ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF ARTS AND SOCIAL SCIENCES

INVESTIGATION OF AUDITORY ASYMMETRY ON THE VERTICAL LOCALIZATION OF SOUND

M.A. THESIS

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JUNE 2019

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SESİN YÜKSEKLİK KONUMLANDIRMASINDA İŞİTSEL ASİMETRİ İNCELEMESİ

YÜKSEK LİSANS TEZİ

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Batuhan Çetinkaya, a M.A. student of ITU Graduate School of Arts and Social Sciences student ID 409151117, successfully defended the thesis/dissertation entitled "Investigation of Auditory Asymmetry on the Vertical Localization of Sound", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To Cem, Dimitri, Görke and Nadir

FOREWORD

A sound occurs in our environment on a momentary basis. Our auditory system processes the ceaseless information and extracts meaningful information in order to understand and communicate with the environment. Sound localization is one of many entitlements of the auditory system. When the term localization is mentioned, people tend to think about the horizontal plane and refer to the left and the right side of our body. Instead, the auditory system is capable of identifying sound sources from each direction. Therefore, sound localization may refer to width, altitude, depth and their combinations on a spherical orientation.

Our ears transmit the auditory input to the contralateral hemispheres of our brain, where different types of stimulus are evaluated. The intention of this research was to study, understand and analyze our vertical perception of sound regarding the auditory asymmetry of the two ears. Since the physicality of the ears are not identical and the positioning of our ears do not serve as a primary function for the vertical localization task, this project aimed to investigate the influences of certain parameters for the perception of height.

I want to thank my thesis advisor Assoc. Prof. Can Karadoğan for his contribution to this research and Assist. Prof. Taylan Özdemir for the creation and development of the thesis.

May 2019 Batuhan Çetinkaya

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ABBREVIATIONS

cm	**:** Centimeters
dB	**:** Decibels
EEG	**:** Electroencephalogram
GB	**:** Gigabytes
SPL	**:** Sound Pressure Level
HRTF	**:** Head Related Transfer Function
Hz	**:** Hertz
I/O	**:** Input / Output
kHz	**:** Kilohertz
LE	**:** Localization Error
m	**:** Meters
ms	**:** Milliseconds
RAM	**:** Random Access Memory

SYMBOLS

sin **:** Sinus function

tan **:** Tangent

o **:** Angular degrees

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INVESTIGATION OF AUDITORY ASSYMMETRY ON THE VERTICAL LOCALIZATION OF SOUND

SUMMARY

In this research, the vertical localization skills of humans have been investigated under auditory asymmetry. Human ears are connected to the brain hemispheres with both ipsilateral and contralateral neural network. As the latter being much stronger than the former, it has been suggested that the perception and processing of an auditory information might differ depending on the ear. While knowing that the musical material is transmitted to the right brain hemisphere; the left ear should be providing stronger information.

It also known that humans do not have an appropriate ear positioning on their head for the vertical localization task. Therefore, several external and individual parameters should be contributing to this task. Gender, musicianship, age and handedness were defined as possible parameters and analyzed over the results. This thesis researched the relation between the auditory asymmetry and the vertical localization. For this reason, an experimental environment was necessary. Five vertically positioned loudspeakers were placed behind a folding screen and 29 subjects participated to the experiment.

Each participant performed the test for each ear, while the other ear was plugged. They were presented 1 kHz and white noise test signals. Each participant had seven questions in a randomized order. The linear difference between the actual location and the response of the subject were defined as localization error (LE). The average values of LE for each specific location and test signal were calculated. A detailed analysis has been conducted on the final section. As a general statement of the results, an auditory asymmetry existed for both of the signals. As a significant result, a left ear superiority with an %18 difference has been found for the white noise signal.

SESİN YÜKSEKLİK KONUMLANDIRMASINDA İŞİTSEL ASİMETRİ İNCELEMESİ

ÖZET

Bu araştırmada, insanların işitsel asimetri başlığı altında dikey konumlandırma kabiliyetleri sorgulandı. İnsan kulakları beyne eş taraflı ve ters taraflı olmak üzere iki tipte sinir ağı bağlanır. Ters yönlü bağların daha güçlü olmasından kaynaklı olarak, kulağa bağlı gelen işitsel sinyallerin algı ve işlenmesinde farklılık meydana gelebilir. Müzikal malzemenin beynin sağ tarafta işlendiği bilgisi dahilinde, sol kulağın daha üstün nitelikte bilgi aktaracağı hipotezi ortaya atıldı. İnsanların kulakları kafanın etrafında, dikey konumu algılayabilmek için yeterli uygun bir pozisyonda değildir.

Bu yüzden harici ve kişiye bağlı faktörler dikey konumlandırmaya katkı sağlıyor olabilir. Cinsiyet, müzisyenlik, yaş ve sağlak/solak olma durumu, olası faktörler olarak seçildi. Bu tez, işitsel asimetri ile dikey konumlandırma arasındaki ilişkiyi inceledi. Bu yüzden, bir deney ortamının hazırlanması gerekliydi. Beş adet dikey olarak yerleştirilmiş ses kaynağı, bir perdenin arkasına gizlendi ve deneye 29 kişi katıldı.

Her katılımcı testi iki kulağına ayrı ayrı gerçekleştirdi ve diğer kulağına tıkaç takıldı. Adayla 1 kHz ve beyaz gürültü sinyalleri dinletildi. Her katılımcıya rastgele sırada 7'şer kez soru soruldu. Sorular sağ ve sol kulak ile 1 kHz ve beyaz gürültü içerdiğinden, toplamda 28 soruya cevap vermiş oldular. Kaynakların gerçek konumları ile adayların cevapları arasındaki çizgisel fark, konumlandırma hatası olarak tanımlandı. Her konum ve sinyal tipi için ayrı ayrı hataların ortalamaları alındı ve araştırmanın son bölümünde detaylı bir analize sokuldu. Sonuçların genel bir değerlendirmesi olarak, işitsel asimetrinin varlığı kanıtlandı ve beyaz gürültü sinyali için sol kulakta katılımcıların yüzde 58'inde bir üstünlük görüldü.

1. INTRODUCTION

Every living being use their senses to assemble knowledge and extract meaningful information about themselves and the environment. The auditory sense and sound have been a longstanding attraction of many fields of science and humanities until this day. The physical, acoustical and psychological parameters of sound have been identified, measured and still being expanded on the account of the academic studies and technology. Our purpose for this research depends on the consequence that these parameters provide the opportunity to be combined or compared. Therefore, a psychoacoustic approach towards the vertical localization of sound has been established. The investigation of the study required a discrimination task from several participants.

This study is an experimental research in psychoacoustics, aiming mostly at students in sound engineering, psychology or neuroscience. It has been divided into four chapters. On the first chapter, we have stated our thoughts and intentions, followed by other studies in the field. The second chapter covered the essential background on the fundamentals of acoustics and several information on psychoacoustics. The analytical approaches and the experimental design were explained in the following chapter. Lastly, we have presented our statistical review of the data collected from the participants. Several combinations of our parameters were coupled with localization errors and response times.

This research has provided support for the idea that the vertical localization abilities of the human ears are disparately related to several determinants. Besides the acoustic parameters, what meaning they are given by our experimental process is a step forward to a better understanding of our perception. In sum, our experiment results have shown that auditory asymmetry can be used as a tool in the analysis of vertical localization. Although future research is needed to expand certain of the experiment conditions and the participant profile, it is hoped that this research contributes to any field of science as a functional study.

1.1. Literature Review

This research concerns certain components of the perceptional mechanism of the auditory system, the functioning of the brain hemispheres and its physiological impacts on the human body. We have conducted an extensive review on the previous studies and publications for the creation of the idea that relies behind this research. We aimed to summarize these studies in order to express our motivations clearly.

In an article by D.W. Batteau, it has been stated that the external ear could be a significant parameter for the localization task (Batteau, 1967, 1968). The earlap, often referred as the pinna, consists of several twists and folds which may create multiple pathways for the incoming acoustic inputs. His suggestion was that the structural complexity of the pinna may be providing spatial information in the interest of locating a sound source. Each pathway from the pinna creates a particular spectral shape, referred as pinna cues or spectral cues. Fisher and Freedman has attempted to present evidence to this suggestion by setting up a behavioral experiment with eight loudspeakers placed in the horizontal plane of the listener with an angular separation of 45 degrees (Fisher & Freedman, 1968). The experiment was conducted with only one ear (the other ear was plugged) and then with two ears.

The perception of the horizontal localization task is measurable within the comparison of interaural time and intensity differences. But such comparison is not available if the perception of altitude is being considered. According to the Farlex Partner Medical Dictionary, the median plane of the human body is defined as the vertical plane in the anatomic position, through the midline of the body that divides the body into right and left halves. Therefore, sound sources on the median plane do not form interaural differences and the spectral or pinna cues are often referred as monaural cues. Several researches have probed the vertical localization abilities of the human ear with spectral cues aligned with the median plane of the human body. It has been demonstrated that vertical localization is accurately performed if the acoustic input has a broad bandwidth. (Roffler & Butler 1968; Gardner & Gardner 1973; Butler & Helwig 1983, Hebran k& Wright 1974b). In another research by J. Blauert, it has been shown that a bias on the vertical localization task can be observed by altering the spectral content of a stimulus (Blauert1969, 1970). Blauert recorded noise signals from the participant's ear canals and manipulated them to imitate the spectral shape of the opposite side. It has been demonstrated that the location judgments were made by the source spectrum and no correlation has been found with its actual location.

Butler (1994) created a location judgment test with 3.5-kHz high-pass noise to be presented to ten subjects in order to localize a 3.5-kHz high-pass noise. The orientation of the experiment was on the median plane, therefore spectral cues acted significantly. He tested the subjects binaurally and monaurally for both ears. Best results were obtained in binaural conditions. In monaural conditions, the left ear estimated source elevation remarkably compared to the right ear. In addition, hearing shifts from the center line was less on the performance of the left ear. These data suggest that the right cerebral hemisphere is superior in processing complex spectral information (Butler, 1994).

The auditory input or stimuli are transmitted to both of the cerebral hemispheres through our ears. There are two types of neural connection between the cerebral hemispheres and the ears. A contralateral connection is the relation between the opposite sides of our body, while an ipsilateral connection refers to the transmission of information occurring on the same side. In the studies of Kimura and Milner, they have stated that each hemisphere received stronger stimulus from the contralateral connection because the neural pathways are stronger than the latter (Kimura 1973; Milner 1962). In an experimental environment, the "right ear score" corresponds to the performance of the left hemisphere, and vice versa. The fact remains as the hemispheric performance is highly related with the contralateral neural connection; we have extracted results from several researches about cerebral dominance. It has been stated that for right-handed subjects, the perception of language and analysis of stimuli are evaluated in the left hemisphere while the right hemisphere processes information in an integrated approach (Bever 1975; Kimura 1973; Levy 1969; Luria 1966; Milner 1971). Consequently, as one might expect, the hemispheric performance may be relevant with handedness. These researches provided information so that it is possible to measure the performance of the right and the left ear.

Hemispheric performance has also been studied under different experimental conditions. Harold W. Gordon carried out an experiment on musicians and non-musicians selected from male and female participants in order to measure ear superiority while presenting musical chords. A left ear trend was detected on the musicians and particularly on males. We may suggest that these findings indicate a correlation of the right hemisphere between the musicianship and gender (Gordon, 1970). We extracted that musicianship and gender could function as a significant parameter to serve our purpose. Likewise, D.J. Bakker tested children with verbal (speech) and non-verbal material (test stimulus or musical content) as an investigation for the auditory asymmetry (Bakker, 1967a and 1968a). Results presented superiority on the left ear for musical material. In addition, the perception of speech material was surpassed by the right ear over the left ear.

A study by C. Ivarsson, Y. De Ribaupierre and F. De Ribaupierri conducted a vertical localization test aligned on the median plane of the human body using four loudspeakers with an angular separation of 11°. Their selection of test stimuli consisted of white noise signals. The experiment session of each participant was recorded for the calculation of reaction time and localization errors. The results presented a superiority on the left ear for the monaural presentation of the experiment. and the highest score was obtained during the binaural listening condition. (Ivarsson; Ribaupierre; Ribaupierri, 1980).This research possessed similar approaches compared to our research. However, our research aims to measure the monaural performance of the ears using five loudspeakers with an angular separation of 10 degrees and an elevation of 25,2 centimeters between. For detailed information, see 3.2 Experimental Setup.

1.2. Purpose of Thesis

The purpose of this research is to investigate auditory asymmetry in the vertical localization of sound. Auditory asymmetry represents contralateral functioning of the brain hemispheres in accordance with the hearing system. The right and the left hemispheres are responsible for processing different types of information. Verbal material is processed in the left hemisphere and non-verbal material is evaluated in the right hemisphere. As it was mentioned in the previous section, the ipsilateral connections exist between the ears and the cerebral hemispheres. However, the contralateral pathways are much stronger. When both ears are exposed to non-verbal material, the right hemisphere will be processing the information. Therefore, it is possible to observe different response times from the candidates and also a left ear superiority under the circumstance that an experiment is conducted to both ears separately.

Our ears are on the right and the left side of the head, thus making the vertical localization a challenge for the listener. In real life, humans are able to detect the altitude of a sound source. But the ear positioning on the left and the right side of the head does not offer a suitable orientation for the vertical localization. Therefore, we have established an assumption that various parameters might be contributing to the height perception.

As mentioned in the previous section, various studies have been attempted to measure hemispheric performances of the brain along with the parameters. Here in our research, we aim to evaluate the auditory asymmetry under the physical features of the listener and it is suggested that a correlation with the perception of height is to be found.

1.3. Hypotheses

Until this point, we have taken our literature review into consideration and explained several concepts in order to express our motivations for the creation of this project. A need arises to state our hypotheses for this research. We are aiming to investigate the factors that influence auditory asymmetry on the vertical localization of sound. It is a probability that the auditory asymmetry exists within our participants and can be measured under monaural listening conditions. We have defined several parameters as gender, musicianship, handedness and response time in order to study on the vertical localization task. An experimental environment has been designed and the data from the participants has been processed for the qualification of our hypotheses. We aimed to acquire participants that were relevant to our parameters and exclude those who presented exceptional conditions.

We suggested and also mentioned in the review of past research that the altitude of a sound source is not equally well-received by listeners between simple and complex tones. The selection of the test stimuli was made upon these conditions so that the type of the signals would accommodate to our suggestion. It contained non-verbal material, an auditory stimulus. The vertical localization abilities of participants were compared between a 1 kHz pure tone (sine wave) and a broadband white noise signal.

The experiment is applied separately to each ear of the listeners. As we have mentioned before, the brain hemispheres do not process the same information in the same speed and accuracy. For this reason, the candidates were given a pair of earplugs so that the contribution of the ear from the far side could be minimized. We suggest that the right and the left ear will have different scores for the vertical localization task. Ideally, superiority on the left ear is expected from the results. However, the experimental and participant conditions might lead to a contrary situation. Therefore, we will be evaluating the superiority of the ears for each type of the stimulus over our parameters on Results and Discussion.

2. THEORETICAL BACKGROUND

This project aims to examine willing candidates' location judgments on a predefined vertical axis. In simple terms, a sound event is happening in a three dimensional space. It is possible to create the pathway of sound within the scope of the project. Sound has to be created, transmitted and understood in order to reach our goal. Therefore, the physical and behavioral features of sound (creation) and hearing system (transmission) is explained in this chapter. Detailed information regarding the functioning of the brain versus an auditory input (understanding) is available later on this chapter.

2.1. Sound

"At a physical level, sound is simply a mechanical disturbance of the medium, which may be air or a solid, liquid or other gas" (Howard & Angus, 1996, p. 2). It is mostly the vibration of an object, which renders it as a source of sound. An initial force is required for an object (or a mass) to vibrate. The vibrations are able to propagate within an elastic medium, air in most of the cases for humans, forming longitudinal pathways referred as sound waves. Waves travel in a medium in a cyclist pattern. We are able to explain the physics of sound with Newton's second law of motion. (Schnupp, Nelken, King, 2010). Following several second-order linear ordinary differential equation with constant coefficients, it is possible to measure the quantity of cycles that occur in one second, also referred as the frequency of a wave and expressed in Hertz (Hz):

$$f = \frac{1}{2}\pi\sqrt{k/m}$$ (Schnupp, Nelken, King, p.7)

The equation above indicates that the mass-spring system has a natural frequency at which it wants to oscillate or in the case of sound, vibrate. This notion is known as the system's resonant frequency. But in fact, the vibration of an object indicates the total amount of motion in each of its components and thus defining the object simultaneously as a single mass, a two half mass, a three third and so on. This behavior is called the modes of vibration (resonant modes).

In real life, the sounds created by each source have their distinct properties because they vibrate in complex patterns. The physical features of the external force and the object (position, direction, dimension, mass, material) will affect the specialty and the amount of the excited resonant modes, in addition to its natural frequency. If the natural frequency and/or resonant modes lie within the human audible frequency range, then these vibrations may be heard as sound. We have presented physical aspects of sound from the source to our ears in Figure 2.1, where the behavior of a pure tone is observed.

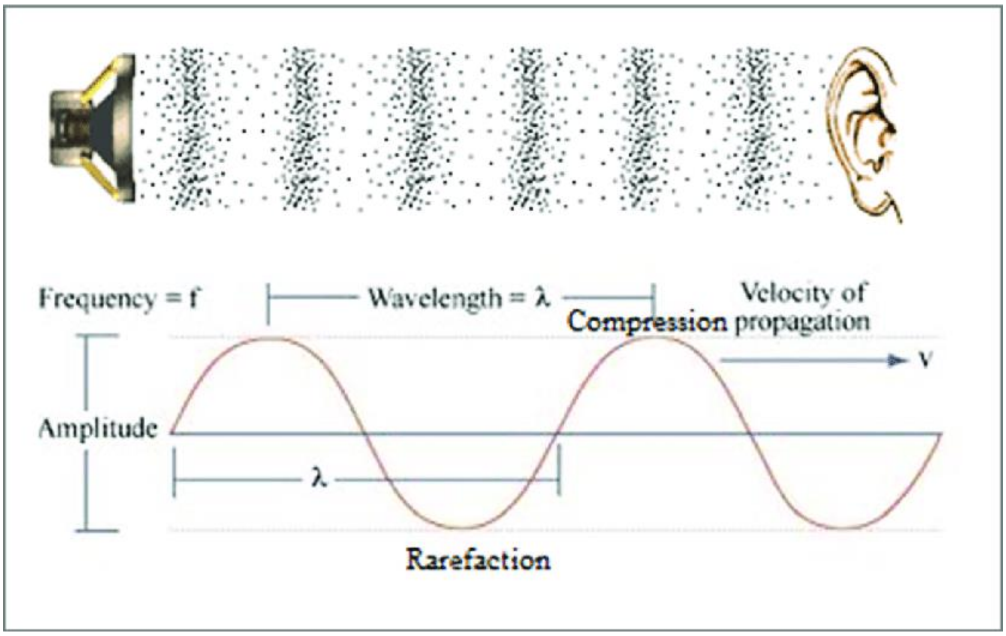

Figure 2.1: The Physical Aspects of Sound (Adapted from: https://www.researchgate.net/figure/1-Sound-wave-http-wwwmediacollegecom-audio-01-sound-waveshtml-This-image-is_fig2_329027353)

2.2. Hearing

Sound waves create pressure changes in the air molecules. An auditory system is capable of converting the pressure fluctuations into firstly mechanical, then hydraulic and lastly electrical signals of which the latter forms the auditory stimulus. “The anatomic structure of the human hearing system consists of the outer ear, the middle ear and the inner ear. The physical structure of the hearing system can be observed in Figure 2.2. The outer ear consists of the external flap called pinna and has an acoustic effect on sounds entering the ear in that it helps us both to locate sound sources and it enhances some frequencies with respect to others. Sound localization is helped mainly by the acoustic effect of the pinna and the concha (Howard & Angus, 1996, p. 74-75). The acoustic input from the outer ear transverses the ear canal and reaches the tympanic membrane; the boundary between the outer and middle ear. The conversion of pressure fluctuations to mechanic vibrations occurs in the middle ear. The middle ear transmits the acoustic input to the inner ear with three bones referred as hammer, anvil and stirrup. The oval window is the boundary between the middle and the inner ear. “The function of the middle ear is twofold: The transmission of the tympanic membrane movement to the fluid which fills the cochlea without significant loss of energy and the protection of the hearing system to some extent from the effects of loud sounds” (Howard & Angus, 1996, p. 76).The inner ear consists of the structure known as the cochlea. An acoustic input causes the movement of the cochlear fluid, perilymph, and the basilar membrane. The frequencies of the input sounds are analyzed in the basilar membrane. “In order that the movements of the basilar membrane can be transmitted to the brain for further processing, they have to be converted into nerve firings. This is the function of the organ of Corti, which consists of a number of hair cells that trigger nerve firings when they are bent. The nerves from the hair cells form a spiral bundle known as the “auditory nerve”. The auditory stimulus is transmitted to the brain by the auditory nerve.” (Howard & Angus, 1996, p. 83). The anatomy of the ear is visually presented below.

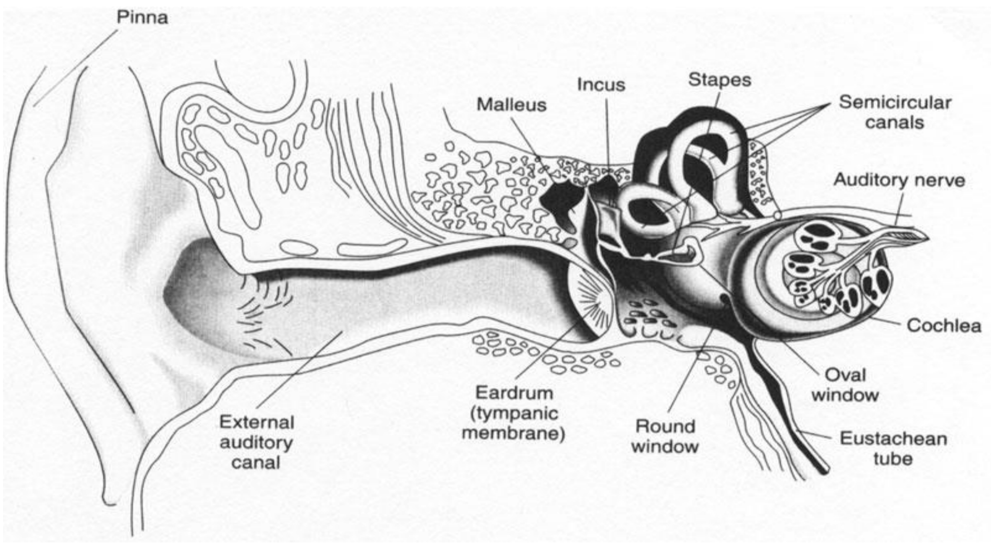

Figure 2.2: The Anatomy of the Ear (Adapted from: https://www.skidmore.edu/~hfoley/Perc9.htm)

2.3. Perception of Sound

The perception of sound can be defined as the cerebral process of recognizing and interpreting an auditory stimulus in order to interact with the environment. It should not be forgotten that the hearing or the listening experience involves the ear and the brain, in addition to the mechanical process.

There are physical cues of sound, such as periodicity and formant frequencies; and then there are perceptual qualities such as pitch, speech sound identity, and spatial location. Our auditory sensations are based on an integrated representation that takes into account multiple cues and is not cast in terms of the physical cues; we hear pitch rather than periodicity, vowel identity rather than formant frequencies, and spatial location rather than interaural disparities. Furthermore, non sensory or cognitive factors will contribute to the auditory performance. These factors include attention, motivation and memory.

The challenging task that the auditory system faces is to process sounds precisely, so that they can be identified, characterized, and localized, in order to obtain meaningful elements in a timely manner. "If in a mixture of sounds, we are able to detect moments of sound that strongly resemble one another; they should be grouped together as probably coming from the same happening. This statement follows from the idea that events in the world tend to have some persistence. They do not change instantly or haphazardly" (Bregman, 1994, p. 24). We hear the sound when the vibrations are physically reached to our ears through an elastic fluid. Reversibly, the mental image created by the hearing process will not be fluctuating particles inside the air, or another medium. The auditory stimulus carries information about the physical properties of its origins and environment. A.S. Bregman also mentions that the auditory system has a betting mechanism which categorizes input information and compares them whether they occurred from the same source (Bregman, 1994).

The accomplishment of a localization task depends on the possibility that the acoustic input function whether as a stimulus, an ambient sound or both. In our case in this project, the test stimuli function as a signal. The brain is capable of heading towards a complex auditory stimulus and ignoring the rest; which is referred as the auditory attention. The interpretation of sound is dependent to the attention of the listener (Currier, 2011). Therefore, listening and hearing cannot be considered as the same task and must be carefully distinguished (Mahmood, 2013).

Mechanism of perception, according to Gimson (1998), follows the same steps of sound production but in revered way: the reception of sound waves by the hearing apparatus of the listener (the physiological stage); then the transmission of the information through the nerve system to the brain where linguistic interpretation of the message takes place (the psychological stage). “It has been argued that the hemispheres of the brain are functionally asymmetrical in their ability to process different classes of information. Essentially these reports have posited the view that the left hemisphere predominates in the processing of verbal stimuli whereas the right hemisphere predominates in the processing of non-verbal stimuli. Cerebral asymmetry has also been conceptualized as reflecting holistic and analytic processing with analytic processing of information input localized in the left hemisphere and holistic processing localized in the right hemisphere” (Milner, 1762; Bakker, 1967, 1968; Gazzaniga, 1967; Kimura, 1967, 1973; Bogen & Gordon, 1971; Bogen, DeZure, Tenhouten, & Marsh, 1772; Cohen, 1972, 1973; Egeth & Epstein, 1972; Bever, 1975; Kinsbourne, 1975).

Communication from a source to a receiver is basically a transfer of information. It happens at many perceptual and cognitive levels simultaneously. Sound can be considered to have different dimensions, of which contains various information for accommodation. And auditory communication can be considered as a sequence of three steps; sound generation, the listener’s perception and processing of the sound: An external force causes an oscillation of the air pressure. Acoustic properties can be assessed under the titles as the dominant frequency, amplitude, envelope (temporal changes in the shape of a sound wave), spectrum (collection of frequencies), and duration (length of time a sound sustains). Afterwards, the acoustic properties of a sound are translated by the human auditory system into the sensation of hearing. This psychoacoustic phenomenon has several qualities such as loudness, attack/body/decay (the shape of a sound from initiation to termination), timbre (particular quality of a sound which serves to distinguish two sound sources), duration, and apparent location of the sound relative to the listener.

3. METHODOLOGY

The localization task is not a clear process; therefore, a localization error is inevitable. The azimuth and elevation of the sound source locations define an imaginary circle or a sphere. Therefore, spherical statistics should be applied in order to analyze data. But in many cases, localization estimates may be correctly analyzed using linear methods. Auditory localization error refers (LE) to the difference of a judged location and the actual location of a sound source. This difference may be restricted to a difference in azimuth or elevation or both (e.g., Carlile et al., 1997).

Depending on the task given to the listener, there are two basic types of localization judgments; relative localization (discrimination task) and absolute localization (identification task). Relative localization judgments are made when one sound source location is compared to another, either simultaneously or sequentially. Absolute localization judgments involve only one sound source location that needs to be directly pointed out. The latter type of judgment occurs when all the potential sound source locations are marked by labels (e.g., number), and the listener is asked to identify the sound source location by label. Our experiment collected localization judgment data out of source locations. Thus, the candidates' task is to actualize a discrimination task, also referred to as categorical localization. The statistical properties of this variable are generally described by spherical statistics due to the spherical/circular nature of angular values. However, if the angular judgments are within a ±90 degrees range (as is the case in our localization experiment), the data distribution can be assumed to have a linear character, which greatly simplifies data analysis. Therefore, the localization error of participants was defined as the linear difference of their response and the actual location of the sound source. Each LE for a specific location was collected and then their average, standard deviation and error rates were calculated.

In order to assess the human ability to localize the sources of incoming sounds, the physical reference space needs to be defined in relation to the position of the human head. This reference space can be described either in the rectangular or polar coordinate system. The rectangular coordinate system x, y, z is the basis of Euclidean geometry and is also called the Cartesian coordinate system. In the head-oriented Cartesian coordinate system the x, y, and z axes are typically oriented as left-right (west-east), back-front (south-north), down-up (nadir-zenith), respectively. The east, front, and up directions indicate the positive ends of the scales. The Euclidean planes associated with the Cartesian coordinate system are the vertical lateral (x-z), the vertical sagittal (y-z), and the horizontal (x-y) planes (see Appendix A: The Orientation of Experimental Setup).

"The linear distribution used to describe localization judgments, and in fact most human judgment phenomena, is the normal distribution, also known as the Gaussian distribution. It is a purely theoretical distribution but it well approximates distributions of human errors, thus its common use in experiments with human subjects. In the case of localization judgments, this distribution reflects the random variability of the localizations while emphasizing the tendency of the localizations to be centered on some direction (ideally the true sound source direction) and to become (symmetrically) less likely the further away we move from that central direction" (Advances in Sound Localization, 2011, p. 62).

Our method for the measurement of localization error was to ask listeners to identify the vertical position of the test stimulus by selecting from a set of numbers. "These locations can be indicated by either visible sound sources or special markers on the curtain covering the sound sources" (Butler et al., 1990; Abel & Banerjee, 1996). "Such approaches restrict the number of possible directions to the predetermined target locations and lead to categorical localization judgments" (Perrett & Noble, 1995). The results of categorical localization are to be calculated as percentages of responses rather than angular deviations.

"Localization accuracy depends mainly on the symmetry of the auditory system of the listener, the type and behavior of the sound source, and the acoustic conditions of the surrounding space. It also depends on the familiarity of the listener with the listening conditions and on the non-acoustic cues available to the listener. For example, auditory localization accuracy is affected by eye position" (Razavi et al., 2007). For this reason, two observing points were presented to the candidates regarding their test positions in order to provide an identical head position while listening to the test stimuli.

3.1 Experimental Setup

The method that is going to be utilized for the experiment becoming clearer for the project, a design for the experiment was necessary to reach our objectives. During this section, the selected environment for the experiment, the placement of the loudspeakers, the set up of the controlling and monitoring system, the selection and presentation of the test stimulus and the processing of experiment data have been explained.

3.1.1 Environment

Experiments were conducted in MIAM Recording Room with dimensions of 10m X 6m X 5,5 m. The ambient sound level was approximately 40 dB SPL. The experimental setup was located on the wall against the entrance so that the participants were not able to take a glance at the equipment behind the folding screen.

3.1.2 Apparatus

The loudspeakers were vertically spaced in 25,2 cm (defining the resolution and accuracy of the experiment) with 10 degrees of angular separation around an imaginary circular hoop of 140 cm radius (see Appendix A: The Orientation of the Experimental Setup). The placement of loudspeakers was actualized through a cabinet with 5 shelves gathered from IKEA of 140 cm height (see Figure 3.1, Figure 3.2, Figure 3.3, Figure 3.4). Sound stimuli were presented through five Adam T5V near field monitors. The frequency response of each loudspeaker was measured under a test with a sine wave signal sweeping through the audible frequency range of 20 Hz to 20 kHz to ensure the presentation of identical sound stimuli. The test tone was recorded for each loudspeaker. Test results did not present irregular data.

The purpose of the experiment relies on the embowering of the loudspeakers. A folding screen has been provided from the Digilab of MIAM and the entire setup was hidden from the candidates. Therefore, the responses were given outside the knowledge of the quantity of the loudspeakers. We have attached a scale of 11 numbers on the folding screen. Even numbers represented the actual locations of the loudspeakers, while the odd numbers indicated the locations between the loudspeakers. Only the number 1 and 11 corresponded with the upper and lower off-limits of the apparatus. The reason for this placement is an expectation of a bias regarding the spectral features of the test stimuli.

Figure 3.1: The Overall View of the Experimental Setup

The generation of the experiment was handled with an Apple Macbook Pro (Mid 2015) with Sierra operating system driven by 16 GB of RAM. Our signal chain was provided by an Orion Antilope sound interface with 16 I/O outputs. An Ableton Live session with five mono tracks, directed to the five different outputs of the interface were created. The sample rate was 44100 Hz. The bit depth was 24 bits. Each track contained 500ms recordings of a 1 kHz sine wave and a flat broadband white noise signal. Test signals were presented manually by the experimenter, followed by the responses to each stimulus.

Figure 3.2: The Placement of the Loudspeakers

Figure 3.3: The Listener’s Aspect

Figure 3.4: The Experimenter's Aspect

3.1.3 Test Stimuli

Hemispheric dominance (also referred as auditory asymmetry) for auditory stimulus can be assessed under various methods. The most common are monaural and dichotic presentations. In a monaural presentation, the subject hears the stimuli presented to one ear. Our desire for the test stimulus was to be relevant with previous studies in the field. Therefore, extracts from our literature review were presented here below for the consistency of our statements. Simon and Agens, published an article in order to demonstrate whether the time required to retrieve information varies on the ear which had been stimulated. In this research, they have presented a monaural 1000 Hz tone of 86 dB intensity and a 500 ms duration (Simon & Agens, 1980). In addition to this research, K. A. Provins and M.A. Jeeves tested ten right-handed and ten left-handed matched groups of normal males were tested on a bilateral response task to simple unilateral auditory stimuli presented in a random sequence to the right and left ears (Provins and Jeeves, 1975). A 1000 Hz tone at constant intensity well above threshold was presented monaurally to either the right or the left ear. Furthermore, R.A. Butler selected ten subjects to localize a 3.5-kHz high-pass noise originating in the vertical plane. Experimental conditions were binaural listening and monaural listening. In comparison with the right ear, location judgments of source elevation were significantly more accurate when listening with the left ear. These data suggest that the right hemisphere is better in processing complex spectral information and demonstrate the essentiality of the auditory cortex contralateral to the stimulated ear for vertical localization accuracy (Butler, 1994).

We have restricted our selection of test stimulus for the experiment as a 1 kHz sine wave and a flat broadband white noise signal of 75 dB intensities and 500 ms duration in order to compare the influences of spectral aspects on the vertical localization task. “The nature of the task appears to be closely related to the arising of the phenomenon. Faster presentation of the items and longer series for instance, appear to influence positively the degree of ear-asymmetry.” (Bartz, Satz and Fennell, 1967; Satz, 1968; Satz, Achenbach, Pattishall and Fennell, 1965; Bartz, Satz, Fennell and Lally, 1967). For this reason, a sequence of seven test stimuli was presented in a randomized order, particular for each candidate.

3.1.4 Data Processing

Each candidate’s session was recorded with a Tascam DR-40V2 recorder from which we have benefited as the security of the candidate’s data and the calculation of the response time. In addition, the answers were also being noted as the participants were responding. For the calculation of response times, we measured the temporal distance between the ending point of the signal and the beginning of the response from the recordings. The response data, profile form and the response times were registered to RStudio version 3.5.1 through Microsoft Excel (See Table D.1). The software averaged localization errors for each ear, specific location and test stimulus. The averages of errors varied as positive and negative. Upon these values, we have extracted hearing shift information. Furthermore, we have filtered the results over the test of the parameters. We have presented our results and findings in Chapter 4: Results and Discussion.

3.2 Participants

17 male and 12 female participants from ages 25 to 35 have signed the consent form to participate in the experiment. There were four non-musicians of which, three were females and of these three, one was left handed. The total number of left handed people was four.

First of all, the main aspects and the purpose of the research were enlightened to the candidates with a consent form. A prior consideration was taken by the experimenter during the explanation of the procedure in order to ensure the unawareness of the candidates about the experimental setup. They were not informed about the quantity of the sound sources. For those who accords with us were asked to fulfill the eligibility form (see Table C.1). After the fulfillment of the requirements, the candidates were guided to reach the testing room. They were placed comfortably on the listening position forming an azimuth of 90 degrees from the apparatus. The candidates were not given a headrest; they were asked to focus on an observing point while the test tone was being generated. Each candidate was given two ear plugs providing 37 dB signal-to-ratio reduction in order to minimize the contribution of the opposite ear.

The test was driven for two ears separately and the opposite ear was plugged. On each candidate’s session, we have changed the initial side. This helped us to create more combinations of our parameters to analyze. Although the necessary information was written on the consent form, the procedure was yet repeated vocally to the candidates before beginning the test: “We will begin with your right/left side. Please place yourself to the listening position and adjust correctly in accordance with the observing point. This is a vertical localization task. I am going to present you a sequence of test signals. Whenever you detect the vertical location of a tone, select an answer from the 11 number scale posted on the folding screen. Present your answer vocally. There will not be a repetition of a signal if you were unable to hear it. I will begin the test if you are ready". Afterwards, they were asked to rotate 180 degrees from the initial position, to plug the opposite ear and the test was repeated for the other ear.

4. RESULTS AND DISCUSSION

The analysis has been conducted under the circumstances that the ears and the auditory stimulus are considered as separated components. We have presented datasets and their visual charts throughout this section in order to understand, compare and comment on our findings from the experiment. It is possible to read from each dataset the quantity of responses, error percentages, their standard deviation and error rate of each ear towards the type of stimulus. Our findings have concluded that the complexity of the auditory stimulus enhanced the vertical localization abilities of the participants. In addition, the localization errors were increased as the altitude of the sound source progressed to the higher and lower extremities of the apparatus.

The analysis of the results provided information about auditory asymmetry and its relations with several parameters on the vertical localization task. The performances of the participants suggested a left ear superiority, which also implies a right cerebral hemispheric dominance, which was an expectation since non-verbal stimuli have been utilized. Initially, we have scoped the localization errors individually. For this reason, each participant’s localization error was calculated and their personal averages were noted. The calculation was defined as the difference between the left and the right ear localization error, respectively. Therefore, negative values correspond to the left ear superiority. Table 4.1 and 4.3 shows these values for 1 kHz and the white noise signal, respectively and green fill-ins represent left ear superiorities.

Results show that for 1 kHz test signal, %59 (17 subjects) of the participants (against 12 subjects - %41) had a left ear superiority with an average error rate of -1,26. We have mentioned that the beginning ear of each participant was altered each session (See 3.2. Participants). We used this information to expand the analysis one step further. It should be noted that on Table 4.1 and 4.3, columns that contain “L” or “R” represent the initial side of the participants and are not related with left or right ear performances. The subjects who had left ear superiority and started the test with their left ears constituted %34; and those who started the test with the right ear were the %24 of the population. For more information, see table 4.2.

Table 4.1: Individual Error Averages for 1 kHz Signal

Init.	LE							Average		Init.	LE							Average
L	0	3	-2	-3	1	-3	-2	-0,8571		R	6	-2	-3	3	-5	-4	1	-0,5714
L	3	4	-4	-1	-1	-2	3	0,2857		R	-5	4	1	-11	4	-6	-3	-2,2857
L	-3	-3	-3	2	1	-1	-1	-1,1429		R	6	-2	-5	8	-2	1	-2	0,5714
L	-7	1	-6	9	1	5	-5	-0,2857		R	-4	-4	0	4	5	2	8	1,5714
L	-2	2	-8	3	-4	2	-8	-2,1429		R	-7	5	2	-1	4	-2	0	0,1429
L	0	5	-5	-3	3	6	-5	0,1429		R	1	0	-1	1	-2	-1	-2	-0,5714
L	7	5	-1	-3	0	-3	0	0,7143		R	4	0	9	8	0	2	-6	2,4286
L	-1	-2	-1	-4	6	7	1	0,8571		R	3	-2	1	1	0	1	-1	0,4286
L	-5	-3	1	3	3	-8	-7	-2,2857		R	-1	4	-3	5	-4	-4	-2	-0,7143
L	3	-9	-2	1	3	-4	-7	-2,1429		R	-4	-1	-6	-3	0	4	-1	-1,5714
L	-2	4	0	4	5	0	1	1,7143		R	-4	-1	5	12	-2	1	2	1,8571
L	3	-1	-5	-8	-5	3	6	-1,0000		R	0	-8	3	2	-7	2	-6	-2,0000
L	-6	4	2	0	4	-7	-4	-1,0000		R	-5	2	6	0	-5	-6	4	-0,5714
L	3	-6	-5	4	-5	7	1	-0,1429		R	1	-4	-2	2	-2	2	4	0,1429
L	5	-4	1	-8	-3	-4	-2	-2,1429										

Table 4.2: Superiority Rates for 1 kHz Signal

1 kHz Left Ear Superiority				1 kHz Right Ear Superiority			
Init	#	Average	%	%	Average	#	Init
Left	10	-1,31	34,48%	17,24%	0,74	5	Left
Right	7	-1,18	24,14%	24,14%	1,02	7	Right
Total	17	-1,26	58,62%	41,38%	0,90	12	Total

If the same analysis were conducted for the white noise signal, it will be found out that %52 (15 participants) of the subjects were dominant on the left ear performances against %38 of the subjects (11 participants). The resting %10 of the population consisted of people with average error rate which equals to zero. The subjects who had a left ear superiority and started the test with their left ears constituted %20; and those who started the test with the right ear were the %31 of the population. (see Tables 4.3 and 4.4).

Table 4.3: Individual Error Averages for White Noise Signal

Init.	LE							Average		Init.	LE							Average
L	3	-3	0	0	0	2	2	0,5714		R	-4	1	-1	0	3	3	-2	0
L	2	0	-2	1	-1	0	-2	-0,2857		R	-3	0	0	-1	-3	2	-3	-1,1429
L	2	4	0	-3	1	1	-1	0,5714		R	0	1	0	-1	0	1	2	0,4286
L	1	-3	-5	0	0	-1	0	-1,1429		R	-10	-1	-2	7	3	3	-7	-1,0000
L	1	2	2	1	1	-1	1	1,0000		R	-1	1	-3	-6	0	-2	1	-1,4286
L	0	-1	-6	-1	1	-2	2	-1,0000		R	1	1	-5	-2	0	1	0	-0,5714
L	-3	0	-1	-3	1	2	4	0		R	0	1	-2	-1	-1	1	-1	-0,4286
L	3	-1	1	1	-1	1	1	0,7143		R	1	2	1	-2	-1	1	2	0,5714
L	2	0	-1	-1	7	2	-1	1,1429		R	0	1	1	2	-1	1	1	0,7143
L	1	2	1	2	2	1	3	1,7143		R	-1	1	-1	-1	2	-1	0	-0,1429
L	1	-1	0	-1	0	2	2	0,4286		R	3	5	3	-1	1	-1	-10	0
L	-8	9	1	-6	-3	0	-1	-1,1429		R	0	0	-2	-12	-5	10	0	-1,2857
L	-2	-7	-4	2	-2	6	3	-0,5714		R	0	-1	-2	-1	-1	0	0	-0,7143
L	2	-7	1	-1	1	-1	-1	-0,8571		R	0	-5	-1	2	1	0	1	-0,2857
L	6	0	-1	1	2	1	2	1,5714										

Table 4.4: Superiority Rates for White Noise Signal

White Noise Left Ear Superiority				White Noise Right Ear Superiority			
Init	Average	#	%	%	#	Average	Init
Left	-0,83	6	20,69%	27,59%	8	0,96	Left
Right	-0,78	9	31,03%	10,34%	3	0,57	Right
Total	-0,80	15	51,72%	37,93%	11	0,86	Total

We have already stated that the localization skills were increased when the test signal had more complex spectral complexity. For this reason, the white noise scores could be considered as the betterment of the responses for the 1 kHz signal. Although 1 kHz results also indicate to slight left ear superiority, we know that the 1 kHz session was a confusing process according to both the interpretation of the results and the feedback from the subjects. Therefore, the superiority information for the white noise serves as stronger information. The overall %18 difference of ear superiority represents an auditory asymmetry and right cerebral hemisphere dominance for the vertical localization of the white noise signal.

4.1. Test Stimuli

We moved on with the analysis with the localization errors of each ear towards the auditory stimuli. Figure 4.1 states that the localization errors are higher in 1 kHz responses compared to the white noise. It is possible to prove this statement by comparing each P_n with P_{n+5} on Table 4.5 (i.e. P_1 and P_6 indicates to the performances of the left ear to the stimulus sent from the L_1). This observation will lead to a situation where each error rate for the 1 kHz signal is always higher than the one for the white noise signal.

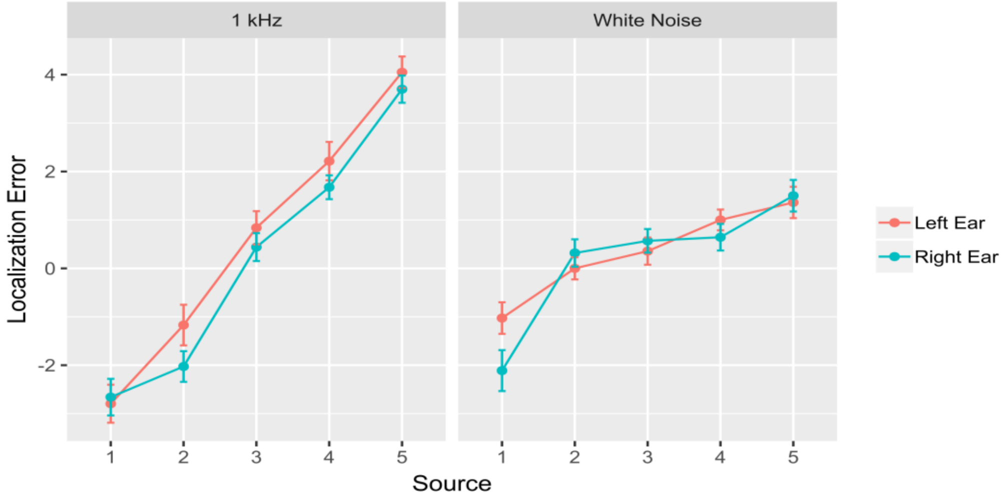

Figure 4.1: Localization errors for the left and the right ear

Table 4.5: LE dataset compared between 1 kHz and white noise

P	Ear	Location	Signal	n	LE	%LE	Shift	Deviation	Error
1	Left	1	1 kHz	41	-2,7949	**25,41%**	Downwards	2,5150	0,3928
2	Left	2	1 kHz	42	-1,1707	**10,64%**	Downwards	2,7194	0,4196
3	Left	3	1 kHz	37	0,8378	**7,62%**	Upwards	2,0885	0,3433
4	Left	4	1 kHz	42	2,2143	**20,13%**	Upwards	2,5713	0,3968
5	Left	5	1 kHz	41	4,0488	**36,81%**	Upwards	2,0851	0,3256
6	Left	1	Noise	39	-1,0263	**9,33%**	Downwards	2,0333	0,3256
7	Left	2	Noise	43	0,0000	**0,00%**	Upwards	1,4960	0,2281
8	Left	3	Noise	45	0,3556	**3,23%**	Upwards	1,8848	0,2810
9	Left	4	Noise	40	1,0000	**9,09%**	Upwards	1,3587	0,2148
10	Left	5	Noise	36	1,3611	**12,37%**	Upwards	1,9443	0,3240
11	Right	1	1 kHz	42	-2,6585	**24,17%**	Downwards	2,4455	0,3773
12	Right	2	1 kHz	38	-2,0263	**18,42%**	Downwards	1,9519	0,3166
13	Right	3	1 kHz	41	0,4390	**3,99%**	Upwards	1,8446	0,2881
14	Right	4	1 kHz	41	1,6750	**15,23%**	Upwards	1,5752	0,2460
15	Right	5	1 kHz	41	4,3649	**39,68%**	Upwards	1,8003	0,2812
16	Right	1	Noise	38	-2,1111	**19,19%**	Downwards	2,6052	0,4226
17	Right	2	Noise	41	0,3171	**2,88%**	Upwards	1,8089	0,2825
18	Right	3	Noise	44	0,5682	**5,17%**	Upwards	1,6196	0,2442
19	Right	4	Noise	42	0,6429	**5,84%**	Upwards	1,7782	0,2744
20	Right	5	Noise	38	4,3586	**39,62%**	Upwards	2,0101	0,3261

We have rearranged Table 4.5 and presented Table 4.6 in order to observe the auditory asymmetry on each type of stimulus. The first 5 rows represent error rates for 1 kHz and the rest is for the white noise signal. The cells that are filled in green indicate to the lower error rate compared in between ears. Here it is possible to observe an auditory superiority on the left ear for the white noise signal. The error rates are averagely on 2 to 4 percent but on the extremities, the left ear had a significantly higher score than the right ear. Only on L_4, the right ear performed better with a %4 difference. However, defining an auditory asymmetry for to the 1 kHz signal would not be a clear statement. The error rates are not remarkably different around the center loudspeakers, compared to white noise. But surprisingly, the differences are getting smaller while the error rates are increasing on the extremities. This leads to a discrepancy where a clear statement of an auditory asymmetry for the 1 kHz is not suitable for this experiment.

Table 4.6: Auditory Asymmetry on 1 kHz and white noise signal

Ear	Loc.	Signal	Shift	%LE	%LE	Shift	Signal	Loc.	Ear
Left	1	1 kHz	Downwards	-25,41%	-24,17%	Downwards	1 kHz	1	Right
Left	2	1 kHz	Downwards	-10,64%	-18,42%	Downwards	1 kHz	2	Right
Left	3	1 kHz	Upwards	7,62%	3,99%	Upwards	1 kHz	3	Right
Left	4	1 kHz	Upwards	20,13%	15,23%	Upwards	1 kHz	4	Right
Left	5	1 kHz	Upwards	36,81%	39,68%	Upwards	1 kHz	5	Right
Left	1	Noise	Downwards	-9,33%	-19,19%	Downwards	Noise	1	Right
Left	2	Noise	Upwards	0,00%	2,88%	Upwards	Noise	2	Right
Left	3	Noise	Upwards	3,23%	5,17%	Upwards	Noise	3	Right
Left	4	Noise	Upwards	9,09%	5,84%	Upwards	Noise	4	Right
Left	5	Noise	Upwards	12,37%	39,62%	Upwards	Noise	5	Right

In addition, error shifts were generally upwards, except for L_1. Despite the elevation of the apparatus and the listener's position, also the placement of a carpet on the ground; it would not be possible to cancel ground reflections completely. In addition, our body functions as a filter especially for auditory inputs coming from the ground. For this reason, it is possible to interpret that the ground reflections and the upper body functioned as a parameter during the experiment and affected error shifts.

4.2. Gender

We have expanded the analysis through genders since the distribution of male and female groups consisted of approximately the same quantity of participants. Since we have found out that error rates for 1 kHz signal were higher in all cases, we did not repeat this analysis until the rest of this section. We have presented the distribution of errors throughout genders on Figure 4.2 which did not present any significant difference in general. For a deeper analysis, we have arranged the dataset for genders and presented on Table 4.7. The original dataset within genders can be seen on Table E.1.

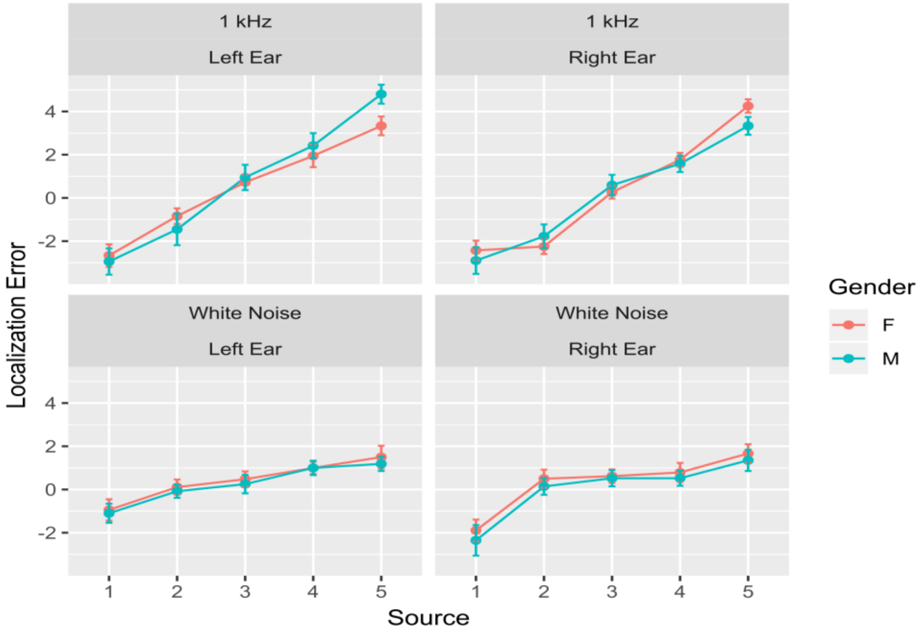

Figure 4.2: Localization errors of genders

Table 4.7: Localization errors of genders

Ear	Loc.	Signal	Gender	Shift	%LE	%LE	Shift	Ear
Left	1	1 kHz	F	Downwards	24,24%	22,08%	Downwards	Right
Left	1	1 kHz	M	Downwards	26,77%	26,36%	Downwards	Right
Left	2	1 kHz	F	Downwards	7,66%	20,45%	Downwards	Right
Left	2	1 kHz	M	Downwards	0,1322	16,16%	Downwards	Right
Left	3	1 kHz	F	Upwards	6,57%	2,39%	Upwards	Right
Left	3	1 kHz	M	Upwards	8,61%	5,37%	Upwards	Right
Left	4	1 kHz	F	Upwards	17,68%	16,02%	Upwards	Right
Left	4	1 kHz	M	Upwards	21,97%	14,35%	Upwards	Right
Left	5	1 kHz	F	Upwards	30,30%	41,59%	Upwards	Right
Left	5	1 kHz	M	Upwards	39,71%	30,30%	Upwards	Right
Left	1	Noise	F	Downwards	8,59%	17,22%	Downwards	Right
Left	1	Noise	M	Downwards	10,00%	21,39%	Downwards	Right
Left	2	Noise	F	Upwards	1,01%	4,55%	Upwards	Right
Left	2	Noise	M	Downwards	0,73%	1,30%	Upwards	Right
Left	3	Noise	F	Upwards	4,33%	5,63%	Upwards	Right
Left	3	Noise	M	Upwards	2,27%	4,74%	Upwards	Right
Left	4	Noise	F	Upwards	9,09%	7,18%	Upwards	Right
Left	4	Noise	M	Upwards	9,09%	4,74%	Upwards	Right
Left	5	Noise	F	Upwards	39,62%	15,15%	Upwards	Right
Left	5	Noise	M	Upwards	10,80%	11,62%	Upwards	Right

On Table 4.7, the cells filled in green represent significant performance differences between the right and the left ear. It is possible that a left ear superiority is found on the 1 kHz answers to L_2 and L_5 for female participants. However, the situation is inverted for males on L_5. We also observed dominance on the left ear of both genders, for the white noise answers to L_1. The right ear performed better on females for the white noise on L_5. The cells that are filled in orange represent significant differences between males and females. For the 1 kHz signal, females had a better score on the left ear while locating L_5. The situation is reversed on males. For the white noise signal, both male and females scored better while locating L_1. Lastly, we have noticed a significant difference on L_5, where males scored approximately the quarter of female error rates.

4.3. Musicianship

Later on, we have compared localization errors over musicianship. Figure 4.3 represents the general diagram obtained from the dataset, which can be found on Table E.2. The analysis was made in two steps. Firstly, we have compared the left ear and then the right ear performances of musicians with non-musicians while indicating lower error rates with a green fill-in on Table 4.8. After, we have calculated the error differences of participants' responses. The objective was to investigate the auditory asymmetry for each specific location and test stimulus. Negative values indicated the left ear superiorities, filled in orange on Table 4.8.

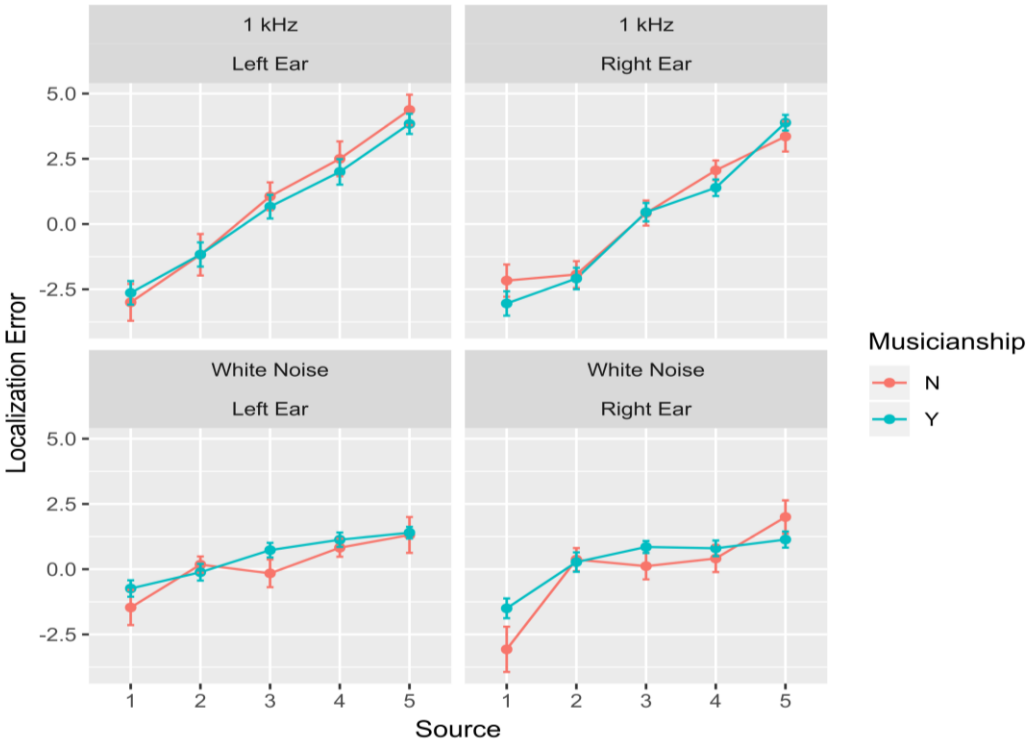

Figure 4.3: Localization errors of musicians and non-musicians over test stimuli

The first analysis showed that the left ear performances of musicians were greater than the non musicians for 1 kHz signal. We have stated that the error rates were higher for 1 kHz, meaning that the localization of a pure tone becomes a challenging task compared to a complex sound. Nevertheless, the musicians located the 1 kHz signal with lower error rates. We may suggest that the musicians have a superior right hemisphere; therefore the left ear of a musician might be more skilled for a harder and blurry task. However, the results were not clear for white noise signal. Since the white noise error rates were already lower than 1 kHz signal in general, the musicians could not present superiority. The upper loudspeakers being responded better by musicians, the superiority shifted to non-musicians as we moved to the lower speakers.

Following the results of the second analysis, we have obtained negative results from the error differences of the white noise signal except for the L_4. We may state an auditory asymmetry for the white noise, regardless of musicianship. However, on 1 kHz, the results were evenly distributed for left and right ear superiorities; therefore the asymmetry was not consistent.

Table 4.8: Auditory Asymmetry over musicianship

Ear	Loc.	Signal	Musician	n	Shift	%LE		%LE	Superior	Shift	n	Musician	Ear
Left	1	1 kHz	N	17	Downwards	27,27%		19,70%	7,58%	Downwards	18	N	Right
Left	1	1 kHz	Y	24	Downwards	23,97%		27,67%	-3,70%	Downwards	24	Y	Right
Left	2	1 kHz	N	17	Downwards	10,70%		17,58%	-6,88%	Downwards	15	N	Right
Left	2	1 kHz	Y	25	Downwards	10,61%		18,97%	-8,37%	Downwards	23	Y	Right
Left	3	1 kHz	N	16	Upwards	9,66%		3,83%	5,83%	Upwards	19	N	Right
Left	3	1 kHz	Y	21	Upwards	6,06%		4,13%	1,93%	Upwards	22	Y	Right
Left	4	1 kHz	N	18	Upwards	39,62%		18,72%	20,91%	Upwards	17	N	Right
Left	4	1 kHz	Y	24	Upwards	18,18%		12,65%	5,53%	Upwards	24	Y	Right
Left	5	1 kHz	N	16	Upwards	39,77%		30,52%	9,25%	Upwards	15	N	Right
Left	5	1 kHz	Y	25	Upwards	27,95%		35,31%	-7,37%	Upwards	26	Y	Right
Left	1	Noise	N	15	Downwards	13,33%		27,92%	-14,59%	Downwards	15	N	Right
Left	1	Noise	Y	24	Downwards	6,72%		13,64%	-6,92%	Downwards	23	Y	Right
Left	2	Noise	N	17	Upwards	1,60%		3,35%	-1,75%	Upwards	19	N	Right
Left	2	Noise	Y	26	Downwards	1,05%		2,48%	-1,43%	Upwards	22	Y	Right
Left	3	Noise	N	19	Downwards	1,44%		1,07%	0,37%	Upwards	17	N	Right
Left	3	Noise	Y	26	Upwards	6,64%		7,74%	-1,10%	Upwards	27	Y	Right
Left	4	Noise	N	17	Upwards	7,49%		3,74%	3,74%	Upwards	17	N	Right
Left	4	Noise	Y	23	Upwards	10,28%		7,27%	3,00%	Upwards	25	Y	Right
Left	5	Noise	N	16	Upwards	11,93%		18,18%	-6,25%	Upwards	16	N	Right
Left	5	Noise	Y	20	Upwards	39,60%		10,33%	29,27%	Upwards	22	Y	Right

4.4. Ages

As another parameter, we have presented localization errors over the ages of participants. Our participant profile mostly consisted of subjects within ages of 25 to 30 and 30 to 35. Therefore, we have filtered the data between these ages and presented visual diagrams (bars and points, respectively) of localization errors on Figure 4.4 and 4.5. The original dataset can be observed on Table E.4. The analysis was again conducted in two steps. In each step, the analysis was for 1 kHz and then for the white noise signal. On the first step, we identified lower error rates (filled in green) inside the same age group between their left and right ears. Afterwards, we determined the lowest error rate (filled in orange) between the two groups of ages.

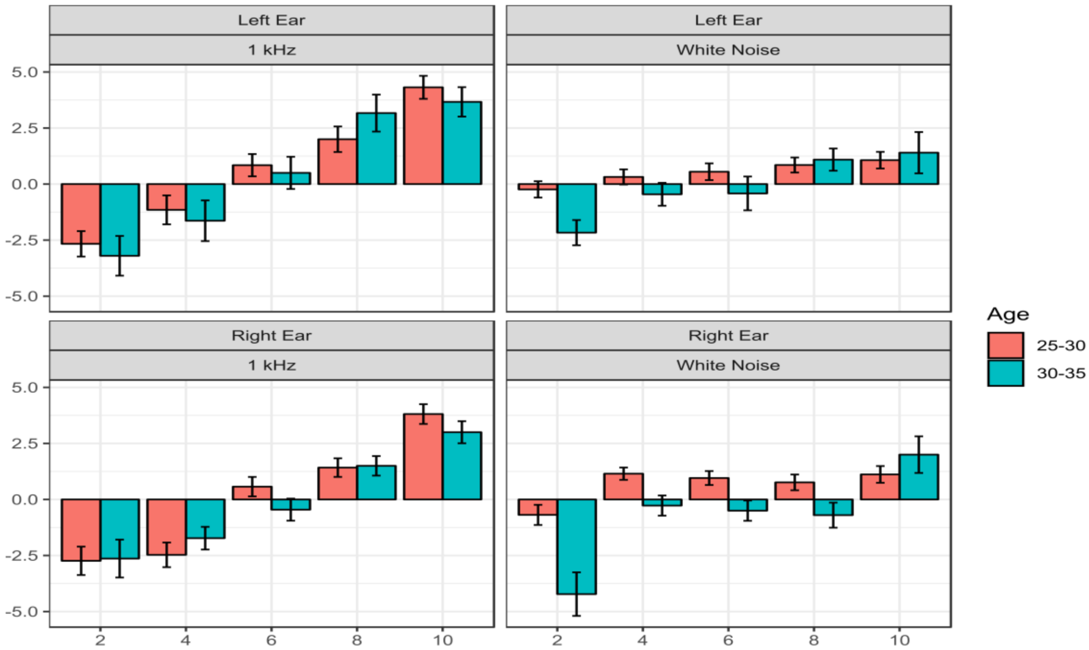

Figure 4.4: Localization errors compared between ages 25-30 and 30-35

The error rates were remarkably high for 1 kHz in general, except for the center loudspeaker. We did not extract any auditory asymmetry compared within the same group, however the data of 1 kHz signal presented a right ear superiority for the older group. The dataset for this analysis is shown below left on Table 4.9a. The same analysis was also conducted for white noise and presented on below right on Table 4.9b. For the white noise signal, we have noticed that in general, the error rates were lower for the younger group. However, a consistent auditory asymmetry was not present if the results were to be compared between the ears of each group.

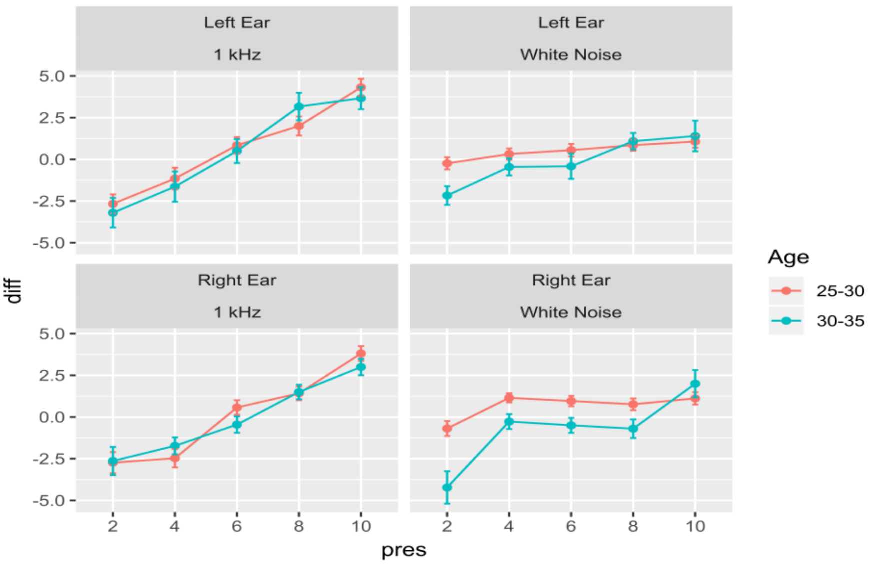

Figure 4.5: LE of age groups over the test stimuli

Table 4.9a: 1 kHz error rates over ages

Ear	Loc.	Signal	Age	n	%LE	Shift
Left	1	1 kHz	25-30	19	24,24%	Downwards
Right	1	1 kHz	25-30	20	24,88%	Downwards
Left	1	1 kHz	30-35	11	29,09%	Downwards
Right	1	1 kHz	30-35	11	23,97%	Downwards
Left	2	1 kHz	25-30	20	10,45%	Downwards
Right	2	1 kHz	25-30	17	22,46%	Downwards
Left	2	1 kHz	30-35	11	14,88%	Downwards
Right	2	1 kHz	30-35	11	15,70%	Downwards
Left	3	1 kHz	25-30	19	7,66%	Upwards
Right	3	1 kHz	25-30	21	5,19%	Upwards
Left	3	1 kHz	30-35	10	4,55%	Upwards
Right	3	1 kHz	30-35	11	4,13%	Downwards
Left	4	1 kHz	25-30	21	18,18%	Upwards
Right	4	1 kHz	25-30	19	12,92%	Upwards
Left	4	1 kHz	30-35	12	28,79%	Upwards
Right	4	1 kHz	30-35	12	0,96%	Upwards
Left	5	1 kHz	25-30	19	39,23%	Upwards
Right	5	1 kHz	25-30	21	34,63%	Upwards
Left	5	1 kHz	30-35	12	33,33%	Upwards
Right	5	1 kHz	30-35	11	27,27%	Upwards

Table 4.9b: Noise error rates over ages

Ear	Loc.	Signal	Age	n	%LE	Shift
Left	1	Noise	25-30	21	2,16%	Downwards
Right	1	Noise	25-30	17	6,25%	Downwards
Left	1	Noise	30-35	12	19,70%	Downwards
Right	1	Noise	30-35	10	38,38%	Downwards
Left	2	Noise	25-30	22	2,89%	Upwards
Right	2	Noise	25-30	20	0,92%	Upwards
Left	2	Noise	30-35	11	4,13%	Downwards
Right	2	Noise	30-35	11	2,48%	Downwards
Left	3	Noise	25-30	20	5,00%	Upwards
Right	3	Noise	25-30	23	8,70%	Upwards
Left	3	Noise	30-35	12	3,79%	Downwards
Right	3	Noise	30-35	12	4,55%	Downwards
Left	4	Noise	25-30	20	7,73%	Upwards
Right	4	Noise	25-30	21	6,93%	Upwards
Left	4	Noise	30-35	11	9,92%	Upwards
Right	4	Noise	30-35	10	6,36%	Downwards
Left	5	Noise	25-30	15	9,70%	Upwards
Right	5	Noise	25-30	17	10,16%	Upwards
Left	5	Noise	30-35	10	39,60%	Upwards
Right	5	Noise	30-35	13	18,18%	Upwards

Followed by these results, the error shifting was another matter to discuss. We have noticed that the hearing shifts were different for the two groups. 1 kHz responses were mostly in the same direction except for the center speaker. However, the older group tended to shift downwards as a response to white noise. The error rates over the total distribution of ages are presented on Figure 4.6 and the original dataset for this diagram can be found on Table E.3.

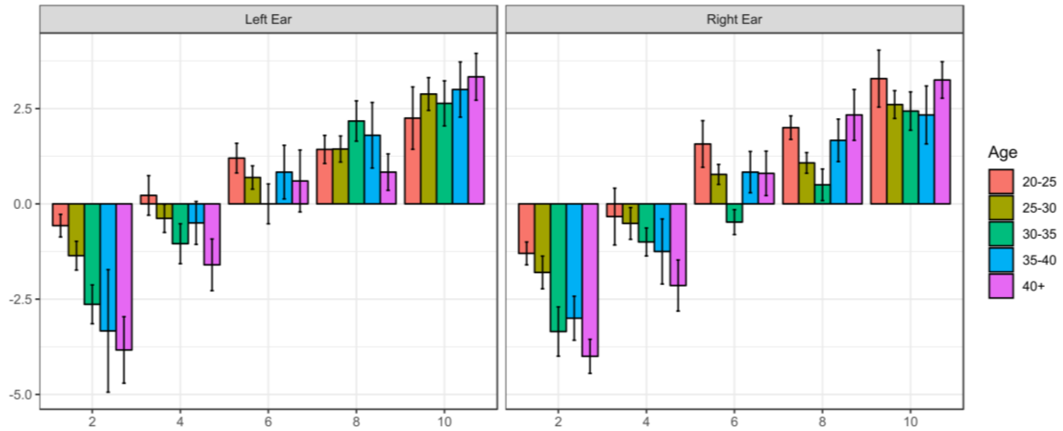

Figure 4.6: Localization error rate over the ages

4.5. Response Times

Response time analysis did not present remarkable results. It may be suggested that response times and localization errors are proportional, given upon the diagram above. Nonetheless, response times were superabundantly excursive. Participants may need a conditioning in order to set a reference point for the response times.

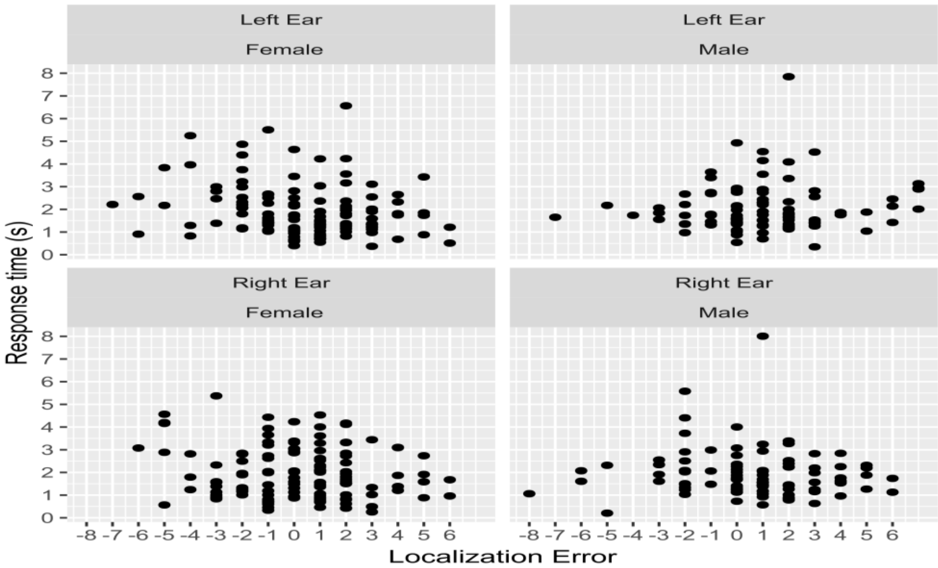

Figure 4.7: Response times

4.6. A Secondary Experiment

An auditory asymmetry exists within our results although several parameters could not satisfy the expectations. At the beginning, handedness was one of our parameters but the lack sufficient number of left handed participants; it was not possible to process this data. Musicianship is a function of a localization task, especially when the task is more challenging. Depending on our participant profile and variables, we have seen that the type of stimulus and its complexity serve as a function for the vertical localization task. Having additional types of stimulus would provide wider spectral contents for comparing results. For this reason, we have conducted a second experiment consisting of additional types of stimulus. 7 participants were selected among the subjects from the main experiment. Auditory inputs were defined as broadband white noise and pink noise signal, in addition, their filtered versions (low-cut and high-cut filter at 3 kHz). The objectives of this experiment were to investigate on which type of stimuli the localization skill was enhanced and how auditory asymmetry was modulated.

The visual diagram of the localization errors for the 6 different test signals are shown in Figure 4.8. First matter to notice is localization error rate on L_1. It seems that the participants did not experience challenges on locating the top source. Best scores for L_1 were obtained for each type of white noise signals mostly on the left ear and the pink noise signal. If these results are compared with the first experiment, certain discrepancies are to be found. The first experiment showed the most accurate scores were on the central sources and error rates increased as the sources moved to the extremities. In this case however, we noticed that the localization task for L_1 was held with the best scores, for almost each type of stimuli. In addition, as the source position was lowered, the error rates seemed to increase. The first experiment detected left ear superiority, especially for the white noise. But the second experiment showed a mixture of asymmetries if statistical values are reviewed (See Table 4.10). We have also noticed a clear right ear superiority on the high pass filtered signals. This was an unexpected result since the processing of a musical material should have been better on the left ear. But it should not be forgotten that a single unrelated answer affected results in a high proportion and it was not possible to exclude certain of those participants, since the total number for the second experiment was seven.

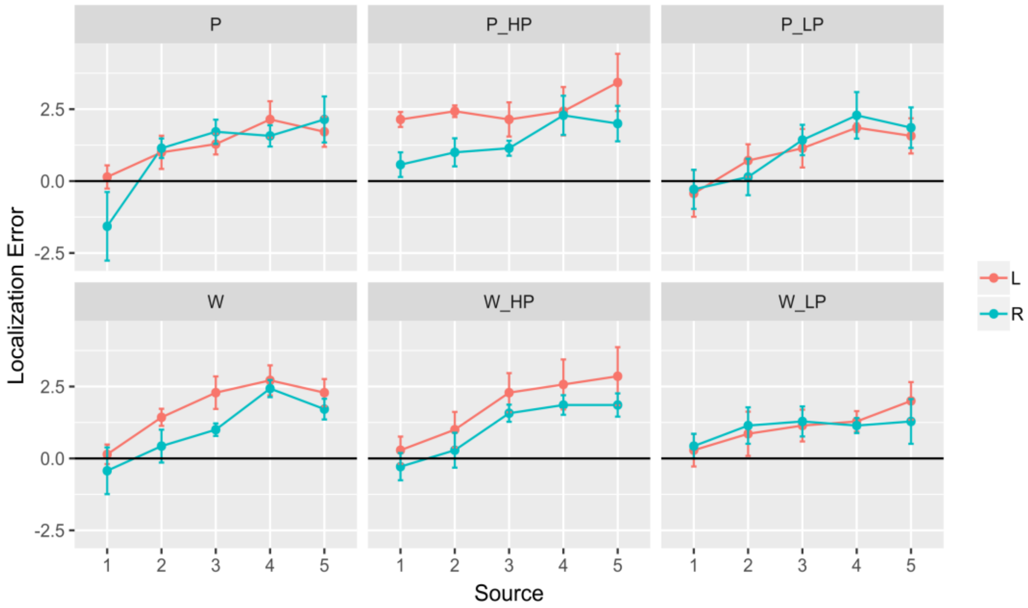

Figure 4.8: Localization errors of the new experiment

Table 4.10: Dataset of the new experiment

Ear	Signal	Loc.	%LE	Diff.	%LE	Ear	Sup.
L	W	2	1,30%	5,19%	-3,90%	R	Left
L	W	4	12,99%	9,09%	3,90%	R	Right
L	W	6	20,78%	11,69%	9,09%	R	Right
L	W	8	24,68%	2,60%	22,08%	R	Right
L	W	10	20,78%	5,19%	15,58%	R	Right
L	W_HP	2	2,60%	5,19%	-2,60%	R	Right
L	W_HP	4	9,09%	6,49%	2,60%	R	Right
L	W_HP	6	20,78%	6,49%	14,29%	R	Right
L	W_HP	8	23,38%	6,49%	16,88%	R	Right
L	W_HP	10	25,97%	9,09%	16,88%	R	Right
L	W_LP	2	2,60%	-1,30%	3,90%	R	Left
L	W_LP	4	7,79%	-2,60%	10,39%	R	Left
L	W_LP	6	10,39%	-1,30%	11,69%	R	Left
L	W_LP	8	11,69%	1,30%	10,39%	R	Right
L	W_LP	10	18,18%	6,49%	11,69%	R	Right

Ear	Signal	Loc.	%LE	Diff.	%LE	Ear	Sup.
L	P	2	1,30%	15,58%	-14,29%	R	Left
L	P	4	9,09%	-1,30%	10,39%	R	Left
L	P	6	11,69%	-3,90%	15,58%	R	Left
L	P	8	19,48%	5,19%	14,29%	R	Right
L	P	10	15,58%	-3,90%	19,48%	R	Left
L	P_HP	2	19,48%	14,29%	5,19%	R	Right
L	P_HP	4	22,08%	12,99%	9,09%	R	Right
L	P_HP	6	19,48%	9,09%	10,39%	R	Right
L	P_HP	8	22,08%	1,30%	20,78%	R	Right
L	P_HP	10	31,17%	12,99%	18,18%	R	Right
L	P_LP	2	-3,90%	-1,30%	-2,60%	R	Right
L	P_LP	4	6,49%	5,19%	1,30%	R	Right
L	P_LP	6	10,39%	-2,60%	12,99%	R	Left
L	P_LP	8	16,88%	-3,90%	20,78%	R	Left
L	P_LP	10	14,29%	-2,60%	16,88%	R	Left

4.7. Discussion

The experiment satisfied several suggestions mentioned earlier in this project. However, the error rates are distributed in high density through the locations, regardless of test stimulus. It is possible to expand this research concerning some of the experimental conditions and obtain enhanced results.

Firstly, in this experiment, we have utilized spectral cues, meaning that different types of stimuli were triggered in order to complete a localization task. Another method for conducting the experiment is to receive support from dynamic cues, meaning that the listener is allowed to move the head while listening to the stimulus.

A study by Joyce Vliegen and A. John Van Opstal in 2004 measured the influence of intensity and duration on a vertical localization task. Since our experiment had sufficient parameters, intensity and duration values were fixed. But combining varying intensities and durations with dynamic and spectral cues would provide comparable results with the experiment in this project.

Another issue to mention is the listening conditions. Our participants performed in monaural conditions in order to measure auditory asymmetry. Furthermore, the same experiment could be conducted also with binaural listening conditions. In this case, an investigation of an auditory asymmetry would not be possible but it would certainly provide information whether the vertical localization task is enhanced.

It is possible to alter the environmental conditions for the betterment of this experiment. Our placement in MIAM Live Studio was approximately on the center of the room. A displacement towards the absorbent wall might serve to the purpose of separating the ears. Lastly, the folding screen barely covered the apparatus, providing the participants a prior knowledge on the limits of the experiment. Another variation of the folding screen might affect our results if such condition is desired to be tested.

5. CONCLUSION

The complexity of the auditory stimulus enhances the vertical localization. The localization errors increase as the source position moved to the extremities. Results show that for the 1 kHz test signal, %59 of the participants had a left ear superiority with an average error rate of -1,26. The subjects who had left ear superiority and started the test with their left ears were %34; and those who started the test with the right ear were the %24 of the population. A clear statement of an auditory asymmetry exists, but a left ear superiority for the 1 kHz is not available for the experiment.

For the white noise signal, %52 of the participants was dominant on the left ear performances against %38 of the subjects. The resting %10 of the population did not represent auditory asymmetry. The subjects who had left ear superiority and started the test with their left ear were %20; and those who started the test with the right ear were the %31 of the population. It is possible to state a left ear superiority for the white noise signal.

This research should be considered as a primitive scope to a gigantic field. Although the analysis of the results was conducted through averages of responses and localization errors, it should not be forgotten that each individual has a distinct hearing ability regarding the physical and physiological qualities. Since the head, the body and the shape of the pinna; also the technical equipment and the environment alter the physical features of the sound arriving to the ears, it is possible to assess each individual response under elaborative conditions.

As for further research suggestion, this experiment could be modified to a larger spherical model for a better resolution of the experiment; meaning that the quantity and / or the distance between the loudspeakers are to be increased. This suggestion implicitly requires a redefinition of the angular separation between the loudspeakers and the focal point where the listener will be positioned. The audiogram results to the corresponding loudness levels of the experiment would serve as a ground reference point since it will be covering the sensitive and unresponsive regions of each participant’s hearing range. Moreover, the integration of HRTF (Head Related Transfer Function) measurements will enable converting impulse responses of the ears for each specific auditory stimulus and location. Since HRTF calculations represent how an auditory input reaches at the outer ear, it is possible to observe the modification of audiogram results under the experimental environment with this method.

Lastly, if ideal opportunities were to be provided, the EEG measurements will provide brain activity during the experiment. These suggestions will aid to monitor and hopefully understand the hearing, the localization abilities and cerebral performance differences (auditory asymmetry) apart from the numeric calculations extracted from the participant’s responses. It is hoped that it would serve as a better understanding of our vertical perception and furthermore our three dimensional perception. Integration of the vertical and spherical features to the sound systems might create alternative approaches to audio reproduction.

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Url-2 <https://www.skidmore.edu/~hfoley/Perc9.htm>, date retrieved 20.04.2019

APPENDIX A: The Orientation of the Experimental Setup

The expectations from the experiment and the accessibility of materials provided feasibility and several restrictions. The loudspeakers required to be angularly separated in order to create a focal point (listening position). The distance of the listener's position to the apparatus and the angle of loudspeakers were inversely proportional.

The loudspeakers were placed into a system with 5 shelves and the dimensions of each shelve allowed us to set up the loudspeakers tilted to a chosen side, defining the natural distance between each tweeter of the loudspeakers as 30 cm. Therefore, the angle and the distance between the loudspeakers are inversely proportional. Considering the upper mentioned information for a meaningful setup and given that the Adam T5V's are near field monitors, we have restricted the distance to be between 100 and 150 cm.

Several values have been attempted; the focal distance was defined as 140 and the angular separation as 10º.2 axes (x_n, z_n) represented the distance from the apparatus and the altitude of loudspeakers. were defined in a three dimensional space and five loudspeakers as L_n ($n \epsilon Z^+$ and $1 \leq n \leq 5$). The center point of the tweeter of L_3 represented the point *O(0,0)*, aligned with *F (140,0)*.Afterwards, the altitude of each loudspeakers was calculated using simple trigonometric approaches:

Given that *sin(10º) =0,17*, *sin (20º) = 0,34*, *tan (10º) = 0,18* and *tan (20º) = 0,36* ;

$140 \times \tan(20º) = x_1 x_1 = 50{,}4$ cm and $x_3 = -25{,}2$ cm

$140 \times \tan(10º) = x_2$ $x_2 = 25{,}2$ cm and $x_4 = -50{,}4$ cm

The loudspeakers needed to be elevated from the front or the back in order to create the angular separation. Therefore;

30 x sin (10º) =5,1 cm of elevation for L2 from the back and L4 from the front
30 x sin (20º) =10,2 cm of elevation for L1 from the back and L5 from the front

The angular separation caused the loudspeakers stay out of alignment. Given that *cos (10º) = 0,98* and *cos (20º) = 0,94;* their position on the x axis was recalculated:

17,8 x cos (10º) = 17,4 cm: 0,4 cm forward shift by L_2 and L_4
*17,8 x cos (20º) = 16,7 cm:*1,1 cm forward shift by L_1 and L_5

APPENDIX B: Participant Consent Form

Investigation of Auditory Asymmetry on the Vertical Localization of Sound

My name is Batuhan Çetinkaya and I am a graduate student in MIAM at Istanbul Technical University, Istanbul, Turkey. I am inviting you to participate in a research study. The study is about measuring the localization skills of your two ears. As part of my data collection procedures, I am soliciting voluntary participation from you. This means, you may choose to participate or not. You will be asked to fulfill an eligibility test questioning a number of your physical information and several skills. I will guide you to the experiment room and the experiment will begin. The experimental setup will be covered with a folding screen. You will be making localization judgments without the knowledge of the quantity of the sound sources utilized for this experiment. Instead of this, the folding screen will be holding a scale of 11 numbers from which your judgments will be chosen. The test will take in two parts (the right and the left ear) and each part contains two stages (two types of test stimuli). Your ear on your opposite side will be blocked by a pair of earplugs for your first use. I will ask you to focus on an observing point and listen to the stimuli. If you are not able to locate the stimuli, a repetition will not be allowed and your answer will be recorded as “N/A”. Afterwards, I will ask you to rotate 180 degrees by your listening position and we will repeat the test for your other ear.

The test will take approximately 10 minutes of your time. Your answers will be recorded with a microphone in order to measure your response time to each stimuli. All information will be kept confidential. In my writing or any presentations, I will use a made-up name for you, *“P_n”* (i.e. $P_{5;}$ indicating the fifth participant), and I will not reveal identifying details about you. The benefit of this research is that you will be helping to evaluate the influences of handedness and musicianship to the auditory symmetry of vertical localization abilities. Possible risk of physical or mental harm for participating in this study is minimum. Our hearing tests cause no detriment towards the hearing system. Our test stimuli were calibrated to a moderate loudness level of 75 dBs.If you encounter a discomfort while using the earplugs, you are free to withdraw from the experiment. If you have any questions about this study, you may contact me at (batuhan.cetinkaya@gmail.com) or (+90546 649 0033). If you agree to participate in this research study after fully reading and understanding the statements above, please sign below to indicate your acceptance to participate. For your future reference, you may ask for a copy of this consent form.

Name of Participant:

Signature: Date:

APPENDIX C: Eligibility Test

Table C.1: Eligibility Test

Name						
Age	< 20	20 - 25	25 - 30	30 - 35	35 - 40	> 40
Height (cm)	< 150	150 - 160	160 - 170	170 - 180	180 - 190	> 190
Handedness	Right Handed			Left Handed		
Musicianship						
Instrument						
Auditory Disorder						
Additional Information						

APPENDIX D: Dataset Template

Table D.1: Dataset Template

Data Set						Questions			
						Left Ear		Right Ear	
						1 kHz	White Noise	1 kHz	White Noise
Participant #	Gender	Age	Musicianship	Handedness	Test Initialization	L_1K_Q[_]	L_W_Q[_]	R_1K_Q[_]	R_W_Q[_]
	M / F		Y / N	L / R	L / R	1 to 5	1 to 5	1 to 5	1 to 5

Data Set						Responses			
						Left Ear		Right Ear	
						1 kHz	White Noise	1 kHz	White Noise
Participant #	Gender	Age	Musicianship	Handedness	Test Initialization	L_1K_R[_]	L_W_R[_]	R_1K_R[_]	R_W_R[_]
	M / F		Y / N	L / R	L / R	1 to 11	1 to 11	1 to 11	1 to 11

Data Set						Response Times			
						Left Ear		Right Ear	
						1 kHz	White Noise	1 kHz	White Noise
Participant #	Gender	Age	Musicianship	Handedness	Test Initialization	L_1K_RT[_]	L_W_RT[_]	R_1K_RT[_]	R_W_RT[_]
	M / F		Y / N	L / R	L / R	x,xxx ms	x,xxx ms	x,xxx ms	x,xxx ms

APPENDIX E: Datasets

Table E.1: Localization error of genders compared between test stimuli

P	Ear	Location	Signal	Gender	n	LE	%LE	Shift	Deviation	Error
1	Left	1	1 kHz	F	21	-2,6667	**24,24%**	Downwards	2,3944	0,5225
2	Left	1	1 kHz	M	20	-2,9444	**26,77%**	Downwards	2,7110	0,6062
3	Left	2	1 kHz	F	20	-0,8421	**7,66%**	Downwards	1,6077	0,3595
4	Left	2	1 kHz	M	22	-1,4545	**13,22%**	Downwards	3,4188	0,7289
5	Left	3	1 kHz	F	18	0,7222	**6,57%**	Upwards	1,5265	0,3598
6	Left	3	1 kHz	M	19	0,9474	**8,61%**	Upwards	2,5489	0,5848
7	Left	4	1 kHz	F	18	1,9444	**17,68%**	Upwards	2,2089	0,5206
8	Left	4	1 kHz	M	24	2,4167	**21,97%**	Upwards	2,8425	0,5802
9	Left	5	1 kHz	F	21	3,3333	**30,30%**	Upwards	1,9833	0,4328
10	Left	5	1 kHz	M	20	4,3681	**39,71%**	Upwards	1,9628	0,4389
11	Left	1	Noise	F	19	-0,9444	**8,59%**	Downwards	2,1549	0,4944
12	Left	1	Noise	M	20	-1,1000	**10,00%**	Downwards	1,9708	0,4407
13	Left	2	Noise	F	18	0,1111	**1,01%**	Upwards	1,4907	0,3514
14	Left	2	Noise	M	25	-0,0800	**0,73%**	Downwards	1,5253	0,3051
15	Left	3	Noise	F	21	0,4762	**4,33%**	Upwards	1,6619	0,3627
16	Left	3	Noise	M	24	0,2500	**2,27%**	Upwards	2,0904	0,4267
17	Left	4	Noise	F	20	1,0000	**9,09%**	Upwards	1,2566	0,2810
18	Left	4	Noise	M	20	1,0000	**9,09%**	Upwards	1,4868	0,3325
19	Left	5	Noise	F	20	4,3586	**39,62%**	Upwards	2,3508	0,5257
20	Left	5	Noise	M	16	1,1875	**10,80%**	Upwards	1,3276	0,3319
21	Right	1	1 kHz	F	21	-2,4286	**22,08%**	Downwards	2,0633	0,4502
22	Right	1	1 kHz	M	21	-2,9000	**26,36%**	Downwards	2,8266	0,6168
23	Right	2	1 kHz	F	20	-2,2500	**20,45%**	Downwards	1,5517	0,3470
24	Right	2	1 kHz	M	18	-1,7778	**16,16%**	Downwards	2,3403	0,5516
25	Right	3	1 kHz	F	19	0,2632	**2,39%**	Upwards	1,2842	0,2946
26	Right	3	1 kHz	M	22	0,5909	**5,37%**	Upwards	2,2395	0,4775
27	Right	4	1 kHz	F	21	1,7619	**16,02%**	Upwards	1,4800	0,3230
28	Right	4	1 kHz	M	20	1,5789	**14,35%**	Upwards	1,7100	0,3824
29	Right	5	1 kHz	F	17	4,5748	**41,59%**	Upwards	1,2910	0,3131
30	Right	5	1 kHz	M	24	3,3333	**30,30%**	Upwards	2,0144	0,4112
31	Right	1	Noise	F	20	-1,8947	**17,22%**	Downwards	2,2582	0,5049
32	Right	1	Noise	M	18	-2,3529	**21,39%**	Downwards	2,9988	0,7068
33	Right	2	Noise	F	20	0,5000	**4,55%**	Upwards	1,8778	0,4199
34	Right	2	Noise	M	21	0,1429	**1,30%**	Upwards	1,7688	0,3860
35	Right	3	Noise	F	21	0,6190	**5,63%**	Upwards	1,4310	0,3123
36	Right	3	Noise	M	23	0,5217	**4,74%**	Upwards	1,8058	0,3765
37	Right	4	Noise	F	19	0,7895	**7,18%**	Upwards	1,9316	0,4431
38	Right	4	Noise	M	23	0,5217	**4,74%**	Upwards	1,6752	0,3493
39	Right	5	Noise	F	18	1,6667	**15,15%**	Upwards	1,8150	0,4278
40	Right	5	Noise	M	20	1,2785	**11,62%**	Upwards	2,2070	0,4935

Table E.2: Localization errors of musicians and non-musicians over test stimuli

P	Ear	Location	Signal	Musician	n	LE	%LE	Shift	Deviation	Error
1	Left	1	1 kHz	N	17	-3,0000	**27,27%**	Downwards	2,9155	0,7071
2	Left	1	1 kHz	Y	24	-2,6364	**23,97%**	Downwards	2,2156	0,4523
3	Left	2	1 kHz	N	17	-1,1765	**10,70%**	Downwards	3,2832	0,7963
4	Left	2	1 kHz	Y	25	-1,1667	**10,61%**	Downwards	2,3157	0,4631
5	Left	3	1 kHz	N	16	1,0625	**9,66%**	Upwards	2,1438	0,5359
6	Left	3	1 kHz	Y	21	0,6667	**6,06%**	Upwards	2,0817	0,4543
7	Left	4	1 kHz	N	18	4,3587	**39,62%**	Upwards	2,8336	0,6679
8	Left	4	1 kHz	Y	24	2,0000	**18,18%**	Upwards	2,3956	0,4890
9	Left	5	1 kHz	N	16	4,3750	**39,77%**	Upwards	2,3345	0,5836
10	Left	5	1 kHz	Y	25	3,0742	**27,95%**	Upwards	1,9296	0,3859
11	Left	1	Noise	N	15	-1,4667	**13,33%**	Downwards	2,6150	0,6752
12	Left	1	Noise	Y	24	-0,7391	**6,72%**	Downwards	1,5438	0,3151
13	Left	2	Noise	N	17	0,1765	**1,60%**	Upwards	1,2862	0,3120
14	Left	2	Noise	Y	26	-0,1154	**1,05%**	Downwards	1,6328	0,3202
15	Left	3	Noise	N	19	-0,1579	**1,44%**	Downwards	2,3157	0,5313
16	Left	3	Noise	Y	26	0,7308	**6,64%**	Upwards	1,4299	0,2804
17	Left	4	Noise	N	17	0,8235	**7,49%**	Upwards	1,4246	0,3455
18	Left	4	Noise	Y	23	1,1304	**10,28%**	Upwards	1,3247	0,2762
19	Left	5	Noise	N	16	1,3125	**11,93%**	Upwards	2,7426	0,6875
20	Left	5	Noise	Y	20	4,3556	**39,60%**	Upwards	0,9947	0,2224
21	Right	1	1 kHz	N	18	-2,1667	**19,70%**	Downwards	2,6178	0,6170
22	Right	1	1 kHz	Y	24	-3,0435	**27,67%**	Downwards	2,2859	0,4666
23	Right	2	1 kHz	N	15	-1,9333	**17,58%**	Downwards	1,9809	0,5115
24	Right	2	1 kHz	Y	23	-2,0870	**18,97%**	Downwards	1,9751	0,4118
25	Right	3	1 kHz	N	19	0,4211	**3,83%**	Upwards	2,0901	0,4795
26	Right	3	1 kHz	Y	22	0,4545	**4,13%**	Upwards	1,6541	0,3526
27	Right	4	1 kHz	N	17	2,0588	**18,72%**	Upwards	1,5601	0,3784
28	Right	4	1 kHz	Y	24	1,3913	**12,65%**	Upwards	1,5591	0,3183
29	Right	5	1 kHz	N	15	3,3571	**30,52%**	Upwards	2,2398	0,5783
30	Right	5	1 kHz	Y	26	3,8846	**35,31%**	Upwards	1,5317	0,3004
31	Right	1	Noise	N	15	-3,0714	**27,92%**	Downwards	3,3619	0,8680
32	Right	1	Noise	Y	23	-1,5000	**13,64%**	Downwards	1,8192	0,3793
33	Right	2	Noise	N	19	0,3684	**3,35%**	Upwards	1,9210	0,4407
34	Right	2	Noise	Y	22	0,2727	**2,48%**	Upwards	1,7507	0,3732
35	Right	3	Noise	N	17	0,1176	**1,07%**	Upwards	2,0881	0,5064
36	Right	3	Noise	Y	27	0,8519	**7,74%**	Upwards	1,1995	0,2308
37	Right	4	Noise	N	17	0,4118	**3,74%**	Upwards	2,1523	0,5220
38	Right	4	Noise	Y	25	0,8000	**7,27%**	Upwards	4,3586	0,3000
39	Right	5	Noise	N	16	2,0000	**18,18%**	Upwards	2,5560	0,6390
40	Right	5	Noise	Y	22	1,1364	**10,33%**	Upwards	1,4572	0,3107

Table E.3: Localization error dataset over the ages

P	Ear	Location	Age	n	LE	%LE	Shift	Deviation	Error
1	Left	1	20-25	7	-0,5714	**5,19%**	Downwards	0,7868	0,2974
2	Right	1	20-25	10	-1,3000	**11,82%**	Downwards	0,9487	0,3000
3	Left	1	25-30	40	-1,3590	**12,35%**	Downwards	2,3895	0,3778
4	Right	1	25-30	37	-1,8000	**16,36%**	Downwards	2,6099	0,4291
5	Left	1	30-35	23	-2,6364	**23,97%**	Downwards	2,4406	0,5089
6	Right	1	30-35	21	-3,3500	**30,45%**	Downwards	2,9607	0,6461
7	Left	1	35-40	4	-3,3333	**30,30%**	Downwards	3,2146	1,6073
8	Right	1	35-40	6	-3,0000	**27,27%**	Downwards	1,4142	0,5774
9	Left	1	40+	6	-3,8333	**34,85%**	Downwards	2,1370	0,8724
10	Right	1	40+	6	-4,0000	**36,36%**	Downwards	1,0954	0,4472
11	Left	2	20-25	10	0,2222	**2,02%**	Upwards	1,6415	0,5191
12	Right	2	20-25	9	-0,3333	**3,03%**	Downwards	2,2361	0,7454
13	Left	2	25-30	42	-0,3810	**3,46%**	Downwards	2,3885	0,3686
14	Right	2	25-30	37	-0,5135	**4,67%**	Downwards	2,5344	0,4167
15	Left	2	30-35	22	-1,0455	**9,50%**	Downwards	2,4588	0,5242
16	Right	2	30-35	22	-1,0000	**9,09%**	Downwards	1,7182	0,3663
17	Left	2	35-40	6	-0,5000	**4,55%**	Downwards	1,3784	0,5627
18	Right	2	35-40	4	-1,2500	**11,36%**	Downwards	1,7078	0,8539
19	Left	2	40+	5	-1,6000	**14,55%**	Downwards	1,5166	0,6782
20	Right	2	40+	7	-2,1429	**19,48%**	Downwards	1,7728	0,6701
21	Left	3	20-25	10	4,3497	**39,54%**	Upwards	1,2293	0,3887
22	Right	3	20-25	7	1,5714	**14,29%**	Upwards	1,6183	0,6117
23	Left	3	25-30	39	0,6923	**6,29%**	Upwards	1,9078	0,3055
24	Right	3	25-30	44	0,7727	**7,02%**	Upwards	1,7369	0,2619
25	Left	3	30-35	22	0,0000	**0,00%**	Upwards	2,4495	0,5222
26	Right	3	30-35	23	-0,4783	**4,35%**	Downwards	1,5629	0,3259
27	Left	3	35-40	6	0,8333	**7,58%**	Upwards	1,7224	0,7032
28	Right	3	35-40	6	0,8333	**7,58%**	Upwards	1,3292	0,5426
29	Left	3	40+	5	0,6000	**5,45%**	Upwards	1,8166	0,8124
30	Right	3	40+	5	0,8000	**7,27%**	Upwards	1,3038	0,5831
31	Left	4	20-25	7	1,4286	**12,99%**	Upwards	0,9759	0,3689
32	Right	4	20-25	9	2,0000	**18,18%**	Upwards	0,9258	0,3086
33	Left	4	25-30	41	1,4390	**13,08%**	Upwards	2,1914	0,3422
34	Right	4	25-30	40	1,0750	**9,77%**	Upwards	1,7155	0,2712
35	Left	4	30-35	23	2,1739	**19,76%**	Upwards	2,5343	0,5284
36	Right	4	30-35	22	0,5000	**4,55%**	Upwards	1,9457	0,4148
37	Left	4	35-40	5	4,3678	**39,71%**	Upwards	1,9235	0,8602
38	Right	4	35-40	6	1,6667	**15,15%**	Upwards	1,3663	0,5578
39	Left	4	40+	6	0,8333	**7,58%**	Upwards	1,1690	0,4773
40	Right	4	40+	6	2,3333	**21,21%**	Upwards	1,6330	0,6667
41	Left	5	20-25	8	4,5689	**41,54%**	Upwards	2,3146	0,8183
42	Right	5	20-25	7	3,2857	**29,87%**	Upwards	1,9760	0,7469
43	Left	5	25-30	34	2,8824	**26,20%**	Upwards	2,5077	0,4301
44	Right	5	25-30	38	2,6053	**23,68%**	Upwards	2,2486	0,3648
45	Left	5	30-35	22	2,6364	**23,97%**	Upwards	2,7697	0,5905
46	Right	5	30-35	24	2,4348	**22,13%**	Upwards	2,4648	0,5031
47	Left	5	35-40	7	3,0000	**27,27%**	Upwards	1,9149	0,7237
48	Right	5	35-40	6	2,3333	**21,21%**	Upwards	1,8619	0,7601
49	Left	5	40+	6	3,3333	**30,30%**	Upwards	1,5055	0,6146
50	Right	5	40+	4	4,5717	**41,56%**	Upwards	0,9574	0,4787

Table E.4: Localization error of age groups over the test stimuli

P	Ear	Location	Signal	Age	n	LE	%LE	Shift	Deviation	Error
1	Left	1	1 kHz	25-30	19	-2,6667	**24,24%**	Downwards	2,4734	0,5674
2	Left	1	Noise	25-30	21	-0,2381	**2,16%**	Downwards	1,6705	0,3645
3	Right	1	1 kHz	25-30	20	-2,7368	**24,88%**	Downwards	2,8253	0,6318
4	Right	1	Noise	25-30	17	-0,6875	**6,25%**	Downwards	1,8518	0,4491
5	Left	1	1 kHz	30-35	11	-3,2000	**29,09%**	Downwards	2,9364	0,8853
6	Left	1	Noise	30-35	12	-2,1667	**19,70%**	Downwards	1,9462	0,5618
7	Right	1	1 kHz	30-35	11	-2,6364	**23,97%**	Downwards	2,8026	0,8450
8	Right	1	Noise	30-35	10	-4,2222	**38,38%**	Downwards	3,0732	0,9718
9	Left	2	1 kHz	25-30	20	-1,1500	**10,45%**	Downwards	2,8887	0,6459
10	Left	2	Noise	25-30	22	0,3182	**2,89%**	Upwards	1,5852	0,3380
11	Right	2	1 kHz	25-30	17	-2,4706	**22,46%**	Downwards	2,2671	0,5499
12	Right	2	Noise	25-30	20	0,1012	**0,92%**	Upwards	1,2258	0,2741
13	Left	2	1 kHz	30-35	11	-1,6364	**14,88%**	Downwards	3,0091	0,9073
14	Left	2	Noise	30-35	11	-0,4545	**4,13%**	Downwards	1,6949	0,5110
15	Right	2	1 kHz	30-35	11	-1,7273	**15,70%**	Downwards	1,6787	0,5062
16	Right	2	Noise	30-35	11	-0,2727	**2,48%**	Downwards	1,4894	0,4491
17	Left	3	1 kHz	25-30	19	0,8421	**7,66%**	Upwards	2,1670	0,4971
18	Left	3	Noise	25-30	20	0,5500	**5,00%**	Upwards	1,6694	0,3733
19	Right	3	1 kHz	25-30	21	0,5714	**5,19%**	Upwards	1,9893	0,4341
20	Right	3	Noise	25-30	23	0,9565	**8,70%**	Upwards	1,4917	0,3110
21	Left	3	1 kHz	30-35	10	0,5000	**4,55%**	Upwards	2,2730	0,7188
22	Left	3	Noise	30-35	12	-0,4167	**3,79%**	Downwards	2,6097	0,7534
23	Right	3	1 kHz	30-35	11	-0,4545	**4,13%**	Downwards	1,6348	0,4929
24	Right	3	Noise	30-35	12	-0,5000	**4,55%**	Downwards	1,5667	0,4523
25	Left	4	1 kHz	25-30	21	2,0000	**18,18%**	Upwards	2,6077	0,5690
26	Left	4	Noise	25-30	20	0,8500	**7,73%**	Upwards	1,4965	0,3346
27	Right	4	1 kHz	25-30	19	1,4211	**12,92%**	Upwards	1,8048	0,4140
28	Right	4	Noise	25-30	21	0,7619	**6,93%**	Upwards	1,6095	0,3512
29	Left	4	1 kHz	30-35	12	3,1667	**28,79%**	Upwards	2,8551	0,8242
30	Left	4	Noise	30-35	11	1,0909	**9,92%**	Upwards	1,6404	0,4946
31	Right	4	1 kHz	30-35	12	0,1052	**0,96%**	Upwards	1,5076	0,4352
32	Right	4	Noise	30-35	10	-0,7000	**6,36%**	Downwards	1,7670	0,5588
33	Left	5	1 kHz	25-30	19	4,3158	**39,23%**	Upwards	2,2374	0,5133
34	Left	5	Noise	25-30	15	1,0667	**9,70%**	Upwards	1,4376	0,3712
35	Right	5	1 kHz	25-30	21	3,8095	**34,63%**	Upwards	2,0154	0,4398
36	Right	5	Noise	25-30	17	1,1176	**10,16%**	Upwards	1,5363	0,3726
37	Left	5	1 kHz	30-35	12	3,6667	**33,33%**	Upwards	2,2697	0,6552
38	Left	5	Noise	30-35	10	4,3556	**39,60%**	Upwards	2,9136	0,9214
39	Right	5	1 kHz	30-35	11	3,0000	**27,27%**	Upwards	1,6330	0,4924
40	Right	5	Noise	30-35	13	2,0000	**18,18%**	Upwards	2,9439	0,8165

CURRICULUM VITAE

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- 2010 – 2014 : Galatasaray University Industrial Engineering (BA)
- 2005 – 2010 : Saint Michel French High-School

SKILLS

Language

- English, French

Software

- Microsoft Word, Excel, Powerpoint, Visio
- AutoCAD
- C / C++ / QBasic
- Adobe Photoshop, Adobe Audition
- Avid Pro Tools, Ableton Live, Logic Pro, FL Studio

Music

- Piano, Keyboard, Electro Guitar, Acoustic Guitar, Bass Guitar, Drums

WORK EXPERIENCE

- 2018 – 2019 : Peyote Taksim Live Engineer
- 2014 – 2015 : Açık Radyo Substitute Live and Recording Engineer
- 2012 – 2013 : Marsh & McLennan Companies Risk Management Internship
- 2012 – 2013 : Arçelik A.S. Manufacturing Internship
- 2011 – 2012 : Marsh & McLennan Companies Risk Consulting Internship

EXTRACURRICULAR

- 2019 : Keyboardist of Monster Oyun Müzikleri Orkestrası
- 2018 – : 80's and 90's Rock Covers with the band "Thunderbolt"
- 2015 – 2017 : Pink Floyd Tribute Project with the band "Floydian Night"
- 2013 – 2014 : The Beatles Tribute Project with the band "Sunnyside"
- 2012 – 2013 : Deep Purple Tribute Project with the band "Dedeler"
- 2010 :Benefit Concert for NesinVakfı (The Association For Children Deprived Of Education)
- 2009 : Benefit Concert for Çağdaş Yaşamı Destekleme Derneği
- 2008 : Benefit Concert for ÇOKSEV (The Foundation For Children With Leukemia
- 2004 : Benefit Concert for Çağdaş Yasamı Destekleme Derneği (The Association for Supporting Contemporary Life)