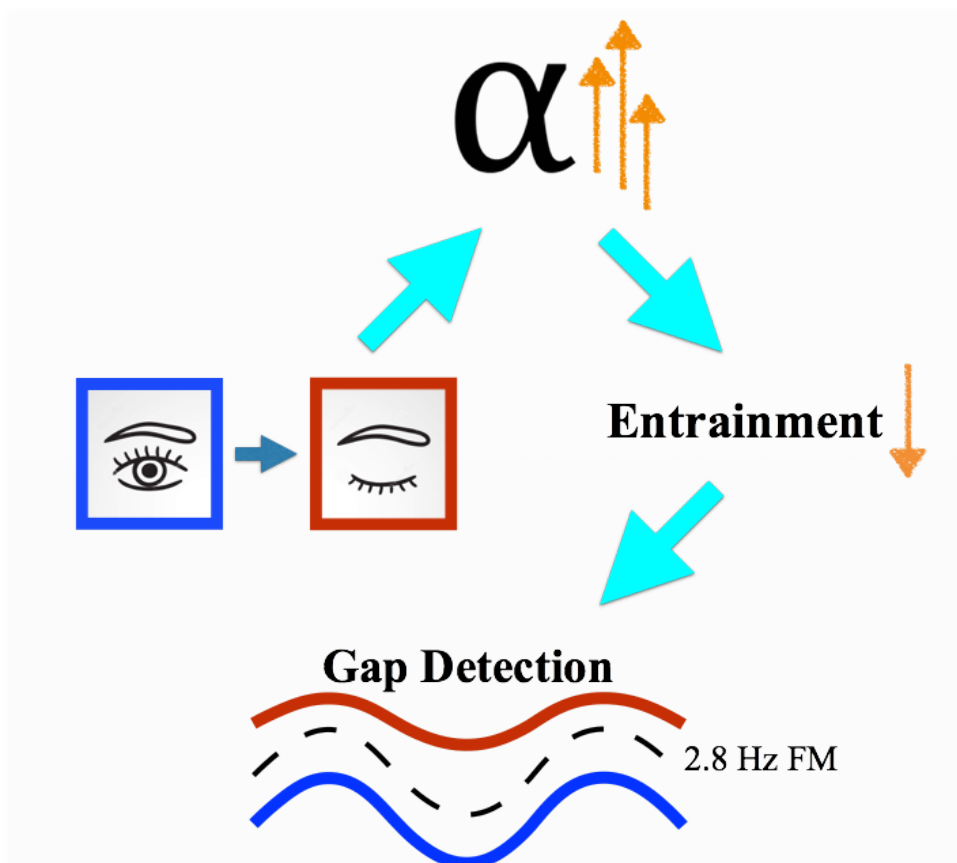
Figure 3. Current hypotheses are: (1) as a result of eyes closure, parieto-occipital alpha power should increase, (2) leading to diminished auditory entrainment as would be suggested by weaker 2.8 Hz neural activity in auditory brain regions and thus (3) gap detection rates would be less modulated by the gap positions in 2.8 Hz FM stimuli resulting in better overall gap detection performance compared with the eyes open condition.

4. METHODS

4.1 Participants

Eleven right-handed healthy participants (age 22–30, 7 female) volunteered to take part in the current research. Out of these eleven, EEG data from eight of the participants (age 22-28, 7 female) were also collected in the Motion Capture Laboratory of Department of Music, Art and Culture Studies, University of Jyväskylä. Instruction and informed consent papers were given to all participants to complete. (Please see the Appendix 1 for the "Instructions and Informed Consent Form".)

4.2 Stimuli

Sound stimuli were modified in MATLAB software (version R2016b, MathWorks) from the script of Henry and Obleser (2012), with permission. 10-second-long FM sound stimuli were created with a sampling rate of 60.000 and frequencies were modulated at 2.8 Hz rate. Carrier frequencies were centered around 800, 1000 or 1200 Hz, which consisted of 30 frequency components. Phase onsets were randomized with eight variations (0, $\pi/4$, $\pi/2$, $3\pi/4$, π, $5\pi/4$, $3\pi/2$, $7\pi/4$). Each 10-second-long sound stimulus included two, three, or four targeted sound gaps, which were placed in 20 equally spaced phase bins.

4.3 Procedure

The experiment consisted of two parts, which were repeated twice on different days within a week. Experimenting time of the day was kept constant, meaning that participants attended both of the days either during morning or afternoon hours. The experimental design is illustrated in Figure 4.

4.3.1 Thresholding

The first part consisted of thresholding, which was designed to obtain participants' sensitivity level to the presented gap durations. An adaptive staircase method (Treutwein, 1995) was applied with several repetitions until the performance of detecting the gaps was between 45-

55%. In total the thresholding runs took around 15-40 minutes and participants completed the thresholding part in a dark room while keeping their eyes open. In this part, participants were asked to press the left mouse button whenever they heard a gap in the sound. Participants were also informed about the possible number of gaps in the sound trials that they are assigned to detect. Each thresholding run (Figure 4a) took about 3 minutes and consisted of twenty 10-second-long FM stimuli. Initially, 40-ms-long gaps were presented. After every run, the experimenter calculated the percentage of gap detection and regenerated new set of thresholding stimuli with shorter gaps if the current performance was higher than 55%. Detecting the presented gaps in the sound got increasingly harder as participants continued with the next repetitions since mainly and the gap durations shortened. If gap detection performance of the current run was below 45%, longer gap durations were used in the following thresholding run. When a participant detected gaps with 45-55% accuracy, the gap duration of this final thresholding was taken as the participant's overall gap detection threshold and thus that gap duration was used in the experimental blocks.
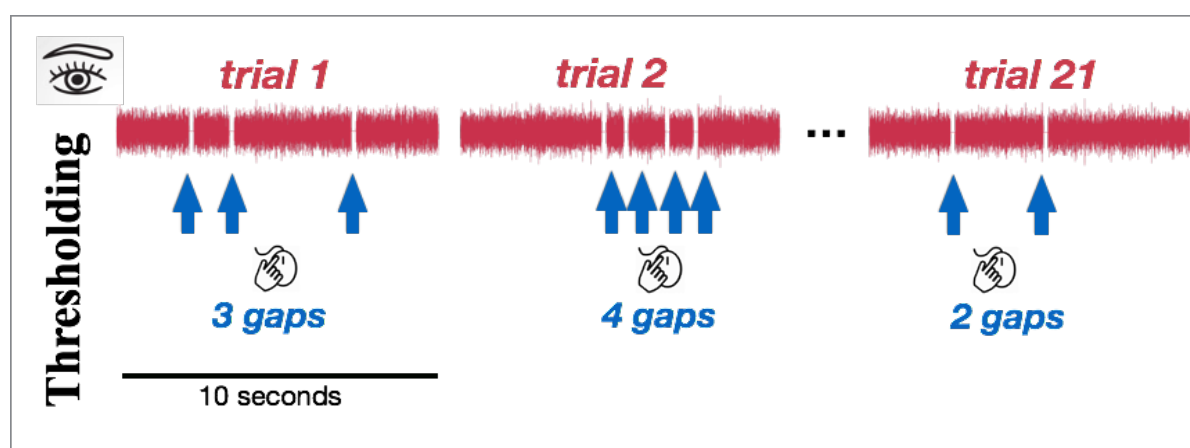
Figure 4a. Thresholding part was designed to obtain participants' sensitivity level to the presented gap durations. Initial 40-ms-long gap durations shortened if participant performed higher than 55%. This procedure repeated until the gap duration with 45-55% detection performance was found.

4.3.2 Experimental blocks

The second part of the experiment was similar with the first part and took less than one hour. This section was different to the threasholding part, as sound trials were presented between 1 second-long "beep" sounds. To initiate the next trial, participants were asked to press the left mouse button after they heard this brief "beep" sound. Therefore participants could continue the experiment at their pace. Each block consisted of 42 FM sound trials and the entire experiment included 4 eyes open and 4 eyes closed blocks in a semi-randomized order (Figure

4b-c). The experimenter informed the participants for the blocks when they need to close their eyes and participants were reminded not to open their eyes until the end of this part. Breaks of 1-5 minutes were given in between of the blocks. Moreover, the entire experiment was conducted in a dark room in order to eliminate visual processing during the eyes open conditions, therefore the only experimental variation between the eye open and the closed conditions was eye closure.
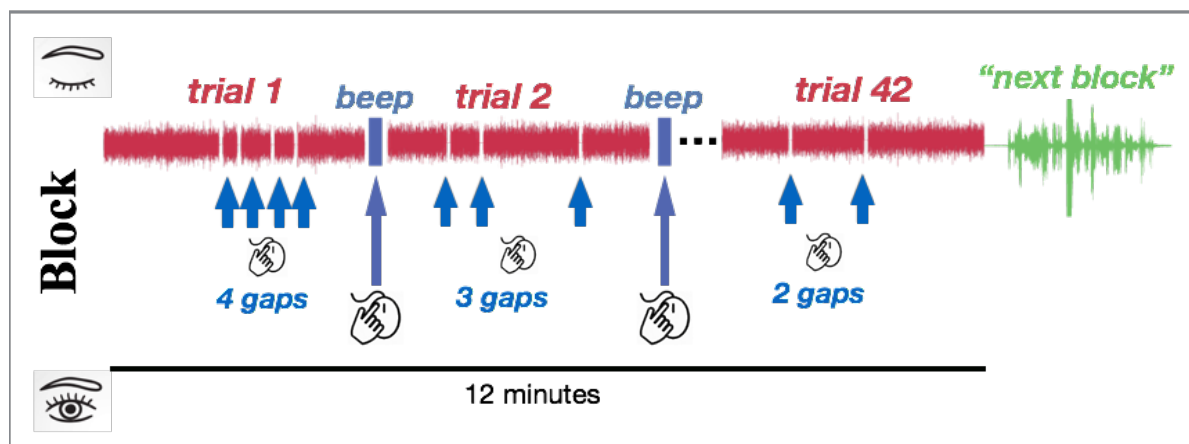
Figure 4b. The obtained individual just-noticeable gap durations were used to create sound stimuli in the experimental blocks. Each block consisted of 42 FM sound trials that participants were asked to detect the gaps either while keeping their eyes open or closed. Moreover, 1-second-long beep sounds were placed in between the trials so that participants could arrange their own pace.
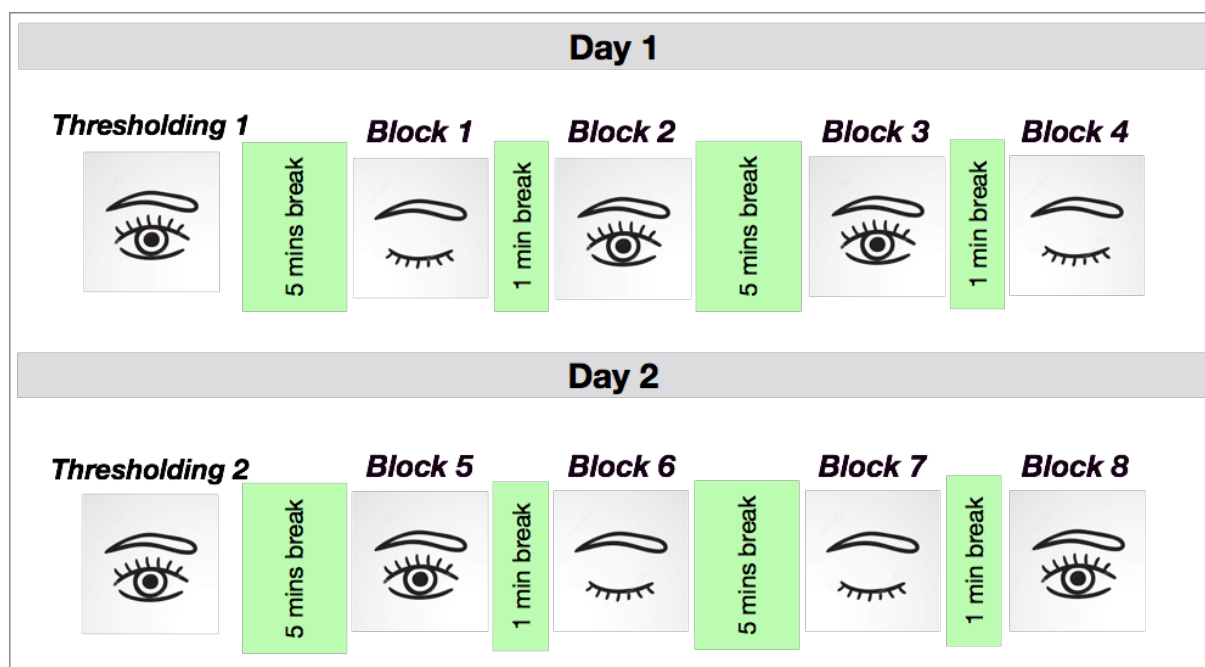
Figure 4c. The experiment consisted of 4 eyes open and 4 eyes closed blocks in a semi-randomized order. Participants who have the even-numbered experimental code completed the experiment in the order as shown in the illustration whereas the odd-numbered participants started the experiment in the

first day with the block order as seen in Day 2 part and completed the experiment in the second day with the order as shown in Day 1. Short breaks were given in between of the trials.

4.3.3 Questionnaire

After the participants completed the entire experiment, questionnaire (see Appendix 2) responses were collected from the participants. The questionnaire was intended to obtain participants' own evaluation of their attentiveness, mind wandering as well as perception of task difficulty and gap detection average performance during the eyes open and closed conditions. Participants responded to the questions by choosing values from a likert scale from 1 (not at all) to 7 (very much).

4.4 Data acquisition and analysis

4.4.1 Behavioral measurement

Behavioral data were acquired through Presentation, the neurobehavioral data acquisition software (Neurobehavioral Systems Inc.). Thresholded gap durations varied between 11 and 20 ms among participants (M=14, SD=2.73). Listeners were instructed to respond as quickly as possible when they hear a sound gap, and a response was considered to be a *hit* if it occurred within 1000 ms after a gap. If there are two or more clicks with an interval shorter than 500 ms, the later responses were reported as *false alarm* in the analysis. Hit and false alarm rates were obtained separately for each of 20 phase bins. Overall, each participant completed 336 sound trials (168 trials for the eyes open and 168 trials for the eyes closed conditions).

4.4.2 Electroencephalogram measurement

Neuroscientists have been studied cortical electrical potentials in animal (Caton, 1875) and human brain (Berger, 1934) for over a century. EEG is a non-invasive brain imaging method, which monitors electrical voltage change between electrodes over time (Wöstmann, Fiedler & Obleser, 2017). With scalp EEG, it is possible to capture sensory, cognitive and motor related events' postsynaptic activity in neuronal populations. Postsynaptic activity can last for tens or hundreds of milliseconds; after temporally aligning the event-onset (time-locked) and by simply getting the average activity of several repetition of the same event, *event related potentials* (ERPs) can be obtained. ERPs have high temporal resolution around 1 ms (Luck,

2014), giving temporal advantage to EEG over other brain imaging methods such as fMRI. (Luck, 2014; Wöstmann, Fiedler & Obleser, 2017)

Considering the above-mentioned characteristics of EEG, for this study neural data were recorded from 64-channel EEG with sampling rate at 512 Hz through ActiveTwo system (BioSemi Inc., Amsterdam). The EEG data were first preprocessed and then analyzed in FieldTrip toolbox (Oostenveld, et al., 2011), MATLAB (version R2016b, MathWorks) in terms of time-amplitude (ERP analysis), frequency-amplitude (evoked power frequency analysis) and time-frequency (total power frequency analysis) decomposition of the EEG signal.

4.4.2.1 Preprocessing

The preprocessing pipeline consisted of 10 steps:

1. Epoching the data according to sound onsets (1 second before and 12 seconds after the sound onset: -1 12 s)
2. Re-referencing the data to mastoid electrodes TP7 and TP8
3. Applying baseline correction (-0.1 0 s)
4. High pass filtering at 0.5 Hz and low pass filtering at 50 Hz
5. Trial-based visual artifact rejection (maximum of 12% out of 168 trials from each participant's data were rejected)
6. Appending the data blocks (4 eyes open and 4 eyes closed blocks) according to the collection days as day-1 and day-2
7. Running an independent component analysis (ICA) on day-1 and day-2 data separately
8. Rejecting line-noise, eye and muscle artifact components (10 -/+ 4 independent components were removed after each ICA)
9. Separating all the eyes open and eyes closed blocks of day-1 and day-2 and combining them according to eye condition
10. Applying average referencing to all electrodes

There were also two problems that occurred during preprocessing. Firstly, in the data collection period, a total of 4 trials (in 4 different participants' data) failed to sustain trial information in the log file. Due to a MATLAB error (deleting the entire "trialinfo" matrix in

the appending data period because of non-matching number of trials in the to-be-appended data), a total of 12 more trials (specifically the last trials of these to-be-appended data blocks) were removed from the missing blocks' corresponding to-be-appended data blocks. Thus, the number of trials remained equal within each to-be-appended data block. The second problem in the preprocessing period was that one participant had a noisy channel and thus the signal from this channel was tried to replace with an average signal obtained from the three neighboring channels. Since the channel noise remained, this participant's data were excluded from further EEG analysis.

4.4.2.2 Event related potential analysis

ERP activity results from sensory stimuli and reveals characteristic features called *ERP components* (Wöstmann, Fiedler & Obleser, 2017). ERP components of auditory responses that arise from the brainstem can be observed as very early components, even around 10 ms. Mid-latency components originate from attention related activation, medial geniculate nucleus and the primary auditory cortex within 10-50 ms. These components are followed with the initial peak (P1: P refers to a positive peak) around 50 ms, which typically has its largest activation pattern in fronto-central areas. P1 activation is an obligatory, low-level sensory response. It is sensitive to stimuli parameters such as sound amplitude; thus P1 is also known as an exogenous component. First negative peak (N1: N refers to a negative peak), around 100 ms is commonly observable after the P1 component and involves in perception of the presented stimuli. (Luck, 2014)

Compared to behavioral responses, ERPs have the advantage of being a constant measure of brain activity arising from stimulus presentation; even in the absence of behavioral response to the stimuli, ERPs can provide information about how human brain processes sensory stimuli. On the other hand, the underlying effect of an ERP component is not as clear as behavioral responses, thus in order to generalize the effects of the event related activity components multiple trials need to be conducted and the signal to be averaged.

In the current research, event related activities were computed separately on individual data for eyes open and closed conditions over the entire time course (-1 11 s) of the FM sound stimuli with the ft_timelockanalysis function of the Fieldtrip toolbox (Oostenveld, et al., 2011). For visualization purposes, a low pass filter was applied at 30 Hz to the grand average

ERP activity across participants. The N1 and P2 topographies of the grand averaged ERP signal were plotted with ft_topoplotER function of Fieldtrip toolbox (Oostenveld, et al., 2011) with 160-210 ms and 260-320 ms latencies subsequently. The latencies of N1 and P2 components was delayed around 70 ms, this issue is further discussed in limitation part of the current work.

4.4.2.3   Frequency analysis

EEG signal is complex, consists of several signals from different sources in the brain that could vary in terms of frequency and intensity over time. Time-locked activity is thus not sufficient to evaluate an EEG signal completely. Therefore, time-frequency analysis is used to decompose spectral features of a signal over time (Cohen, 1995). The amplitude of frequency components in time can be represented on a power scale, which is calculated by squaring the amplitude coefficients of *Fourier* or *wavelet-transforms* (Wöstmann, Fiedler & Obleser, 2017). Further, Wöstmann and colleagues (2017) stress the distinction between two types of neural oscillatory power: total power and evoked power. Frequency representation of ERPs over time is called *evoked power,* which takes phase-locked activation of each trial into account so that the evoked power values of the oscillatory frequencies can reflect consistency across all trials. With evoked power, oscillations which are not phase and time-locked cancel out by trial averaging. *Total power*, on the other hand, reflects time-domain activity (regardless of phase-locked activation) and exhibits intensity level of frequencies over a time period across trials (Wöstmann, Fiedler & Obleser, 2017).

For the total power representation of the current data, to obtain frequency changes of the EEG signal over stimulation period, a Fourier transformation was calculated with the ft_freqanalysis function of the Fieldtrip toolbox (Oostenveld, et al., 2011). The mtmconvol method was applied by using a hanning taper with 100 ms time resolution, and frequency bins were arranged to be centered also at stimulation frequency (2.8 Hz) and its harmonic (5.6 Hz). The power representations of the frequencies were plotted for the entire stimulation period (-0.5 11 s) with the ft_singleplotTFR function of the Fieldtrip toolbox (Oostenveld, et al., 2011).

Total power would not be sufficient to observe entrainment, thus evoked power representations of the current data were also investigated. In order to obtain the evoked

power, since each trial had a random stimulus phase-onset during the stimulation period, phase onsets of each trial were first realigned. Later, time-lock analysis was applied on the realigned data and eventually frequency analysis was employed by using hanning taper with mtmfft method on the time of interest (-0.5 11 s). The topographies of the evoked power signals at 2.8 Hz, 5.6 Hz and alpha range (8-12 Hz) were plotted with corresponding frequency bins ranging as 2.7-2.9 Hz, 5.41-5.75 Hz and 8-12 Hz respectively.

5. RESULTS

5.1 Event related potential analysis

Figure 5a demonstrates all participants' grand average sound-onset time-locked ERP activity from auditory region (electrodes FC1, C1, CP1, CPz, FC2, FCz, Cz, C2, CP2) for eyes open (red) and eyes closed (blue) condition. Peaks after 0 and 10th seconds reflect strong auditory activity as response to sound onset and offset. The grand averaged ERP activity of all participants was replotted in Figure 5b in order to demonstrate N1 and P2 ERP component peaks. Figure 5c and Figure 5d validate that the source of the sound-onset activity, the N1 and P2 components respectively originating from the auditory regions. Two repeated measured t-test revealed no statistically significant difference on amplitude of N1 and P2 ERP components between eyes open and eyes closed conditions (N1: $t(6)=1.11$, $p=.31$ and P2: $t(6)=1.58$, $p=.17$).
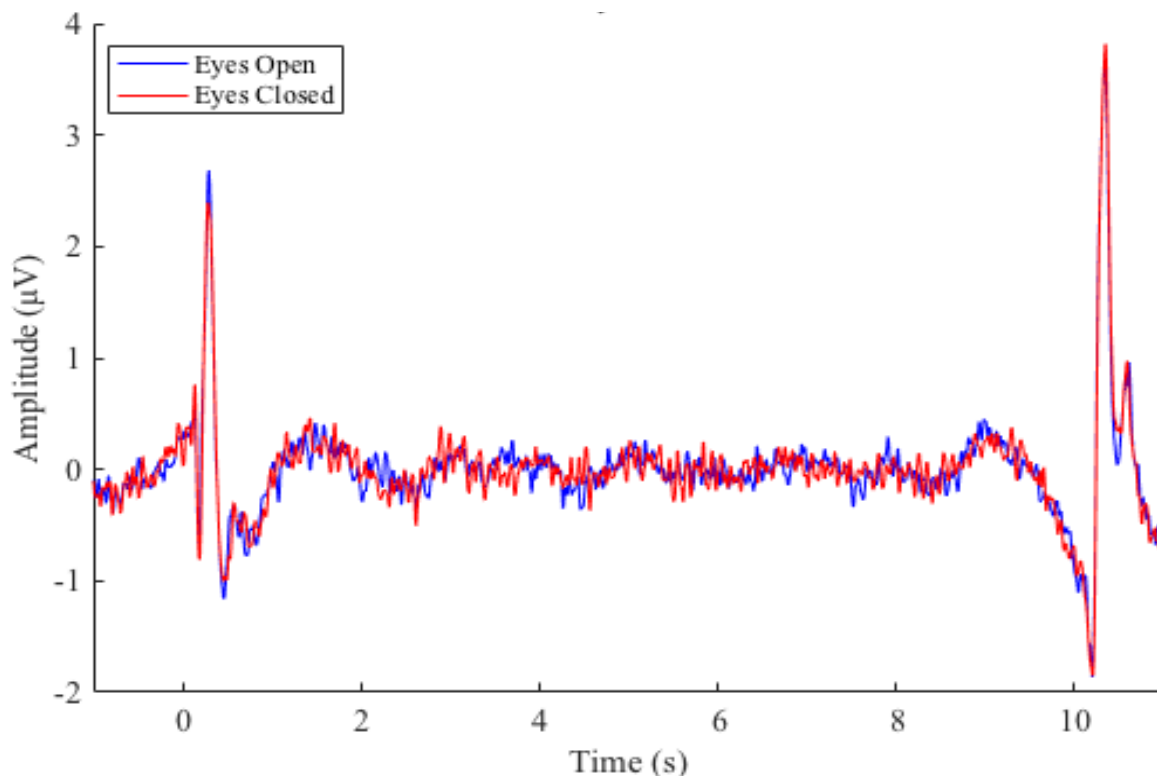
Figure 5a. Event related activity of the auditory electrodes (averaged across participants, N=7) shows strong activation to the sound onset and offset for the eyes open (blue) and the eyes closed (red) condition.
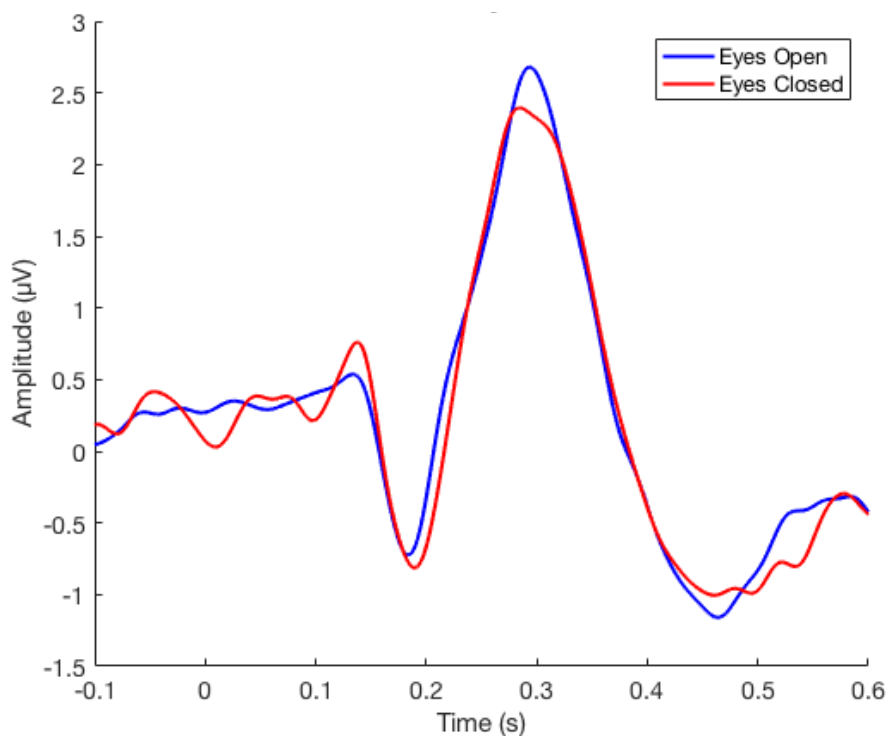
Figure 5b. The event related activity of the auditory electrodes (averaged across participants, N=7) was re-plotted for shorter time duration (-0.1 0.6 s) to reflect peaks for first negative (N1) and second positive (P2) ERP components for the eyes open (blue) and the eyes closed (red) condition.
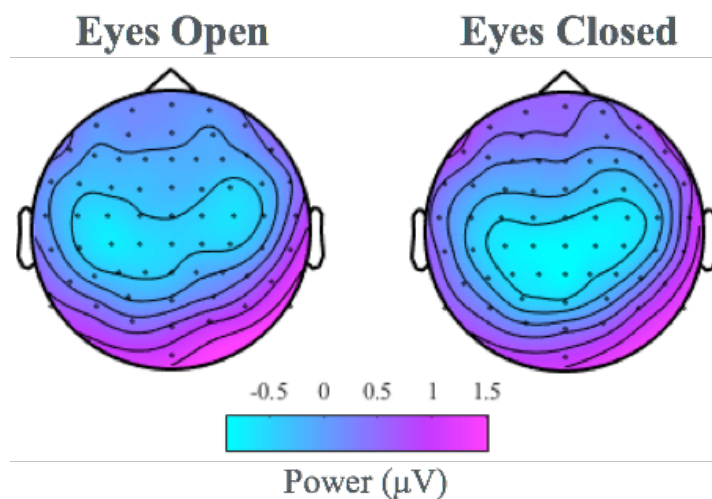
Figure 5c. N1 topography of the auditory electrodes' event related activity (N=7) to the sound-onset reflects a negative peak from the central brain areas.
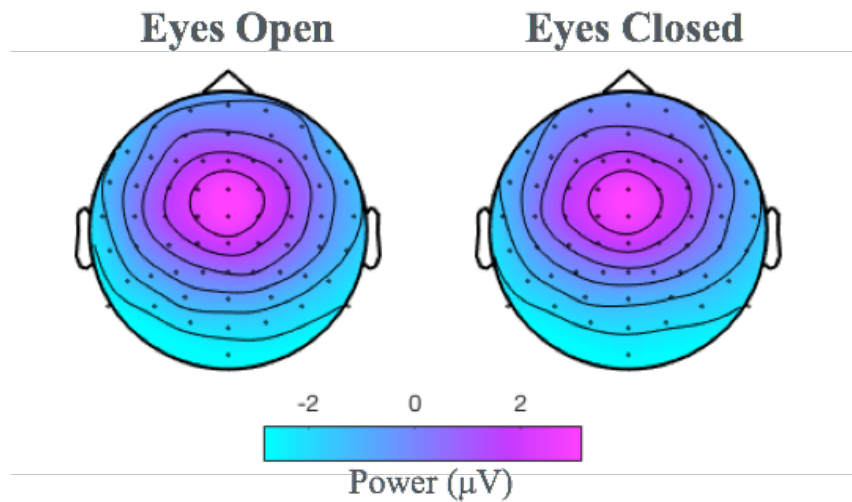
Figure 5d. P2 topography of the auditory electrodes' event related activity (N=7) to the sound-onset reflects a positive peak from the central brain areas.

5.2 Frequency analysis: total power

Figure 6a shows time-frequency decomposition of the neural signal averaged across participants (N=7) as response to 2.8 Hz FM sound stimuli. As expected, strong alpha amplitude (8-12 Hz) was dominating the entire stimulation period in the eyes closed condition. A repeated measured t-test showed statistically significant difference on alpha range (8-12 Hz) total power between eyes open (*M*=.67, *SD*=.50) and eyes closed (*M*=1.36, *SD*=.59) conditions; $t(6)=-2.63$, $p=.04$. The origin of the alpha activity was revealed to be the occipital region (Figure 6b), which is in line with the result of eye closure. Moreover strong stimuli offset neural activation are visible in the total power representations of slow (1-3 Hz) frequency band around 10th second.
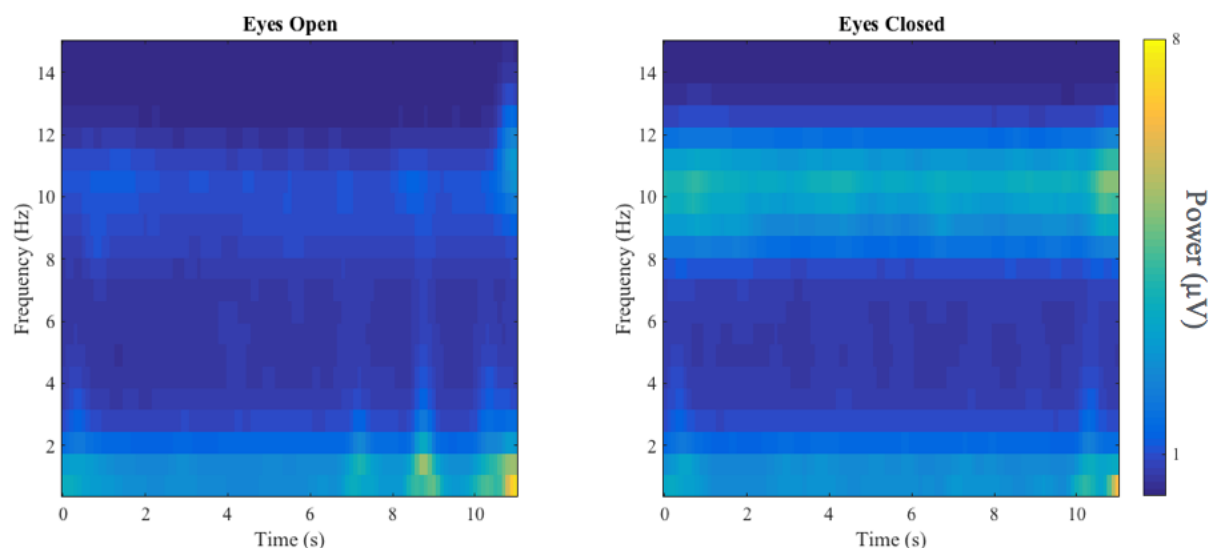
Figure 6a. Time-frequency decomposition of the neural signal as response to FM sound stimulation (N=7) is reflecting a strong alpha range frequency activation in eyes closed condition.
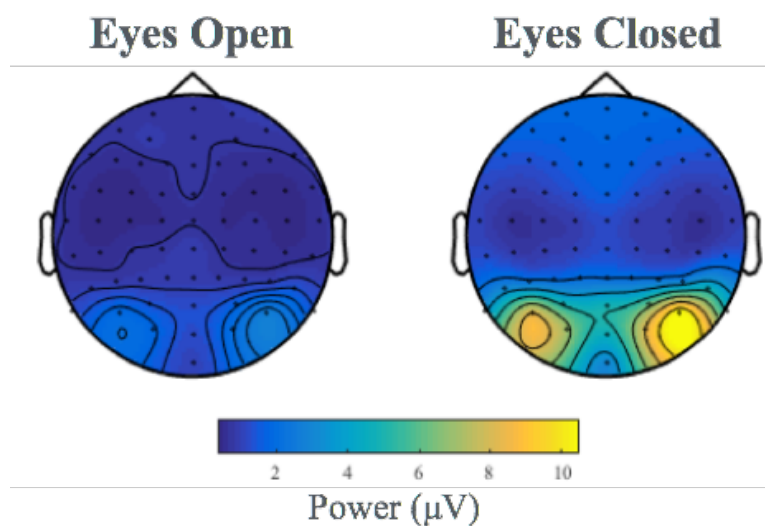
Figure 6b. Alpha frequency range activity topography of the time-frequency decomposition reveals the source of alpha activity as occipital brain regions. The alpha power is stronger during the eyes closed condition compared with the eyes open condition.

5.3 Frequency analysis: evoked power

The neural imprints of auditory entrainment in response to 2.8 Hz FM sound stimulation can be observable in the evoked activity amplitude spectrum (Figure 7a) as distinct amplitude peaks at the stimulation frequency, 2.8 Hz and its harmonic at 5.6 Hz. Noticeably, strong

alpha peaks due to eye closure are still visible in the evoked spectrum. Two repeated measured t-tests on 2.8 Hz and 5.6 Hz evoked power showed no statistically significant difference between eyes open and eyes closed conditions (2.8 Hz: $t(6)$=-1.18, p=.28 and 5.6 Hz: $t(6)$=-.45, p=.67). Another repeated measured t-test revealed statistically significant difference on alpha range (8-12 Hz) evoked power between eyes open and eyes closed conditions; $t(6)$=-2.59, p=.04.

The topographies in Figure 7b reveal that the source of the activity around 2.8 Hz is the fronto-central area and around 5.6 Hz the central region, suggesting auditory entrainment. The third topography for alpha range activity originated from occipital regions as a result of eye closure.
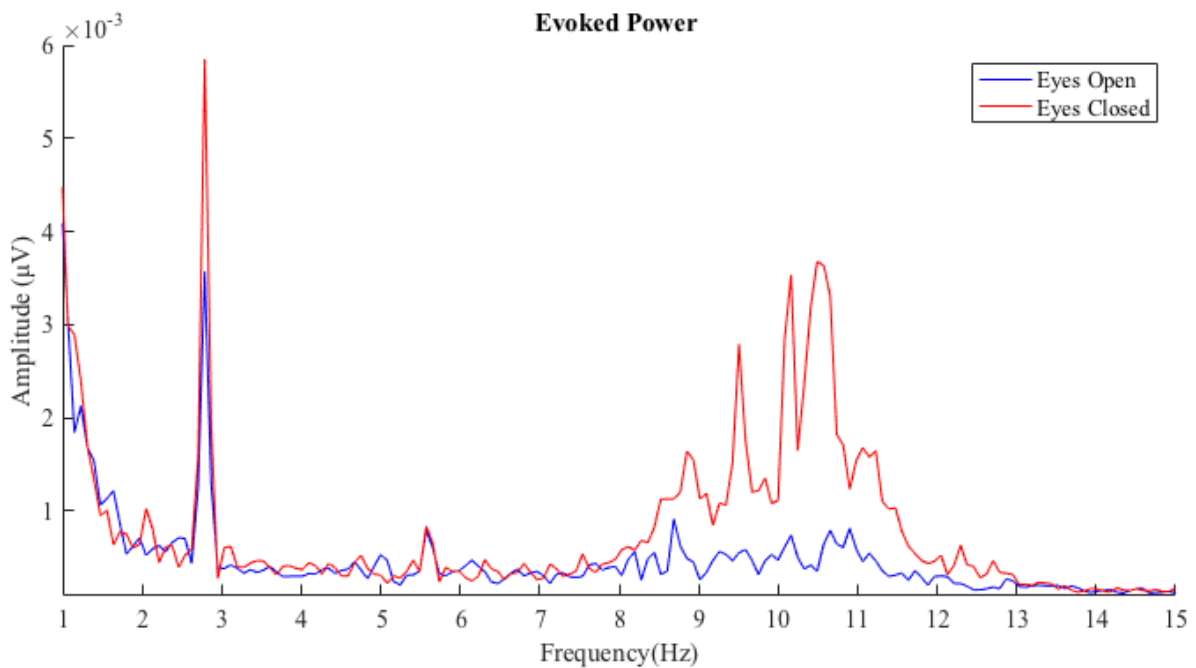
Figure 7a. Evoked activity amplitude spectrum (averaged across participants, N=7) suggests neural entrainment with large amplitude peaks at the stimulation frequency, 2.8 Hz and its harmonic at 5.6 Hz. The eyes closed (red) condition reflects stronger alpha power compared with the eyes open (blue) condition. Strong alpha range (8-12 Hz) oscillations are observable in the eyes closed condition.

In order to visually inspect participants' eyes open and eyes closed entrainment strength, a 45-degree plot was created to compare individual 2.8 Hz bin values of the Cz electrode between the eyes open and closed conditions. Figure 7c reveals that the strong 2.8 Hz peak in the evoked power plot (Figure 7a) is due to only one participant. Hence, it can be suggested that

nine participants out of ten showed similar neural entrainment effect at 2.8 Hz for eyes open and closed conditions and only one participant had stronger entrainment effect at 2.8 Hz in eyes closed condition compared with eyes open condition.
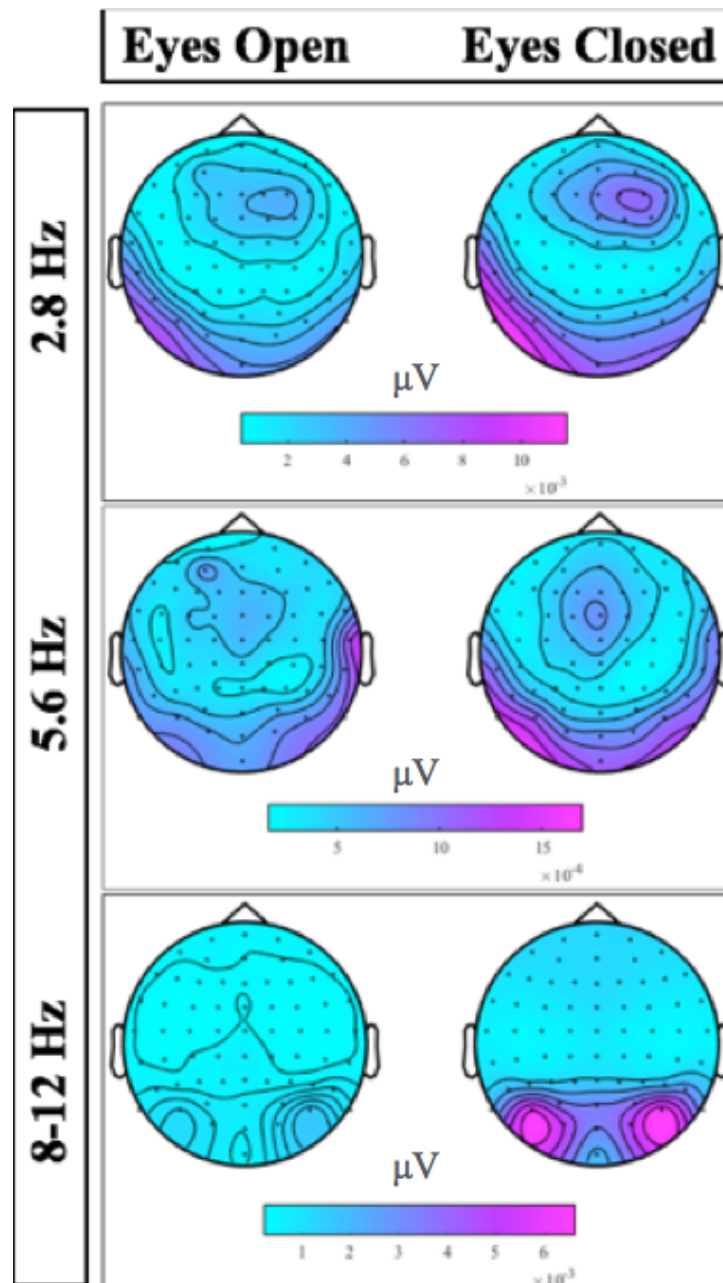
Figure 7b. 2.8 Hz, 5.6 Hz and alpha frequency range (8-12 Hz) topographies of the evoked activity (averaged across participants, N=7) present the source of 2.8 Hz activity as fronto-central and 5.6 Hz activity as central area reflecting auditory entrainment. The eyes closed condition topography of alpha power (8-12 Hz) shows stronger occipital activity as a result of eye closure.
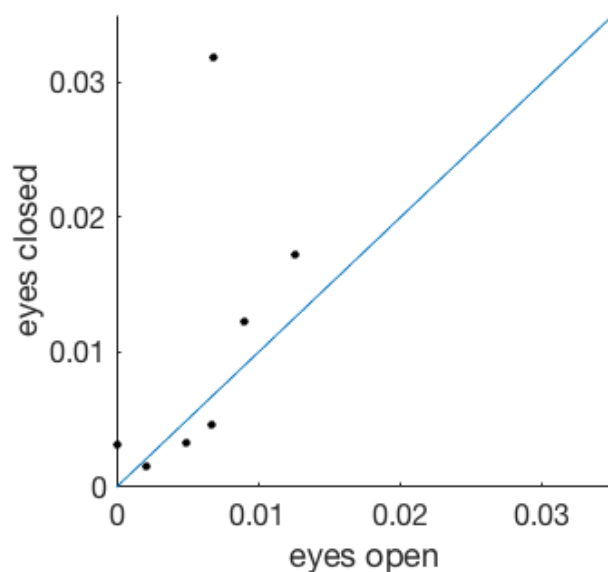
Figure 7c. 45-degree comparison (N=7) for individual 2.8 Hz bin evoked power values of the Cz electrode suggest that the strength of entrainment for eyes open and closed conditions did not differ among participants except only one participant showed stronger entrainment effect at 2.8 Hz in the eyes closed condition compared with the eyes open condition.

5.4   Behavioral analysis of entrainment and gap detection performance

Behavioral data were analyzed by plotting participants' individual (Figure 8a) and grand averaged (N=11, Figure 8b-c) hit rates for all eight gap positions over two cycles of 2.8 Hz FM sound. Individual hit rates varied and this variation suggested to be an effect of entrainment. This fluctuation is still visible when the data were averaged across all participants (Figure 8b); 2.8 Hz cosine fit model fitted 52% of the eyes open average data (R^2=.52) and 28% of the eyes closed average data (R^2=.28). In Figure 8c, z-scored grand averaged across participants' eyes open (blue) and closed (red) gap detection rates were plotted for each gap position against a signal that reflected stimulus phase (black). Incoherency between the grand averaged hit rates and the stimulus phase suggests no consistent optimum gap position across participants.

To compare the average gap detection performance and the strength of behavioral entrainment for the eyes open and eyes closed conditions of the individual data, best-fit cosine function at 2.8 Hz was used. The amplitude value of each cosine fit reflected the level of entrainment while the intercept value of the cosine fit gave the average performance value for individual data. A repeated measured t-test showed no statistically significant difference on entrainment strength (as measured with amplitude values of cosine fits) between the eyes open (*M*=.08,

SD=.01) and eyes closed (*M*=.08, *SD*=.02) conditions; *t*(10)=-.45, *p*=.67. Another repeated measured t-test revealed no statistically significant difference on average performance (as measured with intercept values of cosine fits) between the eyes open (*M*=0.47, *SD*=0.09) and eyes closed (*M*=.45, *SD*=.08) conditions; *t*(10)=-.45, *p*=.67.
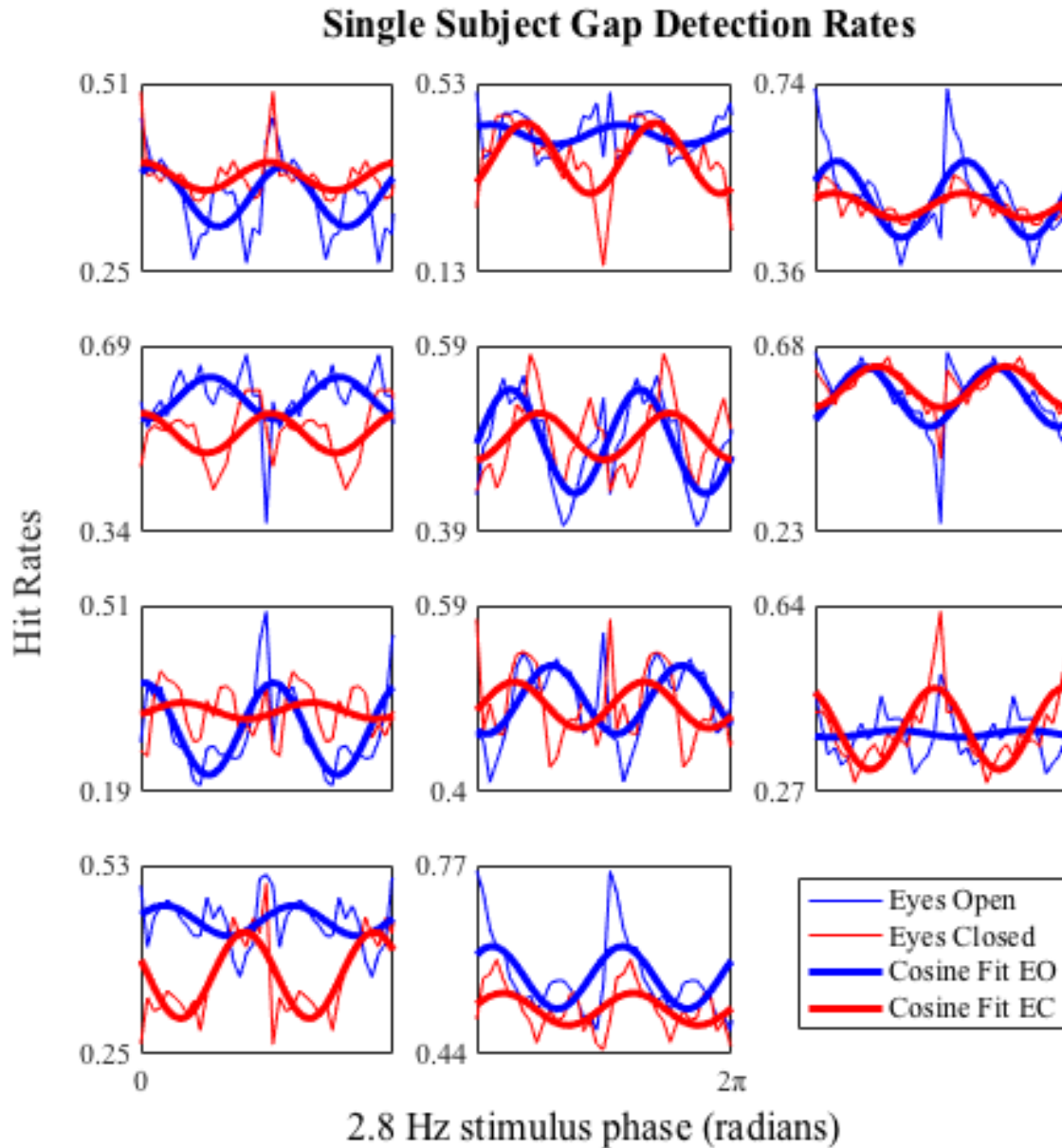
Figure 8a. Participants' (N=11) individual gap detection rates varied as a result of entrainment. Best-fit cosine functions at 2.8 Hz (bold lines) reflect behavioral modulation of entrainment to 2.8 Hz stimuli phase for the eyes open (blue) and eye closed (red) conditions.

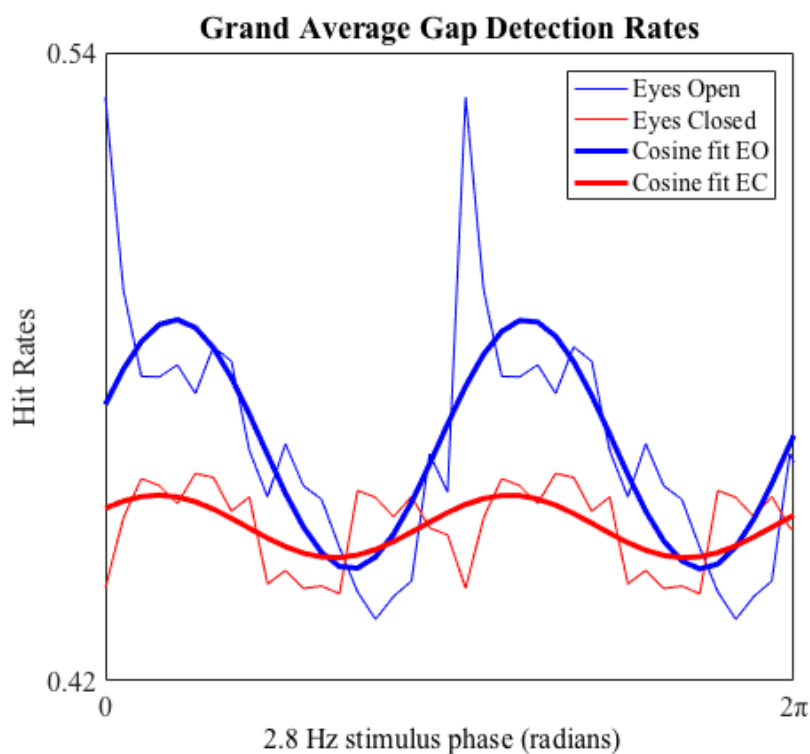*Figure 8b.* Grand average gap detection rates averaged across all participants. 2.8 Hz cosine fit models fitted the eyes open (blue) hit rates with 52% and eyes closed (red) hit rates with 28%.
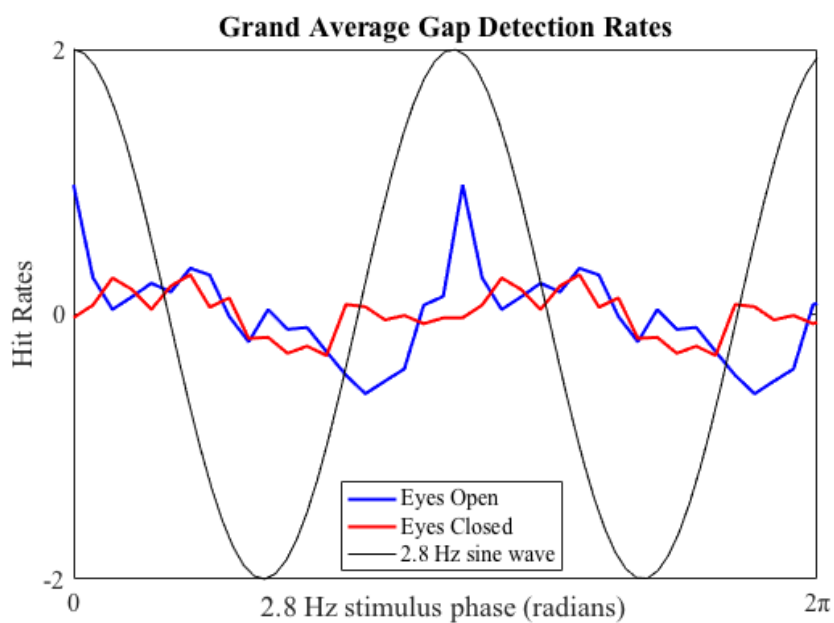
Figure 8c. Z-scored grand averaged (across participants, N=11) eyes open (blue) and closed (red) gap detection rates showed inconsistency with stimulus phase (black) suggesting no optimum gap position across participants.

In order to visualize the behavioral results of individual data, two 45-degree plots were produced; each dot in Figure 8d represents average performance (left figure for the intercept values cosine model fit) and entrainment strength (right figure for the amplitude values of cosine model fit) values for each participant in eyes open (x axis) against eyes closed (y axis) conditions. Positions of the individual data around the 45-degree lines support the conclusion that no difference in the behavioral effects of entrainment and average gap detection performance between conditions was observed in the current data.
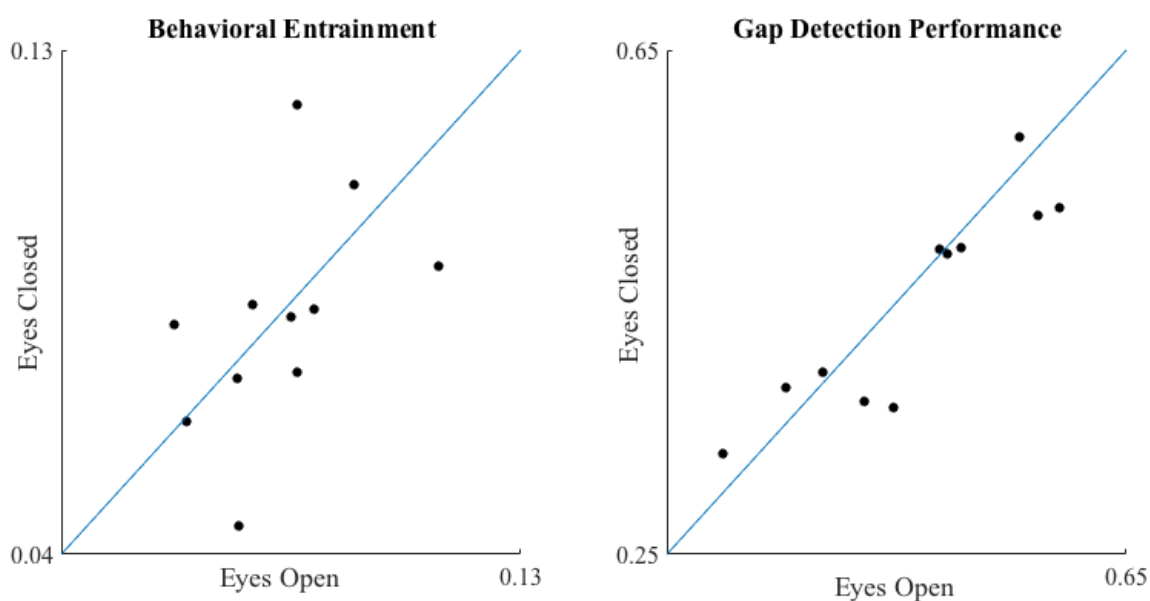
Figure 8d. 45-degree comparisons of cosine model fits for individual data demonstrate that the average gap detection performance (intercept values of cosine fit at 2.8 Hz, figure on the right) and the strength of entrainment (amplitude values of cosine fit at 2.8 Hz, figure on the left) for the eyes open and closed conditions did not differ among participants.

5.5   Interaction of alpha amplitude, neural entrainment and behavioral data

The effects of auditory entrainment were shown at both behavioral (Figure 8a-d) and neural (Figure 7a-c) level and no statistically significant difference on participants' neural and behavioral entrainment strength and gap detection performance were found. Critically, since increased alpha range activation is associated with suppression of irrelevant information and influencing entrainment level and thus the behavioral transition, Henry and colleagues (2017) further suggested that there is an interaction between alpha oscillations, entrainment and behavioral modulation. Hence, by being able to observe separate contribution of alpha oscillations and neural entrainment on behavioral modulation, the effects of eye closure on

gap detection performance could be more clearly demonstrated. For this reason, a Spearman partial correlation was run and no significant interaction among alpha amplitude, neural and behavioral entrainment was found (Figure 9a). Only, a significant correlation was noted in the eyes open condition when the effect of alpha power is partial out, neural entrainment correlated with gap detection performance (Figure 9b); $r(5)=.88$, $p=.02$. A 45-degree plot was further created to visually inspect this significant correlation (Figure 9c).
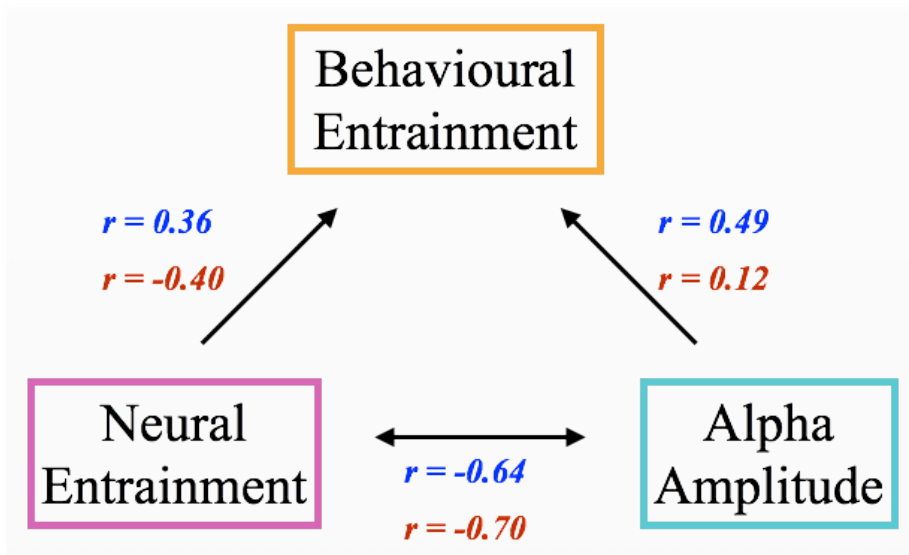
Figure 9a. A Spearman partial correlation was applied for the interaction model among alpha amplitude, neural and behavioral entrainment. No significant correlation was found for eyes open (blue) eyes closed (red) condition.
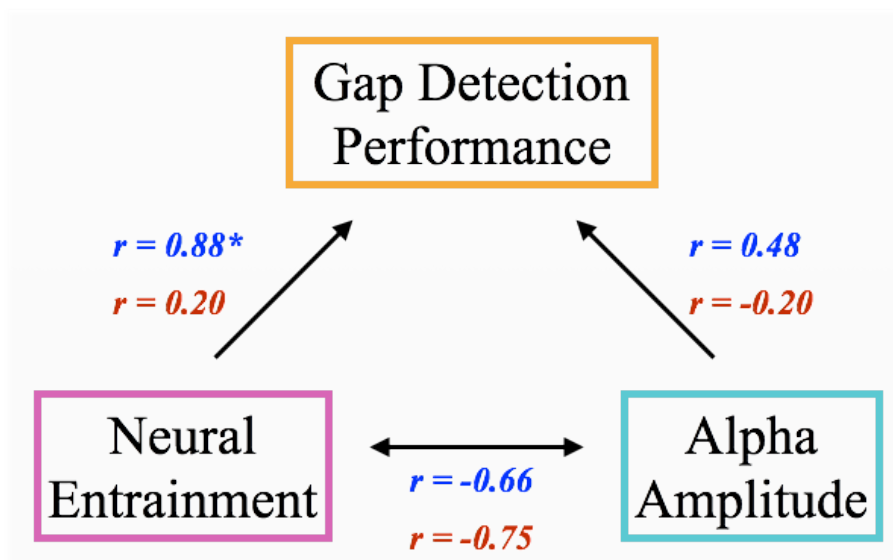
Figure 9b. A Spearman partial correlation was applied for the interaction model among neural entrainment, alpha amplitude and gap detection performance. When the effect of alpha amplitude is partial out, neural entrainment significantly predicts gap detection performance only in eyes open condition (blue) but no significant difference was found for the eyes closed condition (red).
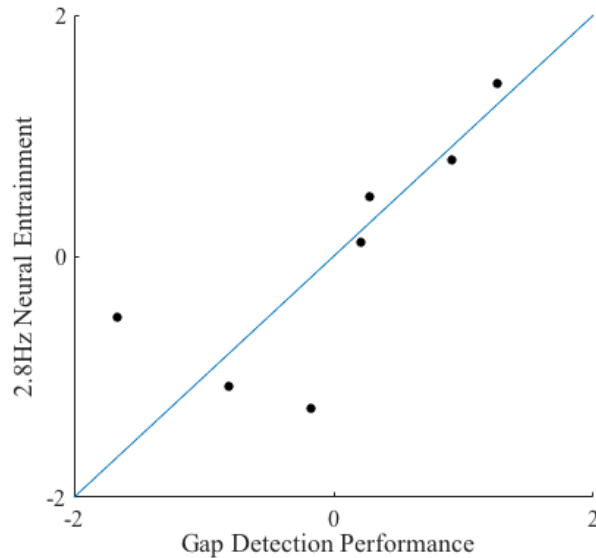
Figure 9c. 45-degree comparison (each dot representing one participant, N=7) shows the significant interaction in eyes open condition between 2.8 Hz neural entrainment and gap detection performance. Neural entrainment at 2.8 Hz has a significant positive correlation with gap detection performance.

5.6 Perceived effects of 2.8 Hz FM sound stimulation

In order to compare questionnaire responses of participants for the eyes open and closed conditions, four repeated measured t-test were run. Results revealed no statistically significant difference on participant's perceived task difficulty ($t(10)$=-.15, p=.88), perceived attentiveness ($t(10)$=1.11, p=.29), self report of mind wandering ($t(10)$=-1.24, p=.24) and perceived gap detection performance ($t(10)$=1.05, p=.32) between the eyes open and eyes closed conditions.

Furthermore, participants' perceived gap detection performance values were correlated with their actual gap detection performances. Interestingly, a significant correlation was found between participants' perceived and actual gap detection performances only in eyes closed condition $r(9)$=.69, p=.02. This finding might suggest that participants are more aware of their actual performances during eyes closed condition.

6. DISCUSSION

This research investigated the neural and behavioral effects of eye closure on auditory entrainment. Participants detected near-threshold gaps embedded in 2.8 Hz FM stimuli in both eyes open and eyes closed conditions. As hypothesized, the long studied effect of eye closure (Berger 1929; Adrian & Matthews, 1934; Schmitt, 2016) increased the alpha band oscillatory power as measured by EEG. Moreover, these results validate the previous researches (Bauer et al., 2018; Henry & Obleser, 2012; Henry et al., 2017), that neural and behavioral entrainment to slow frequency modulated sound stimuli were demonstrated in eyes open condition. However, contrary to the main hypothesis, closing the eyes did not influence the overall gap detection performance in comparison with performance during the open eye condition. Significantly, the current research provides first evidence of entrainment while the eyes kept closed.

6.1   Induced occipital alpha power and its effects on neural and behavioral entrainment

As anticipated, closing the eyes increased occipital alpha power. Since an increase in alpha oscillations are associated with decreased entrainment (Henry et al., 2017; Lakatos et al., 2016; Ruhnaue et al., 2016), during the periods of eye closure neural and behavioral effects of entrainment to 2.8 Hz FM stimuli were expected to be weaker compared to the eyes open periods. Surprisingly, the current grand averaged findings of across participants suggest no difference in both neural and behavioral results of entrainment between eyes open and closed conditions. To the best of our knowledge, no other study has shown entrainment to slow and rhythmic sound stimuli. Critically, since neural entrainment and neural alpha power have an adverse impact on behavioral modulation, in order to detect sole contribution of occipital alpha power as induced by eye closure on behavioral modulation, the interaction among alpha power, neural and behavioral entrainment should be further discussed.

6.2   The interaction between alpha power, neural and behavioral entrainment

6.2.1   Neural entrainment and alpha oscillations

Both neural alpha oscillations and neural entrainment effects auditory gap detection

performance. Alpha amplitude and neural entrainment are negatively correlated (Henry et al., 2017), reflecting two separate oscillatory mechanisms for auditory processing. The current result of the partial non-significant correlation suggests a tendency that when participants have higher oscillatory alpha power, neural entrainment diminishes during both eyes open and closed conditions.

6.2.2 Alpha amplitude and behavioral entrainment

A non-significant trend positively correlated alpha amplitude with behavioral entrainment in both conditions. However, this trend differed when alpha amplitude was related with gap detection performance and alpha amplitude in eyes closed condition. A non-significant negative relation between gap detection performance and alpha amplitude suggested for eyes closed condition, whereas this correlation tends to be positive for eyes open condition. This trend distinction might suggest that alpha amplitude modulates gap detection performance differently during eyes open and closed conditions. Thereby, two distinct role of eye-closure-induced alpha amplitude for auditory processes and its behavioral results under eyes open and closed conditions might be introduced.

6.2.3 Neural entrainment and its behavioral consequences

Neural entrainment is non-significantly associated with behavioral entrainment. However, neural entrainment is significantly related with gap detection performance in eyes open condition and no significant correlation was found for eyes closed condition. In other words, when the influence of alpha amplitude is partial out, neural entrainment correlates significantly with behavioral performance in eyes open condition whereas such prediction cannot be made for eyes closed condition. This finding might also support the suggestion that there are two distinct auditory processing mechanisms for eyes open and eyes closed conditions, neural entrainment influences behavioral gap detection performance differently under eye open and closed periods.

6.3 Impacts of eyes closed state

Previous researches have suggested eye closure as a strategy to improve somatosensory (Brodoehl, Klingner & Witte, 2015; Brodoehl, Klingner, Stieglitz & Witte, 2015) and auditory perception (Schmitt, 2016). As opposed to these findings, some of the questionnaire responses of the current research reported "feeling sleepy" in eyes closed conditions, bringing to mind a daily function of eye closure. People naturally fall asleep with their eyes closed so;

eye closure can be considered as a non-alert and relaxed state. Similarly during one of the pilot sessions of the current research, the participant reported "falling asleep" during a 25-minute-long eyes closed block. Although as a result of this pilot session, it was decided that one block was to be reduced to the length of 12 minutes; a possible adversative contribution of eye closure into task performance must still be considered for future experimental designs.

The current research raises another consideration in the literature by using eye closure as an occipital alpha activity manipulation technique. With an inhibitory function of alpha activity for information processing, Jensen and Mazaheri (2010) state that alpha oscillations are obligatory in task irrelevant regions for an optimum task performance. However, according to the current research, this statement might be seen as incomplete. The current research has shown a power increase in occipital alpha, which should normally play an inhibitory role in visual information processing. However, since the alpha power was manipulated by closing the eyes (versus keeping the room dark in eyes open condition) there was no visual input to suppress in both of the conditions. Thus, the function of increased occipital alpha activity becomes controversial; existence of a task-irrelevant sensory input might be required for inhibitory gating role of alpha oscillations. Therefore more research is necessary in understanding of the function of cortical alpha activity.

6.4 Limitations

ERP results revealed two unusual observations: The N1 component of the grand averaged ERP activity in Figure 5a is observed to be weak. This observation is due to some individual data not having a clear N1 component to sound onset. More importantly, the N1 component is usually expected with around 100 ms latency; however, the current data have the individual latency of N1 peak earliest at around 160 ms. This situation suggests the existence of a delay between the trigger timing and the EEG system, which was used to collect data. Although the issue is under investigation, individual inter-trial phase coherence plots (ITPC; not shown here) and existence of the 2.8 Hz peak at the evoked power representation of the grand averaged ERP activity across all participants (Figure 7a) indicate that the delay is consistent across trials in individual data. As such, it would not have influenced other results in the analysis other than making everything around 70 ms later than expected.

The other unusual observation of the current work is due to the followed preprocessing steps.

As anticipated, strong occipital alpha activity was shown by total power analysis (Figure 6a and Figure 6b). Unexpectedly, in the power representation of the eyes open condition, remarkable power increase in slow frequency range (1-2 Hz) at around 7th and 9th seconds were also observed. Origin of this activity was found to be artifact noise from a single channel only from one participant's data. Thus, for future analysis changing the preprocessing pipeline slightly and applying another ICA could possibly clean the data from this channel artifact.

The current results are not fully conclusive due to lacking to-be-applied analysis. Schmitt (2016) related behavioral benefit of eye closure with strong pre-stimulus alpha fluctuations. Importantly, her research suggested two profiles of participants; participants either benefitted from eye closure through strong pre-stimulus alpha power modulation or suffered from eye closure as related with weaker pre-stimulus alpha fluctuation. Similarly, a to-be-applied single participant level pre-stimulus alpha fluctuation analysis might bring more insights to the current study.

Effects of the stimuli phase on gap detection performance and neural activation also require further work. Henry and Obleser (2012) demonstrated that ERPs are related with neural delta phase but not the phase information of the sound stimuli. A similar effect might also be observed with the current data after conducting necessary analysis.

Moreover, event related activity for missed versus detected gaps as well as false alarm rates (participants' detecting a gap when there is none) between eyes open and closed conditions should be further compared. Hence, more information will be obtained about auditory processing under eyes open and closed conditions.

In addition to the to-be-applied further analyses, it should also be noted that the amount of data is perhaps too small to support the hypothesis. Therefore, in order to bring more insight to the literature about the impacts of eye closure on auditory perception, this research should be further continued by increasing the power size and conducting the above-mentioned to-be-applied analysis.

6.5   Future directions

In the systematic investigation of entrainment and alpha power, both naturalistic speech-like environmental and low-level FM-like stimuli should be used in order to uncover the variables affecting the interaction between entrainment and alpha power. Additionally, more data are required contrasting temporal dynamics of eye closure so that the effects of eye closure on sensory processing can be better understood.

Moreover, instead of experimenting on the limits of participants' alertness, future research should consider daily use of eye closure. For instance, during a phone call when eyes are inattentively closed, the eyes are not usually kept closed for 10 minutes to improve hearing. Rather, possibly a shorter eye closure period can still support alpha modulations and could result in better task performance by avoiding a relaxed state as induced by eye closure. Thus, more naturalistic perspectives should be considered for future research on eye closure like daily strategies.

6.6   Conclusion

The current study suggested two distinct auditory perception mechanism that result from the interaction between eye closure induced alpha oscillations and auditory entrainment. Although the current limitations of the study left the main question "whether eye closure benefits auditory perception or it is just a social myth?" inconclusive, a firm foundation for future work has offered.

As entrainment and alpha range neural oscillations are involved in relevant sensory information processing, failure in entrainment is seen as a possible explanation in some of the symptoms in attention deficit disorder such as seen in dyslexia and schizophrenia (Calderone et al., 2014). Thus, increased knowledge on the interaction between entrainment and alpha oscillations becomes vital in order to further understand these attention related disorders. Daily strategies that are unconsciously employed by healthy populations in sensory processing (such as eye closure to enhance auditory perception) might be another façade in the auditory perception literature. Therefore, a better understanding of entrainment and alpha power mechanism in sensory processing can be achieved. As a result, extended knowledge in brain sensory information processes can initially help us to recognize how human brain

actually works and then various strategies and technologies can be developed for populations who suffer from failure in sensory information processing.

Appendix 1

INSTRUCTIONS and INFORMED CONSENT FORM

- In this experiment we aim to measure your sensitivity to detect sound breaks (gaps) from the presented sound, which composes of different frequencies.
- For this purpose the entire experiment consists of two parts:
  - The first part takes about 30 minutes and it is designed to obtain your sensitivity level to the presented sound. Therefore, there will be several repetitions in this part in which you will be asked to press a mouse button whenever you hear a gap. Detecting the presented gaps in the sound will get harder as you continue with the next repetitions. There will be more than one gap in each sound (2, 3, or 4 are possible). **Please focus on the cross sign in the middle of the screen and listen carefully. When you hear a gap, press the LEFT MOUSE BUTTON as quickly as possible.**
  - The second part of the experiment is similar and takes less than an hour. Different than the first part, in this part of the experiment, sound trials are presented between short "bip" sounds. **To initiate the next trial you should press the LEFT MOUSE BUTTON after you hear a brief "beep" sound**. During this part you will be asked to close your eyes in some part of it while doing the gap detection task. The experimenter will inform the eye closure times. During the eyes closed sessions, it is important that you do **NOT** open your eyes. You will understand the break and the end of the experiment with a distinct sound notification.
- Between the first and second part there will be a break in which you can relax.
- The described procedure will be repeated in 2 different days.

The experiment has no harm and you have the right to leave it uncompleted any time you want. Experimental data will be used anonymously, only. All your personal information will be confidential and kept for at least 5 years to be able to reanalyze the data. However, you have the right to have your personal data deleted at any time.

The experiment is conducted with the supervision of Dr. Geoff Luck at the Department of Music, Art and Culture Studies, University of Jyväskylä, Finland; Dr. Malte Wöstmann and Professor Jonas Obleser at the Department of Psychology, University of Lübeck, Germany. Correspondence concerning this experiment should be addressed to Deniz Duman; Department of Music, Art and Culture Studies, University of Jyväskylä, Finland. E-mail: denizduman92@gmail.com

I hereby declare that I have no auditory-visual health problem. I have been informed by the Experimenter Deniz Duman about the experiment and my rights as a volunteer participant to join this experiment.

Name and Signature of the participant   Date:
E-mail:

Name and Signature of the experimenter   Code:

Appendix 2

1) Age:

2) Gender:

3) Handedness:

4.A) How *difficult* was the eyes <u>closed</u> part?

   not at all   average   very

     1   2   3   4   5   6   7

4.B) How *difficult* was the eyes <u>open</u> part?

   not at all   average   very

     1   2   3   4   5   6   7

5.A) How much *your mind was wandering* during the eyes <u>closed</u> part?

   not at all   average   very much

     1   2   3   4   5   6   7

5.B) How much *your mind was wandering* during the eyes <u>open</u> part?

   not at all   average   very much

     1   2   3   4   5   6   7

6.A) How *attentive* you were during the eyes <u>closed</u> part?

   not at all   average   very

     1   2   3   4   5   6   7

6.B) How *attentive* you were during the eyes <u>open</u> part?

   not at all   average   very

     1   2   3   4   5   6   7

7.A) How many percent of the gaps do you think you detected during eyes <u>closed</u> part?

   0   10   20   30   40   50   60   70   80   90   100

7.B) How many percent of the gaps do you think you detected during the eyes <u>open</u> part?

   0   10   20   30   40   50   60   70   80   90   100

8) Did you apply specific tactic? If yes, please describe:

9) Further Comments:

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