Auditory Inattentional Deafness Investigated with Eye Tracking

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Abstract

This thesis will examine auditory selective attention and inattentional deafness with an eye-tracking approach. Some studies show that if a change happens between two modalities, like a visual task with an audio change or an audio task with a visual change, the inattentional blindness and inattentional deafness could be decreased with the help of the changes in multimodal conditions. The current experiment aims to take the first step and expand the understanding of the effects of multimodal changes on inattentional deafness. The main aim of this thesis is whether the type of environmental sounds affects the recognition of hidden sounds and whether the participants counting the lightning strike (thunder) and the sound of the wave hitting the shore will have an impact on the inattentional deafness or not. Our research questions are; (1) the participants who hear the negative environmental sound (Thunder) and the positive environmental sound (Wave) will be less likely to detect the hidden sound than the participants who hear the hidden sounds in silent conditions, but also we hypothesis that the environmental negative sound will decrease the awareness of the hidden sounds depending on its effects on participants internal mood, (2) participants pupil size will show the difference when hidden sounds are given in the experiment. Results of the experiment showed that the sound type had an impact on participants awareness of the hidden sounds. Our results indicated that the hidden sound awareness affect the pupil size of the participants in general and type of environmental sound had an impact on hidden sound awareness.

Keywords: Environmental sounds; inattentional deafness; selective auditory attention.

INTRODUCTION

Attention is widely studied in the literature within the scope of cognitive neuroscience, psychology and educational sciences. Selective attention means that we have a limited information processing capacity to pay attention to all stimuli from the outside world simultaneously, so we have to choose where or what we need to pay attention (Lavie 1995; Ocasio 2011). Auditory selective attention is also a type of selective attention and basicly means that paying attention to a specific auditory information around us. Also there are many types of attentional errors such as inattentional deafness. Inattentional deafness (ID) means that failing to process some audio stimulus around us especially under high workload situaions (Scheer, Bülthoff, & Chuang, 2018). Inattentional deafness occurance could be change depending on a pleasatness of the audio stimulus. There are some studies which are shown that the more pleasant sounds such as relaxing environmental sounds (that we are exposed to in daily life without being aware of them) could decreased the ocurrance rate of inattentional deafness. According to researchers not all the environmental sounds have a similar pleasantness, Watts, et al. (2009) indicated that the natural water sounds (such as waves, sound of a waterfall, etc.) perceived more pleasant than manmade water sounds (such as fountains). The main aim of this thesis is to understand whether the type of environmental sounds affects the recognition of hidden sounds (inattentional deafness), and whether the type of sound pleasentness will have an impact on the ID or not. We also used eye-tracking tool in our experiment which helps us to collect eye movement, fixation and pupil size data from our participants. The hypothesis are that (1) the participants who hear the negative environmental sound (Thunder) and the positive environmental sound (Wave/Beach) will be less likely to detect the hidden sound than the participants who hear the hidden sounds in silent conditions, but also we hypothesis that the environmental negative sound will decrease the awareness of the hidden sounds depending on its effects on participants internal mood, (2) participants pupil size will show the difference when hidden sounds are given in the experiment. We will investigate and take a closer look to the auditory selective attention which we are going to understand the relationship between sounds, music and attention, another specific part of this thesis that we explain the environmental sounds and how it effect the cognitive performance and categorization of the sounds. After that we are going to understand the types of attentional errors which are inattentional blindness and inattentional deafness. Lastly, we are going to explain the eye-tracker tool to understand the tool and the studies conducted on a related field.

Auditory Selective Attention

Attention, which is widely studied in the literature within the scope of cognitive neuroscience, psychology and educational sciences. Attention is significant for everybody; when people need to study or attend some specific event, they need to be attentive to the actions around them. They may focus on particular circumstances while ignoring others. Attention is also related with other concepts of psychology. According to Knudsen (2007), the information that reaches working memory is chosen by the attentional systems. There are four types of attention: selective attention (we need to block out some features comes from the environment and focus what we need to attend at a certain situation), divided attention (when we need to attend two things at the same time we use divided attention), sustained attention (focusing on a specific event for a certain period of time) and executive attention (ability to control our own emotions, responses, and a function to switch between different information).

Attention, which is widely studied in the literature within the scope of cognitive neuroscience, psychology and educational sciences, was first defined by the pioneer of psychology, William James. In 1980, William James defined attention as a definite and pleasant form of occupancy by the mind while there were several thoughts and uncontrollable situations occurring around us. Attention is significant for everybody; when people need to study or attend some specific event, they need to be attentive to the actions around them. They may focus on particular circumstances while ignoring others. Attention is also related with other concepts of psychology. According to Knudsen (2007), the information that reaches working memory is chosen by the attentional systems.

In psychology, recent years many types of research have been done on the topic of attention, with especially behavioral studies being the prevalent one from the beginning, and the results of previous studies revealed that there are four types of attention: selective attention (we need to block out some features comes from the environment and focus what we need to attend at a certain situation), divided attention (when we need to attend two things at the same time we use divided attention), sustained attention (focusing on a specific event for a certain period of time) and executive attention (ability to control our own emotions, responses, and a function to switch between different information). This thesis will examine selective attention and focus on the specific subcategories that fall under the scope of selective attention. In this particular, Posner and Boies (1971) defined that there are 3 main subcategories for studying attention which are alertness, selectivity, and processing. To investigate the alertness component, they conducted a letter-match task in which participants were asked to find match the letter matches. Letter match task include 2 different letters that appear on display or the matching letters present on display area. For instance, when the participants see the letter ‘a’ and letter ‘B’ they had to answer if these letters are the same or not. In Posner’s experiment participants were asked to match the letter ‘S’ as a stimuli. Results of the letter-match task indicated that selectivity and alertness increased while participants were performing to find the match the letters. Later on, William Ocasio (2011) also examined the types of attention and stated that most of the studies in the literature investigated attention as a center of the confined information processing by an individual. However, Posner and Rothbart (2007) claimed that attention should be commentated under the brain's neural networks, which help operate different types of interconnected processes. In the light of neuroscientific experimentations and the results of many neuroimaging studies in the literature, the researchers listed the types of attention as selective attention, attentional vigilance (also known as selective attention and it refers to control and ability to sustain our attention at a period of time) and executive attention (Ocasio, 2011).

Selective attention refers to attending to selective events that occur around us, and these specific events could be from internal or external sources (Johnston & Dark, 1986, p.44). We have a limited information processing capacity to pay attention to all stimuli from the outside world simultaneously, so we have to choose where or what we need to pay attention (Lavie 1995; Ocasio 2011). Therefore, when competing and distractive events occur, we must select what we need to attend to and behave comprehensibly at the moment. There are many types of research conducted on selective attention, and most of the studies related selective attention to bottom-up processing which is referring to the sole utilization of external elements to direct attention to stimuli that stand out from the background due to their intrinsic salience. (Treiman & Gelade, 1982). In addition, cognitive neuroscience research showed there is also a top-down attention (refers to internal control of attention based on knowledge gained in the past, deliberate plans made in the present, and ongoing objectives) and bottom-up attention relation between attentional processing (Corbetta & Shulman, 2002; Ocasio, 2011). On the top-down processing of the attentional data, Jonston and Dark (1986) claimed that when people face external stimuli from the environment, they tend to act biased.

Researchers began to study the types of selective attention in the first half of the 19^{th} century. However, auditory selective attention was first studied as a selective attention type (Spence & Santangelo, 2010) after World War II. In 1953, Colin Cherry was one of the first cognitive scientists in the literature who studied auditory selective attention. He was also the first scientist to study the cocktail party effect, defined as filtering one specific conversation or a sound while ignoring the others. After that, he experimented with the air traffic controllers, and two different kinds of conversation stimuli were given to the traffic controllers simultaneously. Controllers needed to attend to one of the messages that were given. The results of Colin's experiment showed that while the participants ignored one message through the earphones and followed the other one, they were able to remember some qualitative properties of shadowing messages, such as the gender of the speaker or the tone of the sender of the message (Spence & Santangelo, 2010). This experiment was called the 'dichotic listening task' or 'the speech shadowing task' in the literature. Broadbent studied auditory attention in 1958, and his experiment's results showed that the participants were more likely to ignore environmental information without being aware of them. Irrelevant auditory information processing and working memory relation were first studied and supported by Conway et al. 2001. Lately, Dalton et al. (2009) studied the effects of distractive audio stimuli and the target auditory stimuli, which were given to the left and right ears randomly and unexpectedly. Besides, for the investigation of working memory and auditory selective attention, participants were asked to remember some digits which the experimenters presented while they had the listening task. Results of the experiment showed that participants showed a higher working memory load for detecting the target when a distractive auditory stimulus appears than in the low working memory load condition.

Additionally, Bayramova et al. (2021) conducted a study to understand the relationship between auditory selective attention and working memory load. Their task contained target and distractive letters which were given by loudspeakers to the participants. Participants expected to follow the letters come from the central loudspeaker while they were ignoring the letters which were given from the flanking loudspeakers. Participants have to detect the target letter stimulus which comes from the central loudspeaker. there were 2 distractive conditions which were congruent (distractive and central loudspeakers present same letters at the same time) and incongruent (distractive and central loudspeakers present different letters at the same time). Previous studies showed that the higher incongruent trials increased the attention of the participants towards the target stimulus. Their results indicated that despite the similarities of objectives and distractions and the fact that they were both given in the auditory domain, they discovered that interference from distractions decreased with increased verbal working memory load. These results imply that raising the working memory load can help with attentional concentration even when there are salient distractions present. This may be because the working memory activity places a greater strain on the attentional resources involved in attentional focus (Bayramova et. al., 2021). Another study conducted by Farnie et al. in 2016, they studied on auditory perceptual load and selective attention. Participants were expected to identify that if the sounds that they listened contained a lion sound or a dog sound. Number of different distractive sounds were given concurrently. Results of the study indicated that the auditory selective attention of the participants decreased towards the distractive sounds which contains not animal sounds like a car horn and they were less sensitive to detect the target sound stimulus. We wanted to know that if the sound awareness of the participants related with the sound concept or not. After that question appeared on our mind, we started to review the papers which were about environmental sounds.

In this part, in light of the study conducted by Shih, Huang and Chiang, we will go through the effects of environmental sounds and studies about them. I want to start with the definition of environmental sounds. Environmental sounds refer to the sounds that we are exposed to in daily life without being aware of them. For instance, the sounds of raindrops, door closing, page slipping, dog barking or wave are called environmental sounds. In general, all the sounds that come from the physical environment are placed under the environmental sounds. The one typical feature of environmental sounds is that they happen naturally in everyday life.

Guastavino (2007) conducted a study to understand how people categorize the environmental sounds. To that end, he created an experiment with a free sorting task, and in the task, participants were exposed to traffic noise with human sounds and market noise with human sounds. The results indicated that the participants categorized the environmental sounds based on their level of pleasantness and mechanical nature, and the classifications under these two categories were observed to be category-specific. Still, participants also tended to categorize environmental sounds based on if they have a human activity in them or not.

Gygi (2001) studied the identification of environmental sounds in his dissertation, and he claimed that the identification of the environmental sounds differs from person to person because it has different concerns from one another. According to the results of his study, participants needed to show much more cognitive functions to identify the environmental sounds than acoustic or musical sounds. Herein, it is worth underlining he used 50 different kinds of environmental sounds in total for the identification, which were water pouring, door closing, birds calling, thunder rolling, typing on a keyboard, waves crashing and such. In the light of his dissertation, we used the similar environmental sounds in our experiment as well.

Inattentional Deafness

After we get great amount of information about the auditory selective attention, we were curious to know about the attentional errors, especially kind of errors that occur while we are selectively attended. Inattentional blindness (IB) is the first and famous attentional error placed under selective attention. When we focus on a specific event, we are more likely not to focus on unexpected events happening in the background, and it is called Inattentional Blindness. IB was first studied in the 1970s by Ulrich Neisser. After Neisser's experiment on the topic of IB, Simons and Chabris conducted a study in 1999. In their study, they took a video of two teams (black and white) passing the ball to each other. There were two unexpected visual stimuli in this video; one was a black gorilla and the other was a woman carrying an umbrella while the teams were passing the ball to each other. They asked the participants to count the passes of either the white team or the black team, and while the participants were counting the passes, the gorilla or the woman with an umbrella walked among the members of the teams. As a result, 66% of the participants noticed the woman with an umbrella stimulus, and 44% of the participants saw the black gorilla. Besides, their experiment's results showed that the similarity of the black gorilla as a stimulus would impact participants' perception of the attended object (black or white team).

Figure 1

Inattentional blindness 'Gorilla Experiment'.

Note. Gorillas in our midst: sustained inattentional blindness for dynamic events.

Daniel J Simons, Christopher F Chabris (1999). Perception, 1999, volume 28, pages 1059 -1074.

Rees et al. (1999) conducted a study to understand the neural correlations of IB. Their experiment had some superimposed images, which were pictures and letters as stimuli. Strings of five letters, either high-frequency concrete nouns or arbitrary consonants, were superimposed over the images. The letter stream was composed of either letter strings alone in some scanning epochs or letter strings coupled with 60 percent concrete nouns in others.Their study was conducted with an fMRI, and while having their brains imaged by the experimenters, participants were engaged in a single activity that involved spotting repeated stimuli in the stream (letters or pictures) that they were paying attention to. The fMRI results showed no significant difference between two-word conditions when the participants ignored them. According to their findings, the individuals were intentionally blind to the characteristics that set words apart from random consonant strings rather than being inattentive to the existence of letters when looking at the superimposed pictures.

In addition to aforementioned experiments, there are also some studies conducted to understand the relationship between auditory stimulus effects on IB. Molloy et al. (2015) conducted a study to understand the effects of visual search task on auditory stimuli detection, the results of the experiment indicated that participants audio stimuli detection performances decreased under high-load condition. Besides, when participants' attention was on a visual task the resources that neural mechanisms needed for perceiving a basic auditory signal are less available, which reduces detection and causes the sensation of inattentional deafness.

Pizzighello and Bressan (2008) conducted a research in which participants were presented with visual and auditory tasks; at the same time, the performance of identifying unexpected stimuli was either affected or not. Their results showed that when audio is in the background, IB is decreased. Beanland et al. (2011) conducted a study to understand the relationship between IB and auditory attention. There were 3 categories in their study: visual, auditory, and visual + auditory conditions (dual-task conditions). Results of this study showed that the auditory task performance decreased in dual-task conditions.

Inattentional deafness is another attentional error which is placed under selective attention and means that "Humans can fail to respond to auditory alarms under high workload situations. This failure, termed *inattentional deafness*, is often attributed to high workload in the visual modality, which reduces one's capacity for information processing" (Scheer, Bülthoff and Chuang, 2018, p.1). There are many kinds of research done on the topic of inattentional blindness, but not so much research was done on ID. Furthermore, few studies have been conducted to investigate the relationship between inattentional blindness and inattentional deafness with neuroimaging tools. Our curiosity towards the attentional errors, took us to research about inattentional deafness. Fen et al. (2011) studied inattentional deafness and conducted a study on a phone conversation. Participants were listening to the message from the phone, but while they were attending to the message, there was a change at some point in the conversation. The change was the change of the speaker's identity, but most of the participants were not aware of this change.

The first sustained inattentional deafness experiment was done by Dalton and Fraenkal (2012). They conducted a study which was like in Simon and Chabris' gorilla experiment, there was a gorilla walking through the experimental area but the only difference was that they were recorded a voice message and when the gorilla walks through the scene the voice message was saying 'I am a Gorilla' to the participants. The results of the experiment indicated that the prolonged inattentional deafness by demonstrating how the absence of attention can render a person "deaf" to a persistent and dynamic audio stimulation that is clearly audible under normal listening settings. Eramudugolla et al. (2005) examined the inattentional deafness in their experiment. Participants were listened to auditory stimuli containing 4, 6 or 8 different objects and their task was to notice the salient object change in the experiment. For example, name of a cello was shown in the display area and in the second block of the trial cello was missing. Participants needed to detect the missing object in second block of the trial. To create a distraction between blocks the experimenters played a white noise for 500 ms to the participants while they were having the task. Their findings suggest that explicit change detection is surprisingly challenging even when the listener is aware that a change is likely to occur when attention is not focused on an auditory object within a complex scene.

Simons and Levin (1997) conducted series of experiments to understand change blindness. One of the experiment contained inattentional deafness as well. There was a real world scene and while the participants was walking through the scene someone (experimenter) approach and asks for a direction. While the participant was explaining the direction, two other people who were carrying a door join the scene and walk between the participant and the experimenter. The experimenter who were asking for the direction changed with another experimenter while the the door carrying people were walking through the scene.

More than 50% of the participants did not notice the change even the experimenters voices were totally different from eachother.

Some studies show that if a change happens between two modalities, like a visual task with an audio change or an audio task with a visual change, the IB and ID could be decreased with the help of the changes in multimodal conditions. To understand this phenomenon, the first IB and ID experiment was conducted by Conci, Bilalic, and Gaschler (2020). They aimed to understand how the changes in multimodal settings affect IB and ID. They conducted 3 different conditions and used auditory discrimination tasks in all conditions. In the first condition, there was a video which has only a visual change in it, and in the second condition, there was an auditory change while the last condition had both changes for the investigation of the relation between IB and ID. Their results showed that the two unimodal conditions do not affect the IB rates of the participants. Besides, participants in multimodal conditions had high rates of unexpected stimulus detection time for the IB. With the auditory discriminating challenge and the visual change, they discovered IB. However, the rate of change identification was high for multimodal changes, departing from a shared resource view. (Conci, Bilalic, and Gaschler, 2020, p.191).

Despite all the studies mentioned above, there still exists a lack in literature on the subject in question. The problem is that the studies on inattentional deafness are insufficient to understand the selective attention part of human cognition. With this study, we can have a better understanding of the selective auditory attention and human perception. Moreover, we can understand it more with the help of neuroimaging tools such as eye-tracking.

Eye-Tracking

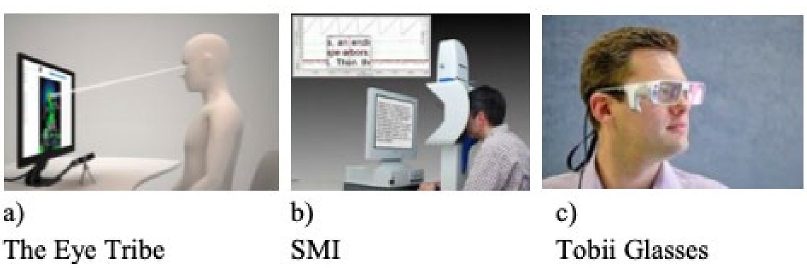
Eye Movements

Eye trackers record eye movements, pupil size, saccades, and gaze directions while the participant is looking through a specific task or an event in the display area at any given time. A. L. Yarbus (1967) explained that the most important purpose of eye movements is to keep the perceived object in the field of vision while shifting the primary points of fixation and thereby enlarging the overall field of vision. There are some parameters of the eye movements which are saccades (gaze is moved from one area of the visual field to another quickly and conjugately by a saccade. The primary function of saccades is to direct attention to a particular object), fixation (when our eyes stop moving and focusing on a specific object that we can gather detailed information about what we see), pupil size (pupil is a black part of the eyes and it could change depend on the light or the emotional mood that you are belong to). It is possible to measure all these elements of eye movements with an eye tracking. Eye trackers gives us a voluntary and involuntary eye movement data for example, fixation duration, saccades, microsaccades or the changes in left pupil size and right pupil size. We can interpret the current emotional and cognitive state of the subject from the eye tracking data.

This thesis will investigate the inattentional deafness using an eye-tracker and we would like to give some information about the eye-tracker tool. Eye-tracker is widely used in the literature for behavioral, attentional or cognitive studies. Depending on their quality, many eye-tracker devices and algorithms are available, such as glass-used eye-trackers, AI-based eye-trackers, or webcam-based eye-trackers. In addition, some popular brands for eye-tracking technologies include Tobii, Gazepoint GP3, Expose, etc.

Figure 2

Types of eye-tracker devices

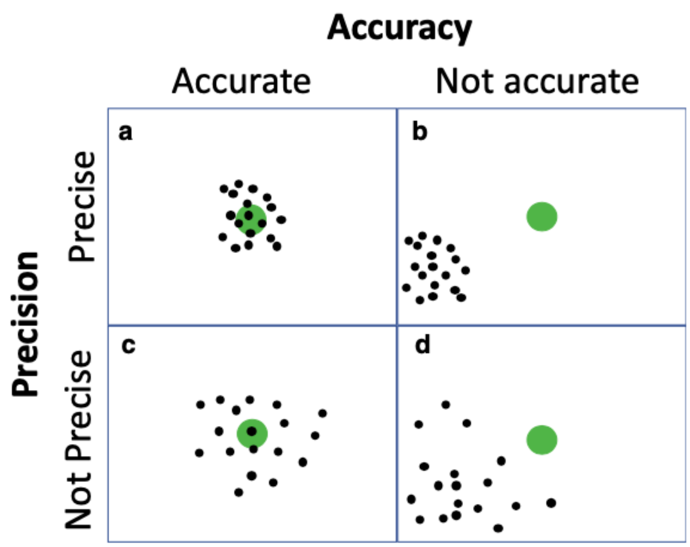


Note. Retrieved from Harezlak, K., Kasprowski, P., & Wasinski, T., 2015. *The Eye Movement Data Storage – Checking the Possibilities*.

The eye-tracker which has a 60 Hz recording quality means that the device records the eye movements every 16.67 ms. and the fixation lasts for 20-300 ms. After every fixation, there will be a saccade movement which helps to end the fixation and start new ones. Therefore, accuracy and the data's precision depend on the participants' fixation on the target in the display area.

Figure 3

Accuracy and precision interactions in eye-tracker studies



Note. Retrieved from Brand, Diamond, Thomas and Gilbert-Diamond, 2020. Evaluating the data quality of the Gazepoint GP3 low-cost eye-tracker when used independently by study participants.

There are some different opinions on the changes in pupil dilations and how it occurs. For example, Konishi, Brown, Battaglini, and Smallwood (2017) explained that when a person loses attention toward external stimuli, their pupil size tend to get larger or smaller, and they conducted a study for the investigation of pupil dilations. Their results indicated that the participants' pupil size get larger in a primary working memory task. This result suggested that the large pupil size did not mean the correct processing of the external information. In our study we expect that the detection of the hidden sounds will have an impact on the pupil size of the participants.

Studies on eye-tracking and attention

Cater, Chalmers, and Ledda (2003) conducted a study and they presented two still images to their participants and wanted them to count the number of teapots that appear on the screen and while they were counting they wanted their participants to mention if they see any quality changes between the graphics of the images. %20 of the participants couldn't notice the quality changes in the images even the eye-tracking data results were validated that the participants fixated on the objects which were as similar as teapot (like a vase). Their results showed that the IB occurred in this experiment but there is no degrading in peripheral vision use of the participants.

Koivisto, Hyönä, and Revonsuo (2004) conducted series of experiments to understand the relationship between eye movements, spatial attention, and stimulus on IB. They recorded eye movements with an eye tracker to understand that if the participants were still looking to the fixation even there was the US on the display. They examined explicit attentional capture as well. In Experiment 1; they research eye movements and spatial attention relation. The first two trials had red and blue digits and they appeared on the display in order, in the third trial the US (black circle) appeared in the center of the display. Half of the participants were required to fixate their eyes in the fixation point and the others were required to follow digits on the display. Participants were questioned that if they saw something different in the third trial that they did not see in the first two trials by the experimenters. Participants had 3 more trials after the US trial but the participants were waiting to see something different in these last 3 trials because they were questioned about it because of this reason these trials called divided attention trials and participants were questioned about the US at the end of the sessions. Results showed that the fixation did not an effect on IB but also it supported that the attention could change independently from fixation in the visual field. Experimenters conducted experiments 2a and 2b after the results of experiment 1. In experiment 2a; they tested if the color of the US affects participants and they changed the color of the US as digit colors (red and blue) or green. In experiment 2b; they added an emotionally neutral stimulus as the US and it was a black digit. The reason why if the category of the stimulus had an impact on IB, the degree of black digit US should be smaller than the black circle US. Results of experiment 2a evinced that unexpected stimulus' color change affects attention. And the results of the 2b showed that black digit unexpected stimulus has a greater effect on IB than black circle unexpected stimulus.

Beanland and Pammer's (2010) study is another example of an eye-tracking study on IB. They researched the importance of eye movements on sustained inattentional blindness tasks and they compared the results of the noticers of unexpected stimulus (US) and non-noticers of US. They conducted series of experiments. Experiment 1; experimenters gave some instructions to the participants that they should fixate their eyes or they are free to move their eyes while they were in the trials. There was a small fixation dot (grey) in the center, 4 black and 4 white 'L' and 'T' shapes in the display. Participants had control trials that there were only black snd white shapes on the display, critical trials and full attention trials include the US in dark grey and the shape of +, H, or X. After all the trials participants were asked to report how many times did white shapes bounced. They did not question about the US before the second critical trial. Us noticer participants were also questioned about the shape, color, speed, and movement of the US, and after that participants had a list which had to choose one of the 8 shapes (A, E, F, H, X, Y, =, and +) on the list for the shape of US. The full attention trial, participants have instructed about the count of the bouncing but focus on the fixation dot. Results of the experiment showed that there was not a significant difference between noticers' and non-noticers' eye moves in this experiment. After the results of the Experiment 1 they conducted another experiment which they called Experiment 1b; the results of the Experiment 1 showed that the noticers and non-noticers made saccades to the US but the real reason was counting the bouncing shapes and sometimes the shapes fell next to the US and experimenters were not sure about the real reason of the saccades to the US. The same design was used in Experiment 1 but US was not given to the participants until the last full attention trial. Results of Experiment 1b were almost the same in Experiment 1 and all participants noticed the US in full attention trial. In experiment 1 and 1b participants have high perceptual load but in Experiment 2 they conducted a study which required low perceptual load with an easy task. 3 main differences were in Experiment 2; first of all the bouncing number of the shapes were decreased and slower, the second difference was in the first critical trial the US shape was 'A' shape and in the second critical trial the US shape was '='. The third and the last difference was US's speed was divided into two subgroups which were fast-US condition and slow-US condition. Results showed that participants noticed the US at one time while having the trials. There was not a significant effect between fast-US and slow-Us conditions. There was not a significant gaze difference between the first critical trial and the second critical trial. Most importantly the results confirmed that even though the participants directly fixate their eyes on display the inattentional blindness occurred.

Aim and hypothesis

Previous studies (Bealand et al., 2011) showed a relationship between auditory stimulus and IB. In addition, some other studies supported the examination of IB with an eye-tracking approach. There are also studies which supported IB studies with the examination of inattentional deafness. Still, there is not much research that investigates the pupil data gathered from the eye-tracker tool to understand ID phenomena in the literature.

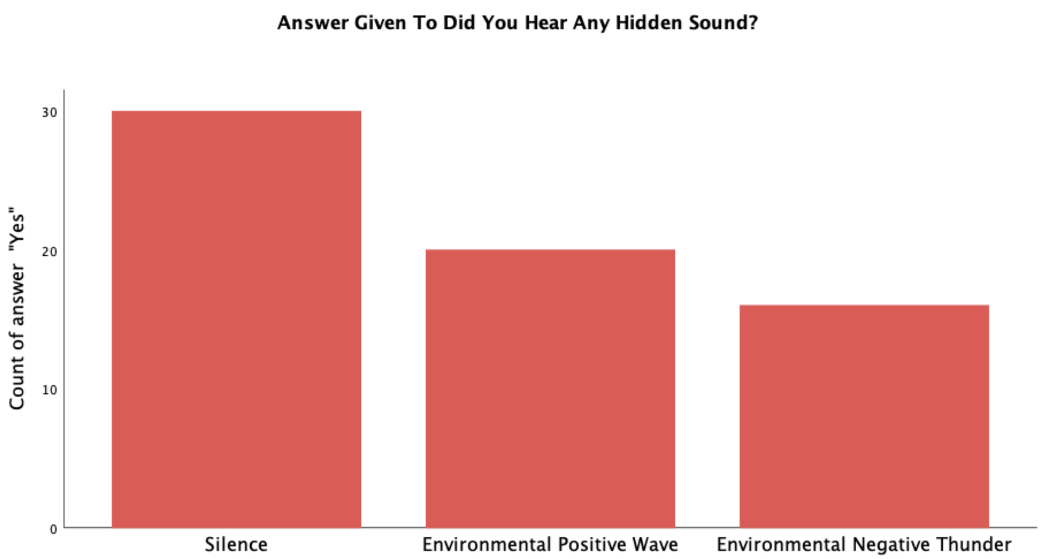
The current experiment aims to take the first step and expand the understanding of the effects of multimodal changes on inattentional deafness. The main aim of this thesis is to understand whether the type of environmental sounds affects the recognition of hidden sounds (inattentional deafness), and whether the type of sound pleasentness will have an impact on the ID or not. If the sound type had an impact on the hidden sound awareness of the participants, it would be possible to understand the effects of ID on human perception.

Another purpose of this thesis to understand whether the type of environmental sounds affects the recognition of hidden sounds (inattentional deafness), and whether the type of sound pleasentness will have an impact on the ID or not.The hypothesis is that (1) the participants who hear the negative environmental sound (Thunder) and the positive environmental sound (Wave/Beach) will be less likely to detect the hidden sound than the participants who hear the hidden sounds in silent conditions, but also we hypothesis that the environmental negative sound will decrease the awareness of the hidden sounds depending on its effects on participants internal mood, (2) participants pupil size will show the difference when hidden sounds are given in the experiment.

2. RESULTS

2.1 Behavioral Results of Inattentional Deafness

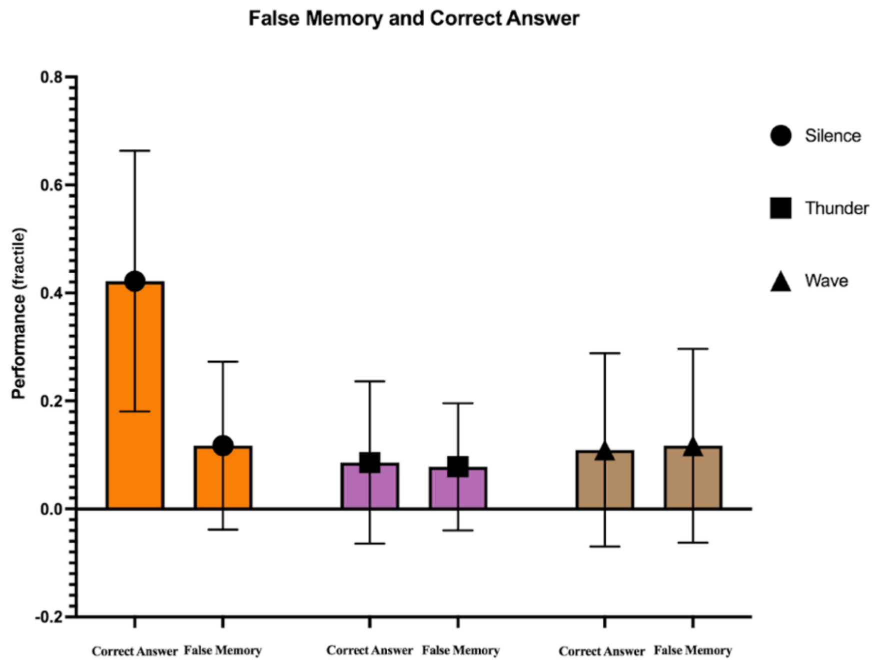
Figure 4



Number of 'yes' answers plotted against background noise

The questionnaire's results showed that the inattentional blindness occurred in our experiment, (F(2, 93)= 8.698, p<.00). Out of 32 participants in the silent control condition, 30 of them chose the 'Yes ' option from the questionnaire, meaning they heard the hidden sounds. Likewise, 20 participants out of 32 in environmental positive sound conditions chose the 'Yes' option. 16 participants from 32 in environmental negative sound condition chose the 'Yes' option.

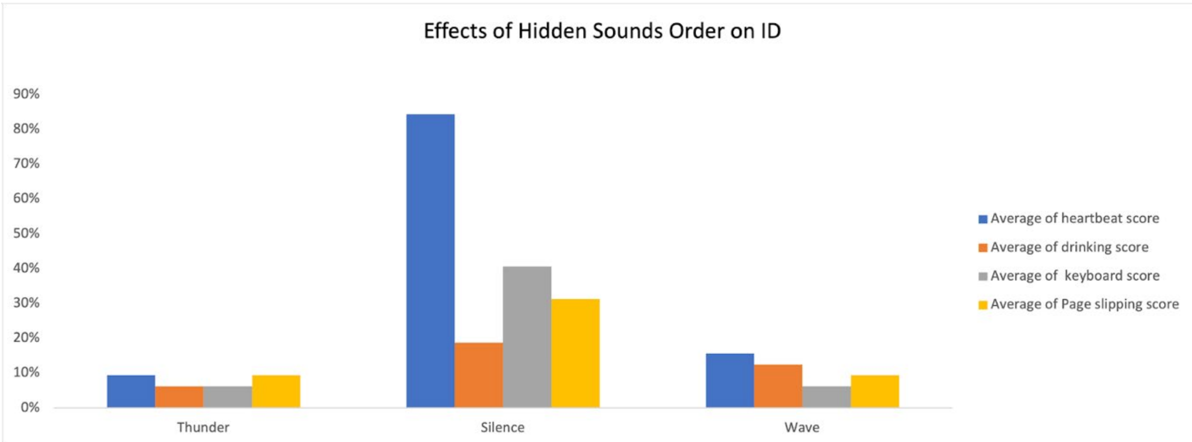
Figure 5



Performance plotted against background noise and correctness of responses.

ANOVA and Post Hoc results of the false memory and correct answer of the inattentional deafness questionnaire's results showed that in the silence condition participants correct answers (*M*= .421, *SD*= .241) and false memory answers (*M*= .117, *SD*= .155) showed significant difference. Besides, in environmental negative sound condition participants correct answers (*M*= .085, *SD*= .150) and false memory answers (*M*= .078, *SD*= .117) and in environmental positive sound condition participants correct answers (*M*= .109, *SD*= .178) and false memory answers (*M*= .117, *SD*= .179). Overall, there is a significant relationship for correct answer and sound conditions , (F(2,93)= 29.927, p<.00). But also there is not a significant relation between false memory of the participants and sound conditions, (F(2,93)= .696, p=.501. Tukey post hoc test results showed that the participants in environmental negative and positive sound conditions significantly performed better than participants in silence condition (*p= .00)*.

Figure 6



Performance plotted on order effect of the hidden sound presentation.

Paired sample t-test was used to understand the effects of hidden sound order on performance of the participants' detection rates. The correlation coefficient shows that there is a significant positive relationship between heartbeat order (*M*=2.08, *SD*= .867) and heartbeat sound detection (*M*=.36, *SD*= .484) score of the participants , r(96) = .274, p=.007. There is not a significant relationship between drinking sound order (*M*=2.67, *SD*= 1.033) and drinking sound detection (*M*=.13, *SD*= .332) score of the participants, r(96) = .061, p=.553. There is not a significant relationship between keyboard sound order (*M*=2.67, *SD*= 1.185) and keyboard sound detection (*M*=.18, *SD*= .384) score of the participants, r(96) = .085, p=.411. There is not a significant relationship between page slipping sound order (*M*=2.58, *SD*= 1.262) and page slipping sound detection (*M*=.17, *SD*= .365) score of the participants, r(96) = .059, p=.566.

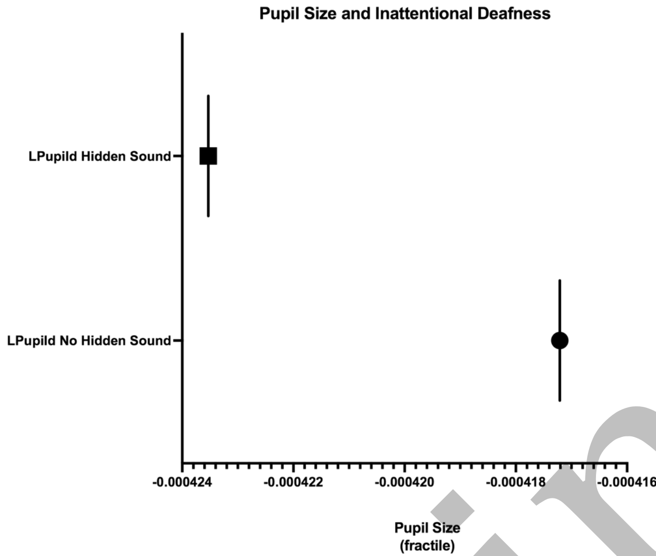
2.2 Pupil Size Analyse And Results of Inattentional Deafness

Figure 7

Performance plotted against background noise and pupil dilation when the hidden sounds are presented and not presented.

Figure 7 shows that the ANOVA and Post Hoc results of the pupil dilation. Left pupil size analyses showed that in the silence condition, Left pupil diameter (Lpupild) no hidden sound (*M*= -.000387, *SD*=.000402) and Left pupil diameter hidden sound (*M*= -.000382, *SD*=.000395), in environmental negative sound condition Left pupil diameter no hidden sound (*M*= -.000438, *SD*=.000482) and Left pupil diameter hidden sound ((*M*= -.000470, *SD*=.000569), and in environmental positive sound condition Left pupil diameter no hidden sound (*M*= -.000438, *SD*=.000495) and Left pupil diameter hidden sound ((*M*= -.000418, *SD*=.000511). The Left pupil diameter no hidden sound and sound conditions significantly differ, ($F(2,583493) = 783.237$, $p<.00$). Left pupil diameter hidden sound and sound conditions significantly differ, ($F(2,163831) = 430.729$, $p<.00$).

Figure 8

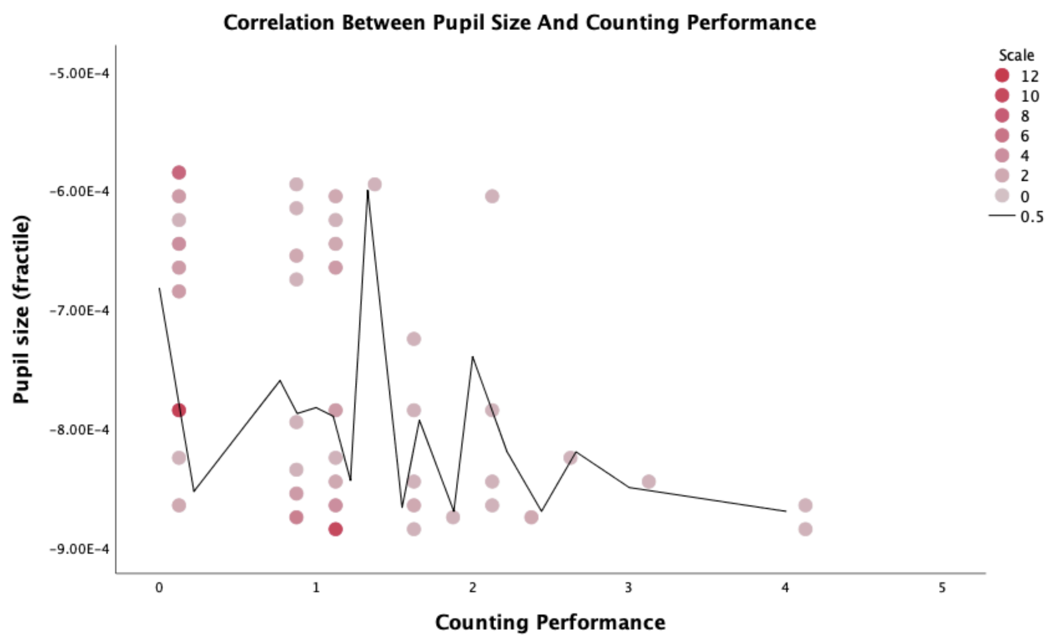


Comparison of pupil size in the moments when the hidden sound comes and does not come.

Paired Sample T-test results of the Left pupil diameter no hidden sounds (*M*=,000417, *SD*=.000484) and Left pupil diameter hidden sounds (*M*=-,000423, *SD*=.000498) showed that there was a significant difference; [t(163833)= 3.693, p<.00].

2.3 Pearson Correlation Results of Pupil Size and Counting Performance

Figure 9



Correlation of pupil size and hidden sound counting performances

Based on the results of the study, the counting performance of the participants (Wave and Thunder sounds) and Left pupil diameter hidden sound are strongly related to a sense of the identification of inattentional deafness, *r*= -.482, p<.00.

DISCUSSION

In this thesis we studied the possible effects of environmental sound type differences on inattentional deafness. Secondly, we determined the effect of hidden sounds on pupil size.We predicted that negative environmental sound, that is the thunder sound and positive environmental sound, that is the wave sound would either negatively or positively affect the participants' ability to detect the hidden sounds when compared to the silent control condition. Besides, we also predicted that the pupil size would be affected during the hidden sound stimuli presentation in all 3 conditions. Depending on the conditions that the participants attend and the changes in pupils would give us a clue to understand attentional errors such as inattentional deafness. Besides, pupil dilation could explain that if there is any emotional effect for the sounds that the participants listen to.

Behavioral results from our questionnaire suggest that the detection performance of hidden sounds is the best in the silent control condition. Still, when we compare the detection accuracy between environmental sound conditions, participants' performance was higher in Wave sound condition than in Thunder sound condition. As a result of this finding, we can understand that the type of environmental sound significantly affected participants' detection performance of hidden sounds. In this way, we could suggest that the participants in the negative environmental sound were more inattentionally deaf than other conditions. These results may be due to the arousal level of the environmental sounds and how it affects participants' performances towards the task. When we take a closer look to the perception of calmness or tranquility is generally associated with environments that have a high proportion of natural sounds and a low proportion of human and technological sounds (Rådsten-Ekman, Axelsson & Nilsson, 2013). According to researchers not all the environmental sounds have a similar pleasantness, Watts, et al. (2009) indicated that the natural water sounds (such as waves, sound of a waterfall, etc.) perceived more pleasant than manmade water sounds (such as fountains). Hence, the results of the study conducted by Rådsten-Ekman et al. in 2013 indicated that the type of the water sound have an effect on general pleasantness of the participants, for instance more pleasant water sounds (i.e. sea sound) have a positive impact on overall environmental pleasentness and less pleasant water sounds (i.e. waterfall) decreased the overall environmental pleasantness of the participants. Ma and Thompson (2015) showed that the higher spectrum or acoustic attributes of environmental sounds have an effect on the arousal level of the participants and their performances on the task.

As human beings, we got used to hearing human and natural sounds around us from the very first day of our lives. Furthermore, we have always had to stay alive and protect ourselves from outside danger from the very early times of human evolution. In this experiment, the negative environmental sounds contained heavy rain, lightning and thunderstorm, while the positive environmental sounds included the waves hitting the shore and relaxing sea sounds. Participants could have felt uncomfortable with the sound of thunder because of their survival instinct. Their attention towards the task could be decreased when we compare it with the silent and environmental positive sound conditions. Occasio (2011) indicated that we need to select what we need to attend to and choose how we should act comprehensively towards the distractive stimulus.

Studies on music can also explain this phenomenon, namely in recent years, there has been a significant increase in studies on low and high-level music processing in the brain, including phenomena such as perception of psycho-acoustic features, performance, and music-driven emotion and attention, all aimed at describing and understanding music-brain interaction: how music engages the brain and how it affects cognition in different ways (Burunat, Alluri, Toiviainen, Numminen, and Brattico, 2014). However, as stated by Janata et al. (2002), humans have evolved in a natural complex auditory scene environment, capable of segregating auditory objects for interaction and survival (Burunat, Alluri, Toiviainen, Numminen, and Brattico, 2014). Hence, in studying music-driven cognitive processes in the brain, more naturalistic approaches are crucial if we aim to (a) map those functional brain areas engaged in acoustically complex environment-conditioned processing and (b) compare the experimental findings resulting from the use of artificially created stimuli with more natural and complex approaches that more reliably replicate the acoustic environments our brains have adapted to (Burunat, Alluri, Toiviainen, Numminen, and Brattico, 2014). This human brain adaptation system could help us understand why our results showed lower accuracy rates in negative environmental sound condition.

Another finding of our experiment from the behavioral analysis of the 8AFC results indicated that the participants in the silence condition had higher correct answer accuracy and lower false memory accuracy when we compared it with the positive and negative environmental sound conditions. Besides, the findings also suggest that the participants developed false memories regarding the type of sounds that are present in their environment . For example, participants who attended the environmental negative sound condition were more likely to choose the 'door closing' among hidden sounds from the questionnaire, while the participants who participated in the environmental positive sound condition tended to select the 'chirm' option. This phenomenon might have taken place due to making associations with similar environments where the background sound can be heard.

Awh, Anllo-Vento and Hillyard (2000) suggested behavioral evidence for the attention-based rehearsal for the locations. For instance, when we go to the beach we used to hear some sounds such as wave sound, sound of the wind, swimming people, bird chirming, etc. and these sounds are the part of this location towards Awh et al. (2000). Even if we imagine a beach we can imagine the sounds from the location as well. People tend to use some cues for the spatial selection of the locations. Some studies supported that if a person attends to memorize these cues (like sounds at the beach), the conservation of location information could be manupulated by attentional cues. In this concept, we could interpret that the participants attended the location of information in negative and positive environmental sound conditions and created false memory due to the places and memories of their own about these locations. For example, birds should have been chirming out there if there is a relaxing wave sound.

Additionally, we analyzed the effect of presentation order of hidden sounds on participants inattentional deafness accuracy rates. As we mention in the methods part of this thesis, we pseudo-randomize the stimuli order of the hidden sounds to prevent confounds and bias in all 3 conditions (see Figure 16). Results showed that the participants performance for detecting the hidden sounds is not affected by the order of the stimuli. When we compared all conditions, participants hidden sound detection had lowest detection score in the 'Drinking, Keyboard, Hearbeat, and Page slipping' order but also 'Heartbeat, Page slipping Drinking and Keyboard' order of the hidden sounds had the highest detection score by the participants in all conditions. From the general results of the relationship between the order effect and the sound awareness, we could interpret that when the Heartbeat sound were given as the first hidden sound, participants' attention towards the hidden sounds may increase in a positive way. In other words, heartbeat sound percieved as a vital and highly related with the survival instinct for everyone, hence the meaning that we attend to the sound of heartbeat, it could make participants' attention performances higher towards the hidden sounds in all conditions. Besides, when we compare the conditions separately, our results showed that the detection of the sounds had lowest scores with the 'Paper, Heartbeat, Keyboard, and Drinking' order in negative environmental sound condition compared with the environmental positive and silent control condition.

The memory system of humans evolved in a way that is most likely to help us remember information about the danger or relevant situations for survival (Nairne et al. 2007; Bui, Friedman, McDonough and Castel, 2013). Horne (2022) indicated that the evolutionary biological responses toward the stimuli coming from outside depends on the selective attention of humans; for survival, we need to select what we should attend to or else we could get easily distracted by the stimulus from the external world (i.e., sights, sounds, etc.). Also, background music affects the listener's internal mood and could strengthen the performance on memory and attention tasks. As Nyugen and Grahn (2017) suggested, different perspectives, such as a negative one, can worsen, or a positive mood can enhance memory. Besides, arousal levels could affect attention and memory performances similarly. May be the reason why our results showed a significant difference between the type of environmental sounds and the detection of hidden sounds, is because of the participant's mood while they are having the task. The arousal level of the sounds could affect the participants' mood towards the task.

The third analysis of our experiment shows that the differences between pupil sizes when inattentional deafness occurs depend on the sound condition. Pupil dilation could occur when we feel excitement or fear depending on a stimulus which comes from outside. Results indicated for all conditions, there was a significant difference between pupil sizes between hidden sound and no hidden sound conditions. For the environmental negative sound condition, the pupil size of the participants gets larger during the exposure of hidden sounds compared to when there are no hidden sounds. In the silent control condition, there was no significant difference between presence of hidden sounds and the pupil sizes of the participants . However, in environmental positive sound condition pupil size of the participants get smaller during the presentation of hidden sounds. In general, our results showed that auditory awareness impacts the pupil size of the participants.

Last finding from our experiment shows that there isa minimal pupil size difference betweeneft pupil diameter in the absence of hidden sounds and Left pupil diameter when there is hidden sound in general analyses. According to Pearson correlation analyses of the study, counting performance of the participants (Wave and Thunder sounds) and Left pupil diameter during hidden sound is strongly related to the inattentional deafness, $r = -.482$, $p < .00$.

CONCLUSION

Future inattentional deafness studies can benefit that the pupils would give us a clue to understand attentional errors.Results may offer the opportunity to improve the researhes on inattentional deafness. Future studies could investigate the types of environmental sounds and their arousal level effect on inattentional deafness.

There are some limitations of this thesis. First of all, the topic of inattentional deafness has not been researched with an eye-tracking approach before, and we are the first ones who wanted to combine the existing data from neuroscientific studies on the subject with psychology and eye-tracking method. Thus it is hard to discuss our results for not being able to use a strong foundation or comparable studies on the topic.

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